JRC SCIENCE FOR POLICY REPORT

Best Available Techniques (BAT) Reference Document on Waste Incineration

Colour code used:

Black - adopted BREF (2006)

~~Strikethrough – deleted text from the adopted BREF (2006)~~

Green – new text in Draft 1

Blue highlights – explanatory notes to the TWG (e.g. on sections moved) or requests for additional inputs from the TWG

Yellow highlights – new references in Draft 1

Industrial Emissions Directive 2010/75/EU
(Integrated Pollution Prevention and Control)

JOINT RESEARCH CENTRE
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Directorate B – Growth and Innovation
~~Sustainable Production and Consumption Unit~~
Circular Economy and Industrial Leadership Unit
European IPPC Bureau

DRAFT 1 (May 2017)

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Title Best Available Techniques (BAT) Reference Document on Waste Incineration

This document is one from the series of foreseen documents listed below (at the time of writing, not all documents have been drafted):

Reference Document on Best Available Techniques (BREF)	**Code**
Ceramic Manufacturing Industry	CER
Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector	CWW
Common Waste Gas Treatment in the Chemical Sector	WGC
Emissions from Storage	EFS
Energy Efficiency	ENE
Ferrous Metals Processing Industry	FMP
Food, Drink and Milk Industries	FDM
Industrial Cooling Systems	*ICS*
Intensive Rearing of Poultry and Pigs	IRPP
Iron and Steel Production	IS
Large Combustion Plants	LCP
Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers Industries	LVIC-AAF
Large Volume Inorganic Chemicals – Solids and Others Industry	LVIC-S
Large Volume Organic Chemical Industry	LVOC
Management of Tailings and Waste-rock in Mining Activities	MTWR
Manufacture of Glass	GLS
Manufacture of Organic Fine Chemicals	OFC
Non-ferrous Metals Industries	NFM
Production of Cement, Lime and Magnesium Oxide	CLM
Production of Chlor-alkali	CAK
Production of Polymers	POL
Pulp and Paper Industry	PP
Production of Speciality Inorganic Chemicals	SIC
Refining of Mineral Oil and Gas	REF
Slaughterhouses and Animals By-products Industries	SA
Smitheries and Foundries Industry	SF
Surface Treatment of Metals and Plastics	STM
Surface Treatment Using Organic Solvents including Wood and Wood Products Preservation with Chemicals	STS
Tanning of Hides and Skins	TAN
Textiles Industry	TXT
Waste Incineration	*WI*
Waste Treatment	WT
~~Wood and Wood Products Preservation with Chemicals~~	~~WPC~~
Wood-based Panels Production	WBP
Reference Document (REF)	
Economics and Cross-media Effects	ECM
~~General Principles of Monitoring~~ Monitoring of emissions to Air and Water from IED installations	~~MON~~ ROM

Electronic versions of draft and finalised documents are publicly available and can be downloaded from http://eippcb.jrc.ec.europa.eu

~~EXECUTIVE SUMMARY~~

~~The BAT (Best Available Techniques) Reference Document (BREF) entitled Waste Incineration (WI) reflects an information exchange carried out under Article 16(2) of Council Directive 96/61/EC (IPPC Directive). This executive summary describes the main findings, a summary of the principal BAT conclusions and the associated consumption and emission levels. It should be read in conjunction with the preface, which explains this document's objectives; how it is intended to be used and legal terms. It can be read and understood as a standalone document but, as a summary, it does not present all the complexities of this full document. It is therefore not intended as a substitute for this full document as a tool in BAT decision making.~~

~~Scope of this document~~

~~The scope of this document is based on Sections 5.1 and 5.2 of Annex 1 of the IPPC Directive 96/61/EC, in so far as they deal with incineration of waste. The scope chosen for the work was not restricted by the installation size limitations in the IPPC Directive, nor by the definitions of waste, recovery or disposal included therein. The selected scope therefore intended to provide a pragmatic view across the incineration sector as a whole, with a particular focus upon those installation and waste types that are most common. The scope of the Waste Incineration Directive was also a factor taken into account when deciding on the scope of the BREF document. The final contents of the BREF reflect the information that was submitted during the information exchange by the TWG.~~

~~The document deals only with the dedicated incineration of waste and not with other situations where waste is thermally treated, e.g. co-incineration processes such as cement kilns and large combustion plants.~~

~~Although incineration provides the main focus of the document, it also includes some information on waste pyrolysis and gasification systems.~~

~~This BREF document does not:~~

- ~~deal with decisions concerning the selection of incineration as a waste treatment option~~
- ~~compare waste incineration with other waste treatment options.~~

~~Waste Incineration (WI)~~

~~Incineration is used as a treatment for a very wide range of wastes. Incineration itself is commonly only one part of a complex waste treatment system that altogether, provides for the overall management of the broad range of wastes that arise in society.~~

~~The incineration sector has undergone rapid technological development over the last 10 to 15 years. Much of this change has been driven by legislation specific to the industry and this has, in particular, reduced emissions to air from individual installations. Continual process development is ongoing, with the sector now developing techniques which limit costs, whilst maintaining or improving environmental performance.~~

~~The objective of waste incineration, in common with most waste treatments, is to treat waste so as to reduce its volume and hazard, whilst capturing (and thus concentrating) or destroying potentially harmful substances. Incineration processes can also provide a means to enable recovery of the energy, mineral and/or chemical content from waste.~~

~~Basically, waste incineration is the oxidation of the combustible materials contained in the waste. Waste is generally a highly heterogeneous material, consisting essentially of organic substances, minerals, metals and water. During incineration, flue-gases are created that will contain the majority of the available fuel energy as heat. The organic substances in the waste will burn when they have reached the necessary ignition temperature and come into contact with oxygen. The actual combustion process takes place in the gas phase in fractions of seconds and simultaneously releases energy. Where the calorific value of the waste and oxygen supply is~~

~~sufficient, this can lead to a thermal chain reaction and self-supporting combustion, i.e. there is no need for the addition of other fuels.~~

~~Although approaches vary greatly, the incineration sector may approximately be divided into the following main sub-sectors:~~

1. ~~Mixed municipal waste incineration – treating typically mixed and largely untreated household and domestic wastes but may sometimes including certain industrial and commercial wastes (industrial and commercial wastes are also separately incinerated in dedicated industrial or commercial non-hazardous waste incinerators).~~

2. ~~Pretreated municipal or other pretreated waste incineration – installations that treat wastes that have been selectively collected, pretreated, or prepared in some way, such that the characteristics of the waste differ from mixed waste. Specifically prepared refuse derived fuel incinerators fall in this sub-sector~~

3. ~~Hazardous waste incineration – this includes incineration on industrial sites and incineration at merchant plants (that usually receive a very wide variety of wastes)~~

4. ~~Sewage sludge incineration – in some locations sewage sludges are incinerated separately from other wastes in dedicated installations, in others such waste is combined with other wastes (e.g. municipal wastes) for its incineration~~

5. ~~Clinical waste incineration – dedicated installations for the treatment of clinical wastes, typically those arising at hospitals and other healthcare institutions, exist as centralised facilities or on the site of individual hospital etc. In some cases certain clinical wastes are treated in other installations, for example with mixed municipal or hazardous wastes.~~

~~Data in this document shows that, at the time of its compilation:~~

- ~~Around 20 - 25 % of the municipal solid waste (MSW) produced in the EU-15 is treated by incineration (total MSW production is close to 200 million tonnes per year)~~
- ~~The percentage of MSW treated by incineration in individual Member States of the EU-15 varies from 0 % to 62 %~~
- ~~The total number of MSW installations in the EU-15 is over 400~~
- ~~Annual MSW incineration capacity in individual European countries varies from 0 kg to over 550 kg per capita~~
- ~~In Europe the average MSW incinerator capacity is just under 200000 tonnes per year.~~
- ~~The average throughput capacity of the MSWI installations in each MS also varies. The smallest plant size average seen is 60000 tonnes per year and the largest close to 500000 tonnes per year~~
- ~~Around 12 % of the hazardous waste produced in EU-15 is incinerated (total production close to 22 million tonnes per year).~~

~~Expansion of the MSW incineration sector is anticipated in Europe over the next 10 – 15 years as alternatives are sought for the management of wastes diverted from landfill by the Landfill Directive and both existing and new Member States examine and implement their waste management strategies in the light of this legislation.~~

~~Key environmental issues~~

~~Waste and its management are a significant environmental issue. The thermal treatment of waste may therefore be seen as a response to the environmental threats posed by poorly or unmanaged waste streams. The target of thermal treatment is to provide for an overall reduction in the environmental impact that might otherwise arise from the waste. However, in the course of the operation of incineration installations, emissions and consumptions arise, whose existence or magnitude is influenced by the installation design and operation.~~

~~The potential impacts of waste incineration installations themselves fall into the following main categories:~~

- ~~overall process emissions to air and water (including odour)~~
- ~~overall process residue production~~
- ~~process noise and vibration~~
- ~~energy consumption and production~~
- ~~raw material (reagent) consumption~~
- ~~fugitive emissions – mainly from waste storage~~
- ~~reduction of the storage/handling/processing risks of hazardous wastes.~~

~~Other impacts beyond the scope of this BREF document (but which can significantly impact upon the overall environmental impact of the whole chain of waste management) arise from the following operations:~~

- ~~transport of incoming waste and outgoing residues~~
- ~~extensive waste pretreatment (e.g. preparation of waste derived fuels).~~

~~The application and enforcement of modern emission standards, and the use of modern pollution control technologies, has reduced emissions to air to levels at which pollution risks from waste incinerators are now generally considered to be very low. The continued and effective use of such techniques to control emissions to air represents a key environmental issue.~~

~~Other than its role in ensuring effective treatment of otherwise potentially polluting unmanaged wastes, many waste incineration installations have a particular role as an energy-from-waste recovery process. Where policies have been implemented to increase the ability of, (most commonly municipal) waste incineration installations to recover the energy value of the waste, this increases the exploitation of this positive environmental contribution. A significant environmental opportunity for the industry is therefore to increase its potential as an energy supplier.~~

~~Applied processes and techniques~~

~~Chapter 2 of this document provides a description of the processes and techniques that are applied in the waste incineration industry. It focuses upon the most commonly applied thermal treatment of incineration, but also includes information on gasification and pyrolysis. The following main activities and areas are described to varying degrees of detail:~~

- ~~incoming waste reception~~
- ~~storage of waste and raw materials~~
- ~~pretreatment of waste (mainly on-site treatments and blending operations)~~
- ~~loading of waste into the furnace~~
- ~~techniques applied at the thermal treatment stage (furnace design etc.)~~
- ~~the energy recovery stage (e.g. boiler and energy supply options)~~
- ~~flue-gas cleaning techniques (grouped by substance)~~
- ~~flue-gas cleaning residue management~~
- ~~emissions monitoring and control~~
- ~~waste water control and treatment (e.g. from site drainage, flue-gas treatment, storage)~~
- ~~ash/bottom ash management and treatment (arising from the combustion stage).~~

~~Where techniques are specific to certain types of wastes, relevant sections are subdivided according to waste type.~~

~~Consumptions and emissions~~

~~The emissions, and material and energy consumptions, that arise from waste incineration installations are described in Chapter 3. Available data are presented on installation emissions to air and water, noise, and residues. Information on raw material consumptions is also provided,~~

~~along with a section that focuses upon energy consumption and output. Most of the data are whole installation data arising from industrial surveys. Some information about the techniques applied in order to achieve these emission levels is also included.~~

~~Although some European installations have yet to be upgraded, the industry is generally achieving operational levels that meet or improve upon the air emission limit values set in Directive 2000/76/EC.~~

~~In circumstances where CHP or heat (as heat or steam) can be supplied, it is possible for very large percentages of the energy value of the waste (approx. 80 % in some cases) to be recovered.~~

~~Techniques to consider in the determination of BAT~~

~~Each technique described in Chapter 4 includes the available relevant information, on: the consumption and emission levels achievable using the technique; some idea of the costs and the cross-media issues associated with the technique, and; information on the extent to which the technique is applicable to the range of installations requiring IPPC permits – for example new, existing, large or small installations, and to various waste types. Management systems, process-integrated techniques and end-of-pipe measures are included.~~

~~The techniques that are included are those that are considered to have the potential to achieve, or contribute to, a high level of environmental protection in the waste incineration industry. The final BAT, as agreed by the TWG, is not covered in Chapter 4, but in Chapter 5. The inclusion of a technique in Chapter 4, but not in Chapter 5 should not be taken as an indication that the technique is not and cannot be BAT - the rationale for excluding the technique from Chapter 5 could, for example, be that the TWG felt that the technique not sufficiently widely applicable for it to be described as *BAT in general*. Furthermore, because it is not possible to be exhaustive and because the situation is dynamic, Chapter 4 cannot be considered to be entirely comprehensive. Other techniques may also provide for levels of performance that meet or exceed the BAT criteria later established in Chapter 5, and when applied locally those techniques may provide particular advantages in the situation in which they are used.~~

~~The techniques included are grouped in approximately the order in which they would appear in the majority of waste incineration installations. The table below gives the title of the chapter subsections and indicates the grouping to which the techniques are listed.~~

Table: Organisation chart for the information in Chapter 4

~~Chapter 4 section number~~	~~Title of section~~
~~4.1~~	~~General practices applied before thermal treatment~~
~~4.2~~	~~Thermal processing~~
~~4.3~~	~~Energy recovery~~
~~4.4~~	~~Flue-gas treatment~~
~~4.5~~	~~Process water treatment and control~~
~~4.6~~	~~Treatment techniques for solid residues~~
~~4.7~~	~~Noise~~
~~4.8~~	~~Environmental management tools~~
~~4.9~~	~~Good practice for public awareness and communication~~

~~Chapter 4 concentrates on techniques that provide particular advantages at each of the main stages generally seen in waste incineration installations. Dividing the techniques in this way does however mean that, although mentioned in some cases, the important aspect of the overall integration of all of the techniques in an installation (sometimes referred to in the BREF as their "inter-process compatibility") is something which requires careful consideration when reading the individual sections of Chapter 4. The subsections on *operational data* and *applicability* are~~

~~generally where such matters are given consideration. Overall compatibility was also been given further consideration when finally deriving the BAT conclusions in Chapter 5.~~

~~Chapter 4 does not generally describe in detail those techniques that, whilst they provide, or contribute to, a high level of environmental performance, are so common that their use may already be considered as standard. An example of this is that, because the applicability of the main combustor designs to the main waste streams is relatively well established, the techniques considered at this stage concentrate mainly on:~~

~~a) the general issue of ensuring the combustion system selected is properly matched to the wastes fed to it, and~~
~~b) on some aspects relating to improving combustion performance e.g. waste preparation, air supply control, etc.~~

~~**BAT for the incineration of waste**~~
~~The BAT chapter (Chapter 5) identifies those techniques that the TWG considered to be BAT in a general sense, based on the information in Chapter 4, taking into account the Article 2(11) definition of best available techniques and the considerations listed in Annex IV of the Directive.~~

~~The BAT chapter does not set or propose emission limit values but suggests the operational consumption and emission values that are associated with the use of BAT. The introduction to Chapter 5 included in this BREF is specifically extended to clarify certain issues that were considered to be of particular relevance to the waste incineration industry, including the links between the Waste Incineration Directive (WID) and IPPC (see the PREFACE of the BREF). These additional specific issues include:~~

- ~~the difference between WID emission limit values and BAT performance~~
- ~~the relationship between BAT and site selection~~
- ~~how to understand and use the BAT described in Chapter 5.~~

~~The following paragraphs summarise the key BAT conclusions but **reference must be made to the BAT chapter itself to be comprehensive**. The generic BAT are intended to apply to the whole sector (i.e. waste incineration, waste gasification and waste pyrolysis of whatever type of waste). Other BAT are given that apply to sub-sectors dealing primarily with specific waste streams. It is therefore anticipated that a specific installation would apply a combination of the generic and waste specific BAT, and that installations treating mixtures of waste, or wastes not specifically mentioned, would apply the generic BAT plus a suitable selection of the waste specific BAT. Further comment on the combining of the BAT is included in the introduction to Chapter 5.~~

~~**Generic BAT**~~
~~A fundamental BAT stresses the importance of the selecting an installation design that is suited to the characteristics of the waste received at the installation in terms of both its physical and chemical characteristics. This BAT is fundamental to ensuring the installation may treat the waste received with a minimum of process disturbances – which themselves may give rise to additional environmental impacts. To this end there is also a BAT about the minimisation of planned and unplanned shutdowns.~~

~~BAT includes establishing and maintaining quality controls over the waste input. This aims to ensure that the waste characteristics remain suited to the design of the receiving installation. Such quality control procedures are compatible with the application of an environmental management system, which is also considered BAT.~~

~~There are several BAT regarding the conditions and management of the storage of incoming wastes prior to their treatment, so that this does not give rise to pollution and odour releases.~~

~~Some specific techniques and conditions of storage are noted. A risk based approach that takes into account the properties of the waste concerned is considered BAT.~~

~~Consideration of the demonstrated ability of some installation designs to very efficiently treat highly heterogeneous wastes (e.g. mixed MSW), and the risks and cross-media effects associated with pretreatment, results in a conclusion that it is BAT to pretreat incoming wastes to the degree required to meet the design specification for the receiving installation, noting that to treat wastes beyond this requires balanced consideration of (possibly limited) benefits, operational factors and cross-media effects.~~

~~The design and operation of the combustion stage is identified as an important primary pollution prevention aspect, and therefore of great relevance to achieving the aims of the IPPC Directive. It is noted in the BAT chapter that flow modelling at the design stage may assist in ensuring that certain key design decisions are well informed. In operation, it is considered BAT to use various techniques (e.g. control of air supply and distribution) to control combustion. The BAT regarding the selection of a design that suits the waste received is of particular relevance here.~~

~~In general the use of the combustion operating conditions specified in Article 6 of Directive 2000/76/EC (WID) are considered to be compatible with BAT. However the TWG noted, that the use of conditions in excess of these (e.g. higher temperatures) could result in an overall deterioration in environmental performance, and that there were several examples of hazardous waste installations that had demonstrated an overall improvement in environmental performance when using lower operational temperatures than the 1100 °C specified in WID for certain hazardous wastes. The general BAT conclusion was that the combustion conditions (e.g. temperature) should be sufficient to achieve the destruction of the waste but, in order to limit potential cross-media impacts, generally not significantly in excess of those conditions. The provision of auxiliary burner(s) for achieving and maintaining operational conditions is considered to be BAT when waste is being burned.~~

~~When gasification or pyrolysis is used, in order to prevent the generation of waste by disposal of the reaction products of these techniques, it is BAT either, to recover the energy value from the products using a combustion stage, or to supply them for use. The BAT associated emission levels for releases to air from the combustion stage of such installations are the same as those established for incineration installations.~~

~~The recovery of the energy value of the waste is a key environmental issue for the sector, presenting an area where the sector may make a significant positive contribution. Several BAT cover this aspect, dealing with:~~

- ~~specific techniques that are considered to be BAT~~
- ~~the heat transfer efficiencies expected of boilers~~
- ~~the use of CHP, district heating, industrial steam supply and electricity production~~
- ~~the recovery efficiencies that may be anticipated.~~

~~With CHP and steam/heat supply generally offering the greatest opportunity for increasing energy recovery rates, policies affecting the availability of suitable customers for steam/heat generally play a far greater role in determining the efficiency achievable at an installation than the detail of its design. For mainly policy and economic reasons, electricity generation and supply is often the energy recovery option selected at individual installations. Options for CHP, district heating and industrial steam supply are only well exploited in a few European Member States – generally those that have high heat prices and/or that have adopted particular policies. The supply of energy for the operation of cooling systems and desalination plants is something that is done, but is in general poorly exploited – such an option may be of particular interest in warmer climate zones, and in general expands the options for the supply of waste derived energy.~~

~~The flue-gas treatments applied at waste incineration installations have been developed over many years in order to meet stringent regulatory standards and are now highly technically advanced. Their design and operation are critical to ensure that all emissions to air are well controlled. The BAT that are included:~~

- ~~cover the process of selection of FGT systems~~
- ~~describe several specific techniques which are considered to be BAT~~
- ~~describe the performance levels that are anticipated from the application of BAT.~~

~~The performance ranges agreed by the wider TWG resulted in some split views. These were mainly from one Member State and the Environmental NGO, who believed that lower emission values than the ranges agreed by the remainder of the TWG could also be considered to be BAT.~~

~~The BAT regarding waste water control include:~~

- ~~the in-process recirculation of certain effluents~~
- ~~the separation of drainage for certain effluents~~
- ~~the use of on-site effluent treatment for wet scrubber effluents~~
- ~~BAT associated performance levels for emissions from scrubber effluent treatment~~
- ~~the use of specific techniques.~~

~~The performance ranges agreed by the wider TWG resulted in some split views from one Member State and the Environmental NGO, who believed that lower emission values than the ranges given could also be considered to be BAT.~~

~~BAT regarding residue management include:~~

- ~~a bottom ash burnout TOC level of below 3 %, with typical values falling between 1 and 2 %~~
- ~~a list of techniques, which when suitably combined may attain these burnout levels~~
- ~~the separate management of bottom ash from fly ash and a requirement to assess each stream produced~~
- ~~the extraction of ferrous and non-ferrous metals from ash for their recovery (where present in ash to sufficient degree to make this viable)~~
- ~~the treatment of bottom ashes and other residues using certain techniques - to the extent required for them to meet the acceptance criteria at the receiving recovery or disposal site.~~

~~In addition to these generic BAT, more specific BAT are identified for those sub-sectors of the industry treating mainly the following wastes:~~

- ~~municipal wastes~~
- ~~pretreated or selected municipal wastes~~
- ~~hazardous wastes~~
- ~~sewage sludge~~
- ~~clinical waste.~~

~~The specific BAT provide, where it has been possible, more detailed BAT conclusions. These conclusions deal with the following waste stream specific issues:~~

- ~~in-coming waste management, storage and pretreatment~~
- ~~combustion techniques~~
- ~~energy recovery performance.~~

~~Emerging techniques~~

~~The section on emerging techniques is not comprehensive. A number of the techniques supplied by the TWG and included in earlier drafts of this document were transferred into this section. In~~

~~the majority of cases the techniques included have only been demonstrated on a pilot or trial scale.~~

~~The degree of demonstration (as measured by overall throughput and operational hours) of pyrolysis and gasification on the main European waste streams is low compared with incineration and operational difficulties are reported at some installations. However, both gasification and pyrolysis are applied in the sector and therefore, according to the BREF definition, cannot be considered to be *emerging techniques*. For this reason the information concerning these techniques is included in Chapter 4.~~

~~**Concluding remarks**~~

~~**Information exchange**~~
~~This BREF is based on several hundred sources of information, and over 7000 consultation comments supplied by a very large working group. Some of the information was overlapping and therefore, not all of the documents supplied are referenced in the BREF. Both industry and Member States supplied important information. Data quality was generally good, particularly for emissions to air, allowing valid comparisons to be made in some cases. This was not however uniformly the case, and data regarding costs was difficult to compare owing to inconsistencies in data compilation and reporting. The consumption and emissions data given are predominantly for whole installations or groups of techniques, rather than individual ones. This has lead to some important BAT conclusions being expressed as quantitative overall performance targets, with certain technical options presented that when suitably combined, may give rise to that performance.~~

~~**Level of consensus**~~
~~There was a very good general level of consensus. There was full agreement, and no split views, in relation to the technique related BAT. There was also generally good consensus upon the quantitative BAT, although the operational emission levels associated with the use of BAT did give rise to some split views, with one Member State and the Environmental NGO recording split views in relation to many of the BAT associated emission levels for releases to both air and water.~~

~~**Recommendations for future work and R&D projects**~~
~~The information exchange and its result, i.e. this BREF, provide a step forward in achieving the integrated prevention and control of pollution from waste incineration. Further work could continue the process by providing:~~

- ~~information regarding the techniques used to, and costs of, upgrading existing installations – such information may be derived from experience of implementing WID in Member States and might usefully be compared with the costs/performance at new installations~~
- ~~the more detailed cost information that is required to undertake a more precise assessment of variations in technique affordability with plant size and waste type~~
- ~~information regarding smaller installations – very little information was provided regarding small installations~~
- ~~information regarding installations that treat industrial non-hazardous wastes and the impact on installations of treating mixtures of wastes e.g. sewage sludge or clinical waste with MSW~~
- ~~a more detailed evaluation of the impact on pollution prevention of detailed combustion design features e.g. grate design~~
- ~~further information on emerging techniques.~~
- ~~ammonia consumption and emission (mainly to air and water) levels for different FGT systems (mainly wet, semi-wet and dry) and their relative NO_X reduction efficiency~~
- ~~the impact of the dust removal temperature range upon PCDD/F releases to air and residues~~
- ~~further experiences with continuous emissions monitoring for Hg (to air and water).~~

~~Other important recommendations for further work beyond the scope of this BREF but arising from the information exchange are:~~

- ~~the need for consideration of the overall impact of competition for waste treatment, in particular competition from industries co-incinerating wastes a study of such might usefully include consideration of: relative reliability of, and risks to, the supply of the total waste management service; overall emissions and energy recovery according to various degrees of diversion, and; consider and identify key risk factors e.g. waste fuel quality assurance.~~
- ~~it may be useful to assess the impact on adopted waste strategies (i.e. the balance of technologies used on a national scale), and on achieved thermal treatment installation efficiencies, of the degree of integration of energy and waste management policy in EU Member States (and other countries). Such studies may identify how policy on energy and waste interact and give examples, both positive and negative.~~
- ~~the need to understand in more detail of the impact of absolute and relative energy prices (for electricity and heat) upon the typically achieved energy efficiency of installations, and the role and impact of subsidies and taxation schemes~~
- ~~the identification of the typical barriers to developing new installations and the approaches that have proved successful~~
- ~~the development of suitable standards for the use of bottom ash such standards have proved helpful in improving markets for the use of bottom ash~~
- ~~the costs and benefits of further reducing emissions from the waste incineration industry when compared to reductions at other industrial and anthropogenic sources of pollution.~~

~~The EC is launching and supporting, through its RTD programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially these projects could provide a useful contribution to future BREF reviews. Readers are therefore invited to inform the EIPPCB of any research results which are relevant to the scope of this document (see also the preface of this document).~~

PREFACE

1. Status of this document

Unless otherwise stated, references to 'the Directive' in this document refer to Directive 2010/75/EU of the European Parliament and the Council on industrial emissions (integrated pollution prevention and control) (Recast). ~~means the Council Directive 96/61/EC on integrated pollution prevention and control. As the Directive applies without prejudice to Community provisions on health and safety at the workplace, so does this document~~.

This document is a working draft of the European IPPC Bureau (of the Commission's Joint Research Centre). It is not an official publication of the European Union and does not necessarily reflect the position of the European Commission.

~~This document forms part of a series presenting the results of an exchange of information between EU Member States and industries concerned on best available technique (BAT), associated monitoring, and developments in them. It is published by the European Commission pursuant to Article 16(2) of the Directive, and must therefore be taken into account in accordance with Annex IV of the Directive when determining "best available techniques".~~

~~2. Relevant legal obligations of the IPPC Directive and the definition of BAT~~

~~In order to help the reader understand the legal context in which this document has been drafted, some of the most relevant provisions of the IPPC Directive, including the definition of the term "best available techniques", are described in this preface. This description is inevitably incomplete and is given for information only. It has no legal value and does not in any way alter or prejudice the actual provisions of the Directive.~~

~~The purpose of the Directive is to achieve integrated prevention and control of pollution arising from the activities listed in its Annex I, leading to a high level of protection of the environment as a whole. The legal basis of the Directive relates to environmental protection. Its implementation should also take account of other Community objectives such as the competitiveness of the Community's industry thereby contributing to sustainable development.~~

~~More specifically, it provides for a permitting system for certain categories of industrial installations requiring both operators and regulators to take an integrated, overall look at the polluting and consuming potential of the installation. The overall aim of such an integrated approach must be to improve the management and control of industrial processes so as to ensure a high level of protection for the environment as a whole. Central to this approach is the general principle given in Article 3 that operators should take all appropriate preventative measures against pollution, in particular through the application of best available techniques enabling them to improve their environmental performance.~~

~~The term "best available techniques" is defined in Article 2(11) of the Directive as "the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole." Article 2(11) goes on to clarify further this definition as follows:~~

~~"techniques" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;~~

~~"available" techniques are those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;~~

~~"best" means most effective in achieving a high general level of protection of the environment as a whole.~~

~~Furthermore, Annex IV of the Directive contains a list of "considerations to be taken into account generally or in specific cases when determining best available techniques... bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention". These considerations include the information published by the Commission pursuant to Article 16(2).~~

~~Competent authorities responsible for issuing permits are required to take account of the general principles set out in Article 3 when determining the conditions of the permit. These conditions must include emission limit values, supplemented or replaced where appropriate by equivalent parameters or technical measures. According to Article 9(4) of the Directive, these emission limit values, equivalent parameters and technical measures must, without prejudice to compliance with environmental quality standards, be based on the best available techniques, without prescribing the use of any technique or specific technology, but taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In all circumstances, the conditions of the permit must include provisions on the minimisation of long distance or transboundary pollution and must ensure a high level of protection for the environment as a whole.~~

~~Member States have the obligation, according to Article 11 of the Directive, to ensure that competent authorities follow or are informed of developments in best available techniques.~~

2. Participants in the information exchange ~~Objective of this Document~~

As required in Article 13(3) of the Directive,~~ requires~~ the Commission has established a forum to promote the exchange of information, which is composed of representatives from Member States, the industries concerned and non-governmental organisations promoting environmental protection (Commission Decision of 16 May 2011 establishing a forum for the exchange of information pursuant to Article 13 of the Directive 2010/75/EU on industrial emissions (2011/C 146/03), OJ C 146, 17.05.2011, p. 3).

Forum members have nominated technical experts constituting the technical working group (TWG) that was the main source of information for drafting this document. The work of the TWG was led by the European IPPC Bureau (of the Commission's Joint Research Centre).
~~to organise "an exchange of information between Member States and the industries concerned on best available techniques, associated monitoring and developments in them", and to publish the results of the exchange.~~

~~The purpose of the information exchange is given in recital 25 of the Directive, which states that "the development and exchange of information at Community level about best available techniques will help to redress the technological imbalances in the Community, will promote the worldwide dissemination of limit values and techniques used in the Community and will help the Member States in the efficient implementation of this Directive."~~

~~The Commission (Environment DG) established an information exchange forum (IEF) to assist the work under Article 16(2) and a number of technical working groups have been established under the umbrella of the IEF. Both IEF and the technical working groups include representation from Member States and industry as required in Article 16(2).~~

~~The aim of this series of documents is to reflect accurately the exchange of information which has taken place as required by Article 16(2) and to provide reference information for the permitting authority to take into account when determining permit conditions. By providing relevant information concerning best available techniques, these documents should act as valuable tools to drive environmental performance.~~

~~4. Information Sources~~

~~This document represents a summary of information collected from a number of sources, including in particular the expertise of the groups established to assist the Commission in its work, and verified by the Commission services. All contributions are gratefully acknowledged.~~

3. Structure and contents of ~~How to understand and use~~ this document

~~The information provided in this document is intended to be used as an input to the determination of BAT in specific cases. When determining BAT and setting BAT-based permit conditions, account should always be taken of the overall goal to achieve a high level of protection for the environment as a whole.~~

Chapters 1 and 2 provide general information on the industrial sector concerned and on the industrial processes used within the sector.

Chapter 3 provides data and information concerning current emission and consumption levels, reflecting the situation in existing installations at the time of writing.

Chapter 4 describes in more detail the techniques to prevent or, where this is not practicable, to reduce the environmental impact of installations in this sector that were considered in ~~emission reduction and other techniques that are considered to be most relevant for~~ determining BAT ~~and BAT-based permit conditions~~. This information includes, where relevant, the environmental performance levels (e.g. emission and consumption levels) which can be achieved by using the techniques, the associated monitoring and the costs and the cross-media issues associated with the techniques ~~consumption and emission levels considered achievable by using the technique, some idea of the costs and the cross-media issues associated with the technique, and the extent to which the technique is applicable to the range of installations requiring IPPC permits, for example new, existing, large or small installations. Techniques that are generally seen as obsolete are not included~~.

Chapter 5 presents the BAT conclusions as defined in Article 3(12) of the Directive ~~techniques and the emission and consumption levels that are considered to be compatible with BAT in a general sense. The purpose is thus to provide general indications regarding the emission and consumption levels that can be considered as an appropriate reference point to assist in the determination of BAT-based permit conditions or for the establishment of general binding rules under Article 9(8). It should be stressed, however, that this document does not propose emission limit values. The determination of appropriate permit conditions will involve taking account of local, site-specific factors such as the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In the case of existing installations, the economic and technical viability of upgrading them also needs to be taken into account. Even the single objective of ensuring a high level of protection for the environment as a whole will often involve making trade-off judgements between different types of environmental impact, and these judgements will often be influenced by local considerations.~~
~~Although an attempt is made to address some of these issues, it is not possible for them to be considered fully in this document. The techniques and levels presented in the (BAT) chapter(s) to be added will therefore not necessarily be appropriate for all installations. On the other hand, the obligation to ensure a high level of environmental protection including the minimisation of long-distance or transboundary pollution implies that permit conditions cannot be set on the basis of purely local considerations. It is therefore of the utmost importance that the information contained in this document is fully taken into account by permitting authorities.~~

Chapter 6 presents information on 'emerging techniques' as defined in Article 3(14) of the Directive.

Chapter 7 presents concluding remarks and recommendations for future work.

4. Information sources and the derivation of BAT

This document is based on information collected from a number of sources, in particular through the TWG that was established specifically for the exchange of information under Article 13 of the Directive. The information has been collated and assessed by the European IPPC Bureau (of the Commission's Joint Research Centre) who led the work on determining BAT, guided by the principles of technical expertise, transparency and neutrality. The work of the TWG and all other contributors is gratefully acknowledged.

The BAT conclusions have been established through an iterative process involving the following steps:

- identification of the key environmental issues for the Waste Incineration sector;
- examination of the techniques most relevant to address these key issues;
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide;
- examination of the conditions under which these environmental performance levels were achieved, such as costs, cross-media effects, and the main driving forces involved in the implementation of the techniques;
- selection of the best available techniques (BAT), their associated emission levels (and other environmental performance levels) and the associated monitoring for this sector according to Article 3(10) of, and Annex III to, the Directive.

Expert judgement by the European IPPC Bureau and the TWG has played a key role in each of these steps and the way in which the information is presented here.

Where available, economic data have been given together with the descriptions of the techniques presented in Chapter 4. These data give a rough indication of the magnitude of the costs and benefits. However, the actual costs and benefits of applying a technique may depend strongly on the specific situation of the installation concerned, which cannot be evaluated fully in this document. In the absence of data concerning costs, conclusions on the economic viability of techniques are drawn from observations on existing installations.

5. Review of BAT reference documents (BREFs)

BAT is a dynamic concept and so the review of BREFs is a continuing process. For example, new measures and techniques may emerge, science and technologies are continuously developing and new or emerging processes are being successfully introduced into the industries. In order to reflect such changes and their consequences for BAT, this document will be periodically reviewed and, if necessary, updated accordingly.

~~Since the best available techniques change over time, this document will be reviewed and updated as appropriate.~~

6. Contact information

All comments and suggestions should be made to the European IPPC Bureau at the Joint Research Centre ~~Institute for Prospective Technological Studies~~ at the following address:

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~~6. Interface between the IPPC and the Waste Incineration Directives~~

~~The following presentation of the issues is related to the interface between Directive 2000/76/EC of 4 December 2000 on the incineration of waste (WI Directive) and Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control (IPPC Directive).~~

~~It should be noted that the ultimate interpretation of Community law is a matter for the European Court of Justice and therefore it cannot be excluded that interpretation by the Court may raise new issues in the future.~~
~~The WI Directive contains, among others, the following explicit reference to the IPPC Directive:~~

~~Recital 13 of the WI Directive states that *"Compliance with the emission limit values laid down by this Directive should be regarded as a necessary but not sufficient condition for compliance with the requirements of Directive 96/61/EC. Such compliance may involve more stringent emission limit values for the pollutants envisaged by this Directive, emission limit values for other substances and other media, and other appropriate conditions."*~~

~~The recital makes clear that compliance with the emissions limit values laid down in the WI Directive does not remove the obligation to operate in compliance with all the provisions of the IPPC Directive, including a permit containing emission limit values or equivalent parameters and technical measures determined according to the provisions of Article 9(4) or Article 9(8) of the latter. As presented in the standard BREF preface, a certain flexibility is anchored in the provisions of Article 9(4) of the IPPC Directive as well as in the definition of BAT. However, if stricter conditions, compared to the conditions of the WI Directive, are determined by a competent authority or through general binding rules to be necessary to fulfil the requirements of the IPPC Directive for a particular permit, these stricter conditions shall apply.~~

Text in black is original text from the adopted (2006) BREF. ~~Strikethroughs mark text that was deleted in Draft 1~~. Text in green is new text in Draft 1

Please note that the following are not colour-coded for readability and efficiency:
- typo corrections,
- relocation of words within the same paragraph,
- changes in punctuation, capitalisation, hyphenation, and brackets.

Please also note that when large text sections are repositioned within the document, *placeholders highlighted in blue* indicate the repositioning but no strikethrough is used.

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SCOPE

This BREF for waste incineration covers the following activities specified in Annex I to Directive 2010/75/EU:

5.2 Disposal or recovery of waste in waste incineration plants:
  (a) for non-hazardous waste with a capacity exceeding 3 tonnes per hour;
  (b) for hazardous waste with a capacity exceeding 10 tonnes per day.

5.2 Disposal or recovery of waste in waste co-incineration plants:
  (a) for non-hazardous waste with a capacity exceeding 3 tonnes per hour;
  (b) for hazardous waste with a capacity exceeding 10 tonnes per day;
whose main purpose is not the production of material products and:

- which combust only waste, other than waste defined in Article 3(31)(b) of Directive 2010/75/EU; or
- where more than 40 % of the resulting heat release comes from hazardous waste; or
- which combust mixed municipal waste.

5.3 (a) Disposal of non-hazardous waste with a capacity exceeding 50 tonnes per day involving the treatment of slags and/or bottom ashes from the incineration of waste.

5.3 (b) Recovery, or a mix of recovery and disposal, of non-hazardous waste with a capacity exceeding 75 tonnes per day involving the treatment of slags and/or bottom ashes from the incineration of waste.

This document does not address the following:

- Pre-treatment of waste prior to incineration; this may be covered by the BAT conclusions for Waste Treatment (WT).
- Treatment of incineration fly ashes and other residues resulting from flue-gas cleaning (FGC). These may be covered by the BAT conclusions for Waste Treatment (WT).
- Incineration or co-incineration of exclusively gaseous waste.
- Treatment of waste in plants covered by Article 42(2) of Directive 2010/75/EU.

Other reference documents which could be relevant for the activities covered by these BAT conclusions are the following:

- Waste Treatment (WT);
- Economics and Cross-Media Effects (ECM);
- Emissions from Storage (EFS);
- Energy Efficiency (ENE);
- Industrial Cooling Systems (ICS);
- Monitoring of Emissions to Air and Water from IED installations (ROM);
- Large Combustion Plants (LCP).

~~The following comments are relevant to the scope of this document:~~

1. ~~The scope of this document is mainly influenced by the scope of the information provided by, and decisions of, the members of the Technical Working Group (TWG) on waste incineration, and the time and resources available.~~

2. ~~Annexe 1 of the IPPC Directive (96/61/EC) provided the starting point for the scope of this BAT reference document, where it includes sections as follows:~~

> ~~*5.1. Installations for the disposal or recovery of hazardous waste as defined in the list referred to in Article 1 (4) of Directive 91/689/EEC, as defined in Annexes II A and II B*~~

~~*(operations R1, R5, R6, R8 and R9) to Directive 75/442/EEC and in Council Directive 75/439/EEC of 16 June 1975 on the disposal of waste oils (2), with a capacity exceeding 10 tonnes per day*~~

~~*5.2. Installations for the incineration of municipal waste as defined in Council Directive 89/369/EEC of 8 June 1989 on the prevention of air pollution from new municipal waste incineration plants (3) and Council Directive 89/429/EEC of 21 June 1989 on the reduction of air pollution from existing municipal waste incineration plants (4) with a capacity exceeding 3 tonnes per hour*~~

~~The TWG working on this document decided at an early stage that the document should not be restricted by the size limitations in these sections of the IPPC Directive, nor by the definitions of waste, and recovery or disposal included therein. This being the case, the selected scope of the document aimed to reflect a pragmatic view across the incineration sector as a whole, with a particular focus upon those installations and waste types that are most common. The scope of the Waste Incineration Directive 76/2000/EC was also a factor taken into account by the TWG when deciding on the scope for the document.~~

3. ~~The document seeks to provide information concerning dedicated waste incineration installations. It does not cover other situations where waste is thermally treated, e.g. co-incineration processes such as some cement kilns and large combustion plants - these situations are (or will be) covered by the BREF that deals specifically with those industries. While some of the techniques that are included here may be technically applicable to other industries (i.e. those that are not dedicated incinerators) that incinerate waste, or a proportion of waste, whether the techniques identified here, or the performance levels they give rise to, are BAT for those sectors, has not been a part of the scope of this work.~~

4. ~~Although incineration provides the main focus of this document, three main thermal treatment techniques are described, in general as they relate to some common waste streams. These are:~~

   - ~~incineration~~
   - ~~pyrolysis~~
   - ~~gasification.~~

   ~~Various incineration techniques are covered. Incineration is applied to the treatment of a very wide variety of wastes. Pyrolysis and gasification are less widely applied to wastes, and generally to a narrower range of wastes.~~

   ~~Combinations of incineration, pyrolysis and gasification are also referred to. Each of the techniques and combinations of techniques are covered in this document within the context of their application to the treatment of various wastes (although this does not imply any definition of the meaning of *waste* - see also comment 5 below)~~

5. ~~In addition to the thermal treatment stage of the installation this document also covers (to varying degrees):~~

- ~~waste reception, handling and storage~~
- ~~the effect of waste pretreatment on the selection and operation of waste incineration processes (in some cases this includes a description of the techniques applied)~~
- ~~applied flue-gas treatment techniques~~
- ~~applied residue treatments techniques (for the main residues commonly produced)~~
- ~~applied waste water treatment techniques~~
- ~~some aspects of energy recovery, the performance achieved and techniques used (details of electrical generation equipment etc. are not included).~~

6. ~~If an installation is referred to or included in this document this does not have any legal consequence. It does not mean that the installation is legally classed as an *incinerator* nor does it imply that the material being treated is legally classed as *waste*~~

7. ~~No size threshold has been applied when gathering information. However, it is noted that, to date, limited information has been supplied concerning smaller incineration processes~~

8. ~~This document does not deal with decisions concerning the selection of incineration as a waste treatment option. Neither, does it compare incineration with other waste treatments.~~

9. ~~There is another BREF that deals with "Waste Treatments". It has a wide scope and covers many other installations and techniques that are applied to the treatment of waste.~~

1 GENERAL INFORMATION ON WASTE INCINERATION

For the TWG: to be updated. Please provide information.

1.1 Purpose of incineration and basic theory

[1, UBA, 2001], [64, TWGComments, 2003]
Incineration is used as a treatment for a very wide range of wastes. Incineration itself is commonly only one part of a complex waste treatment system that altogether, provides for the overall management of the broad range of wastes that arise in society.

The incineration sector has undergone rapid technological development over the last 25 ~~10 to 15~~ years. Much of this change has been driven by legislation specific to the industry and this has, in particular, reduced emissions to air from individual installations. Continual process development is ongoing, with the sector now developing techniques which limit costs, whilst maintaining or improving environmental performance.

The objective of waste incineration is to treat wastes so as to reduce their volume and hazard, whilst capturing (and thus concentrating) or destroying potentially harmful substances that are, or may be, released during incineration. Incineration processes can also provide a means to enable recovery of the energy, mineral and/or chemical content from waste.

Basically, waste incineration is the oxidation of the combustible materials contained in the waste. Waste is generally a highly heterogeneous material, consisting essentially of organic substances, minerals, metals and water. During incineration, flue-gases are created that will contain the majority of the available fuel energy as heat.

The organic fuel substances in the waste will burn when they have reached the necessary ignition temperature and come into contact with oxygen. The actual combustion process takes place in the gas phase in fractions of seconds and simultaneously releases energy where the calorific value of the waste and oxygen supply is sufficient, this can lead to a thermal chain reaction and self-supporting combustion, i.e. there is no need for the addition of other fuels.

The main stages of incineration process are:

1. drying and degassing – here, volatile content is evolved (e.g. hydrocarbons and water) at temperatures generally between 100 and 300 °C. The drying and degassing process do not require any oxidising agent and are only dependent on the supplied heat.

2. pyrolysis and gasification - pyrolysis is the further decomposition of organic substances in the absence of an oxidising agent at approximately 250 – 700 °C. Gasification of the carbonaceous residues is the reaction of the residues with water vapour and CO_2 at temperatures, typically between 500 and 1 000 °C, but can occur at temperatures up to 1 600 °C. Thus, solid organic matter is transferred to the gaseous phase. In addition to the temperature, water, steam and oxygen support this reaction.

3. oxidation - the combustible gases created in the previous stages are oxidised, depending on the selected incineration method, at flue-gas temperatures generally between 800 and 1 450 °C.

These individual stages generally overlap, meaning that spatial and temporal separation of these stages during waste incineration may only be possible to a limited extent. Indeed the processes partly occur in parallel and influence each other. Nevertheless it is possible, using in-furnace technical measures, to influence these processes so as to reduce polluting emissions. Such measures include furnace design, air distribution and control engineering.

In fully oxidative incineration the main constituents of the flue-gas are: water vapour, nitrogen, carbon dioxide and oxygen. Depending on the composition of the material incinerated and on the operating conditions, smaller amounts of CO, HCl, HF, HBr, HI, NO_X SO_2, VOCs, PCDD/F, PCBs and heavy metal compounds (among others) are formed or remain. Depending on the combustion temperatures during the main stages of incineration, volatile heavy metals and inorganic compounds (e.g. salts) are totally or partly evaporated. These substances are transferred from the input waste to both the flue-gas and the fly ash it contains. A mineral residue fly ash (dust) and heavier solid ash (bottom ash) are created. In municipal waste incinerators, bottom ash is approximately 10 vol-% and approximately 20–30 wt-% of the solid waste input. Fly ash quantities are much lower, generally only a few per cent of input. The proportions of solid residue vary greatly according to the waste type and detailed process design.

For effective oxidative combustion, a sufficient oxygen supply is essential. The air ratio number 'n' of the supplied incineration air to the chemically required (or stoichiometric) incineration air, usually ranges from 1.2 to 2.5, depending on whether the fuel is gas, liquid or solid, and the furnace system.

~~The~~ Combustion ~~stage~~ is only one stage of the overall incineration process ~~installation~~. Incinerators usually comprise a complex set of interacting technical components which, when considered together, effect an overall treatment of the waste. Each of these components has a slightly different main purpose, as described in Table 1.1 below:

Table 1.1: Purpose of various components of a waste incinerator

Objective	Responsibility of
• destruction of organic substances • evaporation of water • evaporation of volatile heavy metals and inorganic salts • production of potentially exploitable slag • volume reduction of residues	Furnace
• recovery of useable energy	Energy recovery system
• removal and concentration of volatile heavy metals and inorganic matter into solid residues e.g. flue-gas cleaning residues, sludge from waste water treatment • minimising emissions to all media	Flue-gas cleaning

Source: [1, UBA, 2001], [64, TWGComments, 2003]

1.2 Overview of waste incineration in Europe

The scale of use of incineration as a waste management technique varies greatly from location to location. For example, in European Member States the variation of incineration in municipal waste treatments ranges from zero to 62 per cent.

[9, VDI, 2002] In EU-15 Member States (MS) an annual quantity of approximately 200 million tonnes of waste may be considered suitable for thermal waste treatment. However, the total installed capacity of thermal waste treatment plants is only in the order of 50 million tonnes.

Table 1.2 below gives an estimate of the treatment of the waste arising in each MS for municipal waste, hazardous waste and sewage sludge. Deposited waste is included because a considerable proportion of these wastes may, in future, be diverted to other waste treatment methods, including incineration.

Note: as definitions and waste categories differ from one country to another, some of the values given may not be directly comparable.

[*to the TWG: This section is to be updated at a later stage.*]

Table 1.2: Amounts of municipal waste (MSW), hazardous waste (HW) and sewage sludge (SS) in EU-15 MS, and their treatment

Country	Municipal Solid Waste (MSW)				Hazardous Waste (HW)				Sewage Sludge (SS)	
	Total estimated MSW-production (in 10^6 tonnes)	Year of data source	% landfilled *(or amount in 10^6 tonnes)*	% incinerated *(or amount in 10^6 tonnes)*	Total estimated HW-production (in 10^6 tonnes)	Year of data source	Amount landfilled (in 10^6 tonnes)	Amount incinerated (in 10^6 tonnes)	Total estimated SS-production (in 10^6 tonnes as dry solids)	Year of data source
Austria	1.32	1999	51	35	0.97	1999	*Not supplied*	0.11	0.39	1999
Belgium	4.85	1997	42	35	2.03	1997	0.79	0.14	0.85	1997
Denmark	2.77	1996	15	56	0.27	1996	0.09	0.1	0.15	1997
Finland	0.98	1997	77	2	0.57	1997	0.28	0.1	0.14	1997
France	48.5	2000	55	26	*Not supplied*	1997 2001	*Not supplied*	0.77 (note 5)	0.82	1997
Germany	45	2000	30	29	9.17	2000	2.7	0.85	2.48	1998
Greece	3.20	1993	93	0	*Not supplied*	1993	*Not supplied*	*Not supplied*	*Not supplied*	*Not supplied*
Ireland	1.80	1998	100	0	0.23	1995	0.03	0.03	0.39	1997
Italy	25.40	1995	85	8	*Not supplied*	1995	*Not supplied*	*Not supplied*	*Not supplied*	*Not supplied*
Luxembourg	0.30	1995	24	48	0.14	1995	*Not supplied*	*Not supplied*	*Not supplied*	*Not supplied*
Portugal	4.6	2002	71	20	0.25	2001	*Not supplied*	*Not supplied*	0.24	2000
Spain	17	1997	85	10	2	1997	*Not supplied*	0.03	*Not supplied*	*Not supplied*
Sweden	3.80	1999 (note 1)	24 *(0.92)*	38 *(1.44)*	0.27	1999	*Not supplied*	0.1		1997
Netherlands	10.2	2002	11	76	2.7	2002	0.6	0.28	0.69	1999
United Kingdom	27.20	1999	85	6	2.37	1996	0.86	0.24	1.2	1999 (note 3)
EU-15 Totals (note 6)	**196.92**				**21.92**		**5.35**	**2.72**	**7.58**	

Notes
1 Swedish Waste Management 2000 (RVF)
2
3 ENDS Report 312 January 2001 (figures include co-incineration (50 %/50 %)
4 The balance to 100 % for the treatment methodologies is e.g. due to recovery and recycling
5 Hazardous waste incinerated in external dedicated units
6 Totals given are a simple addition of figures provided and therefore are of mixed years. Percentages landfilled etc. not averaged as figures have little meaning without actual mass data.
Source: [1, UBA, 2001], [64, TWGComments, 2003]

Table 1.3 shows the quantities of some wastes arising and number of waste incinerator plants in other European Countries:

Table 1.3: Annual quantities of municipal and hazardous waste arising and the number of incineration plants in some Accession Countries

Country	Data year	Municipal waste in 10^6 tonnes	Total number of MSWI	MSWI (>3 t/h)	Hazardous waste in 10^6 tonnes	Total number of HWI	HWI (>10 t/d)
Bulgaria	1998	3.199	0	0	0.548	0	0
Czech Republic	1999	4.199	3	3	3.011	72	14
Estonia	1999	0.569	0	0	0.06	1	0
Hungary	1998	5	1	1	3.915	7	*Not supplied*
Latvia	1998	0.597	0	0	0.0411	0	0
Lithuania	1999	1.211	0	0	0.2449	0	0
Poland	1999	12.32	4	1	1.34	13	4
Romania	1999	7.631	0	0	2.323	3	3
Slovakia	1999	3.721	2	2	1.738	*Not supplied*	1
Slovenia	1995	1.024	0	0	0.025	0	0
Totals		**39 470**	**10**	**7**	**13.25**	**96**	**22**

NB: Totals are simple column totals and therefore include mixed year data
Source: [1, UBA, 2001], [64, TWGComments, 2003]

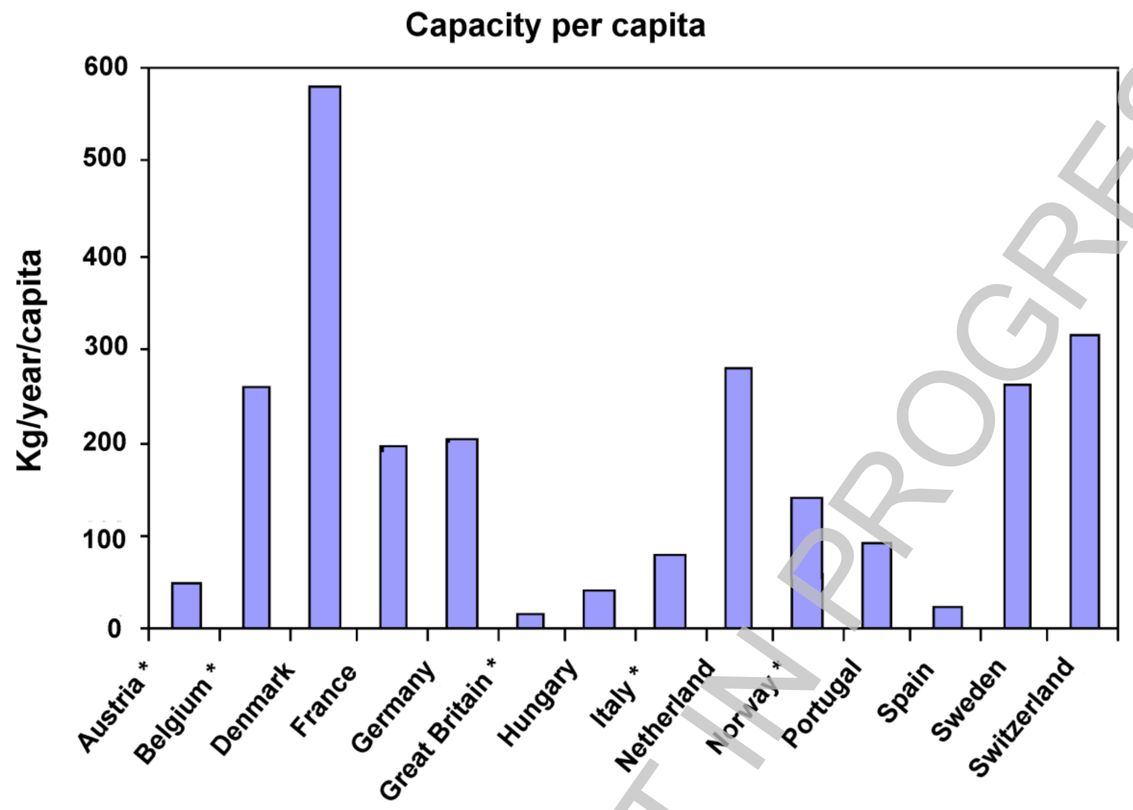
Table 1.4 shows the number and total capacity of existing incineration plants (not including planned sites) for various waste types:

Table 1.4: Geographical distribution of incineration plants for municipal, hazardous and sewage sludge waste

Country	Total number of MSW-incinerators	Capacity Mt/yr	Total number of HW-incinerators	Capacity Mt/yr	Total number of dedicated sewage sludge incinerators	Capacity Mt/yr (dry solids)
Austria	5	0.5	2	0.1	1	
Belgium	17	2.4	3	0.3	1	0.02
Denmark	32	2.7	2	0.1	5	0.3
Finland	1	0.07	1	0.1		
France	210[1]	11.75	20[3]	1.0		
Germany	59	13.4	31[2]	1.23	23	0.63
Greece	0		0			
Ireland	0		11			
Italy	32	1.71	6	0.1		
Luxembourg	1	0.15	0			
Portugal	3	1.2	0			
Spain	9	1.13	1	0.03		
Sweden	30	2.5	1	0.1		
Netherlands	11	5.3	1	0.1	2	0.19
United Kingdom	17	2.97	3	0.12	11	0.42
Norway	11	0.65				
Switzerland	29	3.29	11	2	14	0.1
Totals	**467**	**49.7**	**93**	**5.28**	**57**	**1.66**

1 On 6 Jan 2003 123 MSW incinerators were operating with combined capacity of 2 000t/h
2 Figure includes installations used in the chemical industry
3 Dedicated commercial sites only (i.e. not including in-house plants)
Source: [1, UBA, 2001], [64, TWGComments, 2003]

Figure 1.1 shows the variation in per capita capacity for municipal waste incineration:



* means incomplete data

Source: [42, ISWA, 2002], [64, TWGComments, 2003]

Figure 1.1: Municipal waste incineration capacity per capita

1.3 Plant sizes

The size of installations varies greatly across Europe. Variations in size can be seen within and between technology and waste types. The largest MSW plant in Europe has a capacity in excess of 1 million tonnes of waste per year.
Table 1.5 below shows the variation in average MSW incinerator capacity by country:

Table 1.5: Average MSW incineration plant capacity by country

Country	Average MSW incinerator capacity (k tonnes/yr)
Austria	178
Belgium	141
Denmark	114
France	132
Germany	257
Italy	91
Netherlands	488
Portugal	390
Spain	166
Sweden	136
United Kingdom	246
Norway	60
Switzerland	110
AVERAGE	**193**
Source: [11, Assure, 2001], [64, TWGComments, 2003]	

Table 1.6 below shows the typical application range of the main different incineration technologies:

Table 1.6: Typical throughput ranges of thermal treatment technologies

Technology	Typical application range (tonnes/day)
Moving grate (mass burn)	120 - 720
Fluidised bed	36 – 200
Rotary kiln	10 – 350
Modular (starved air)	1 – 75
Pyrolysis	10 - 100
Gasification	250 - 500
NB: values are for typical applied ranges –each is also applied outside the range shown. *Source:* [10, Juniper, 1997], [64, TWGComments, 2003]	

~~1.4 Overview of legislation~~

~~The waste incineration sector has been the subject of extensive legislative requirements at regional, national and European level for many years.~~

~~In addition to the requirements of the IPPC Directive, the incineration (and associated) sector is also subject to the requirements of specific legislation. At present, the following EU directives are in force for waste incineration plants:~~

- ~~89/369/EEC for new municipal waste incineration plants~~
- ~~89/429/EEC for existing municipal waste incineration plants~~
- ~~94/67/EC for the incineration of hazardous waste (including co-incineration)~~
- ~~2000/76/EC for the incineration of waste (including co-incineration).~~
- ~~Regulation (EC) No. 1774/2002 of the European Parliament and of the Council of 3 October 2002, laying down health rules concerning animal by-products not intended for human consumption.~~

~~It should be noted that Directive 2000/76/EC progressively repeals the first three directives. This directive sets the minimum requirements in respect of permissible emissions, monitoring and certain operational conditions. The scope of 2000/76/EC is broad (certain exclusions are specifically listed in Article 2) and does not have a lower capacity limit.~~

~~Directive 2000/76/EC requires that its standards are adopted as follows:~~

- ~~new waste incineration plants, from 28 December 2002~~
- ~~existing waste incineration plants, by 28 December 2005 at the latest.~~

~~In the meantime, existing waste incineration plants have to comply with Directives 89/369/EEC, 89/429/EEC and 94/67/EC. [2, infomil, 2002]~~

1.5 Waste composition and process design

The precise design of a waste incineration plant will depend on ~~change according to~~ the type of waste that is being treated. The following parameters and their variability are key drivers:

- waste chemical composition
- waste physical composition, e.g. particle size
- waste thermal characteristics, e.g. calorific value, moisture levels, etc.

Processes designed for a narrow range of specific inputs can usually be optimised more than those that receive wastes with greater variability. This in turn can allow improvements to be made in process stability and environmental performance, and may allow a simplifying of downstream operations such as flue-gas cleaning. As flue-gas cleaning is often a significant contributor to overall incineration costs (i.e. approximately 15 to 35 % of the total capital investment) this can then lead to reduced treatment costs at the incinerator. The external costs (i.e. those generally beyond the IED installation boundary) ~~IPPC permit assessment boundary)~~ of pretreatment, or the selective collection of certain wastes, can however add significantly to the overall costs of waste management and to emissions from the entire waste management system. Often, decisions concerning the wider management of waste (i.e. the complete waste arising, collection, transportation, treatment, disposal etc.) take into account a very large number of factors. The selection of the incineration process can form a part of this wider process.

The waste collection and pretreatment systems utilised can have a great impact on the type and nature of waste that will finally be received at the incinerator (e.g. mixed municipal waste or RDF) and hence on the type of incinerator that is best suited to this waste. Provision for the separate collection of various fractions of household waste can have a large influence over the average composition of the waste received at the MSWI. For example, the separate collection of some batteries and dental amalgam can significantly reduce mercury inputs to the incineration plant. [64, TWGComments, 2003]

The cost of the processes used for the management of residues arising at the incinerator, and for the distribution and use of the energy recovered also play a role in the overall process selection.

In many cases, waste incinerators may have only limited control over the precise content of the wastes they receive. This ~~then~~ results in the need for some installations to be designed so that they are sufficiently flexible to cope with the wide range of waste inputs they could receive. This applies to both the combustion stage and the subsequent flue-gas cleaning stages.

The main types of waste to which incineration is applied as a treatment are:

- municipal wastes (residual wastes - not pretreated)
- pretreated municipal wastes (e.g. selected fractions or RDF)
- non-hazardous industrial wastes and packaging
- hazardous wastes
- sewage sludges
- clinical wastes.

[64, TWGComments, 2003] Many incineration plants accept several of these types of waste. Waste itself is commonly classified in a number different ways:

- by origin, e.g. household, commercial, industrial, etc.
- by its nature, e.g. putrescible, hazardous, etc.
- by the method used for its management, e.g. separately collected, recovered material, etc.

These different classes overlap. For example, wastes of various origins may contain putrescible or hazardous fractions.

Table 1.7 below provides data concerning the content of waste arising in Germany. The term *hazardous waste* refers to those wastes classified as hazardous under Directive 91/689/EC. Sewage sludge includes sludge from the waste water treatment of communities and industries:

The hazardous waste directive 91/689/EEC has been repealed and replaced by the waste framework directive 2008/98/EC.

Table 1.7: Typical composition of waste in Germany

Parameter	Municipal waste	Hazardous waste	Sewage sludge
Calorific value (upper) (MJ/kg)	7 – 15	1 – 42	2 – 14
Water (%)	15 – 40	0 – 100	3 – 97
Ash	20 – 35	0 – 100	1 – 60
Carbon (% d.s.)	18 – 40	5 – 99	30 – 35
Hydrogen (% d.s.)	1 – 5	1 – 20	2 – 5
Nitrogen (% d.s.)	0.2 – 1.5	0 – 15	1 – 4
Oxygen (% d.s.)	*15 - 22*	*not supplied*	10 – 25
Sulphur (% d.s.)	0.1 - 0.5	*not supplied*	0.2 - 1.5
Fluorine (% d.s.)	0.01 – 0.035	0 - 50	0.1 - 1
Chlorine (% d.s.)	0.1 – 1	0 - 80	0.05 - 4
Bromine (% d.s.)	*not supplied*	0 - 80	No data
Iodine (% d.s.)		0 - 50	No data
Lead mg/kg d.s.)	100 – 2 000	0 – 200 000	4 – 1 000
Cadmium mg/kg d.s.)	1 – 15	0 – 10 000	0.1 – 50
Copper mg/kg d.s.)	200 – 700	*not supplied*	10 – 1 800
Zinc mg/kg d.s.)	400 – 1 400	*not supplied*	10 – 5 700
Mercury mg/kg d.s.)	1 – 5	0 – 40 000	0.05 – 10
Thallium mg/kg d.s.)	<0.1	*not supplied*	0.1 – 5
Manganese mg/kg d.s.)	250	*not supplied*	300 – 1 800
Vanadium mg/kg d.s.)	4 – 11	*not supplied*	10 – 150
Nickel mg/kg d.s.)	30 – 50	*not supplied*	3 – 500
Cobalt mg/kg d.s.)	3 – 10	*not supplied*	8 – 35
Arsenic mg/kg d.s.)	2 – 5	*not supplied*	1 – 35
Chrome mg/kg d.s.)	40 - 200	*not supplied*	1 – 800
Selenium mg/kg d.s.)	0.21 - 15	*not supplied*	0.1 – 8
PCB mg/kg d.s.)	0.2 – 0.4	Up to 60 %	0.01 – 0.13
PCDD/F (ng I-TEQ/kg)	50 – 250	10 – 10 000	8.5 – 73

NB:
% d.s. means percentage dry solids
the calorific value for sewage sludge relates to raw sludge of >97 % d.s.
Sub-fractions of HW can show variations outside these ranges
Source: [1, UBA, 2001], [64, TWGComments, 2003]

The range of installation designs is almost as wide as the range of waste compositions.

New plants have the advantage that a specific technological solution can be designed to meet the specific nature of the waste to be treated in the plant. They also benefit from years of industry development and knowledge of the practical application of techniques and may therefore be designed for high environmental standards, whilst containing costs.

Existing plants have significantly less flexibility when selecting upgrade options. Their design may be the product of 10 to 20 years of process evolution. Often in Europe this will have been motivated by requirements to reduce emissions to air. The next stage of process development will often then be highly (or even totally) dependent upon the existing design. Many site-specific local solutions can be seen in the sector. Many of these would probably be constructed in a different way if completely rebuilt. [6, EGTEI, 2002]

1.6 Key environmental issues

Waste itself, and its management, are themselves a significant environmental issue. The thermal treatment of waste may therefore be seen as a response to the environmental threats posed by poorly or unmanaged waste streams.

The target of thermal treatment (see also Section 1.1) is to provide for an overall reduction in the environmental impact that might otherwise arise from the waste. However, in the course of the operation of incineration installations, emissions and consumptions arise, whose existence or magnitude are influenced by the installation design and operation. This section therefore, briefly, summarises the main environmental issues that arise directly from incineration installations (i.e. it does not include the wider impacts or benefits of incineration). Essentially these *direct impacts* fall into the following main categories:

- overall process emissions to air and water ~~(including odour)~~
- overall process residue production
- process noise and vibration
- energy consumption and production
- raw material (reagent) consumption
- fugitive emissions and odour – mainly from waste storage
- reduction of the storage/handling/processing risks of hazardous wastes.

Other impacts beyond the scope of this BREF document (but which can significantly impact upon the overall environmental impact of an entire project) arise from the following operations:

- transport of incoming waste and outgoing residues
- extensive waste pretreatment on-site or off-site (e.g. preparation of waste-derived fuels and the associated refuse treatment).

1.6.1 Process emissions to air and water

Emissions to air have long been the focus of attention for waste incineration plants. Significant advances in technologies for the cleaning of flue-gases in particular have lead to major reductions in the emissions to air.

However, the control of emissions to air remains an important issue for the sector. As the entire incineration process is usually under slightly negative pressure (because of the common inclusion of an induced draught extraction fan), routine emissions to air generally take place exclusively from the stack. [2, infomil, 2002]

A summary of the main emissions to air from stack releases (these are described in more detail in Section 3.2.1) is shown below:

- particulate matter, ~~–particulate matter –~~ various particle sizes
- acid and other gases, –including HCl, HF, HBr, HI, SO_2, NO_X and NH_3 ~~amongst others~~
- heavy metals, –including Hg, Cd, Tl, As, Ni and Pb~~, amongst others~~
- carbon dioxide – A green house gas, not covered under the IED or this BREF
- other carbon compounds ~~(non-GHG),~~ –including, CO, hydrocarbons (VOCs), PCDD/F and PCB

~~Other~~ Releases to air from other sources may include: ~~, if there is no measure to reduce them:~~

- odour, –from handling and storage of untreated waste
- green house gases (GHGs) –from decomposition of stored wastes e.g. methane, CO_2

- dusts, –from dry reagent handling and waste storage areas.

The principle potential sources of releases to water (process dependent) are:

effluents from air pollution control devices,		e.g. salts, heavy metals (HMs)
final effluent discharges from waste water treatment plants,		e.g. salts, heavy metals
boiler water	- blowdown bleeds,	e.g. salts
cooling water	- from wet cooling systems,	e.g. salts, biocides
road and other surface drainage,		e.g. diluted waste leachates
incoming waste storage, handling and transfer areas,		e.g. diluted incoming wastes
raw material storage areas,		e.g. treatment chemicals
residue handling, treatment and storage areas,		e.g. salts, HMs, organics.

The waste water produced at the installation can contain a wide range of potentially polluting substances depending upon its actual source. The actual release made will be highly dependent on the treatment and control systems applied.

1.6.2 Installation residues production

The nature and quantity of residues produced are a key issue for the sector. This is because they provide both: (1) a measure of the completeness of the incineration process, and (2) generally represent the largest potential waste arising at the installation.

[64, TWGComments, 2003], [1, UBA, 2001] Although the types and quantities of residue arising varies greatly according to the installation design, its operation and waste input, the following main waste streams are commonly produced during the incineration process:

- bottom ash and/or slag
- boiler ashes
- filter dust
- other residues from the flue-gas cleaning (e.g. calcium or sodium chlorides)
- sludge from waste water treatment.

In some cases these ~~above~~ waste streams are segregated, while in other cases they are combined within or outside the process.

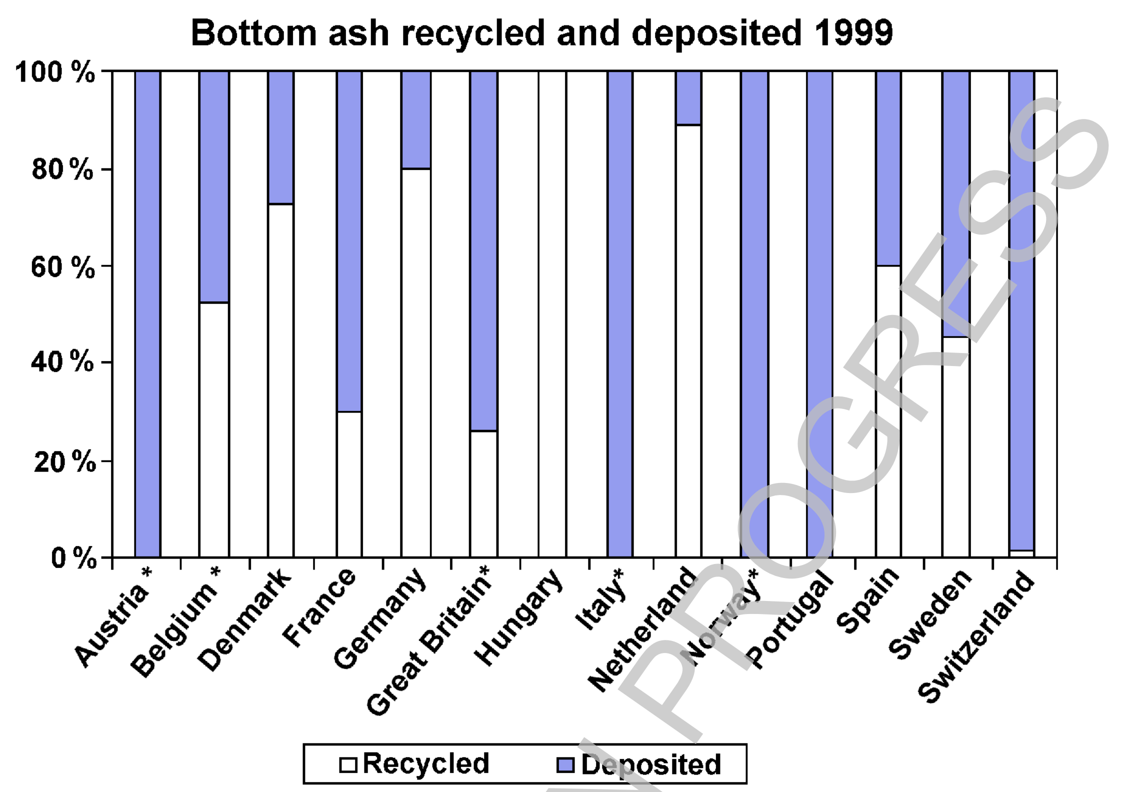
Some thermal treatment residues (most commonly vitrified slags from very high temperature processes) can be used directly without treatment. Substances which can be obtained after the treatment of the bottom ashes are:

- construction materials
- ferrous metals
- non ferrous metals.

In addition, some plants using wet FGC processes with additional specific equipment recover:

- calcium sulphate (Gypsum)
- hydrochloric acid
- sodium carbonate
- sodium chloride.

Of these outputs, although very dependent upon the waste type, bottom ashes are generally produced in the largest quantities. In many locations, often depending on local legislation and practice, bottom ash is treated for recycling as an aggregate replacement.



* means incomplete data
Source: [42, ISWA, 2002]

Figure 1.2: Bottom ash recycled and deposited from MSWI in 1999

[*For the TWG: Please provide up-to-date information for figure 1.2.*]

Residues produced from the flue-gas cleaning are an important source of waste production. The amount and nature of these varies, mainly according to the types of waste being incinerated and the technology that is employed.

1.6.3 Process noise and vibration

[2, infomil, 2002] The noise aspects of waste incineration are comparable with other heavy industries and with power generation plants. It is common practice for new municipal waste incineration plants to be installed in completely closed building(s), as far as possible. This normally includes operations such as the unloading of waste, mechanical pretreatment, flue-gas treatment, and the treatment of residues. Usually, only some parts of flue-gas cleaning systems (pipes, tubes, SCR, heat exchangers, etc.), cooling facilities and the long-term storage of bottom ash are carried out directly in the open air.

The most important sources of external noise are:

- vehicles used for the transport of waste, chemicals and residues
- mechanical pretreatment of waste, e.g. shredding, baling, etc.
- exhaust fans, extracting flue-gases from the incineration process and causing noise at the outlet of the stack
- ~~noise, related to~~ the cooling system (from evaporative cooling, especially air cooling)
- turbine generators ~~noise~~ (high level so usually placed in specific sound-proofed buildings)
- boiler pressure emergency blowdowns (these require direct release to atmosphere for boiler safety reasons)

- compressors for compressed air
- ~~noise related to~~ the transport and treatment of bottom ash (if on the same site).

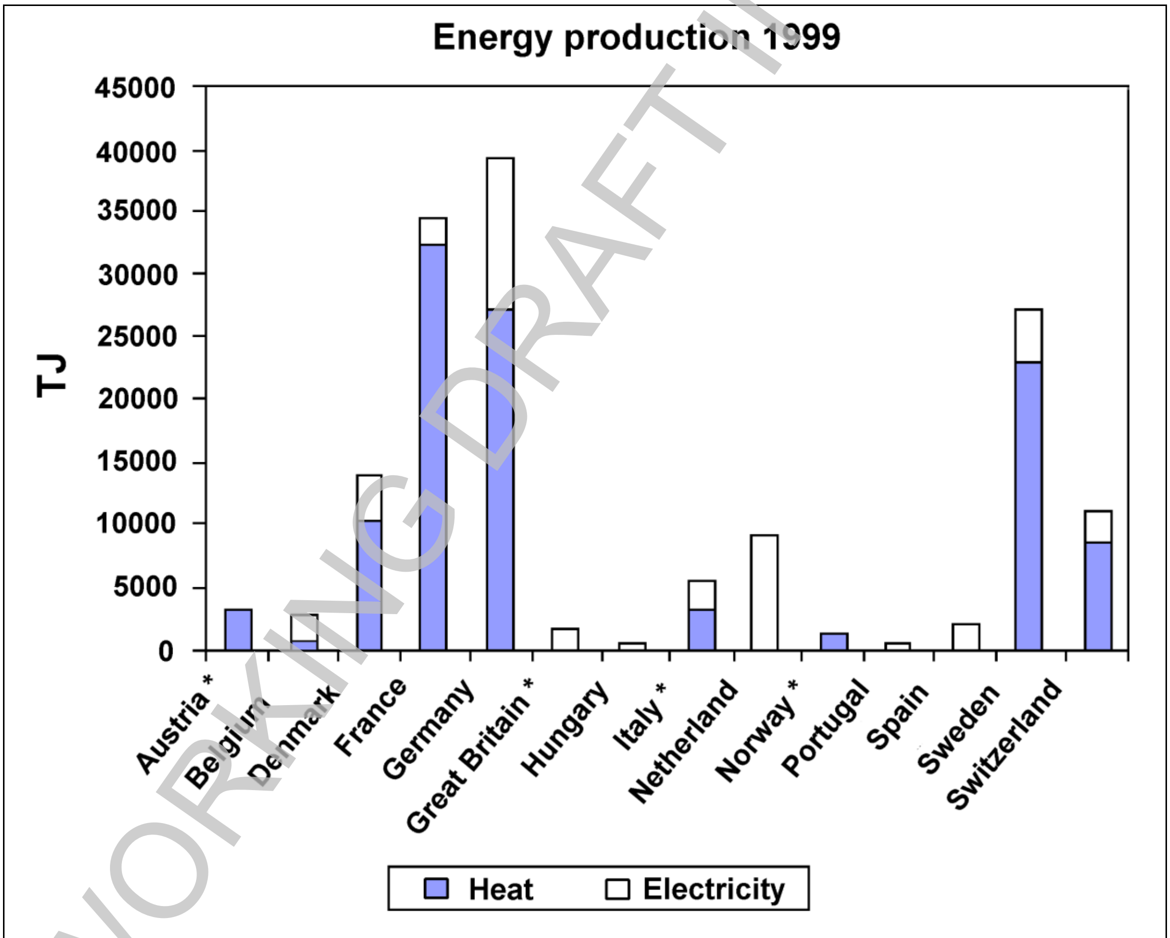
SCR systems and flue-gas ducts give rise to little noise and are often not inside buildings. Other installation parts are not usually significant for external noise production but may contribute to a general external noise production by the plant buildings.

1.6.4 Energy production and consumption

Waste incinerators both produce and consume energy. In a large majority of cases, the energetic value of the waste exceeds the process requirements, ~~This may~~ resulting in the net export of energy. This is often the case with municipal waste incinerators in particular.

Given the total quantities of waste arising, and its growth over many years, the incineration of waste can be seen to offer a large potential source of energy. In some MSs this energy source is already well exploited. This is particularly the case where ~~the use of~~ CHP is used. Energy issues are discussed in more detail later in this document (see Sections 3.5 and 4.4).
[64, TWGComments, 2003]

Figure 1.3 below shows the production of heat and electricity from municipal waste incineration plants for various countries in 1999:



* means incomplete data
Source: [42, ISWA, 2002]

Figure 1.3: Energy production by municipal waste incinerators in Europe (1999)

[For the TWG: Please provide up-to-date information for figure 1.2.]

Most wastes contain some biomass. ~~(to differing degrees). In such cases,~~ The energy derived from the biomass fraction may be considered to substitute for fossil fuel and therefore the recovery of energy from that fraction be considered to contribute to a reduction in the overall carbon dioxide emissions from energy production. In some countries, this attracts subsidies and tax reductions. [64, TWGComments, 2003]

Energy inputs to the incineration process can include:

- waste
- support fuels, (e.g. diesel, natural gas):
  - for start-up and shutdown
  - to maintain required temperatures with lower CV wastes
  - for flue-gas reheating before treatment or release
- imported electricity:
  - for start-up and shutdown phases when all lines are stopped and for plants without electricity generation.

(Note: some of the above energy inputs contribute to steam/heat production where boilers are used and are therefore the energy is partially recovered in the process.)

Energy production, self-consumption and export can include:

- electricity
- heat (as steam or hot water)
- syngas (for pyrolysis and gasification plants that do not burn the syngas on site).

The efficient recovery of the energy content of the waste is generally considered to be a key issue for the industry.
[74, TWGComments, 2004]

1.6.5 Consumption of raw materials and energy by the installation

Waste incineration plants ~~(process dependent)~~ may consume the following:

- electricity, for process plant operation
- heat, for specific process needs
- fuels, support fuels (e.g. gas, light oils, coal, char)
- water, for flue-gas treatment, cooling and boiler operation
- flue-gas cleaning ~~treatment~~ reagents, e.g. caustic soda, lime, sodium bicarbonate, sodium sulphite hydrogen peroxide, activated carbon, ammonia, and urea
- water treatment reagents, e.g. acids, alkalis, tri-mercapto tri-azine, sodium sulphite, etc.
- high pressure air, for compressors.
  [74, TWGComments, 2004]

1.7 Economic information

[43, Eunomia, 2001] [64, TWGComments, 2003]
The economic aspects of incineration vary greatly between regions and countries, not only due to technical aspects but also depending on waste management ~~treatment~~ policies. ~~A study [43, Eunomia, 2001] of these aspects provided to the TWG gives information on the situation in EU MSs – some information from this study has been included in the annex to this document.~~

The costs of incineration are generally affected by the following factors:

- The gate price charged for incoming waste
- costs of land acquisition
- scale (there may often be significant disadvantages for small scale operation)
- plant utilisation rate
- the actual requirements for the treatment of flue-gases/effluents, e.g. the imposed emission limit values can drive the selection of particular technologies that in some circumstances impose significant additional capital and operational costs
- the treatment and disposal/recovery of ash residues, e.g. bottom ash may often be used for construction purposes, in which case, the landfilling cost is avoided. The costs of treatment for fly ash varies significantly, owing to the different approaches and regulations applied regarding the need for treatment prior to recovery or disposal, and the nature of the disposal site
- the efficiency of energy recovery, and the revenue received for the energy delivered. The unit price of energy delivered, and whether revenues are received for just heat or electricity us for both are both important determinants of net costs
- the recovery of metals and the revenues received from this
- taxes or subsidies received for incineration and/or levied on emissions - direct and indirect subsidies can influence gate fees significantly i.e. in the range of 10 – 75 %
- architectural requirements
- development of the surrounding area for waste delivery access, and other infrastructure
- availability requirements, e.g. availability may be increased by doubling each pump but this imposes additional capital costs
- planning and building cost/ depreciation periods, taxes and subsidies, capital cost market
- insurance costs
- administration, personnel, salary costs.

The owners and operators of incineration plants may be municipal bodies, as well as private companies. Public/private partnerships are also common. The finance cost of capital investments may vary depending upon the ownership.

Waste incineration plants receive fees for the treatment of the waste. They can also produce and sell electricity, steam, and heat, and recover other products, such as bottom ashes for use as civil construction material, iron scrap and non-ferrous scrap for use in the metal industry, HCl, salt or gypsum. The price paid for these commodities, and the investment required to produce them, has a significant impact on the operational cost of the installation. It can also be decisive when considering specific technical investments and process designs (e.g. whether heat can be sold at a price that justifies the investment required for its supply). The prices paid for these commodities vary from one MS to another or even from one location to another.

In addition, significant differences occur due to the variations in emission requirements, salary costs and depreciation periods, etc. For these reasons, the gate fees in Table 1.8 are only comparable to a limited extent:

Table 1.8: Gate fees in European MSW and HW incineration plants

Member states	Gate fees in EUR/t incineration plants	
	Municipal waste	**Hazardous waste**
Belgium	56 – 130	100 – 1 500
Denmark	40 – 70	100 – 1 500
France	50 – 120	100 – 1 500
Germany	100 – 350	50 – 1 500
Italy	40 – 80	100 – 1 000
Netherlands	90 – 180	50 – 5 000
Sweden	20 – 50	50 – 2 500
United Kingdom	20 – 40	Not available
Source: **[1, UBA, 2001]**		

[*For the TWG (especially Germany): Please provide up-to-date information for Table 1.8.*]

It is important not to confuse the real cost of the gate fee 'needed' in order to pay for the investment and operation, and the market price that is adopted in order to deal with competition. Competition with alternative methods of waste management (e.g. landfills, fuel production, etc.) as well as investment costs and operational expenses have an effect on the final gate fee at incineration plants. Competition prices vary greatly from one MS or location to another.

Table 1.9 shows (except where noted) the variation in municipal waste incineration costs across MSs. Note that the costs presented in
Table 1.9 are different to those in Table 1.8 above (which presents data on *gate fees)*:

Table 1.9: Comparative costs of MSW incineration in different MSs

	Pre-tax[2] costs net of revenues in EUR per tonne waste input	**Tax (for plant with energy recovery)**	**Revenues from energy supply (EUR per kWh)**	**Costs of ash treatment (EUR per tonne of ash unless otherwise specified)**
A	326 @ 60 kt/yr 159 @150 kt/yr 97 @ 300 kt/yr		Electricity: 0.036 Heat: 0.018	Bottom ash: 63 Flue-gas residues: 363
B	72 average	EUR 12.7/t (Flanders)	Electricity: 0.025	Not available
DK	30 – 45	EUR 44/t	Electricity: 0.05	Bottom ash: 34 Flue-gas treatment residues: 80
FIN	None		For gasification, Electricity 0.034 Heat 0.017	
F	86 - 101 @ 37.5 kt/yr 80 - 90 @ 75 kt/yr 67 - 80 @ 150 kt/yr		Electricity 0.033 - 0.046 Heat: 0.0076 - 0.023	Bottom ash: EUR 13 – 18 per tonne input
D	250 (50 kt/yr and below)[1] 105 (200 kt/yr) [1] 65 @ 600 kt/yr[1]		Electricity 0.015 – 0.025	Bottom ash:25 - 30 Fly ash/air pollution control residues: 100 - 250
EL	None		Not known	Not known
IRL	None		Not known	Not known
I	41.3 – 93 (350 kt, depends on revenues for energy and packaging recovery)		Electricity: 0.14 (old) 0.04 (market) 0.05 (green cert.)	Bottom ash: 75 Fly ash and air pollution control residues: 29

L	97 (120 kt)		Electricity: 0.025 (estimated)	Bottom ash EUR 16/t input waste Flue-gas residues: EUR 8/t input waste
NL	71 – 110[1] 70 – 134[1]		Electricity: 0.027 - 0.04 (estimated)	
P	46 – 76 (est.)			No data
E	34 – 56		Electricity: 0.036	
S	21 – 53		Electricity: 0.03 Heat: 0.02	
UK	69 @ 100kt/yr 47 @ 200kt/yr		Electricity: 0.032	Bottom ash recycled (net cost to operator) fly ash circa 90
NB: 1. These figures are gate fees, not costs 2. Pre-tax cost refers to gross costs without any tax. *Source:* [43, Eunomia, 2001, 64, TWGComments, 2003]				

[*For the TWG: Please provide up-to-date information for Table 1.9.*]

The following table illustrates how the capital costs of an entire new MSWI installation can vary with the flue-gas and residue treatment processes applied:

Table 1.10: Specific investment costs for a new MSWI installation related to the annual capacity and some types of FGC in Germany

Type of flue-gas cleaning	**Specific investment costs (EUR/tonne waste input/yr)**			
	100 ktonnes/yr	**200 ktonnes/yr**	**300 ktonnes/yr**	**600 ktonnes/yr**
Dry	670	532	442	347
Dry plus wet	745	596	501	394
Dry plus wet with residue processing	902	701	587	457
Source: [1, UBA, 2001], [64, TWGComments, 2003]				

[*For the TWG (especially Germany): Please provide up-to-date information for Table 1.10.*]

Table 1.11 shows some examples of average specific incineration costs (1999) for municipal waste and hazardous waste incineration plants (all new plants). The data indicates that the specific costs for incineration are heavily dependent on the financing costs of the capital and, therefore, by the investment costs and the plant capacity. Significant cost changes can occur and depend on the set-up, such as the depreciation period, interest costs, etc. Plant utilisation can also have a significant influence on the incineration costs.

Table 1.11: Example of the comparative individual cost elements for MSW and HW incineration plants

Cost structure	**Incineration plant for**	
	Municipal waste with a capacity of 250 ktonnes/yr in EUR 10^6	**Hazardous waste with a capacity of 70 ktonnes/yr in EUR 10^6**
Planning/approval	3.5	6
Machine parts	70	32
Other components	28	28
Electrical works	18	20
Infrastructure works	14	13
Construction time	7	7
Total investment costs	**140**	**105**

Capital financing cost	14	10
Personnel	4	6
Maintenance	3	8
Administration	0.5	0.5
Operating resources/energy	3	2.5
Waste disposal	3.5	1.5
Other	1	0.5
Total operational costs	**29**	**12.5**
Specific incineration costs (without revenues)	**Approx. EUR 115/tonne**	**Approx. EUR 350/tonne**
NB: The data provides an example in order to illustrate differences between MSWI and HWI. Costs of each and the differential between them vary. *Source:* [1, UBA, 2001], [64, TWGComments, 2003]		

[*For the TWG (especially Germany): Please provide up-to-date information for Table 1.11.*]

Energy prices:

[43, Eunomia, 2001] Revenues are received for energy sales. The level of support per kWh for electricity and/or heat generation varies greatly. For example, in Sweden and Denmark, gate fees are lower, at least in part because of the revenue gained from the sales of thermal energy as well as electricity. Indeed, in Sweden, the generation of electricity is often not implemented in the face of considerable revenues for heat recovery.

In some other countries, support for electricity production has encouraged electrical recovery ahead of heat recovery. The UK, Italy, and Spain, amongst others, have at some stage, supported incineration through elevated prices for electricity generated from incinerators.
In other MSs, the structure of incentives available for supporting renewable energy may also affect the relative prices of alternative waste treatments and hence competition prices.
The potential revenues from energy sales at waste incineration facilities constitute an incentive for all concerned parties to include energy outlets in the planning phase for incineration facilities [64, TWGComments, 2003].

Revenues received for recovery of packaging materials:

[43, Eunomia, 2001] These have also influenced relative prices. For example, in Italy and the UK, incinerators have received revenues associated with the recovery of packaging material.

It should be noted that, legislative judgements concerning recovery and disposal may influence whether incinerators can legally benefit from these revenues [64, TWGComments, 2003]

[*For the TWG (especially Italy and the UK): Please provide up-to-date information on packaging materials.*]

Taxes on incineration:

[43, Eunomia, 2001] In Denmark, the tax on incineration is especially high. Hence, although underlying costs tend to be low (owing primarily to scale, and the prices received for energy), the costs net of tax are of the same order as that of several other countries where no tax is in place. This tax along with a landfill tax were adopted in Denmark to promote waste treatment in compliance with the waste hierarchy. This has resulted in a large shift from landfill to recycling, but with the percentage of waste being incinerated remaining constant [64, TWGComments, 2003].

[*For the TWG (especially Denmark): Please provide up-to-date information on taxes.*]

2 APPLIED PROCESSES AND TECHNIQUES

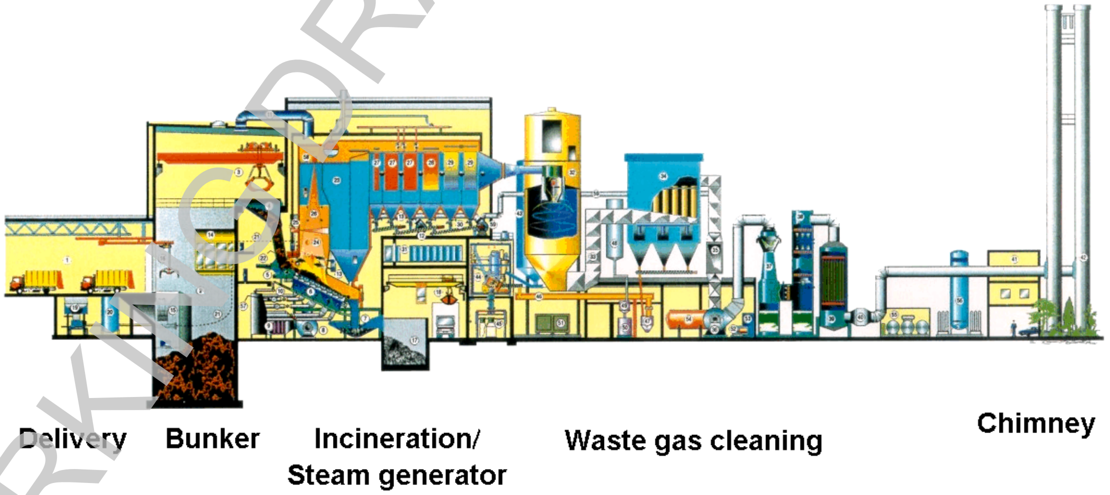
2.1 Overview and introduction

~~The basic linear structure of a~~ A typical waste incineration plant will ~~may~~ include the following operations:

- incoming waste reception;
- storage of waste and raw materials;
- pretreatment of waste (where required, on-site or off-site);
- loading of waste into the process;
- thermal treatment of the waste;
- energy recovery (e.g. boiler) and conversion;
- flue-gas cleaning (FGC);
- flue-gas cleaning residue management; ~~(from flue-gas treatment)~~
- flue-gas discharge;
- emissions monitoring and control;
- waste water control and treatment (e.g. from site drainage, flue-gas cleaning ~~treatment~~, storage);
- ash/bottom ash management and treatment (arising from the combustion stage);
- solid residue discharge/disposal.

~~Each of these stages is generally adapted in terms of design~~, Each stage will be designed for the specific type(s) of waste that are treated at the installation. Information describing these stages is included later in this chapter.

Many installations operate continuously, 24 hours a day, nearly 365 days a year. Control systems and maintenance programmes play an important role in securing the availability of the plant. [74, TWGComments, 2004]



Source: [1, UBA, 2001]

Figure 2.1: Example layout of a municipal solid waste incineration plant with a wet FGC system

~~In the example shown above (Figure 2.1), the incoming waste storage and handling stages are on the left of the diagram, before the incineration stage. The flue-gas cleaning system is shown labelled as *waste gas cleaning*, to the right of the furnace and boiler. The example shown is a~~

~~wet FGC system with several unit operations. Other modern installations use FGC systems with fewer process units.~~

~~Although incineration is by far the most widely applied,~~ There are three main types of thermal waste treatment ~~relevant to this BREF~~:

- **incineration** - full oxidative combustion (by far the most common process);
- **pyrolysis** - thermal degradation of organic material in the absence of oxygen;
- **gasification** - partial oxidation.

The reaction conditions and products of ~~for~~ these thermal treatments are shown in Table 2.1. ~~vary, but may be differentiated approximately as follows:~~

Table 2.1: Typical reaction conditions and products from incineration, pyrolysis and gasification processes

	~~Combustion~~ Incineration	Pyrolysis	Gasification
Reaction temperature (ºC)	800–1450	250–700	500–1 600
Pressure (bar)	1	1	1–45
Atmosphere	Air	Inert/nitrogen	Gasification agent: O_2, H_2O
Stoichiometric ratio	> 1	0	< 1
Products from the process			
Gas phase:	CO_2, H_2O, O_2, N_2	H_2, CO, hydrocarbons, H_2O, N_2	H_2, CO, CO_2, CH_4, H_2O, N_2
Solid phase:	Ash, slag	Ash, coke	Slag, ash
Liquid phase:		Pyrolysis oil and water	

Source: **Adapted from[9, VDI, 2002]**

Pyrolysis and gasification plants follow a similar basic structure to waste incineration plants but there are some significant differences: ~~installations, but differ significantly in detail. The main differences are as follows:~~

- **pretreatment**, may be more extensive to provide a narrow profile feedstock and additional equipment is required for handling, treating and storing the rejected material;
- **loading**, greater attention required to sealing;
- **thermal reactor**, to replace (or in addition to) the combustion stage;
- **product handling**, gaseous and solid products require handling, storage and possible further treatments;
- **product combustion**, may be a separate stage and include energy recovery by combustion of the products and subsequent gas/water/solid treatments and management.

2.2 Pretreatment, storage and handling techniques

The different types of wastes that are incinerated may need different types of pretreatment, storage and handling operations. This section ~~is organised in such a way that it~~ describes ~~in order~~ the most relevant of these operations for the following wastes: ~~each type of waste, in particular for~~:

- municipal solid waste;
- hazardous wastes;
- sewage sludge;
- clinical wastes.

2.2.1 Municipal solid waste (MSW)

2.2.1.1 Collection and pretreatment outside the MSW incineration plant

Although beyond the immediate scope of this document, it is important to recognise that the local collection and pretreatment applied to MSW ~~can~~ will strongly influence the nature of the material received at the incineration plant. ~~The requirements concerning~~ The pretreatment and other operations carried out at the incinerator should therefore be consistent with the collection system in place.

Recycling schemes may mean that some fractions have been removed. Their effect will be roughly as follows.

Table 2.2: Prime Main impacts of waste selection and pretreatment on residual waste

Fraction removed	~~Prime~~ Main impacts on remaining waste
Glass and metals	• Increase in calorific value • Decrease in quantity of recoverable metals in slag
Paper, card and plastic	• Decrease in calorific value • Possible reduction in chlorine loads if PVC common
Organic wastes, e.g. food and garden wastes	• Reduction in moisture loads (particularly of peak loads) • Increase in net calorific value
Bulky wastes	• Reduced need for removal/shredding of such wastes
Hazardous wastes	• Reduction in hazardous metal loading • Reduction in some other substances, e.g. Cl, Br, Hg
Source: [74, TWGComments, 2004]	

One study assessing the effect of selective collection on the remaining household waste (called 'grey waste') gave the following conclusions:

- Glass collection decreased the throughput (-13 %) and increased the LHV (+15 %) of the residual 'grey waste'.
- Packaging and paper collection decreased the throughput (-21 %) and ~~decreased~~ the LHV (-16 %) of the 'grey waste'.
- In general, the throughput and LHV of the 'grey waste' decreased when the efficiency of the selective collection increased. The maximum impact of selective collection was -42 % for the throughput and -3 % for the LHV of the 'grey waste'.
- Selective collection had an effect on the grey waste quality - it significantly increased the content of the fine fraction ~~element,~~ which can be particularly rich in heavy metals (fines increased from 16 % to 33 %).
- The bottom ash ratio decreased due to selective collection (-3 %).
[74, TWGComments, 2004]

The degree to which separate collection and similar schemes affect the final waste delivered to the installation ~~are seen~~ depends on the effectiveness of the separation and pretreatment systems employed. This varies greatly. Some residual fractions are always likely to remain in the delivered waste.

Reject materials from recycling plants, monofractions of waste, commercial and industrial wastes, and some hazardous wastes may also be part of ~~found in~~ the delivered waste.

2.2.1.2 Municipal solid waste pretreatment within the incineration plant

In-bunker mixing is commonly used to blend MSW. This usually involves ~~consists of~~ using the same waste grab ~~that is also~~ used for hopper loading. Most commonly, the pretreatment of MSW is limited to the shredding of pressed bales, bulky waste, etc., although sometimes more extensive shredding is carried out using: ~~used. The following equipment is used:~~

- crocodile shears;
- shredders;
- mills;
- rotor shears.

For fire-safety reasons, the following arrangements may be used:

- separation of the dumping areas from the storage in the bunker;
- separation of hydraulic plants (oil supply, pump and supply equipment) from the cutting tools;
- collection devices for leaked oil;
- decompression release in the housing to reduce explosion damage.

~~It is generally necessary to pretreat (i.e. crush)~~ Bulky waste is usually pretreated by crushing when it~~s size is greater~~ is bigger than ~~that of~~ the ~~feed~~ equipment that feeds it to the furnace. ~~Another reason for~~ Pretreatment by mixing, crushing or shredding is also carried out to homogenise the waste so that it has more consistent combustion characteristics (e.g. for some wastes with a high LHV). ~~This may be achieved by mixing, crushing or shredding the waste.~~ Additional waste pretreatment is unusual for grate furnace plants, but may be essential for other furnace designs.

2.2.1.3 Waste delivery and storage

The general principles of storage are described in the BREF on Emissions from Storage (EFS BREF), published in July 2006. Waste delivery, storage and handling are also adressed by the BREF on Waste Treatement (WT). This section serves to outline some issues that are specific to MSW.

2.2.1.3.1 Waste control

The waste delivery area is ~~the location~~ where the delivery trucks, trains, or containers arrive in order to dump the waste into the bunker, usually after visual control and weighing. The dumping is carried out through openings between the delivery area and the bunker. Tilting and sliding beds may be used to facilitate ~~help~~ waste transfer to the bunker. The openings can be closed to prevent the escape of odours, act as a fire-break and reduce the risk of vehicle accidents. ~~locked, and therefore also serve as odour and seal locks, as well as fire and crash-protecting devices~~. Enclosure of the delivery area can be ~~one~~ effective ~~means of avoiding~~ in reducing odour, noise and emission problems from the waste.

2.2.1.3.2 Bunker

The bunker is usually a waterproof, concrete chamber ~~bed~~. The waste is piled and mixed in the bunker using cranes equipped with grapples. The mixing of wastes helps to achieve a balanced heat value, size, structure, composition, etc. of the material dumped into the incinerator filling hoppers.

Fire protection equipment is used in the bunker area and feeder system, for example:

- fireproofed cabling for the cranes;
- safety design for the crane cabs;
- fire detectors;
- automatic water cannon sprays, with or without foam.

Crane cabs are designed to provide ~~in such a way that~~ the crane operator with a good view ~~has a good overview~~ of the entire bunker. The cab has its own ventilation system, independent from the bunker.

The ~~primary incineration~~ air for the furnaces ~~plants~~ is often extracted from the bunker area ~~. In order~~ to remove dust and odours and any methane generated by fermentation of the wastes. ~~excessive dust development and gas formation (e.g. methane) from fermenting processes, as well as the accumulation of odour and dust emissions, Depending on the~~ The calorific value of the waste as well as the layout and the concept of the plant will determine whether the air from the bunker is used as ~~, preference is most often given to supplying the bunker air to either the~~ primary or secondary air. [74, TWGComments, 2004]

The bunker usually has a storage capacity of ~~several days (commonly~~ 3 to 5 days~~)~~ of plant operational throughput. This is very dependent on local factors and the specific nature of the waste.

Additional safety devices may be implemented such as: dry standpipe at the waste hopper level, foam nozzle above the waste hopper, fire detection for the hydraulic group, fire-resistant walls between the bunker and the furnace hall, fire-resistant walls between the furnace hall and the control room, water curtains on the window between the control room and the furnace, smoke and fire extraction (5–10 % of the surface of the roof).
[74, TWGComments, 2004]

2.2.2 Hazardous wastes

~~**2.2.2.1 Brief description of the sector**~~

The hazardous waste incineration sector comprises two main subsectors:

- merchant incineration plants;
- dedicated incineration plants.

The main differences between these are summarised in the table below.

Table 2.3: Summary of the differences between operators in the HWI market

Criteria	Merchant plants	Dedicated plants
Ownership	Private companies, municipalities or partnerships	Usually private companies (used for their own wastes)
Characteristics of wastes treated	• Very wide range of wastes • Knowledge of exact waste composition may be limited in some cases	• Wide range of wastes • Often ~~only~~ the waste ~~arising~~ only originates frin ~~within~~ one company or even from one process • Knowledge of waste composition generally higher
Combustion technologies applied	• Predominantly rotary kilns • Some dedicated technologies for dedicated or restricted specification wastes	• Rotary kilns ~~plus~~ • A wide variety of specific techniques for dedicated or restricted specification wastes
Operational and design considerations	• Flexibility and wide range of performance required to ensure good process control	• Process can be more closely designed for a narrower specification of feed in some cases
Flue-gas cleaning ~~treatment~~	• Wet scrubbing often applied to give flexibility of performance~~, as well as~~ • A range of FGC techniques (often applied in combination with wet scrubbing)	• Wet scrubbing often applied to give flexibility of performance ~~as well as~~ • A range of FGC techniques (often applied in combination with wet scrubbing)
Cost/market considerations	• Operators usually compete in an open (global) market for business • Some plants benefit from national/regional policies regarding the destination of wastes arising in that country/region • Movement of hazardous waste in the EU is controlled by Transfrontier Shipment Regulations which limits the scope of open global market	• Competition more limited or in some cases non-existent • Higher disposal costs tolerated by users in some cases for reasons of waste producer policy on in-house disposal

Source: Discussions with TWG

[EURITS, 2002 #41]. The individual incineration capacity of rotary kilns used in the merchant sector varies between 30 000 tonnes and 100 000 tonnes a year. The mass capacity for an individual design varies considerably with the average calorific value of the waste, with the principal factor being thermal capacity.

The following sections refer mainly to the delivery, storage and pretreatment of hazardous waste for the merchant sector.

2.2.2.1 Waste acceptance

Due to the very wide variety of wastes encountered, their high potential hazardousness, and elevated uncertainties over the precise knowledge of the waste composition, significant effort is required to assess, characterise and trace incoming wastes through the entire process. The systems adopted need to provide a clear audit trail that allows the tracing of any incidents to their source. This then enables procedures to be adapted to prevent further incidents.

The exact procedures required for waste acceptance and storage depend on the chemical and physical characteristics of the waste.

Identification and analysis of wastes
[1, UBA, 2001] For each type of hazardous waste, a declaration of the nature of the waste made by the waste producer is submitted so that the waste manager can then decide on the appropriate storage and treatment required. ~~whether the treatment of each specific type of waste is possible.~~ Such a declaration may include:

- data on the waste producer and responsible persons;
- data on the waste code and other designations for the waste;
- data on the origin of the waste;
- analytical data on particular toxic materials;
- general characteristics, including combustion parameters, such as Cl, S, calorific value, water content;
- other safety/environmental information;
- legally binding signature;
- additional data upon request of the accepting plant.

Some types of waste require additional measures. Homogeneous, production-specific waste can often be adequately described in general terms. Additional measures are usually required for waste of a less well-known composition (e.g. waste from refuse dumps or from the collections of hazardous household waste), including the ~~investigation~~ inspection of each individual waste container.

When the waste composition cannot be described in detail (e.g. small amounts of pesticides or laboratory chemicals), the waste management company may agree with the waste producer on specific packaging requirements, making sure that the waste will not react during transport, when it is accepted for incineration, or within containers. For example, risks may arise from:

- wastes with phosphides;
- wastes with isocyanates;
- wastes with alkaline metals (for example, or other reactive metals);
- cyanide with acids;
- wastes forming acid gases during combustion;
- wastes with mercury.

[74, TWGComments, 2004]

Delivered wastes generally undergo specific waste acceptance ~~admission~~ controls, ~~whereby the previously received declaration by the waste producer provides the starting point~~. ~~After comparison by~~ Visual and analytical investigations of the waste are compared with the data contained in the declaration received from the waste producer. The waste is either accepted and allocated to the appropriate storage area, or rejected in the case of significant deviations.

2.2.2.2 Storage

The general principles of storage are described in the BREF on Emissions from Storage (EFS BREF), published in July 2006. Waste delivery, storage and handling are also adressed by the BREF on Waste Treatement (WT). However, this section serves to outline some issues that are specific to the incineration of hazardous waste ~~industry~~.

In general, the storage of wastes needs, additionally, to take into account the unknown nature and composition of wastes, as this gives rise to additional risks and uncertainties. In many cases, this uncertainty means that higher specification storage systems are applied for wastes than for well-characterised raw materials.

A common practice is to ensure, as far as possible, that hazardous wastes are stored in the same containers (drums) that are used for transportation; thus avoiding the need for additional handling and transfer. Good communication between the waste producer and the waste manager help to ensure wastes are stored, transferred, etc. such that risks all along the chain are well managed. It is also important that only well-characterised and compatible wastes are stored in tanks or bunkers.

~~For~~ Hazardous waste ~~incineration,~~ storage arrangements ~~for some substances~~ may need to comply with the Seveso III Directive on the control of major accident hazards ~~be consistent with the COMAH/(Seveso II) requirements~~, as well as BAT described in the ~~storage~~ EFS BREF and/or the WT BREF. There may be circumstances where the ~~*major accident and hazard* (MAH)~~ prevention/mitigation measures for major accident hazards take precedence.

[EURITS, 2002 #41] Appropriate waste assessment is an essential element in the selection of storage and loading options. Some issues to note are the following:

- For the storage of **solid hazardous waste**, many incinerators are equipped with a bunker (500–2 000 m^3) from where the waste is fed into the installation by cranes or feed hoppers.
- **Liquid hazardous waste and sludges,** which are usually stored in a tank farm. Some tanks have storage under an inert (e.g. N_2) atmosphere. Liquid waste is pumped via pipelines to the burners and introduced into the rotary kiln and/or the post-combustion chamber (PCC). Sludges can be fed to rotary kilns using special 'viscous-matter' pumps.
- Some incinerators are able to feed certain substances, such as toxic, odorous, reactive and corrosive liquids, by means of a **direct injection** device, directly from the transport container into either the kiln or the PCC.
- Almost half of the merchant incinerators in Europe are equipped with conveyors and elevators to transport and introduce **drums** and/or small packages (e.g. lab packs) directly into the rotary kiln. These may be via airlock systems, and can use inert gas flood systems.

2.2.2.2.1 Storage of solid hazardous waste

[1, UBA, 2001] Solid and unpumpable pasty hazardous waste that has not been degassed and does not smell is stored temporarily in bunkers. Storage and mixing areas can be separated in the bunker. This can be achieved through several design segments. Cranes feed both solid and pasty waste products. The bunker must be designed to prevent emissions into the ground. ~~in such a way that ground emissions can be prevented.~~

The bunker and container storage should ~~must~~ be enclosed unless there are health and safety reasons for not enclosing them (e.g. danger of explosion and fire) ~~exist~~. ~~The air in the bunker is usually removed and used as incineration air~~. Combustion air for the incinerator is usually taken from the waste storage area to prevent emissions of dust and odours. ~~In anticipating fires, monitors such as heat-detecting cameras are used, in addition to constant monitoring by personnel (control room, crane operator).~~ Waste storage areas should be constantly monitored to ensure the early detection of any fires. Visual monitoring by the control room operator and/or crane operator can be supported be the use of heat-detecting cameras.

2.2.2.2.2 Storage of pumpable hazardous waste

[1, UBA, 2001] Larger amounts of fluid and pumpable pasty wastes are temporarily stored in tanks. ~~that must be available in~~ Sufficient numbers and sizes of tanks must be available to accommodate separate storage of incompatible types of waste (e.g. oxidisers stored separately from flammable materials to prevent fires/explosions, and acids stored separately from sulphides to prevent hydrogen sulphide production). ~~reacting liquids separately (danger of explosion, polymerisation).~~

Tanks, pipelines, valves and seals must be adapted to the waste characteristics in terms of construction, material selection, and design. They must be sufficiently corrosion-proof and offer the option of cleaning and sampling. Flat bed tanks are generally only deployed for large loads.

It may be necessary to homogenise the tank contents with mechanical or hydraulic agitators. Depending on the waste characteristics, the tanks must be heated indirectly and insulated. Tanks are set in catch basins that must be designed for the stored material, with bund volumes chosen so that they can hold the liquid waste in the event of leakage.

2.2.2.2.3 Storage ~~for~~ of containers and tank containers

[1, UBA, 2001] For safety reasons, hazardous waste is most often accumulated in special containers. These containers are then delivered to the incineration plant. Delivery is also taken of bulk liquids.

The delivered containers may be stored or the contents transferred. In some cases, according to a risk assessment, the waste may be directly injected via a separate pipeline into the furnace. Heated transfer lines may be used for wastes that are only liquid at higher temperatures.

Storage areas for containers and tank containers are usually located outside, with or without roofs. Drainage from these areas is generally controlled, as contamination may arise.

2.2.2.3 Feeding and pretreatment

~~Because of~~ The wide range of chemical and physical properties ~~specification~~ of some hazardous wastes may cause difficulties ~~may occur~~ in the incineration process. Some degree of waste blending or specific pretreatment is ~~thus~~ often carried out to produce a more consistent feed material. ~~in order to achieve more even loads.~~
[2, infomil, 2002] ~~It is also necessary for acceptance criteria to be developed for each installation. Such a recipe will describe the range of concentrations within which key combustion and chemical waste characteristics should be maintained, in order to ensure the process runs predictably, to prevent exceeding the process capacity, and thus to comply with operational and environmental (e.g. permit conditions) requirements.~~

Each installation develops waste acceptance criteria that specify the allowable ranges for the key combustion and chemical properties of incoming wastes. The application of these criteria ensures that the process operates streadily and predictably to comply with operational and environmental (e.g. permit conditions) requirements.

Factors that set such ranges include:

- the capacity of the flue-gas cleaning system ~~technology capacity~~ for individual pollutants (e.g. scrubber flow rates, etc.);
- the ~~existence~~ presence or absence of a particular flue-gas cleaning technique;
- ~~emission limit values required~~
- heat throughput rating of the furnace;
- design of the waste feed mechanism and the physical suitability of the waste received.

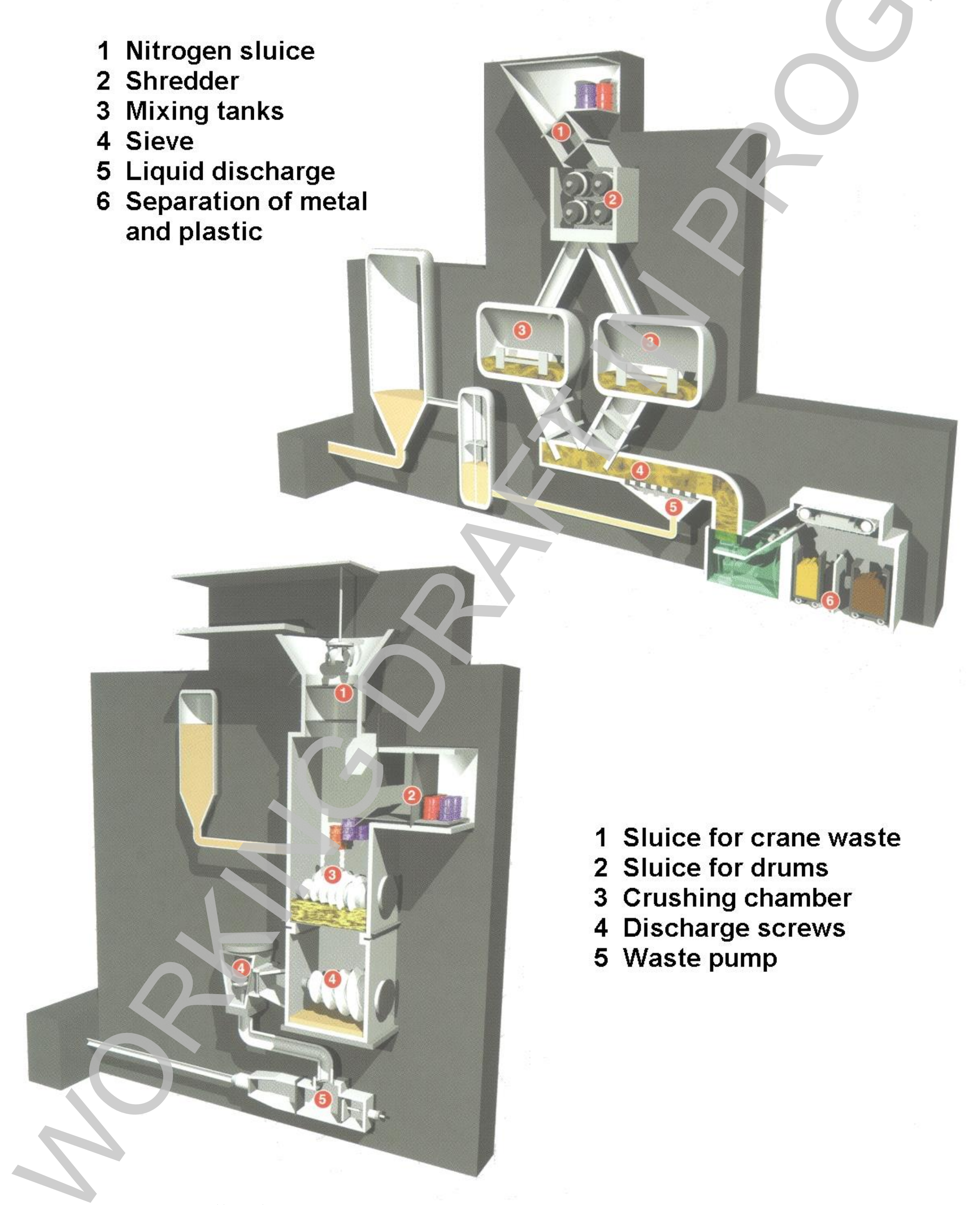
[EURITS, 2002 #41] Some incinerators have dedicated and integrated homogenisation processes ~~installations~~ for the pretreatment of waste. These include the following:

- A shredder for bulky solids (e.g. contaminated packages) [74, TWGComments, 2004].
- A dedicated shredder purely for drums. Depending on the installation, drums containing solid and/or liquid waste can be treated. The shredded residues are then fed via the bunker and/or tanks.
- A shredder combined with a mechanical mixing device. This results in a homogenised fraction which is pumped directly into the kiln by means of a thick-matter pump. Some shredders can deal with both drums and/or solid waste in packages of up to 1 tonne.

Other forms of pretreatment may be carried out depending on the waste composition and the individual characteristics of the incineration plant, ~~together with the availability of other treatment means for any wastes produced, other pretreatment may also be carried out.~~ for example [1, UBA, 2001]:

- neutralisation (for waste acceptance, pH values from 4 to 12 are normal);
- sludge drainage;
- solidification of sludge with binding agents.

~~The following~~ Figure 2.2 shows ~~an example of some~~ two hazardous waste pretreatment systems used at ~~some~~ merchant HWIs.



Source: [25, Kommunikemi, 2002]

Figure 2.2: Examples of ~~some~~ hazardous waste pretreatment systems used at some merchant HWIs

2.2.3 Sewage sludge

2.2.3.1 Composition of sewage sludge

The composition of sewage sludge varies according to many factors, including:

- system connections, e.g. industrial inputs can increase heavy metal loads;
- coastal locations, e.g. for salt water inclusion;
- treatments carried out at the treatment works, e.g. crude screening only, anaerobic sludge digestion, aerobic sludge digestion, addition of treatment chemicals;
- weather/time of year, e.g. rainfall can dilute the sludge.

The composition of sewage sludge varies greatly. Typical composition ranges for dewatered communal and industrial sewage sludge are given below.

Table 2.4: Average composition of dewatered communal sewage sludge and industrial sewage sludge after dewatering

Component	Communal sewage sludge	Industrial sewage sludge
Dry solids (%)	10–45	-
Organic material (% of dry solids)	45–85	-
Heavy metals mg/kg d.s.):	-	-
Cr	20–77	170
Cu	200–600	1 800
Pb	100–700	40
Ni	15–50	170
Sb	1–5	< 10
Zn	500–1 500	280
As	5–20	< 10
Hg	0.5–4.6	1
Cd	1–5	< 1
Mo	4–20	-
Source: [2, infomil, 2002], [64, TWGComments, 2003]		

~~Particularly~~ Important factors to take into account when incinerating sewage sludge are:

- the dry solids content (typically this varies from 10 % up to 45 % - this can have a major impact on the incineration process);
- whether the sludge is digested or not;
- the lime, limestone and other conditioning contents of the sludge;
- the composition of the sludge as primary-, secondary-, bio-sludge, etc.;
- odour problems, especially during sludge feeding in the storage areas.
  [64, TWGComments, 2003] [74, TWGComments, 2004]

2.2.3.2 Pretreatment of sewage sludge

2.2.3.2.1 Physical dewatering

[1, UBA, 2001, 64, TWGComments, 2003]
Mechanical drainage before incineration reduces the volume of the sludge mixture, ~~by the reduction of the water content. An~~ and increases ~~in~~ the heat value ~~is associated with this process~~. This allows independent and economical incineration. The success of mechanical drainage depends on the selected machines, the conditioning carried out, and the type and composition of the sludge.

Through mechanical drainage of the sewage sludge in decanters, centrifuges, belt filter presses and chamber filter presses, a dry solids (DS) level of between 10 % and 45 % can be achieved.

Often the sludge is conditioned before the mechanical drainage to improve its drainage. This is achieved with the help of additives that contain flock-building materials. It is necessary to differentiate between inorganic flocking substances (iron and aluminium salts, lime, coal, etc.) and organic flocking substances (organic polymers). Inorganic substances not only act as flocking substances but are also builders, i.e. they increase the inorganic content substantially, and hence increase the amount of ash produced. ~~the unburned proportion of the drained sludge (ash). For this reason, mostly~~ Organic conditioning substances are generally preferred because they are destroyed in the incinerator and do not increase the amount of ash produced. ~~used in the treatment of sewage sludge.~~

2.2.3.2.2 Drying

[1, UBA, 2001, 64, TWGComments, 2003]
Often a substance that has been dried by mechanical drainage is still too wet ~~insufficiently dry~~ for auto-thermal incineration. ~~In this case,~~ A thermal drying plant ~~for additional drying~~ can be used to increase the heat value and reduce the volume of the sludge before the incineration furnace. ~~In this case, the sewage sludge is further reduced in volume and the heat value is further increased.~~

The drying/dewatering of sewage sludge is carried out in separate or connected drying plants. The following dryer plants are utilised:

- disk dryer;
- drum dryer;
- fluidised bed dryer;
- belt dryer;
- thin film dryer/disk dryer;
- cold air dryer;
- thin film dryer;
- centrifugal dryer;
- solar dryer;
- combinations of different types.

Drying processes can be divided~~,~~ ~~in principal,~~ into two groups:

- partial drying, up to approximately 60–80 % dry solids;
- complete drying, up to approximately 80–90 % dry solids.

[74, TWGComments, 2004]

An alternative to external drying is the *in situ* drying of sludge by incineration together with higher calorific waste. In such cases, the water from the dewatered sludge helps to prevent the ~~otherwise possible~~ high temperature peaks that ~~can~~ could be seen if ~~only~~ high CV waste was ~~were~~ incinerated on its own.

For auto-thermal incineration in ~~mono-~~sewage sludge mono-incineration plants, the drainage of raw sewage up to ~~a dry substance content of~~ 35 % dry solids ~~per cent~~ is generally sufficient. This can be achieved by mechanical dewatering and may not require thermal drying.

The required dry ~~substance~~ solids content for auto-thermal incineration in a given installation will depend on the composition of the sludge (energy content of the dry solids, largely related to the content of organic material). This is influenced by the nature of the sludge ~~as such, but also by the applied~~ and any pretreatments that are applied, e.g. ~~by~~ sludge digestion, or ~~by~~ the use of organic or inorganic sludge conditioners.

~~For the simultaneous incineration of sewage sludge with other waste streams in municipal waste incineration plants (typically with a max. 10 % weight of drained sewage sludge (i.e. dryness of 20 – 30 %), Additional sludge drying may be required.~~
Sludge drying may be required to enable the simultaneous incineration of sewage sludge with other waste streams in municipal waste incineration plants. Typical operating conditions for the MSWI feed are a maximum of 10 % drained sewage sludge with 20–30 % dry solids.
[74, TWGComments, 2004]

The heat required for the drying process is usually extracted from the incineration process. ~~In some~~ In direct drying processes, the sewage sludge ~~to be dried~~ comes into direct contact with the thermal carrier (e.g. in convection dryers ~~or direct dryers (e.g.~~ belt, double-deck and fluidised bed dryers~~)~~. ~~During the drying process emissions to air are produced that is~~ The drying process produces a mixture of steam, air, and gases released ~~gases~~ from the sludge which is generally injected into the furnace. ~~and hot gases are produced in the direct drying process. The vapour and gas mixture must be cleaned. Generally, the steam from the drying process is injected in into the furnace. Direct dryers can be used in an indirect system by the recirculation of evaporation vapours. This system has clear advantages and is often used (but hardly or not in combination with sludge incineration).~~

In indirect drying systems (e.g. worm, disk, thin film dryers), the heat is injected via steam generators or thermal oil plants and the heating fluid is not in contact with the sludge. Heat transfer occurs between the wall and the sludge.

Contact dryers generally achieve a dry solids level of 35–40 %. The evaporated water produced through the drying process is only contaminated with leaking air and small amounts of volatile gases. The steam can be condensed almost totally from the vapour and the remaining inert gases can be used as incinerator feed air to prevent the emission of odours. ~~deodorised in the boiler furnace.~~ The treatment of the condensate may be complicated due to the presence of NH_4OH, TOC, etc.

2.2.3.2.3 Sludge digestion

Sludge digestion decreases the organic content of ~~organic material in~~ the sludge and anaerobic digestion also produces biogas ~~(at least in the case of anaerobic digestion)~~. Digested sludge can generally be dewatered more easily than non-digested sludge, ~~thus allowing~~ producing a slightly higher dry solids content. ~~after mechanical dewatering~~.
[64, TWGComments, 2003]

2.2.4 Clinical waste

2.2.4.1 Nature and composition of clinical wastes

Special attention is required when dealing with clinical wastes to manage the specific risks ~~of these wastes~~ (e.g. infectious contamination, needles), the aesthetic standards (residues of operations etc.) and their incineration behaviour (very variable calorific value and moisture contents).

Specific clinical waste often contains materials with a very high LHV (plastics, etc.), but also residues with a very high water content (e.g. blood). Clinical waste therefore usually requires long incineration times to ensure thorough waste burnout and acceptable ~~that the~~ residue quality ~~is good~~.

Similar to hazardous wastes, the composition of ~~specific~~ clinical wastes varies greatly and ~~.~~ ~~Clinical waste~~ may include ~~(to varying degrees)~~:

- infectious agents;
- contaminated clothing/wipes and swabs;
- pharmaceutical substances;
- sharp materials, e.g. hypodermic needles;
- veterinary wastes;
- body parts;
- used medical equipment;
- packaging materials;
- laboratory wastes;
- radioactive contaminated materials.

In some cases, a distinction is made between the incineration routes for pathological (potentially infectious waste) and non-pathological waste. The treatment of pathological waste is sometimes restricted to dedicated incinerators, while non-pathological waste is, in some cases, incinerated with other wastes in non-dedicated incinerators, e.g. MSWIs.

2.2.4.2 Handling, pretreatment and storage of clinical waste

The risks associated with the handling of clinical waste can generally be reduced by limiting contact with the waste and by ensuring good storage conditions ~~, e.g.~~ through the use of:

- dedicated containers and the provision of washing/disinfection facilities;
- sealed and robust combustible containers, e.g. for sharps and biological hazard materials;
- automatic furnace loading systems, e.g. dedicated bin lifts;
- segregated storage and transfer areas (especially where co-incineration with other wastes takes place);
- refrigerated or freezer storage, if required.

Pretreatment may be carried out using:

- steam disinfection, e.g. autoclaving at elevated temperature and pressure;
- boiling with water.

Each of these may allow the waste to be sufficiently sterilised to permit its subsequent handling in a similar manner to municipal wastes. Work and storage areas are usually designed to facilitate disinfection.

Appropriate cleaning and disinfection equipment ~~are~~ is usually installed for the cleaning of returnable containers. The solid wastes from disinfection are collected for disposal. The waste water from disinfection is collected and then recycled in the incineration process (e.g. in the FGC or with the ~~fed~~ waste feed) or treated and discharged. [74, TWGComments, 2004]

Pretreatment may be applied to improve the homogeneity of the waste, such as shredding or maceration, although safety aspects require careful consideration with some clinical wastes.

Clinical waste is also incinerated in hazardous waste and other incineration plants with other types of waste. If incineration does not take place immediately, the wastes require temporary storage. In some cases, where it is necessary for clinical waste to be stored for longer than 48 hours, the waste is kept in cooled storage areas with a restricted maximum temperature (e.g. +10 °C).

2.3 The thermal treatment stage

Different types of thermal treatments are applied to the different types of wastes.~~, however not all thermal treatments are suited to all wastes.~~ This chapter and Table 2.5 review the concepts and applications behind the most common technologies, in particular:

- grate incinerators;
- rotary kilns;
- fluidised beds;
- pyrolysis and gasification systems.

They also cover some other more specific technologies.
[EGTEI, 2002 #6]

Municipal solid waste can be incinerated in ~~several combustion systems including~~ travelling grates, rotary kilns and fluidised beds. Fluidised bed technology requires MSW to be of a certain particle size range, which ~~— this~~ usually requires some degree of pretreatment and/or the separate ~~selective~~ collection of the waste.

~~**Incineration of s**~~ **Sewage sludge** can be incinerated ~~this takes place~~ in rotary kilns, multiple hearth or fluidised bed incinerators. Co-combustion in grate-firing systems, coal combustion plants and industrial processes is also applied. Sewage sludge often has a high water content and therefore usually requires drying or the addition of supplementary fuels to ensure stable and efficient combustion.

~~**Incineration of h**~~ **Hazardous and ~~medical~~ clinical waste** is usually incinerated in rotary kilns ~~are most commonly used,~~ but grate incinerators (including co-firing with other wastes) are ~~also~~ sometimes applied to solid wastes, and fluidised bed incinerators to some pretreated materials. Static furnaces are also widely applied at on-site facilities at chemical plants.

Other processes have been developed that are based on the decoupling of the phases which ~~also~~ take place in an incinerator: drying, volatilisation, pyrolysis, carbonisation and oxidation of the waste. Gasification using gasifying agents such as~~,~~ steam, air, carbon oxides or oxygen is also applied. These processes aim to reduce flue-gas volumes and associated flue-gas treatment costs. Some of these processes ~~developments met~~encountered technical and economic~~al~~ problems when they were scaled up to commercial, industrial sizes, and their development has been abandoned. ~~are therefore pursued no longer.~~ Some are used on a commercial basis (e.g. in Japan) and others are being tested in demonstration plants throughout Europe, but they still have only a small share of the overall treatment capacity when compared to incineration.

Table 2.5: Summary of the current successful application of thermal treatment processes techniques to the main applied to different waste types at dedicated installations

Technique	~~Untreated~~ Municipal solid waste	~~Pretreated MSW and RDF~~ Other non-hazardous waste	Hazardous waste	Sewage sludge	Clinical waste
Grate - intermittent/reciprocating	56 %	43 %	0 %	0 %	0 %
Grate - vibration ~~travelling~~	0 %	0 %	11 %	0 %	0 %
Grate - moving ~~rocking~~	24 %	27 %	0 %	0 %	0 %
Grate - roller	12 %	10 %	0 %	0 %	0 %
Grate - water-cooled	22 %	48 %	17 %	0 %	0 %
Grate plus rotary kiln	0.5 %	0 %	2 %	0 %	0 %
Rotary kiln	2 %	0 %	70 %	0 %	0 %
Static hearth	0 %	0 %	0 %	0 %	67 %
Static furnace	0 %	0 %	16 %	0 %	0 %
Fluidised bed - bubbling	2 %	13 %	0 %	90 %	0 %
Fluidised bed - circulating	3 %	8 %	0 %	10 %	0 %
Pyrolysis	0 %	0 %	0 %	0 %	0 %
Gasification	0.5 %	0 %	0 %	0 %	33 %

NB: This table shows ~~only considers the application of~~ the technologies applied ~~described~~ at the plants participating in the 2016 data collection for the WI BREF review, classified by the prevalent type of waste incinerated in 2014. ~~dedicated installations. It does not therefore include detailed consideration of the situations where more than one type of waste is processed.~~

Source: ~~[64, TWGComments, 2003]~~ [81, TWG 2016].

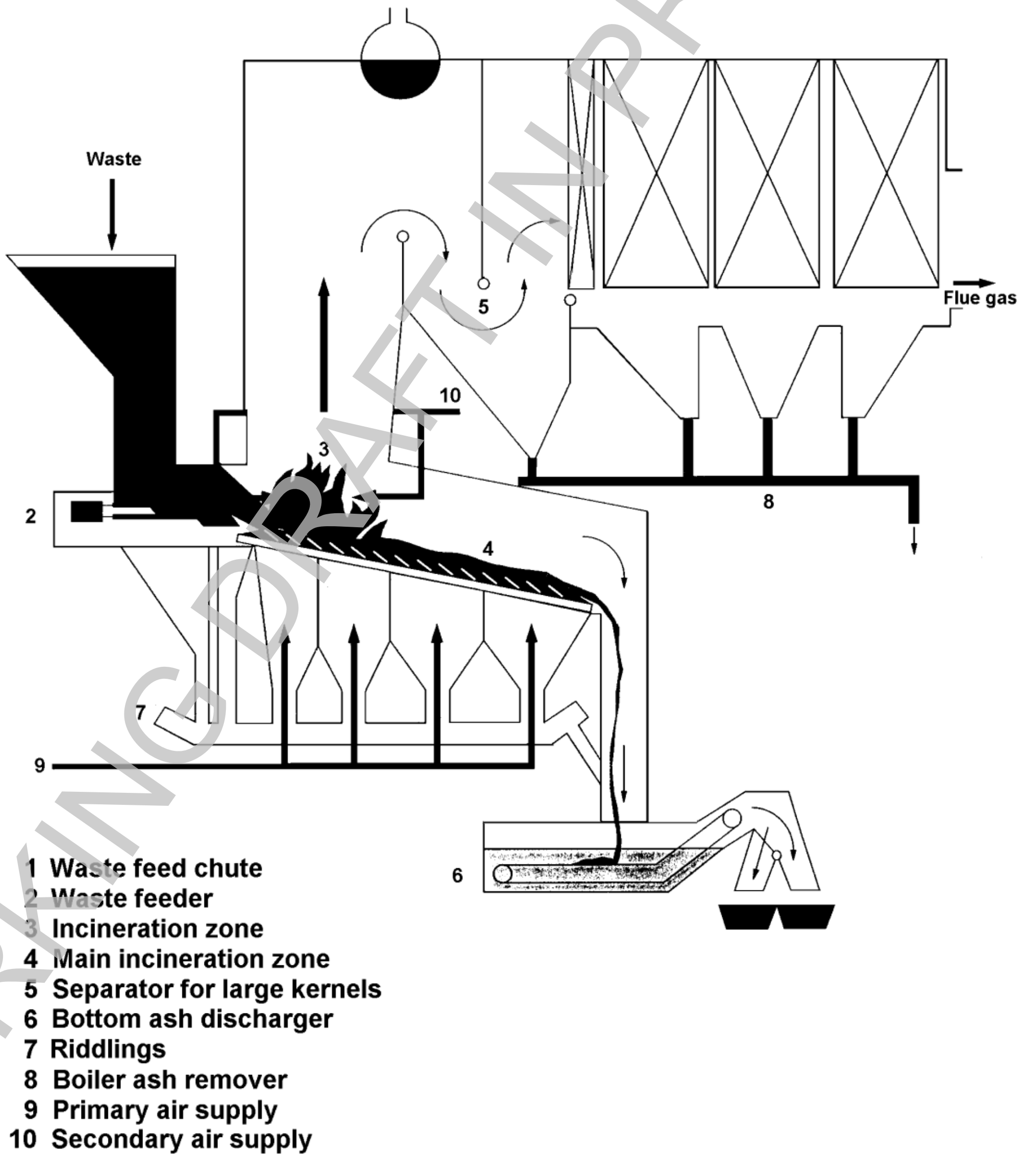
2.3.1 Grate incinerators

Grate incinerators are widely applied for the incineration of mixed municipal wastes. In Europe, approximately 90 % of installations treating MSW use grates. Other wastes commonly treated in grate incinerators, often as additions with MSW, include commercial and industrial non-hazardous wastes, sewage sludges and certain clinical wastes.

Grate incinerators usually have the following components:

- waste feeder;
- incineration grate;
- bottom ash discharger;
- incineration air duct system;
- incineration chamber;
- auxiliary burners.

Figure 2.3 shows an example of a grate incinerator with a heat recovery boiler.



Source: [1, UBA, 2001]

Figure 2.3: Grate, furnace and heat recovery stages of an example municipal waste incineration plant

2.3.1.1 Waste feeder

The waste is discharged from the storage bunker into the feeding chute by an overhead crane, and then fed into the grate system by a hydraulic ramp or another conveying system. The grate moves the waste through the various zones of the combustion chamber in a tumbling motion.

The filling hopper is used as a continuous waste supplier. It is filled in batches by the overhead crane. As the filling hopper surface is exposed to great stress, materials with high friction resistance are selected (e.g. boilerplates or wear-resistant cast iron). The material must survive occasional hopper fires unscathed.

The waste hopper may sometimes be fed by a conveyor. In that case, the overhead crane discharges waste into an intermediate hopper that feeds the conveyor. [74, TWGComments, 2004]

If the delivered waste has not been pretreated, it is generally very heterogeneous in both size and nature. The feed hopper is therefore dimensioned in such a way that bulky materials fall through and bridge formations and blockages are avoided. These blockages must be avoided as they can result in uneven feeding to the furnace and uncontrolled air ingress to the furnace.

Feeder chute walls can be protected from heat by using:

- water-cooled double shell construction;
- membrane wall construction;
- water-cooled stop valves;
- fireproof brick lining.

If the feed chute is empty, stop valve equipment (e.g. door seals) can be used to avoid flashbacks and ~~for the prevention of~~ to prevent uncontrolled air infiltration into the furnace. A uniform amount of waste in the filling chute is recommended for uniform furnace management.

The junction between the lower end of the filling chute and the furnace consists of a dosing mechanism. The dosing mechanism may be driven either mechanically or hydraulically. Its feeding rate is generally adjustable. Different construction methods have been developed for the various types of feeder systems, such as:

- chain grates/plate bands;
- feeder grates;
- variable taper feed chutes;
- RAM feeders;
- hydraulic ramp;
- feed screws.

[74, TWGComments, 2004]

2.3.1.1.1 Addition of sewage sludge to a municipal waste incinerator ~~Sewage sludge incineration in MSWI plants~~

To the TWG: former Section 2.3.1.8

Sewage sludge is sometimes incinerated with other wastes in municipal grate incineration plants (see Section 2.3.3 for information regarding the use of fluidised beds and other technologies).

Where added to MSWI, it is often the feeding techniques that represent a significant proportion of the additional investment costs.

The following three supply technologies are used:

- Dried sewage sludge (~ 90 % dry solids) is blown as dust into the furnace.
- Drained sewage sludge (~ 20–30 % dry solids) is supplied separately through sprinklers into the incineration chamber and distributed on a grate. The sludge is integrated into the bed material by overturning the waste on the grates. Some operational experiences have shown that ~~show~~ up to 20 mass-% sludge (at 25 % dry solids) can be incinerated using this technique. Other experiences have shown that if the sludge ratio is too high (e.g. > 10 %), a high fly ash content or unburnt material in bottom ash may occur.
- Drained, dried or ~~semi -~~partially dried sludge (~ 50–60 % dry solids) is added to the municipal waste and the mixture is fed ~~mixed with the remaining waste or fed together~~ into the incineration chamber. ~~This~~ Mixing can occur in the waste bunker through targeted doses by the crane operator, or it can be controlled in a feeding hopper by pumping dewatered sludge into the hopper or into the bunker by spreading systems. [74, TWGComments, 2004]

2.3.1.1.2 Addition of clinical waste to a municipal waste incinerator

To the TWG: former Section 2.3.19

(Denmark 2002) Clinical waste is sometimes incinerated with other wastes in municipal waste incineration plants ~~added into an existing municipal waste incinerator~~. Clinical waste is combusted in the same furnace as the MSW.

Infectious clinical waste is ~~must be~~ placed straight into the furnace, without first being mixed with other categories of waste and without direct handling. ~~This is a legislative requirement (IED Article 50).~~ A separate loading system with airlocks is ~~often~~ ~~are also~~ used. The airlock helps to prevent the uncontrolled entry of ~~uncontrolled~~ combustion air and the possibility of fugitive emissions in the loading area.

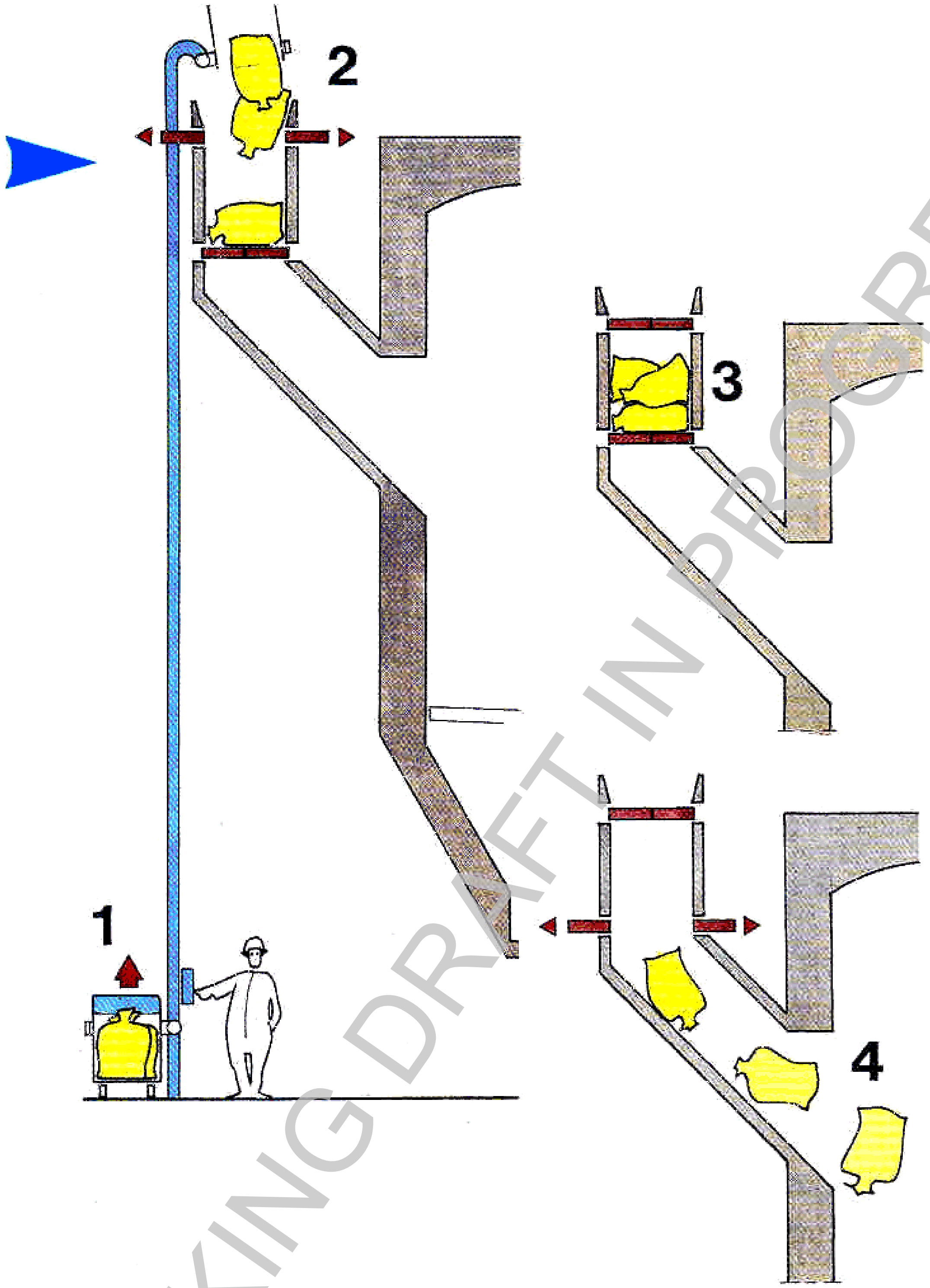
~~In some cases the waste is loaded into the same hopper as the MSW.~~

The combined incineration of non-infectious clinical waste with municipal solid waste can be ~~also~~ carried out without a separate loading system. For example, automatic loading systems ~~are implemented in order~~ can be used to put the clinical waste directly into the feed hopper with MSW.

National regulations sometimes limit the ratio of clinical waste that may be treated in combined incineration (e.g. in France < 10 % thermal load)

~~Note that Article 6.7 of Waste Incineration Directive requires that infectious clinical waste should be placed straight in the furnace, without first being mixed with other categories of waste and without direct handling. [74, TWGComments, 2004]~~
Flue-gases from the different wastes are then treated in common FGC systems.

In Figure 2.4 below the order of the stages for a separate loading system are shown.



Source: [49, Denmark, 2002]

Figure 2.4: Examples of the stages of a clinical waste loading system used at a municipal waste incinerator

2.3.1.2 Incineration grate

The incineration grate accomplishes the following functions:

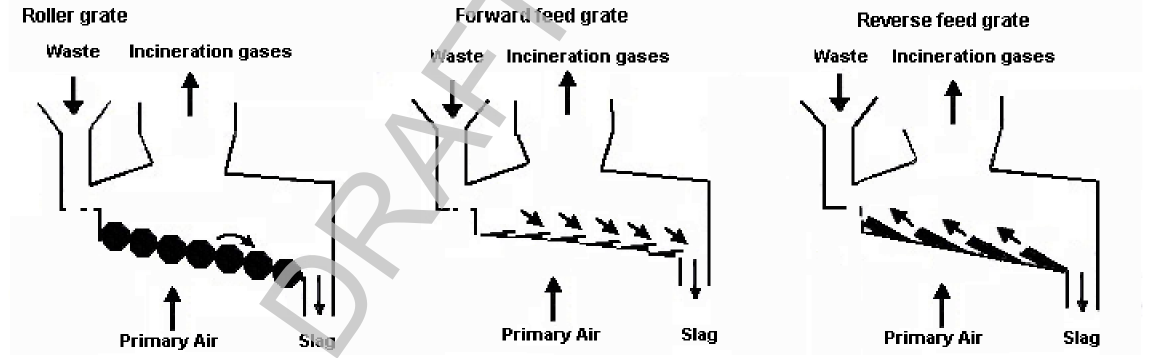
- transport of materials to be incinerated through the furnace;
- stoking and loosening of the materials to be incinerated;
- positioning of the main incineration zone in the incineration chamber, possibly in combination with furnace performance control measures.

A target of the incineration grate is a good distribution of the incineration air into the furnace, according to combustion requirements. A primary air blower forces incineration air through small grate layer openings into the fuel layer. More air is generally added above the waste bed to complete combustion.

It is common for some fine material (sometimes called riddlings or siftings) to fall through the grate. This material is recovered in the bottom ash remover or ~~. Sometimes it is~~ recovered separately. ~~and~~ It can ~~may~~ be recycled to the grate for repeated incineration or removed directly for disposal. When the siftings are recirculated in the hopper, care should be taken not to ignite the waste in the hopper. [74, TWGComments, 2004]

Normally, the residence time of the wastes on the grates is not more than 60 minutes. [74, TWGComments, 2004]

In general, one can differentiate between continuous (roller and chain grates) and discontinuous (push grates) feeder principles. Figure 2.5 shows some types of grates.



Source: [1, UBA, 2001]

Figure 2.5: Different grate types

Grate cooling is carried out to control metal temperatures and thereby improve grate life. The cooling medium can be air or water (other liquids may also be used, such as oils or other heat-conducting fluid). (*from Section 4.3.14*) ~~Most grates are cooled, most often with air. In some cases a liquid cooling medium (usually water) is passed through the inside of the grate.~~ The flow of the liquid cooling medium is from colder zones to progressively hotter ones in order to maximise the heat transfer. The heat absorbed by the liquid cooling medium may be ~~transferred for use~~ used in the incineration process or ~~for external supply~~ supplied to an external process.

The use of air-cooled grates in Europe is very common, with approximately 90% of incinerated MSW being treated in plants using air-cooled grates. Air is supplied below the grate and passes through the grate spacings. The main function of this air is to provide the necessary oxygen for oxidation, and the flow rate is designed according to this requirement. Simultaneously, this air ~~provides cooling to~~ cools the grates. When more excess air is introduced, additional cooling is supplied but a larger amount of flue-gas is produced. (*from Section 4.3.14*)

Water cooling is most often applied where the calorific value of the waste is higher e.g. > 12–15 MJ/kg for MSW. The design of the water-cooled system is slightly more complex than air-cooled systems.

The addition of water cooling may allow the grate metal temperature and local combustion temperature to be controlled with greater independence from the primary air supply (normally between the grate bars). This may then allow the temperature and air (oxygen) supply to be optimised to suit specific on-grate combustion requirements and thereby improve the combustion performance. The temperature of the liquid can be used to monitor the reactions (some are endothermic, some exothermic, and to differing degrees) occurring in the waste bed above the grate. These reactions can then be controlled by varying the amount of air supplied through that section of the grate to the waste above. This separation of the cooling and air supply functions increases the control of the process. (*from Section 4.3.14*) Greater control of the grate temperature can allow the incineration of higher calorific value wastes without the normally increased operational and maintenance problems.

Different grate systems can be distinguished by the way the waste is conveyed through the different zones in the combustion chamber. Each has to fulfil requirements regarding primary air feeding, conveying velocity and raking, as well as mixing of the waste. Other features may include additional controls, or a more robust construction to withstand the severe conditions in the combustion chamber.

2.3.1.2.1 Rocking grates

[4, IAWG, 1997] The grate sections are placed across the width of the furnace. Alternate rows are mechanically pivoted or rocked to produce an upward and forward motion, advancing and agitating the waste.

2.3.1.2.2 Reciprocating grates

~~[4, IAWG, 1997] Many modern facilities (for municipal wastes) use reciprocating grates. The quality of burnout achieved is generally good.~~

This design consists of sections that span the width of the furnace but are stacked above each other. Alternate grate sections slide back and forth, while the adjacent sections remain fixed. Waste tumbles off the fixed portion and is agitated and mixed as it moves along the grate. Numerous variations of this type of grate exist, some with alternating fixed and moving sections, others with combinations of several moving sections to each fixed section. In the latter case, the sections can either move together or at different times in the cycle.

There are essentially two main reciprocating grate variations:

1. Reverse reciprocating grate
The grate bars oscillate back and forth in the reverse direction to the flow of the waste. The grate is sloped from the feed end to the ash discharge end and is comprised of fixed and moving grate steps.

2. Push forward grate
The grate bars form a series of many steps that oscillate horizontally and push the waste in the direction of the ash discharge.

2.3.1.2.3 Travelling grates

This type of grate consists of a continuous metal belt conveyor or interlocking linkages that move along the length of the furnace. The reduced potential to agitate the waste (it is only mixed when it transfers from one belt to another) means that it is seldom used in modern facilities. [IAWG, 1997 #4]

2.3.1.2.4 Roller grates

This design consists of a perforated roller that traverses the width of the grate area. Several rollers are installed in series and a stirring action occurs at the point where ~~transition when~~ the material tumbles off the rollers. [4, IAWG, 1997]

~~2.3.1.2.5 Cooled grates~~

To the TWG: moved to Section 2.3.1.2

~~Most grates are cooled, most often with air. In some cases a liquid cooling medium (usually water) is passed through the inside of the grate. The flow of the cooling medium is from colder zones to progressively hotter ones in order to maximise the heat transfer. The heat absorbed by the cooling medium may be transferred for use in the incineration process or for external supply.~~

~~Water cooling is most often applied where the calorific value of the waste is higher e.g.>12 - 15 MJ/kg for MSW. The design of the water cooled system is slightly more complex than air cooled systems.~~

~~The addition of water cooling may allow grate metal temperature and local combustion temperature to be controlled with greater independence from the primary air supply (normally between the grate bars). This may then allow temperature and air (oxygen) supply to be optimised to suit specific on-grate combustion requirements and thereby improve combustion performance. Greater control of grate temperature can allow incineration of higher calorific value wastes without the normally increased operational and maintenance problems.~~

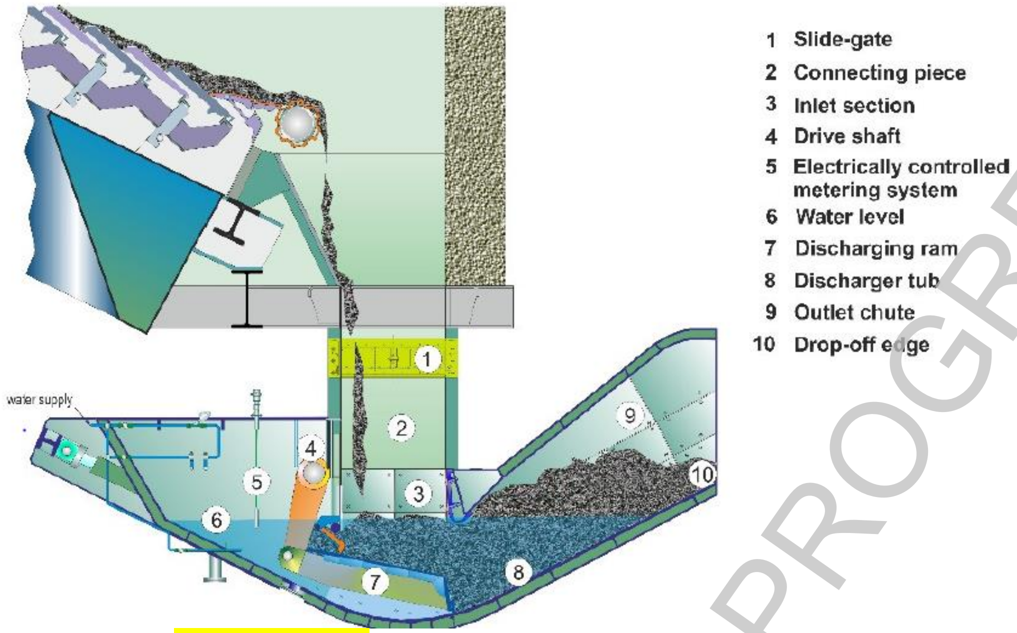
2.3.1.3 Bottom ash discharger

The bottom ash discharger is used to cool and discharge ~~for cooling and~~ ~~removal of~~ the solid residue (bottom ash) that accumulates at the end of ~~on~~ the grate. It also serves as an air seal for the furnace, preventing flue-gas emissions and uncontrolled air ingress to ~~the false air to enter into~~ the furnace ~~and cools and humidifies the ash~~.

Water-filled ram-type ~~pressure pistons, and~~ ~~drag~~ constructions and belt conveyors are commonly used to extract the bottom ash. ~~Other bottom ash discharges, such as belt conveyors are also commonly used. Grate ashes,~~ as well as any bulky objects ~~are thus conveyed~~.

The water used for cooling is separated from the grate ash at the exit and may be recirculated to the ash discharger. A water top-up feed is usually required to maintain an adequate water level in the discharger. The top-up water replaces ~~losses~~ water lost with the removed bottom ash and evaporation losses. In addition, a water drain may be needed to prevent the build-up of salts – such bleed systems can help to reduce the salt content of the residues if the flow rates are adjusted specifically for this purpose. The bottom ash removal shaft is usually fireproof and is constructed in such a way that bottom ash caking is avoided.

The bottom ash can be discharged dry by operating a ram-type discharger without water. In this case, air sealing of the furnace is achieved by piling up the bottom ash in the inlet section. The bottom ash is cooled down by the air without increasing the surface temperature of the discharger. [82, Germany, 2014]



Source: ~~[1, UBA, 2001]~~ [82 Germany 2014]

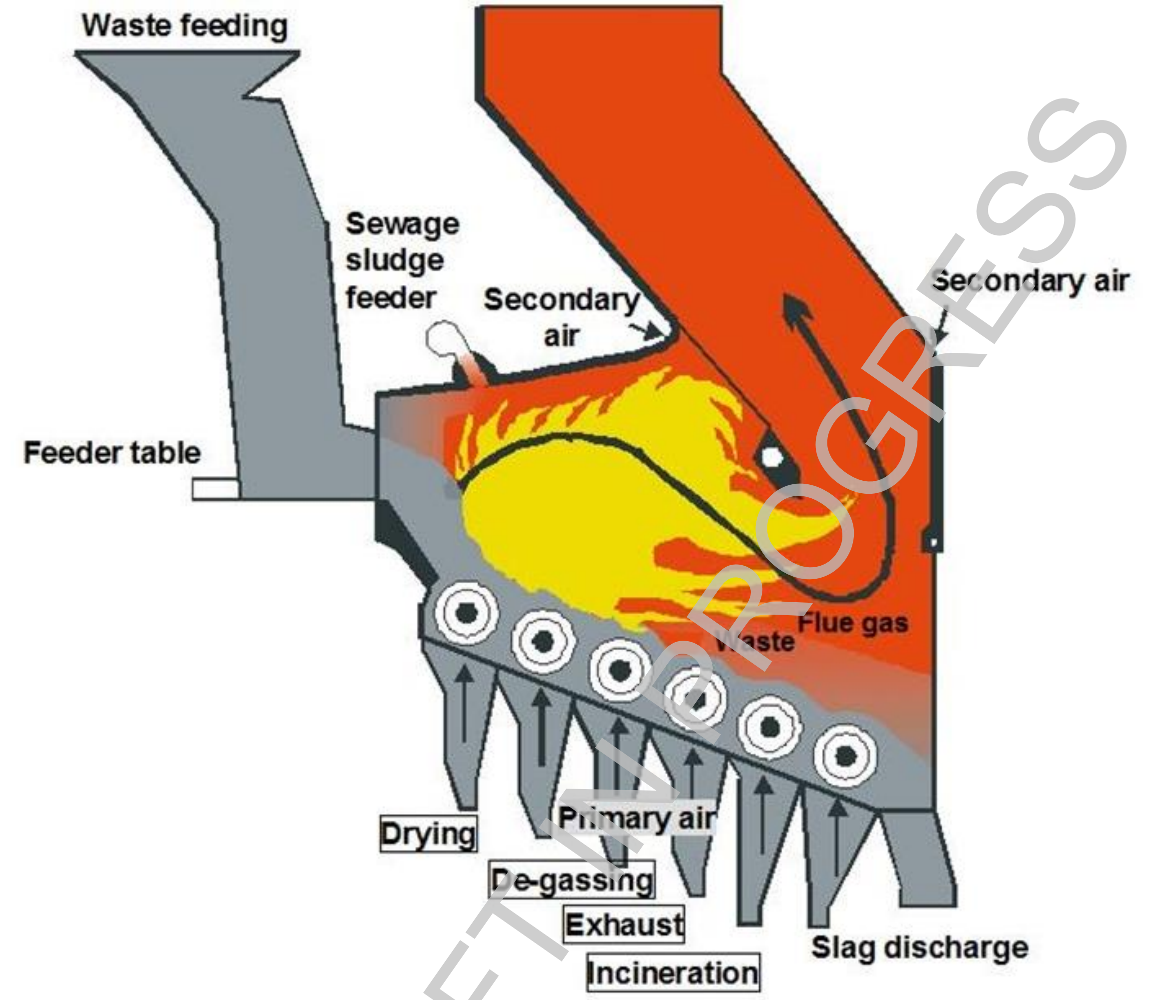
Figure 2.6: Example of a ram-**type** bottom ash discharger **~~of ash remover~~ used at a grate-**based **incinerator**

2.3.1.4 Incineration chamber and boiler

~~Combustion takes place above the grate in the incineration chamber (see Figure 2.7). As a whole,~~ The incineration chamber (see Figure 2.7) typically consists of a grate situated at the bottom, cooled and non-cooled walls on the furnace sides, and a ceiling or boiler surface heater at the top. ~~As~~ Municipal waste generally has a high volatile content, so the volatile gases are driven off and burn above the grate with only a small part of the actual incineration taking ~~takes~~ place on or near the grate.

The following requirements influence the design of the incineration chamber:

- form and size of the incineration grate - the size of the grate determines the size of the cross-section of the incineration chamber;
- vortexing and homogeneity of flue-gas flow - complete mixing of the flue-gases is essential for good flue-gas incineration;
- sufficient residence time for the flue-gases in the hot furnace - sufficient reaction time at high temperatures is needed to ensure ~~must be assured for~~ complete incineration;
- partial cooling of flue-gases by the injection of secondary air - in order to avoid fusion of hot fly ash at the boiler, the flue-gas temperature must not exceed an upper limit at the incineration chamber exit.



Source: [1, UBA, 2001]

Figure 2.7: Example of an incineration chamber

The detailed design of a combustion chamber is usually linked to the grate type. Its precise design demands certain compromises as the process requirements change with the fuel characteristics. ~~Each supplier has their own combination of grate and combustion chamber, the precise design of which is based on the individual performance of their system and their specific experiences. European operators of MSW have found no fundamental advantage or disadvantage for the different designs of the combustion chamber.~~

A design that is not appropriate would lead to poor retention of combustible gases in the combustion zones, poor gas phase burnout and higher emissions *(To the TWG:text from Section 4.3.3)*.

In general, three different designs can be distinguished. The nomenclature comes from the flow direction of the flue-gases in relation to the waste flow: unidirectional current; countercurrent and medium current (see Figure 2.8).

Unidirectional current, co-current, or parallel flow furnace

In a co-current combustion arrangement, primary combustion air and waste are guided in a co-current flow through the combustion chamber. Accordingly, the flue-gas outlet is located at the end of the grate. Only a comparatively low amount of energy is exchanged between the combustion gases and the waste on the grate.

The advantage of unidirectional current concepts is that the flue-gas has the longest residence time in the ignition area and that it ~~must~~ passes through the maximum temperature zone. To facilitate ignition, the primary air is preheated.~~ must be~~. ~~pre-warmed with very low heat values~~.

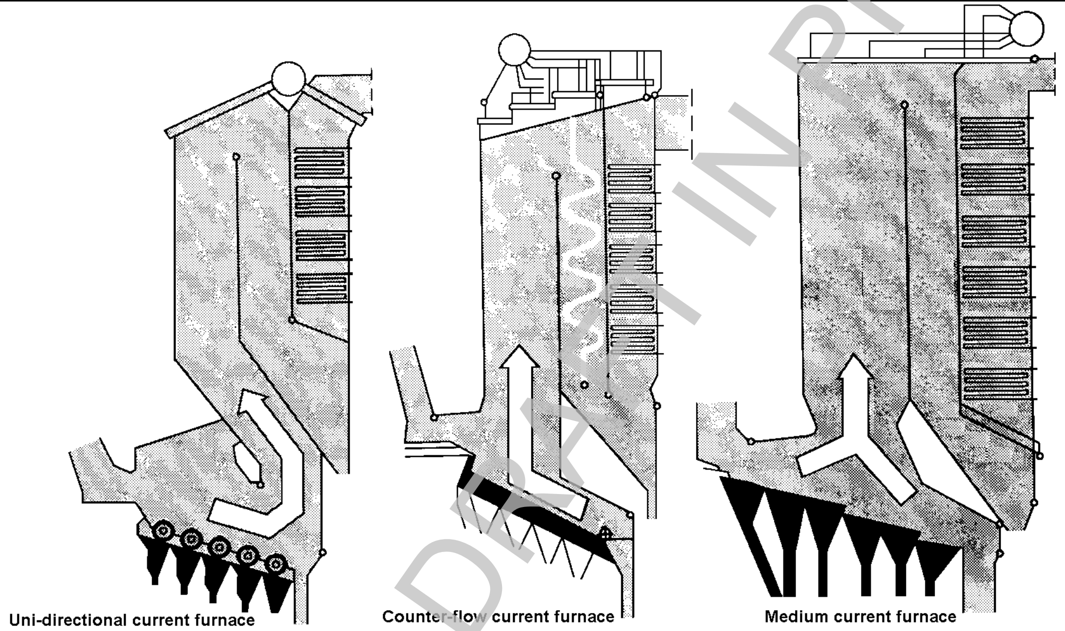
Counter-flow or countercurrent furnace

In this case, primary combustion air and waste are guided in a countercurrent flow arrangement through the combustion chamber and the flue-gas outlet is located at the front end of the grate. The hot flue-gases facilitate the drying and ignition of the waste.

Special attention must be paid to avoid the passage of unburned gas streams. As a rule, counter-flow current concepts require higher secondary or upper air additions.

Medium current or centre-flow furnace

The composition of municipal solid waste varies considerably and the medium current concept is a compromise for a wide feed value spectrum. A good mixture of all partial flue-gas currents must be considered through mixture-promoting contours and/or secondary air injections. In this case, the flue-gas outlet is located in the middle of the grate.



Source: [1, UBA, 2001]

Figure 2.8: Various furnace designs with differing direction of the flue-gas and the waste flow

Table 2.6 compares different types of incineration chamber design types in terms of their geometric characteristics, suitability to different waste types, and additional considerations regarding specific air supply requirements for example.

Table 2.6: A comparison of the features of some different incineration chamber designs

Type	Design features	Comments
Co-current or parallel flow	• Exit to combustion chamber at end of furnace • Gas flow in same direction as waste movement	• Suited to higher LHV wastes • All evolved gases must pass through maximum temperature zone and have long retention time • Primary air heating required in ignition zone
Countercurrent or counter-flow	• Exit to combustion chamber at start of furnace • Gas flow in opposite direction to the waste	• Suited to low-LHV / high-moisture / high-ash waste (as hot gases from volatilisation zone pass over the drying zone) • Higher secondary air requirements to ensure gas burnout
Medium current or centre-flow	• Exit to combustion chamber in middle of furnace	• Compromise of the above for wide spectrum of waste • Furnace configuration/secondary air important to ensure gas burnout
Split-flow	• Exit from combustion chamber in middle position but split by central section	• Central section aids retention of gases and allows secondary air to be injected from additional locations • Mainly used for very large furnaces

Source: [1, UBA, 2001, 2, infomil, 2002, 4, IAWG, 1997, 15, Segers, 2002]

Split-flow systems are mainly applied to larger furnaces because of the additional secondary air mixing it allows in central positions of the furnace. In smaller furnaces, adequate mixing may be achieved using side wall injection of the secondary air.

A balanced combustion chamber design ensures that gases evolved from the waste are well mixed and retained at a sufficient temperature in the combustion chamber to allow the combustion process to be fully completed. This principle is applicable to all incineration processes. (*text from Section 4.3.3*).

2.3.1.5 Incineration air feeding

The incineration air fulfils the following objectives:

- provision of oxidant;
- cooling;
- avoidance of slag formation in the furnace;
- mixing of flue-gas.

Air is added at various places in the combustion chamber. It is usually described as primary or secondary, although tertiary air and recirculated flue-gases are also used.

The primary air is generally taken from the waste bunker. This maintains a slight negative pressure ~~lowers the air pressure~~ in the bunker hall and eliminates most odour and dust emissions from the bunker area. Primary air is blown by fans into the areas below the grate, where its distribution can be closely controlled using multiple wind boxes, and distribution valves.

The air can be preheated if the calorific value of the waste degenerates to such a degree that it becomes necessary to pre-dry the waste. The primary air is blown ~~will be forced~~ through the grate layer into the fuel bed. It cools the grate bar and carries oxygen into the incineration bed.

Secondary air is blown into the incineration chamber at high speeds via, for example, injection lances or from internal structures. This is carried out to ensure complete incineration and is responsible for the intensive mixing of flue-gases, and prevention of the free passage of unburned gas streams.

2.3.1.6 Incineration temperature, residence time~~,~~ ~~minimum~~ and oxygen content

Incinerators are designed and operated to achieve a good burnout of the combustion gases by ensuring that the combustion gases are maintained at a minimum temperature for a minimum residence time at a minimum oxygen level. Typical values are a minimum temperature of 850 °C to 1100 °C for at least 2 seconds at an oxygen level of at least 6 %.

~~To achieve good burn out of combustion gases a minimum gas phase combustion temperature of 850 °C (1100 °C for some hazardous wastes) and a minimum residence time of the flue-gases, above this temperature, of two seconds after the last incineration air supply have been established in legislation~~. ~~(Directive 2000/76/EC and earlier legislation). Derogations from these conditions are allowed in legislation if they provide for a similar level of overall environmental performance. [74, TWGComments, 2004]~~

~~A minimum oxygen content of 6 % was required by earlier legislation but removed from the most recent EC Directive on incineration.~~

~~Operational experiences have in some cases shown that lower temperatures, shorter residence times and lower oxygen levels can, in some situations, still result in good combustion and may result in overall improved environmental performance. However, low oxygen content may lead to significant corrosion risk and therefore require specific material protection. [74, TWGComments, 2004]~~

The carbon monoxide content of the flue-gas is a key indicator of the quality of combustion.

2.3.1.7 Auxiliary burners

At start-up, auxiliary burners are ~~commonly~~ used to heat up the furnace to a specified temperature before any waste is added. ~~This is the main use of auxiliary burners.~~ ~~These~~ During operation, the burners are ~~usually~~ switched on automatically if the temperature falls below the specified value. ~~during operation~~. During shutdown, the burners are ~~often only~~ used ~~if~~ when there is unburnt waste in the furnace to keep the furnace temperature at the desired level. [74, TWGComments, 2004]

2.3.2 Rotary kilns

Rotary kilns are very robust and almost any waste, regardless of type and composition, can be incinerated. Rotary kilns are, in particular, very widely applied for the incineration of hazardous wastes~~. The technology is also commonly used for clinical wastes (~~ and most hazardous clinical waste is incinerated in high-temperature rotary kiln incinerators. [64, TWGComments, 2003], ~~but less so for municipal wastes.~~

Operating temperatures of rotary kilns ~~used for wastes~~ range from around 500 °C (as a gasifier) to 1 450 °C (as a high-temperature ash melting kiln). Higher temperatures are sometimes encountered, but usually in non-waste incineration applications. When used for conventional oxidative combustion, the kiln temperature is generally above 850 °C. Kiln temperatures in the range of 900–1 200 °C are typical when incinerating hazardous wastes.

Generally, and depending on the waste input, the higher the operating temperature, the greater the risk of fouling and thermal stress damage to the refractory kiln lining. Some kilns have a cooling jacket (using air or water) that helps to extend refractory life, and therefore the time between maintenance shutdowns.

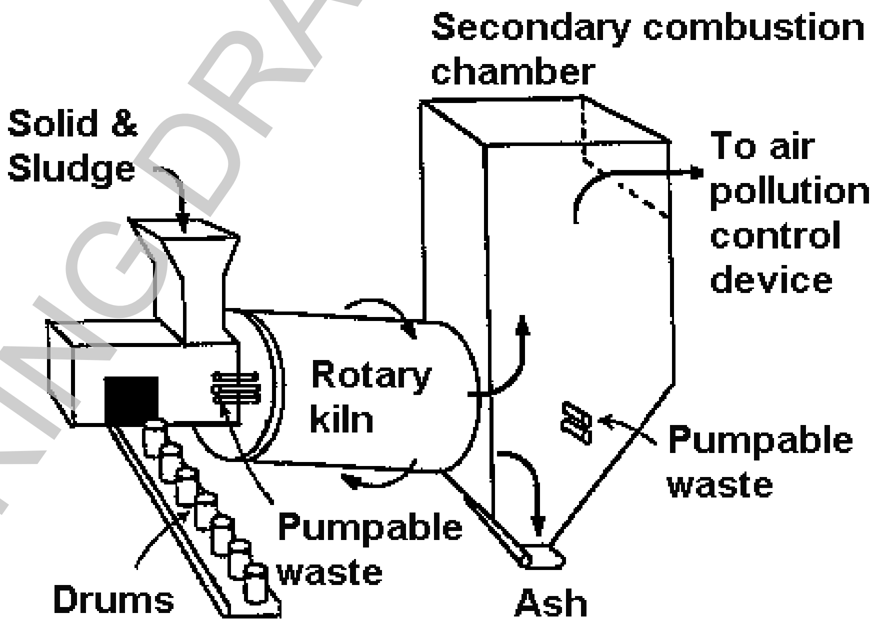
Water cooling is usually used together with higher temperatures in the kiln. The rotary kiln water cooling system consists of two cooling circuits. The primary cooling water circuit delivers primary cooling water on top of the rotary kiln and distributes it evenly to guarantee an equal cooling effect over the whole shell of the kiln. Water is then collected in ~~four~~ water collection basins located under the kiln, from where ~~and~~ it ~~continues to~~ flows ~~freely~~ into the water collection tank. Water is circulated back through a filter and a heat exchanger with a circulation pump. Evaporation is compensated with additional make-up water, which is automatically buffered with NaOH in order to avoid corrosion.

The secondary circuit removes heat from the primary circuit through heat exchangers and transfers it for use. ~~If there is no need for energy recovery, a multi-sectional air cooling system can be used for removing heat from the system. In order to avoid freezing, a water-glycol mixture is circulated through the liquid-air heat-exchangers.~~

The system delivers cooling water through hundreds of spray nozzles situated all over the shell of the kiln, keeping the temperature of the shell at 80–100 °C, whereas for air cooling the steel shell temperature is typically a few hundred degrees higher. The rotary kiln cooling increases the heat transfer through the refractory enough to reduce the rate of chemical erosion to a minimum. ~~Higher temperatures can be used in the kiln.~~

~~According to theoretical calculations and practical measurements at example installations,~~ The heat transfer through the furnace into the cooling water varies between 0.5 MW and 3.0 MW, depending on the size of the rotary kiln and the thickness of the refractory. The thickness of the refractory includes the remaining brick lining and the solidified bottom ash layer. ~~For example, in 1995 Kommunikemi (DK) reported an average kiln heat recovery of 2.2 MW.~~ (*from Section 4.3.15*)

A schematic drawing of a rotary kiln incineration system is shown below.



Source: [EGTEI, 2002 #6]

Figure 2.9: Schematic of a rotary kiln incineration system

The rotary kiln consists of a cylindrical vessel slightly inclined on its horizontal axis. The vessel is usually located on rollers, allowing the kiln to rotate or oscillate around its axis (reciprocating motion). The waste is conveyed through the kiln by gravity as it rotates. Direct injection is used particularly for liquid, gaseous or pasty (pumpable) wastes – especially where they present safety risks and require particular care to reduce operator exposure.

The residence time of the solid material in the kiln is determined by the horizontal angle of the vessel and the rotation speed: a residence time of between 30 and 90 minutes is normally sufficient to achieve good waste burnout.

Solid waste, liquid waste, gaseous waste, and sludges can all be incinerated in rotary kilns. Solid materials are usually fed through a non-rotating hopper; liquid waste may be injected into the kiln through burner nozzles; pumpable waste and sludges may be injected into the kiln via a water-cooled tube.

In order to increase the destruction of toxic compounds, a post-combustion chamber is usually used ~~added~~. Additional firing using liquid waste or ~~additional~~ support fuel may be carried out to maintain the temperatures required to ensure the complete destruction of compounds in the exhaust gas. ~~the waste being incinerated.~~

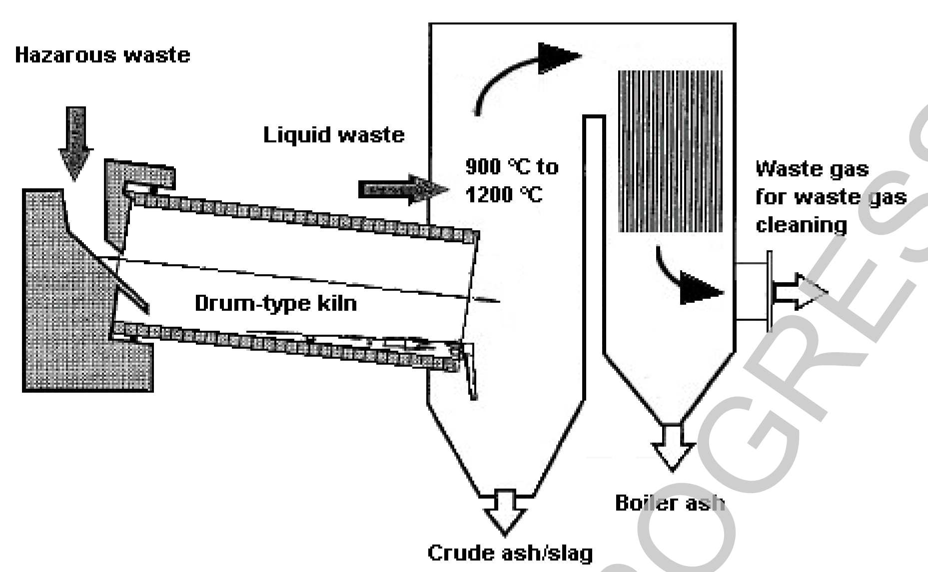
~~2.3.2.1 Kilns and post combustion chambers for hazardous waste incineration~~

~~The operational kiln temperature of installations for incineration usually varies from 850 °C up to 1300 °C. The temperature may be maintained by burning higher calorific (e.g. liquid) waste, waste oils, heating oil or gas. Higher temperature kilns may be fitted with water-based kiln cooling systems, which are preferred for operation at higher temperatures. Operation at higher temperatures may result in molten (vitrified) bottom ash (slag), at lower temperatures the bottom ashes are sintered.~~

~~The temperatures in the post combustion chamber (PCC) typically vary between 900 – 1 200 °C depending on the installation and the waste feed. Most installations have the ability to inject secondary air into the post combustion chamber. Due to the high temperatures and the secondary air introduction, the combustion of the exhaust gases is completed and organic compounds (e.g. PAHs, PCBs and dioxins) including low molecular weight hydrocarbons, are destroyed. Derogations from these conditions are allowed in legislation if they provide for a similar level of overall environmental performance. In several countries exemptions from the 1100 °C rule are granted, on the~~ **~~basis of studies demonstrating that lowering the temperature in the PCC does not influence the quality~~** ~~of air emissions.~~

2.3.2.2 Rotary ~~Drum~~ kiln with post-combustion chamber for hazardous waste incineration

For the incineration of hazardous waste, a combination of rotary ~~drum-type~~ kilns and post-combustion chambers has proven successful, as this combination can treat solid, pasty, liquid and gaseous wastes uniformly (see Figure 2.10).



Source: [1, UBA, 2001]

Figure 2.10: Rotary (drum-type) kiln with post-combustion chamber

~~Drum-type~~ Rotary kilns between 10 metres and 15 metres in length, with a length to diameter ratio usually in the range of 3 to 6, and with an inner diameter between 1 metre and 5 metres are usually deployed for hazardous waste incineration.

Some ~~drum-type~~ rotary kilns have throughputs of up to 70 000 tonnes/yr each. ~~In correlation to the average heat value of the waste,~~ Where heat recovery is carried out, steam generation is directly correlated with the average heat value of the waste. ~~increases correspondingly.~~

~~Drum-type~~ Rotary kilns ~~plants~~ are highly flexible in terms of waste inputs and typical operating ranges are: ~~characteristics. The following range is usual in the composition of the waste input menu:~~

- solid wastes: 10–70 %;
- liquid wastes: 25–70 %;
- pasty wastes: 5–30 %;
- barrels: up to 15 %.

The ~~operational kiln~~ operating temperature is usually between 850 °C and 1 300 °C. ~~of installations for incineration usually varies from 850 °C up to 1300 °C~~. The temperature may be maintained by burning higher calorific (e.g. liquid) waste, waste oils, heating oil or gas. Higher temperature kilns may be fitted with water-based kiln cooling systems. ~~which are preferred for operation at higher temperatures.~~ Operation at higher temperatures may result in molten (vitrified) bottom ash (slag), whilst at lower temperatures the bottom ashes are sintered.

To protect ~~the drum-type~~ rotary kilns from temperatures of up to 1 200 °C, ~~it is~~ they are lined ~~equipped~~ with refractory bricks that have ~~Bricks with~~ a high content of Al_2O_3 and SiO_2 ~~are used~~. The decision regarding the selection of bricks appropriate for each application is a function of the waste composition. The bricks can be attacked by alkaline metal compounds (formation of low melting eutectic alloys), as well as by HF (formation of SiF_4). To protect refractory bricks from chemical attack and from the mechanical impact of falling barrels, a hardened slag layer will usually be formed at the beginning of the operation by feeding wastes with ~~the help of~~ good slag-forming properties ~~wastes~~ or ~~materials as~~ mixtures of glass and/or sand ~~and glass~~. Later on, the kiln ~~temperature~~ is usually managed so as to maintain ~~keep~~ this slag layer, by controlling the temperature, ~~based on~~ the mineral content ~~matter~~ of the wastes and sometimes using ~~perhaps some~~ additives such as ~~e.g.~~ sand. [74, TWGComments, 2004]

There have been tests with other ~~surfacing systems~~ surface types but neither injected nor stamped refractory masses have proved successful. The surfacing of ~~the drum-type~~ rotary kilns with special alloyed steels has only been ~~was only~~ successful in some special applications. The durability of the fireproof surface~~ing~~ remains dependent upon the waste input. A service life of between 4 000 hours and 16 000 hours is normal.

~~Cooling the drum-type kilns is a means of lengthening their service life. Several positive experiences have been noted at various plants.~~

~~Drum-type~~ Rotary kilns are tilted towards the post-combustion chamber. This, along with the slow rotation (approximately 3–40 rotations per hour), facilitates the transport of solid hazardous wastes that are fed into the upper end ~~from the front side~~, as well as the bottom ash produced during incineration, in the direction of the post-combustion chamber. These are then removed together with the ash from the post-combustion chamber via a wet bottom ash discharger. ~~remover.~~ The residence time for solid wastes is typically greater ~~generally amounts to more~~ than 30 minutes.

The post-combustion chamber provides for the necessary residence time for the incineration of the flue-gases produced in the kiln ~~during incineration~~, as well as for the incineration of directly injected liquid and gaseous wastes. ~~Minimum residence times in excess of two seconds are the basic requirement of EC Directive 2000/76/EC.~~ The size of the post-combustion chamber and gas flows predict the actual residence times achieved. Reducing residence times can increase the risk of incomplete gas burnout. ~~A minimum gas phase combustion temperature of 850 °C (1100 °C for some hazardous wastes) and a minimum residence time of the flue-gases, above this temperature, of two seconds after the last incineration air supply have been established in legislation (IED, Article 50). Derogations from these conditions are allowed in legislation if they provide for a similar level of overall environmental performance.~~

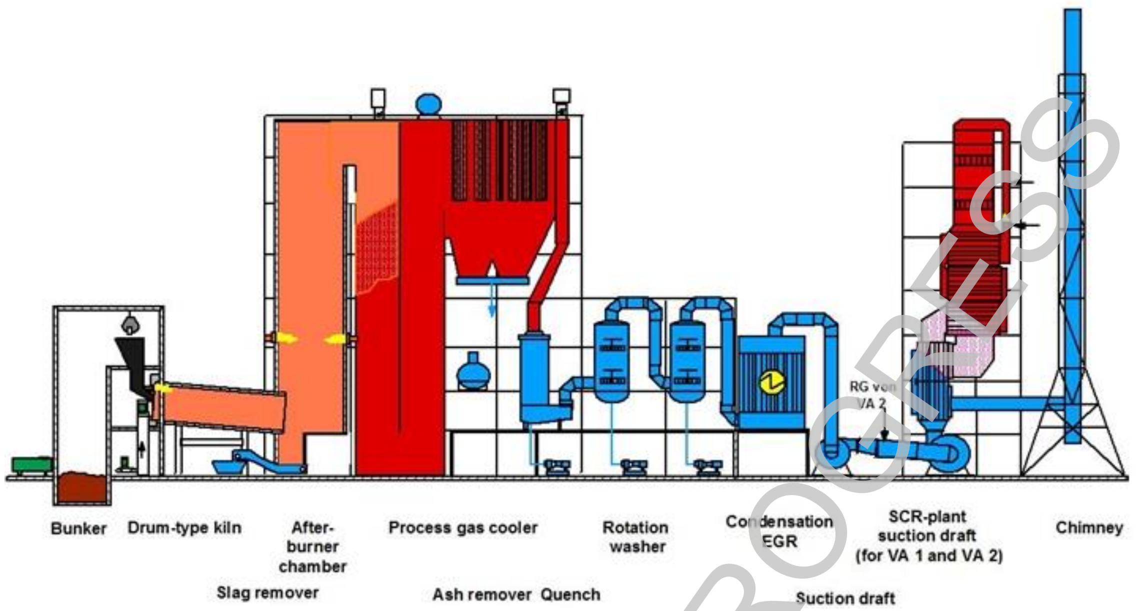
The temperatures in the post-combustion chamber ~~(PCC)~~ typically vary between 900 °C and 1 200 °C depending on the installation and the waste feed. Most installations have the ability to inject secondary air into the post-combustion chamber. Due to the high temperatures and the secondary air introduction, the combustion of the exhaust gases is completed and organic compounds (e.g. low molecular weight hydrocarbons, PAHs, PCBs and dioxins) are destroyed. ~~including low molecular weight hydrocarbons, are destroyed.~~ ~~Derogations from these conditions are allowed in legislation if they provide for a similar level of overall environmental performance. In several countries exemptions from the 1100 °C rule are granted, on the basis of studies demonstrating that lowering the temperature in the PCC does not influence the quality of air emissions.~~

~~Operational experiences have in some cases shown that lower temperatures, shorter residence times and lower oxygen levels can, in some situations, still result in good combustion and may result in lower overall emissions to air. [74, TWGComments, 2004]~~

A ~~drum-type~~ rotary kiln incineration plant with an incineration capacity of 45 000 tonnes/yr is shown in Figure 2.11. The plant is divided into three main areas:

- ~~drum-type~~ rotary kiln with post-combustion chamber;
- waste heat boiler for steam generation;
- multi-step flue-gas cleaning.

There is, in addition, the infrastructure for waste and fuel ~~the~~ storage, the feed system, and the storage, treatment and disposal of ~~for~~ the waste and waste waters (from wet gas scrubbing) produced during incineration.



Source: [1, UBA, 2001]

Figure 2.11: Example of a rotary (drum-type) kiln plant for hazardous waste incineration

2.3.3 Fluidised beds

Fluidised bed incinerators are widely applied to the incineration of finely divided wastes, e.g. RDF and sewage sludge. ~~It has~~ Fluidised beds have been used for decades~~, mainly~~ for the combustion of homogeneous fuels such as ~~. Among these are~~ coal, raw lignite, sewage sludge, and biomass ~~(e.g. wood)~~.

The fluidised bed incinerator is a lined combustion chamber in the form of a vertical cylinder. In the lower section, a bed of inert material, (e.g. sand or ash) on a grate or distribution plate is fluidised with preheated combustion air. The waste for incineration is continuously fed into the fluidised sand/ash bed from the top or side via a pump, a star feeder or a screw-tube conveyor [66, UllmansEncyclopaedia, 2001].

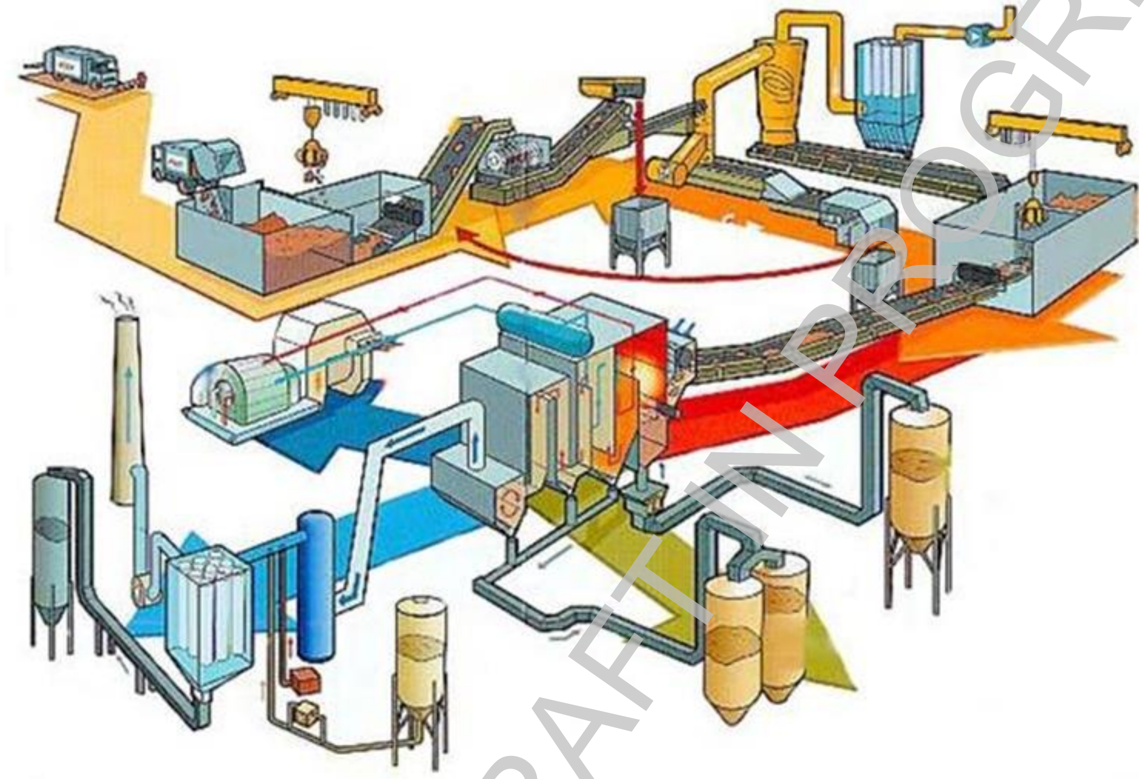
~~Preheated air is introduced into the combustion chamber via openings in the bed-plate, forming a fluidised bed with the sand contained in the combustion chamber. The waste is fed to the reactor via a pump, a star feeder or a screw-tube conveyor.~~

In the fluidised bed, drying, volatilisation, ignition and combustion take place. The temperature in the free space above the bed (the freeboard) is generally between 850 °C and 950 °C. Above the fluidised bed material, the freeboard is designed to allow a sufficient residence time ~~retention~~ of the gases in the combustion zone. In the bed itself, the temperature ~~of~~ is lower and may be around 650 °C ~~or higher~~.

Because of the ~~well-mixed nature of~~ good mixing in the reactor, fluidised bed incineration systems generally have a uniform ~~distribution of~~ temperature and oxygen concentration, which results in stable operation. For heterogeneous wastes, fluidised bed combustion requires the selection and pretreatment of ~~a preparatory process step for~~ the waste so that it conforms with size specifications. ~~For some waste this may be achieved by a combination of selective collection of wastes and/or pretreatment e.g. shredding. Some types of fluidised beds (e.g. the rotating fluidised bed) can receive larger particle size wastes than others. Where this is the case the waste may only require only a rough size reduction.~~
[64, TWGComments, 2003] [74, TWGComments, 2004]

Pretreatment usually consists of sorting and crushing larger inert particles, and shredding. Removal of ferrous and non-ferrous materials may also be required. The particle size of the waste must be small, often with a maximum diameter of 50 mm. However, it is reported that average acceptable diameters for rotating fluidised beds are 200–300 mm. [74, TWGComments, 2004]

The schematic diagram below shows an installation that pretreats mixed MSW for incineration in a fluidised bed incineration plant. Several pretreatment stages are shown including mechanical pulverisation and pneumatic separation, along with the final stages of incineration, FGC and residue storage.



Source: [1, UBA, 2001]

Figure 2.12: Schematic diagram showing pretreatment of MSW prior to fluidised bed combustion

During incineration, the fluidised bed contains the unburned waste and the ash produced. The ash surplus is usually removed at the bottom of the furnace. [1, UBA, 2001, 33, Finland, 2002]

The heat produced by the combustion can be recovered by devices either integrated inside the fluidised bed or at the exit of the combustion gases or a combination of layouts.

The relatively high cost of pretreatment processes required for some wastes has restricted the ~~economic~~ commercial use of these systems to larger scale projects. This has been overcome in some cases by the selective collection of some wastes, and the development of quality standards for refuse~~waste~~-derived fuels (~~W~~RDF). ~~Such quality systems have provided a means of producing a more suitable feedstock for this technology.~~ The combination of a prepared quality-controlled waste ~~(instead of mixed untreated waste)~~ and fluidised bed combustion can allow improvements in the control of the combustion process, and the potential for a simplified, and therefore less expensive, flue-gas cleaning stage.

The following table shows the properties of various waste fractions that are treated in fluidised beds.

Table 2.7: **Properties of various refuse-derived fuel (RDF) fractions treated in fluidised beds**

		Commercial waste	**Pretreated construction waste**	**Sorted and pretreated household waste**
Lower heating value as received	MJ/kg MWh/t	16–20 4.4–5.6	14–15 3.8–4.2	13–16 3.6–4.4
Moisture	wt-%	10–20	15–25	25–35
Ash	wt-%	5–7	1–5	5–10
Sulphur	wt-%	< 0.1	< 0.1	0.1–0.2
Chlorine	wt-%	< 0.1–0.2	< 0.1	0.3–1.0
Storage properties	wt-%	Good	Good	Good as pellets
Source: [33, Finland, 2002]				

The following fluidised bed furnace technologies can be differentiated according to the gas speeds and design of the nozzle plate:

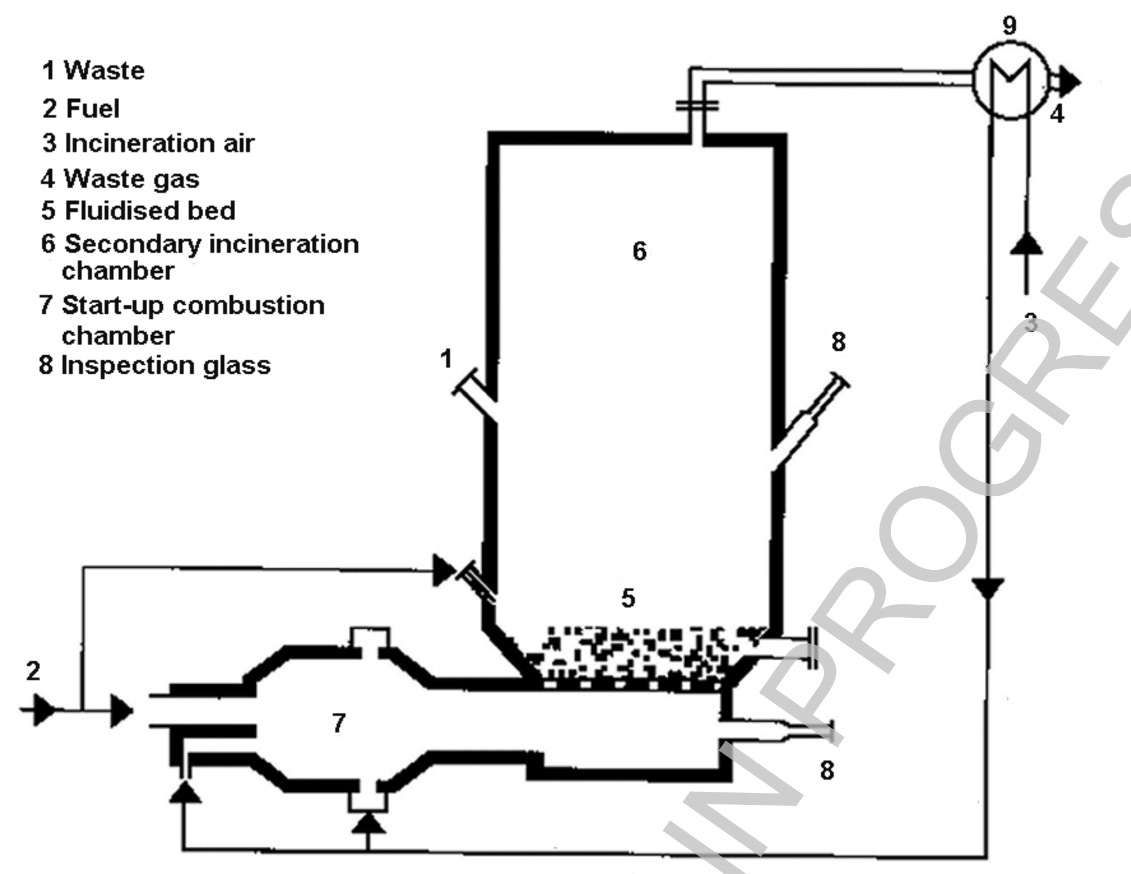
- **Stationary (or bubbling) fluidised bed** (atmospheric and pressurised): The inert material is mixed, but the resulting upwards movement of solids is not significant (see Figure 2.13).
- **Rotating fluidised bed** is a version of the bubbling fluidised bed: ~~Here,~~ The fluidised bed is rotated ~~in the incineration chamber. This~~ which results in a longer residence time in the incineration chamber. Rotating fluidised bed incinerators have been used for mixed municipal waste ~~for about ten years~~ since the 1990s.
- **Circulating fluidised bed**: The higher gas speeds in the combustion chamber are responsible for the partial removal of the fuel and bed material, which is fed back into the incineration chamber by a recirculation duct (see ~~diagram~~ Figure 2.14).

In order to start up the incineration process, the fluidised bed must be heated to at least the minimum ignition temperature of the ~~added~~ waste feedstock (or higher where required by legislation). This may be accomplished by preheating the air with oil or gas burners, which remain operative until incineration can occur independently. The waste falls into the fluidised bed, where it is crushed through abrasion and incineration. Usually, the majority of the ash is transported with the flue-gas flow and requires separation in FGC equipment, although the actual proportion of bottom ash (removed from the base of the bed) and fly ash depends on the fluidised bed technology and the waste itself. [1, UBA, 2001].

Fouling problems, common in waste incineration boilers, can be managed by controlling the waste quality (mostly keeping chlorine, potassium, sodium and aluminium low) and by boiler and furnace design. Fluidised bed furnaces generally have less fouling problems than grate furnaces ~~Some boiler and furnace designs can be used in fluidised beds (but not in mixed waste grate boilers)~~ because of the more stable temperatures and the presence of the bed material.

2.3.3.1 Stationary (or bubbling) fluidised bed incineration for sewage sludge

~~This type of~~ The stationary or bubbling fluidised bed (BFB) is commonly used for sewage sludge, ~~as well as for~~ and other industrial sludges, e.g. petrochemical and chemical industry sludges. ~~The stationary, or bubbling fluidised bed~~ It consists of a cylindrical or rectangular lined incineration chamber, a nozzle bed, and a start-up burner located below (see Figure 2.13).



Source: [1, UBA, 2001]

Figure 2.13: Main components of a stationary/bubbling fluidised bed

Preheated air flows up through a distribution plate and fluidises the bed material. Depending on the application, various bed materials (silica sand, basalt, mullite, etc.) and bed material particle sizes (approximately 0.5–3 mm) can be used.
[2, infomil, 2002], [64, TWGComments, 2003]

The waste can be loaded via the head, on the sides with belt-charging machines, or directly injected into the fluidised bed. In the bed, the waste is crushed and mixed with hot bed material, dried and partially incinerated. The remaining fractions (volatile and fine particles) are incinerated above the fluidised bed in the freeboard. The remaining ash is removed with the flue-gas at the head of the furnace.

Drainage and drying pretreatment stages can be used so that the waste burns without the need for additional fuels. Recovered heat from the incineration process may be used to provide the energy for waste drying.

At start-up or when the sludge quality is low (e.g. with old sludge or a high share of secondary sludge), additional fuel (oil, gas and/or waste fuel) can be used to reach the prescribed furnace temperature (typically 850 °C). Water can be injected into the furnace to control the temperature.

The furnace ~~is usually~~ must be preheated to its operating temperature before waste feeding starts. For this purpose, a start-up incineration chamber (see Figure 2.13) may be located below the nozzle bed. This has an advantage over an overhead burner, as the heat is introduced directly into the fluidised bed. Additional preheating may be provided by fuel lances that protrude over the nozzle bed into the sand bed. ~~The sewage sludge is supplied when the furnace temperature reaches the operating temperature, e.g. 850 °C.~~

The size of the furnace is largely determined by the required evaporation (furnace cross-section), the heat turnover in the furnace (furnace volume) and the required amount of air.

Example operational parameters for a fluidised bed sewage sludge incinerator are shown in Table 2.8.

Table 2.8: Main operational criteria for stationary fluidised beds

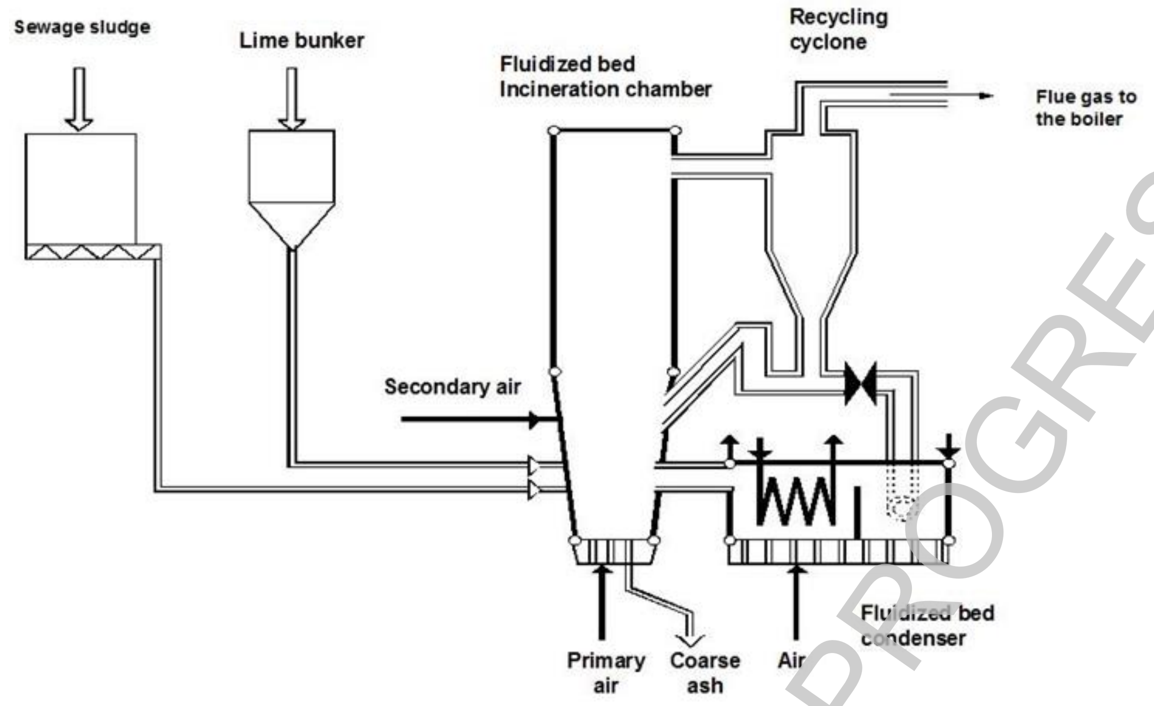
Parameter	Unit	Value
Steam load	kg/m^2h	300–600
Feed air amount	Nm^3/m^2h	1 000–1 600
Heat turnover	GJ/m^3h	3–5
Final incineration temperature	°C	850–950
Residence time, open space and afterburner zone	s	min. 2
Preheating of atmospheric oxygen	°C	400–600
Source: [1, UBA, 2001]		

The preheating of air can be eliminated completely with higher calorific fuels (e.g. dried sewage sludge, wood, animal by-products). The heat can be removed via membrane walls and/or immersed heat-exchange systems.

Some processes incorporate drying as a first step. Steam for the drying may be produced by a boiler and then used as the heating medium with no direct contact between the steam and the sludge. Sludge vapours can be extracted from the dryer and condensed. The condensed water typically has a high COD (approximately 2 000 mg/l) and N content (approximately 600–2 000 mg/l) and may contain other pollutants (e.g. heavy metals) from the sewage sludge, and therefore will often require treatment before final discharge. The remaining non-condensates may be incinerated. After incineration, the flue-gases can be cooled in a heat exchanger in order to preheat the incineration air to temperatures of approximately 300 °C and in some cases over 500 °C. The remaining heat in the steam boiler can be recovered and used for the production of saturated steam (pressure level approximately 10 bar), which in turn can be used for the partial pre-drying of sludge. [64, TWGComments, 2003]

2.3.3.2 Circulating fluidised bed (CFB) for sewage sludge

The circulating fluidised bed (CFB, see Figure 2.14 below) is especially appropriate for the incineration of dried sewage sludge with a high ~~heat~~ calorific value. It works with fine bed material and at high gas speeds that remove ~~the greater part~~most of the solid material particles from the fluidised bed chamber with the flue-gas. The particles are then separated in a downstream cyclone and returned to the incineration chamber.



Source: [1, UBA, 2001]

Figure 2.14: Main components of a circulating fluidised bed

The advantage of this process is that a high heat turnover~~s~~ and a more uniform temperature along the height can be reached with a low reaction volume. The p~~P~~lant size is generally larger than for a BFB and a wider range of waste inputs can be treated. The waste is injected at the side into the incineration chamber and is incinerated at 850–950 °C. The surplus heat is removed through membrane walls and via heat exchangers. The fluidised bed condenser is placed between recycling cyclones and the CFB, and cools the returned ash. Using this method, the heat removal can be controlled.

2.3.3.3 Spreader-stoker furnace

[64, TWGComments, 2003]
This system can be considered an intermediate system between grate and fluidised bed incineration.

The waste (e.g. RDF, sludge) is blown into the furnace pneumatically at a height of several metres. Fine particles participate directly in the incineration process, while the larger particles fall on the travelling grate, which is moving in the opposite direction to the waste injection. As the largest particles are spread over the greatest distance, they spend the longest time on the grate in order to complete the incineration process. Secondary air is injected to ensure that the flue-gases are adequately mixed in the incineration zone.

Compared to grate incineration, the grate construction is less complicated due to the relatively smaller thermal and mechanical load. When compared to fluidised bed systems, the uniformity of particle size is less important and there is a lower risk of clogging.

2.3.3.4 Rotating fluidised bed

[74, TWGComments, 2004]
This system is a development of the bubbling bed for waste incineration. Inclined nozzle plates, wide bed ash extraction chutes and upsized feeding and extraction screws are specific features to ensure reliable handling of solid waste. Temperature control within the refractory-lined combustion chamber (bed and freeboard) is by flue-gas recirculation. This allows the incineration of fuels with a wide range of calorific values, e.g. co-combustion of sludges and pretreated wastes.

2.3.4 Pyrolysis and gasification systems

2.3.4.1 Introduction to gasification and pyrolysis

[9, VDI, 2002] Alternative technologies for thermal waste treatment have been ~~developed since the 1970s. In general these have been~~ applied to selected waste streams and on a smaller scale than incineration.

These technologies attempt to separate the components of the reactions that occur in conventional waste incineration plants by controlling process temperatures and pressures in specially designed reactors (see Table 2.9)

Table 2.9: Typical reaction conditions and products of incineration, pyrolysis and gasification processes

	~~**Combustion**~~ **Incineration**	**Pyrolysis**	**Gasification**
Reaction temperature (°C)	800–145	250–700	500–1 600
Pressure (bar)	1	1	1–45
Atmosphere	Air	Inert/nitrogen	Gasification agent: O_2, H_2O
Stoichiometric ratio	> 1	0	< 1
Products from the process			
• **Gas phase:**	CO_2, H_2O, O_2, N_2	H_2, CO, hydrocarbons, H_2O, N_2	H_2, CO, CO_2, CH_4, H_2O, N_2
• **Solid phase:**	Ash, slag	Ash, coke	Slag, ash
• **Liquid phase:**		Pyrolysis oil and water	

Source: Adapted from[9, VDI, 2002]

As well as specifically developed pyrolysis/gasification technologies, standard incineration technologies (i.e. grates, fluidised beds, rotary kilns, etc.) may be adapted to be operated under pyrolytic or gasifying conditions, i.e. with reduced oxygen levels (sub-stoichiometric), or at lower temperatures. Often pyrolysis and gasification systems are coupled with downstream combustion of the syngas generated (see Section 2.3.4.4 on combination processes).

As well as the normal targets of waste incineration (i.e. effective treatment of the waste), the additional aims of gasification and pyrolysis processes are to:

- convert certain fractions of the waste into process gas (called syngas);
- reduce gas cleaning requirements by reducing flue-gas volumes.

Both pyrolysis and gasification differ from incineration in that they may be used for recovering the chemical value of the waste (rather than its energetic value). The chemical products derived may in some cases then be used as feedstock for other processes. However, when applied to wastes, it is more common for the pyrolysis, gasification and a combustion-based process to be combined, often on the same site as part of an integrated process. When this is the case, the installation ~~is, in total, generally recovering~~ recovers the energy value rather than the chemical value of the waste, as ~~would~~ a normal incinerator would.

In some cases, the solid residues arising from such processes contain pollutants that, in an incineration system, would be transferred to the gas phase, and then, with efficient flue-gas cleaning, be removed with the FGC residue. [64, TWGComments, 2003]

The following systems and concepts have been developed (with different levels of proven success on an industrial scale):

Pyrolysis - incineration systems for wastes:

System 1:	Pyrolysis in a rotary kiln - coke and inorganic matter separation - incineration of pyrolysis gas.
System 2:	Pyrolysis in a rotary kiln - separation of inert materials - combustion of the solid carbon-rich fraction and the pyrolysis gas.
System 3:	Pyrolysis in a rotary kiln - condensation of pyrolysis gas components - incineration of gas, oil and coke.
System 4:	Pyrolysis on a grate - directly connected incineration.
System 5:	Pyrolysis on a grate (with a subsequent melting furnace for low-metal-content molten bottom ash production) - circulating fluidised bed (burnout of particles and gas).

Gasification systems for wastes:

System 1:	Fixed bed gasifier - pretreatment drying required for lumpy material.
System 2:	Slag bath gasifier - as fixed bed but with molten bottom ash discharge.
System 3:	Entrained flow gasifier - for liquid, pasty and fine granular material that may be injected into the reactor by nozzles.
System 4:	Fluidised bed gasifier - circulating fluid bed gasifier for pretreated municipal waste, dehydrated sewage sludge and some hazardous wastes.
System 5:	Bubbling bed gasifier - similar to bubbling fluidised bed combustors, but operated at a lower temperature and as a gasifier.

Pyrolysis - gasification systems for wastes:

System 1:	Conversion process - pyrolysis in a rotary kiln - withdrawal and treatment of solid phase - condensation of gas phase - subsequent entrained flow gasifier for pyrolysis gas, oil and coke.
System 2:	Combined gasification-pyrolysis and melting - partial pyrolysis in a push furnace with directly connected gasification in a packed bed reactor with oxygen addition (e.g. Thermoselect).

2.3.4.2 Gasification

[64, TWGComments, 2003] Gasification is the partial combustion of organic substances to produce gases that can be used as feedstock (through some reforming processes) or as a fuel.

[1, UBA, 2001] There are several different gasification processes available or being developed which are, in principle, ~~suited~~ suitable for the treatment of municipal wastes, certain hazardous wastes and dried sewage sludge.

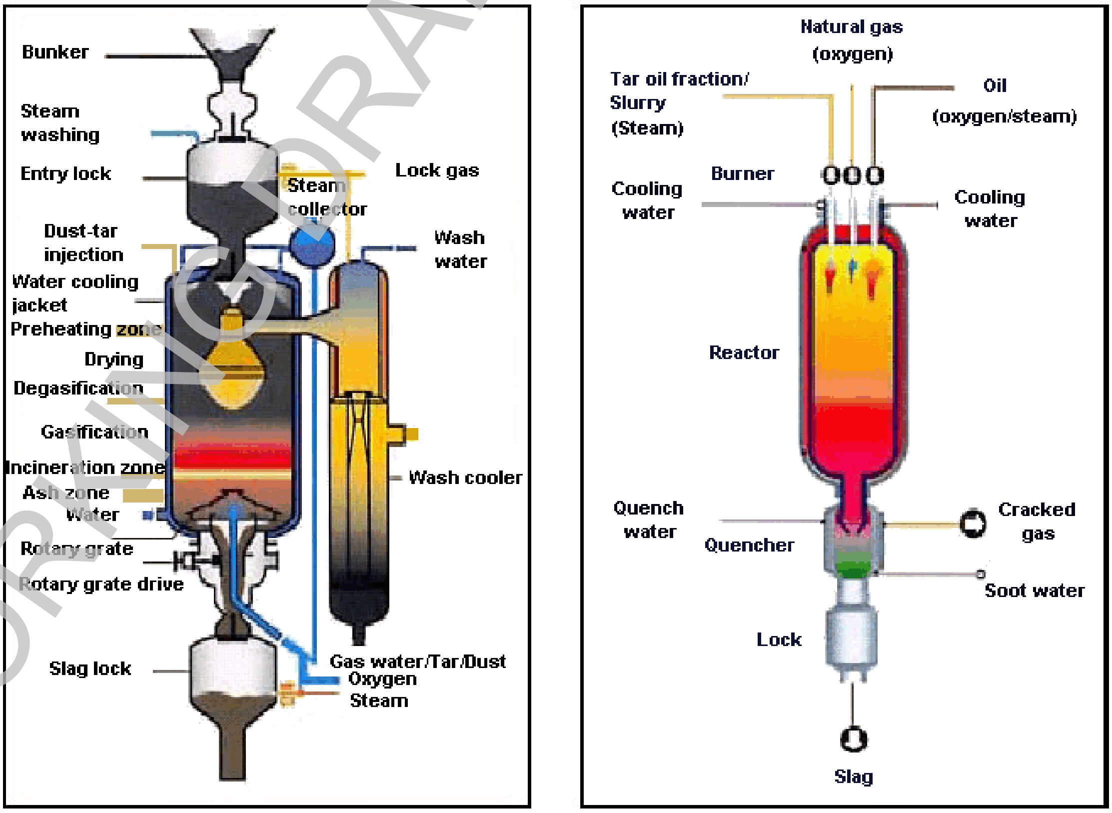
It is important that the properties ~~nature (size, consistency)~~ of the wastes ~~fed keeps~~ are kept within certain predefined limits. This often requires special pretreatment of municipal waste. ~~, for example.~~

The special features of the gasification process are:

- smaller gas volume compared to the flue-gas volume in incineration (by up to a factor of 10 by using pure oxygen);
- predominant formation of CO rather than CO_2;
- high operating pressures (in some processes);
- accumulation of solid residues as slag (in high-temperature slagging gasifiers);
- small and compact aggregates (especially in pressurised~~e~~ gasification);
- material and energetic utilisation of the synthesis gas;
- smaller waste water flows from synthesis gas cleaning.

The following gasification reactors are used:

- fluidised bed gasifier (see Figure 2.17);
- current flow gasifier;
- cyclone gasifier;
- packed bed gasifier.



Source: [1, UBA, 2001]

Figure 2.15: Representation of a packed bed and current flow gasifier

For utilisation in entrained flow, fluidised bed or cyclone gasifiers, the feed~~ing~~ material must be finely granulated. Therefore pretreatment is necessary, especially for municipal wastes. Hazardous wastes, on the other hand, may be gasified directly if they are liquid, pasty or finely granulated.

2.3.4.2.1 Examples of gasification processes

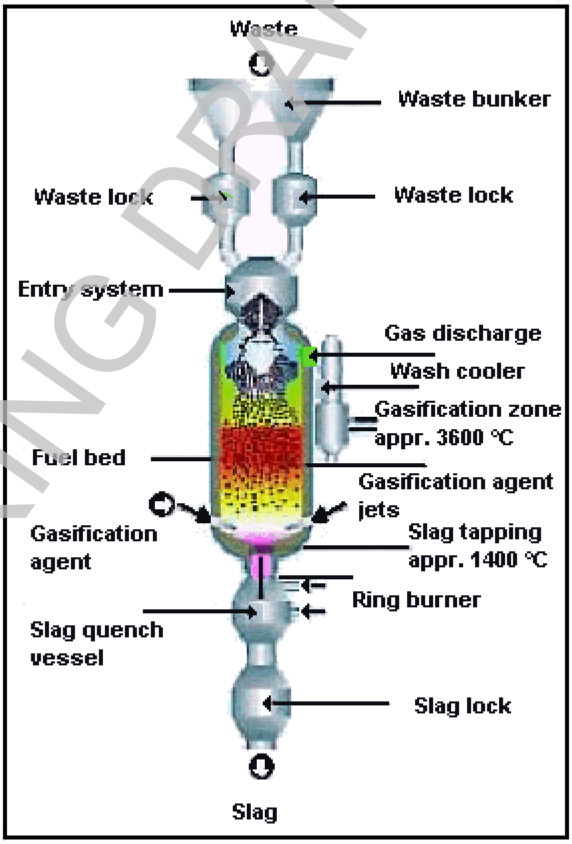
[1, UBA, 2001]

In Germany, an entrained flow gasifier is at present in use for the gasification of fluid hazardous wastes at Sekundärrohstoffverwertungszentrum (SVZ; Centre for Secondary Raw Materials Utilisation) at Schwarze Pumpe.
[*For the TWG (especially Germany): This section is based on out-of-date information. Please comment on whether to keep it and if so please provide up-to-date information on this section.*]

The fluid wastes enter the reactor via the burner system and are transformed into ~~synthesis-~~gas at temperatures of 1 600–1 800 °C. Since 1995, approximately 31 000 tonnes of waste oil have been treated ~~disposed of~~ in this plant.

Lumpy charging material is required for the packed bed gasifier, but drying is sufficient as a pretreatment process. SVZ Schwarze Pumpe GmbH runs six packed bed gasifiers for gasification of coal waste mixtures. The feed rate proportion for waste is up to 85 %. The reactors, each with a throughput of 8–14 tonnes per hour, treat mainly compacted waste plastics, dehydrated sewage sludge and contaminated soils. The waste enters the reactor through the entry lock and is transformed into syn~~thesis-~~gas at approximately 800–1 300 °C and 25 bar with the help of steam and oxygen (the gasification agent).

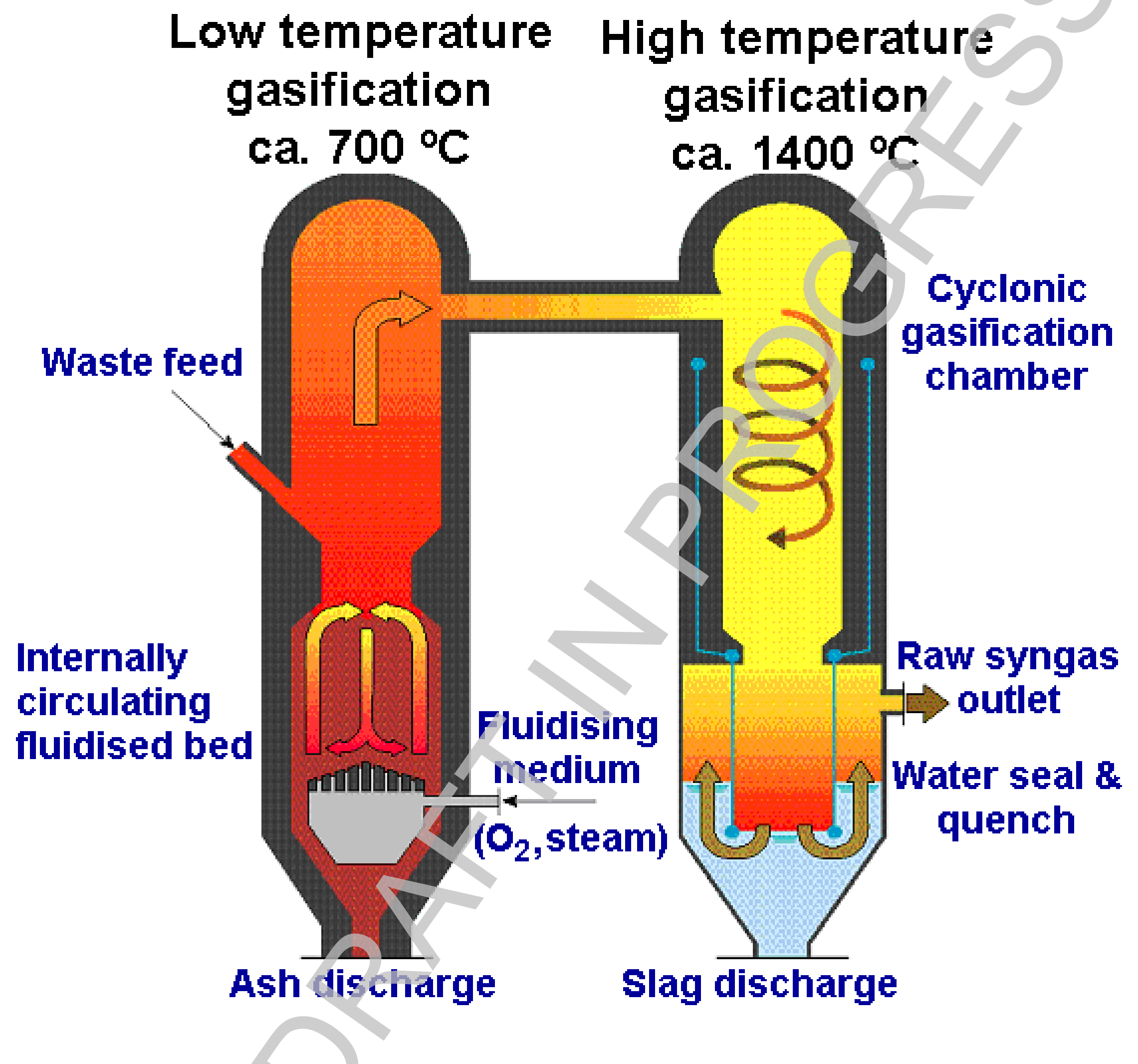
A development from these packed bed gasifiers is the slag bath gasifier shown in Figure 2.16 below. One such plant is currently operating on a trial basis, receiving up to 70 % waste, at a throughput rate of 30 tonnes per hour. The gasifier operates at a temperature of up to 1 600 °C and the slag is discharged as a liquid.



Source: [1, UBA, 2001]

Figure 2.16: Slag bath gasifier

A waste gasification process based on a fluidised bed in combination with current flow gasification is used in Japan (see Figure 2.17 below).



Source: [68, Ebara, 2003]

Figure 2.17: Fluidised bed gasifier with a high-temperature slagging furnace

This process is designed to generate syngas from plastic packaging waste or other high calorific waste material. The main components of the process are a fluidised bed gasifier and a second stage high-temperature gasifier. The fluidised bed enables rapid gasification of comparatively heterogeneous materials, which are pelletised for smooth feeding. Several per cent of non-combustible components, even metal pieces, are acceptable, as the ash is continuously discharged from the fluidised bed. The high-temperature gasifier is designed as a cyclone, to collect the fine ash particles on the wall. After vitrification, the slag is discharged through a water seal. Both reactors are operated under elevated pressure, typically 8 bar.

The first plant of this technology was in commercial operation in the year 2001 to treat plastic packaging waste. The capacity of this demonstration plant is 30 tonnes per day. An additional plant of 65 tonnes per day started operation in 2002. The syngas produced is fed to an adjacent ammonia production plant. Other similar plants are under construction. [68, Ebara, 2003]
[*For the TWG: Please provide up-to-date information on this plant type.*]

~~Other variations on gasification processes have been tried and are being developed, for a variety of waste stream.~~

2.3.4.3 Pyrolysis

[1, UBA, 2001] Pyrolysis is the degassing of wastes in the absence of oxygen, during which pyrolysis gas and a solid coke are formed. The heat values of pyrolysis gas typically lie between 5 MJ/m^3 and 15 MJ/m^3 based on municipal waste and between 15 MJ/m^3 and 30 MJ/m^3 based on RDF. In a broader sense, 'pyrolysis' is a generic term including a number of different technology combinations that constitute, in general, the following technological steps:

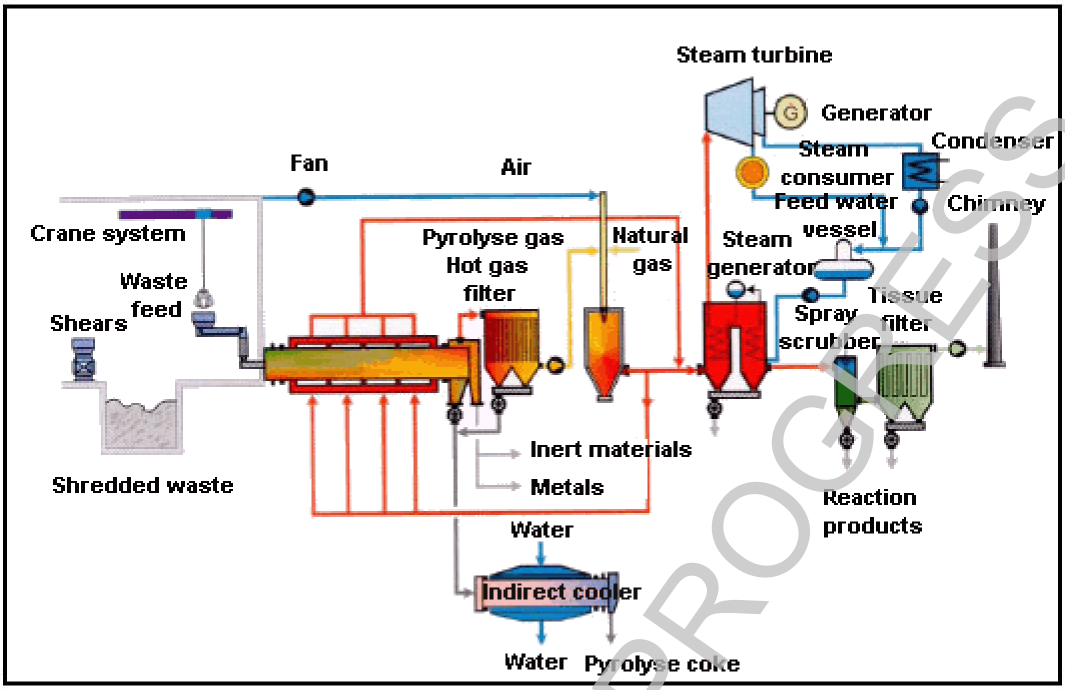
- **Smouldering process**: Formation of gas from volatile waste particles at temperatures between 400 °C and 600 °C.
- **Pyrolysis**: Thermal decomposition of the organic molecules of the waste between 500 °C and 800 °C, resulting in formation of gas and a solid fraction.
- **Gasification**: Conversion of the carbon share remaining in the pyrolysis coke at 800 °C to 1 000 °C with the help of a gasification substance (e.g. air or steam) in a process gas (CO, H_2).
- **Incineration**: Depending on the technology combination, the gas and pyrolysis coke are combusted in an incineration chamber.

A pyrolysis plant for municipal waste treatment is operational in Germany, and another was due to start up at the end of 2003 in France.
[*For the TWG (especially France and Germany): Please provide up-to-date information on these plants in Germany and France.*]

~~Other pyrolysis projects exist in Europe and elsewhere (notably in Japan) receiving certain specific types or fractions of waste, often after pretreatment.~~

Pyrolysis plants for waste treatment usually include the following basic process stages:

1. Preparation and grinding: the grinder improves and standardises the quality of the waste presented for processing, and so promotes heat transfer.
2. Drying (depends on process): a separated drying step improves the LHV of the raw process gases and increases the efficiency of gas-solid reactions within the rotary kiln.
3. Pyrolysis of wastes, where in addition to the pyrolysis gas a solid carbon-containing residue accumulates which also contains mineral and metallic portions.
4. Secondary treatment of pyrolysis gas and pyrolysis coke, through condensation of the gases for the extraction of energetically usable oil mixtures and/or incineration of gas and coke for the destruction of the organic ingredients and simultaneous utilisation of energy.



Source: [1, UBA, 2001]

Figure 2.18: Structure of a pyrolysis plant for municipal waste treatment

In general, the temperature of the pyrolysis stage is between 400 °C and 700 °C. At lower temperatures (approximately 250 °C), other reactions occur to some extent. This process is sometimes called conversion (e.g. conversion of sewage sludge).

In addition to the thermal treatment of some municipal wastes and sewage sludge, pyrolysis processes are also used for:

- decontamination of soil;
- treatment of synthetic waste and used tyres;
- treatment of cable tails as well as metal and plastic compound materials for substance recovery.

The potential advantages of pyrolysis processes may include:

- the possibility of recovering the material value of the organic fraction, e.g. as methanol;
- the possibility of increased electrical generation using gas engines or gas turbines for generation (in place of steam boilers);
- reduced flue-gas volumes after combustion, which may reduce the FGC capital costs to some degree;
- the possibility of meeting specifications for external use of the produced char by washing (e.g. chlorine content).

[64, TWGComments, 2003] [74, TWGComments, 2004]

2.3.4.3.1 Example of a pyrolysis process

[For the TWG (especially the Netherlands): This section is based on out-of-date information. Please comment on whether to keep it and if so please provide up-to-date information on this section.]

[2, infomil, 2002]
In this example, solid industrial sludges and shredded paint waste/chemical packaging are treated.

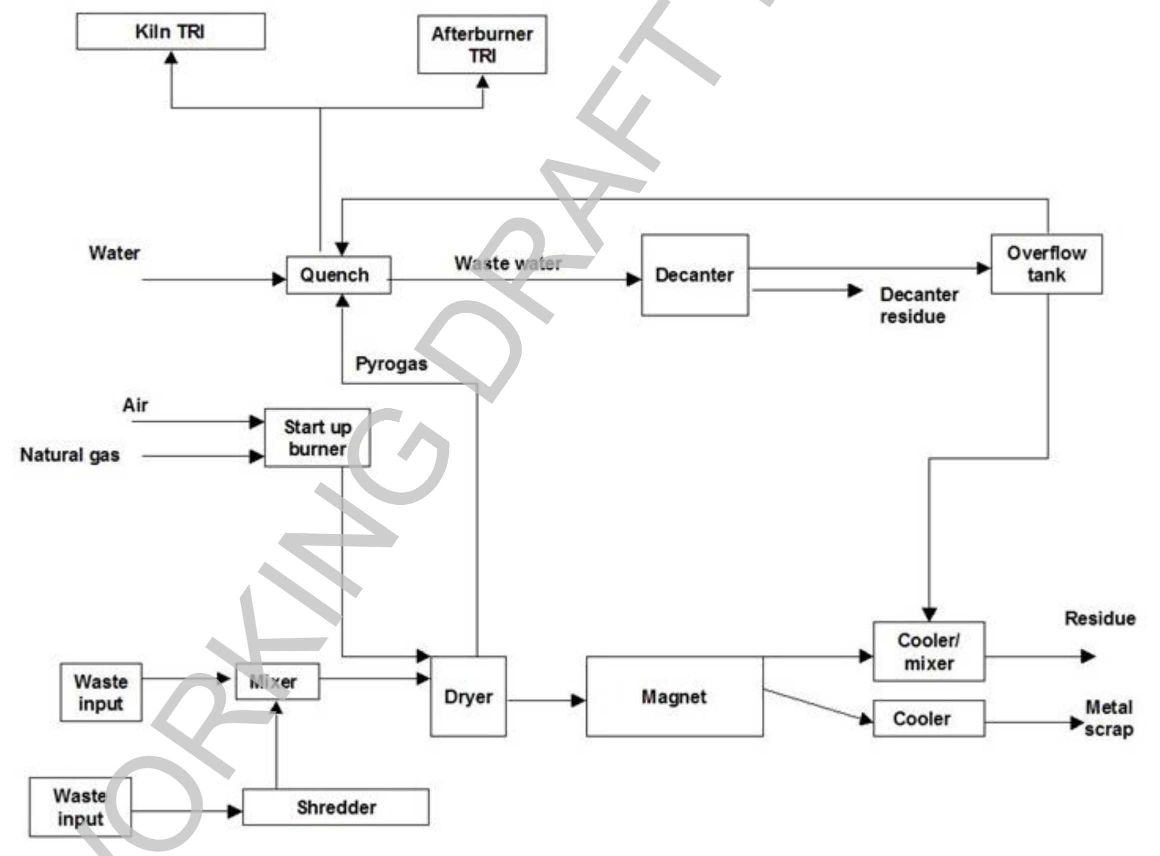
The pyrolysis unit is combined with a thermal treatment plant for polluted soil, in which syngas from the pyrolysis unit is used as fuel. The pyrolysis unit consists of two parallel reactors. Both are equipped with screws, which transport the feed material through the reactors. Feed materials include the filter cake and sediment of other on-site process waste water treatment facilities, as well as paint waste. The average organic material content varies between 25 % and 85 %, and the average water content is approximately 25 %.

At start-up, the reactors are heated up with natural gas to approximately 500 °C. Then feeding starts and the use of natural gas is stopped. The amount of air is kept below stoichiometric demand, resulting in a gasification process. The gasification temperature is approximately 900–1 200 °C. The capacity of each reactor is approximately 4 tonnes/hour.

The syngas is cooled down in a quench condenser. The remaining syngas (LHV approximately 7 MJ/Nm^3) is used as fuel in another unit for the thermal treatment of polluted soil. Incineration and flue-gas treatment take place according to Dutch emission standards. The condensed water of the quench is treated in a decanter for the separation of carbon. The water fraction is used for moisturising the reactor residues.

The residue of the reactor (temperature level approximately 500 °C) passes a magnetic separation system for removal of the iron from the paint waste and the packaging fraction. The remaining fraction is cooled down and moisturised with condensed water, for disposal to landfill.

A general process scheme, including the main mass flows, is given in the figure below.



Source: [2, infomil, 2002]

Figure 2.19: Process scheme of ATM's pyrolysis unit

The main advantage of this pyrolysis unit is that the surplus LHV present in the treated filter cake, sediment and paint waste can be used directly in the thermal treatment unit for polluted soil. The energy efficiency, therefore, is at least comparable with that of waste incineration. Furthermore, the iron scrap fraction (15 %) is removed for recycling, while the volume of the treated waste is reduced by approximately 50 %. The remaining residues can partly be treated in ATM's own facilities. Overhead costs are reduced by the fact that it uses the incinerator and flue-gas treatment of a large polluted soil and waste treatment plant.

2.3.4.3.2 Example of pyrolysis in combination with a power plant

[*For the TWG (especially Germany): This section is based on out-of-date information on a plant that may not be in operation anymore. Please comment on whether to keep it and if so please provide up-to-date information on this section.*]

[1, UBA, 2001]
In this example, the pyrolysis unit is designed to be added to an existing power plant. It consists of two lines of ~~drum-type~~ rotary kilns with a scheduled annual municipal waste throughput of 50 000 tonnes each. The existing boiler unit will be supplied at full load with up to 10 % of the furnace thermal output from pyrolysed substitute fuels.

Specifications of the ConTherm plant

Heating in the absence of oxygen, to approximately 500 °C in an indirectly heated ~~drum-type~~ rotary kiln ~~plant~~, thermally decomposes the prepared waste fuels. The organic components are broken down into gaseous carbohydrates. Coke, pyrolysis gas, metals and inert materials are produced.

The metals in the fed waste are now present in their metal form and can be withdrawn in a state of high purity. For this purpose, there is a reutilisation plant at the end of ~~drum-type~~ rotary kilns where the solid residue is separated into individual fractions. The residue is separated into a coarse fraction (metals, inerts) and a fine fraction; 99 % of the carbon is contained as coke in the fine fraction. After sifting, the coarse fraction is supplied to a wet ash remover, cooled and separated into ferrous and non-ferrous metals in a reprocessing plant.

The thermal energy is emitted through the furnace shell by radiation and to a lesser degree by convection to the waste within the ~~drum-type~~ rotary kiln. The pyrolysis ~~drum-type~~ rotary kiln is designed for the waste to be heated to approximately 450–550 °C and gasified within 1 hour.

The resulting pyrolysis gas consists of:

- vaporised water;
- carbon monoxide;
- hydrogen;
- methane;
- high-order carbohydrates.

A cyclone dedusts the pyrolysis gas. The deposited dusts and carbon particles are added to the pyrolysis coke.

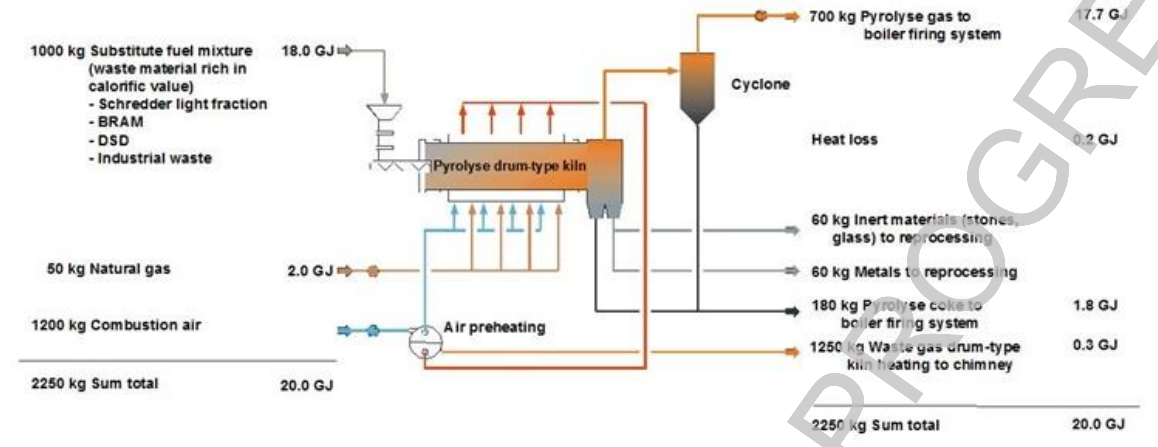
Integration of the ConTherm plant into the power plant

The power plant has a maximum furnace thermal output of 790 MW. In addition to the regular fuels (coal, coke and petroleum coke), pyrolysis coke and pyrolysis gas can also be used.

The coke is first fed into the coal bunkers, ground together with the coal and then blown into the boiler with dust burners. The incineration of the pyrolysis product runs at temperatures of approximately 1 600 °C. During the incineration, the organic agents are transformed into CO_2 and water. Due to the high ratio of sulphur to chlorine in the crude flue-gas, and because of the cooling to approximately 120 °C, any new formation of dioxins is prevented. All toxic agents that have not changed into their gaseous phase are bound into the melting chamber granulate together with the recycled airborne dust and the ground inert material.

Energy balance and weight assessment

The energy and mass balance of the ConTherm plant are illustrated in the following diagram.



Source: [1, UBA, 2001]

Figure 2.20: Energy balance and weight assessment of the ConTherm plant

Depending on the calorific value of the RDF (e.g. 15–30 MJ/m^3), it is possible to reduce the use of primary fuel such as coal to within the range of 0.5–1.0 tonne of hard coal per tonne of RDF.

Data on emissions to air were not supplied.

Costs

Due to the connection of the pyrolysis plant to a coal-fired power station and the utilisation of the pyrolysis products in the power station, new installations (and hence capital costs) are limited to:

- waste reception and storage (bunker);
- the ~~drum-type~~ rotary kiln system with the required heating installations; and
- the reprocessing system for valuable substances.

The power plant shares the incineration unit, waste heat utilisation system, flue-gas cleaning system and the chimney. Using the process equipment, machinery and infrastructure of the power plant results in reduced investment costs and hence reduced interest payments. In addition, staff, operation and maintenance costs are also reduced. Thus, disposal costs per tonne of waste are also reduced, and may be below those of stand-alone incineration plants.
[1, UBA, 2001]

2.3.4.4 Combination processes

This term is used for processes consisting of a combination of different thermal processes (pyrolysis, incineration, gasification).

2.3.4.4.1 Pyrolysis-incineration

[For the TWG (especially Germany and Netherlands): This section is based on out-of-date information. Please comment on whether to keep it and if so please provide up-to-date information on this section.]

[1, UBA, 2001]
The following techniques are at various stages of development:

1. Pyrolysis in a ~~drum-type~~ rotary kiln with subsequent high-temperature incineration of pyrolysis gas and pyrolysis coke. In Germany, the full commissioning of a plant of this type was not completed.

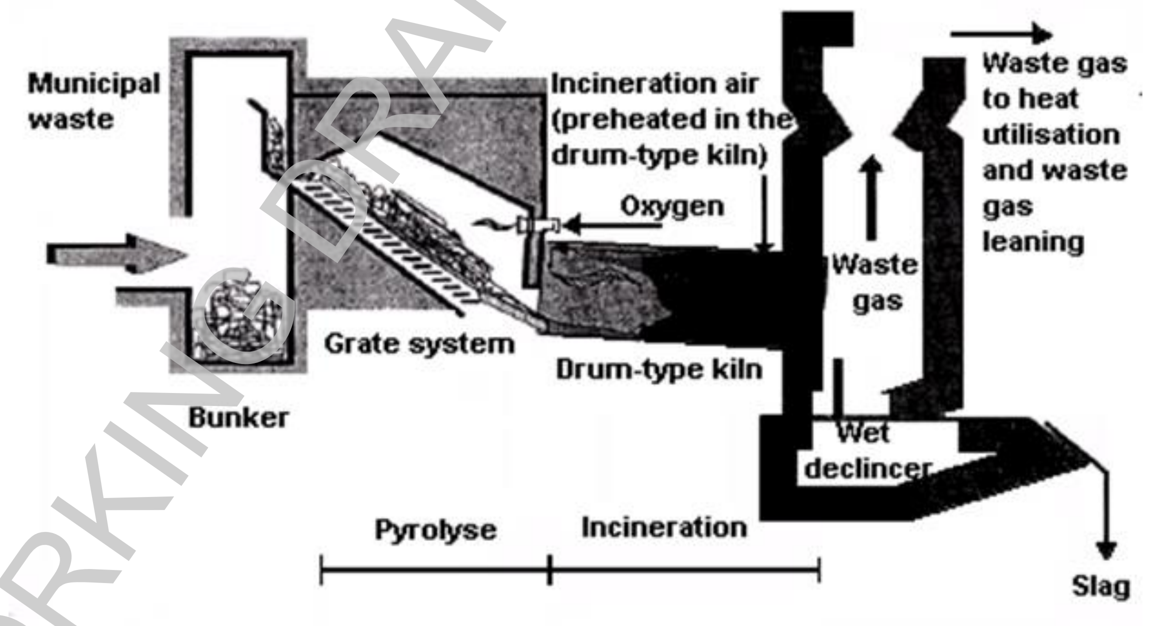
2. Pyrolysis in a ~~drum-type~~ rotary kiln, followed by condensation of the gaseous tars and oils, and subsequent high-temperature incineration of pyrolysis gas, pyrolysis oil and pyrolysis coke.

3. Pyrolysis on a grate with directly connected high-temperature incineration.

The solid residues from these processes are granular, which can be advantageous for later reutilisation or disposal. Sewage sludge (dehydrated or dried) may be co-treated with the municipal waste fractions.

Process 2 (above) is similar to Process 1 in principle, but differs in two main aspects:

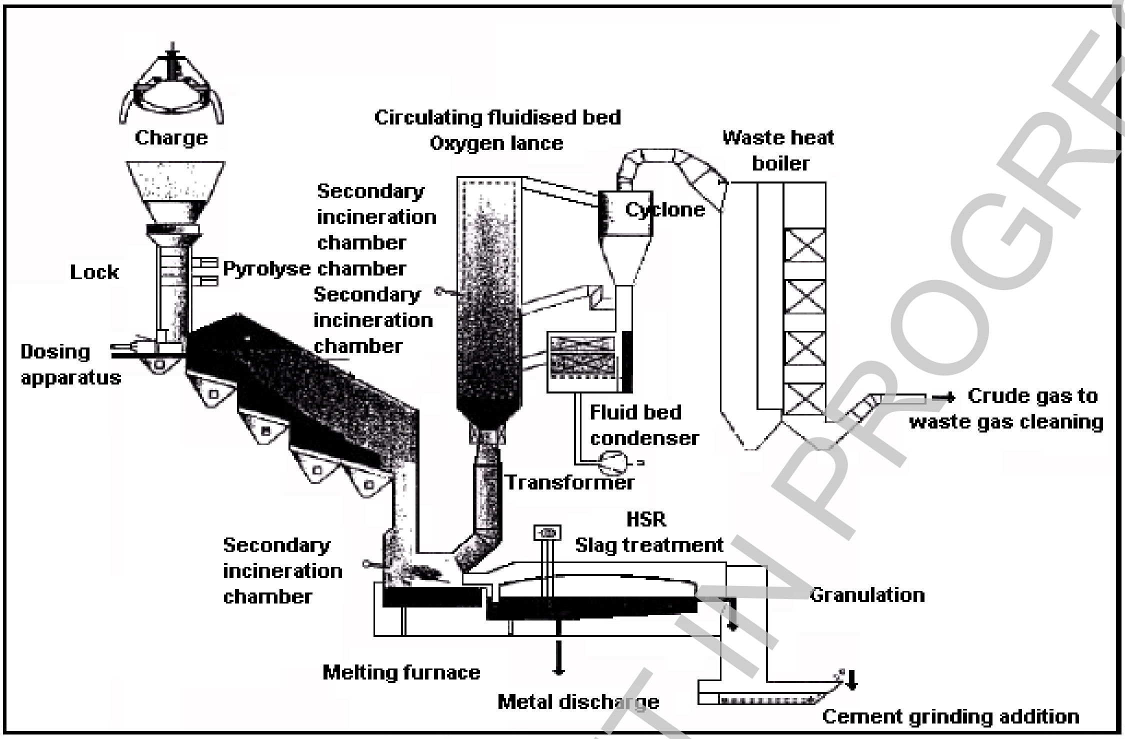
- the pyrolysis gases are cooled on leaving the ~~drum-type~~ rotary kiln, to deposit oil, dust and water;
- this is followed by oxidative high-temperature treatment in a special aggregate furnace, where the pyrolysis products, oil-water-dust mixture, pyrolysis coke and pyrolysis gas are combusted, and the solid residues are transformed into a liquid melt.



Source: [1, UBA, 2001]

Figure 2.21: Pyrolysis on a grate with directly connected high-temperature incineration

Pyrolysis on a grate with directly connected high-temperature incineration (see Figure 2.21) was developed from conventional grate incineration but with the objective of producing a liquid melt. The wastes are first pyrolysed on a grate by direct heating. This heat originates from the partial incineration of the pyrolysis gases with pure oxygen. In a second step, the products, pyrolysis gas, coke and inert substances are combusted or melted, respectively, at high temperatures in a directly connected ~~drum-type~~ rotary kiln. The accumulating melt residue contains glass, stones, metals and other inert materials and is different from the corresponding product of Process 1 above.



Source: [1, UBA, 2001]

Figure 2.22: The RCP process

The RCP process (see Figure 2.22) is a development of the pyrolysis on a grate with directly connected high-temperature incineration process. The molten bottom ash is depleted of metallic components and upgraded to a cement additive in a special secondary treatment stage. In Germany, the RCP process concept is now being applied for the first time on an industrial scale at a plant with a throughput of 90 000 tonnes/yr (investment costs approximately EUR 88 million) connected to an existing incineration plant for municipal wastes at Bremerhaven.

The flue-gas cleaning techniques applied for the three pyrolysis combination processes named above do not, in principle, differ from the systems used in municipal waste incineration plants. The same residues and reaction products accumulate. Their type and composition mainly depend upon the flue-gas cleaning system selected. However, in contrast to municipal waste incineration, filter dusts can be recycled into the melting chamber.

<u>Example pyrolysis-combustion installation for clinical wastes in the Netherlands</u>

[2, infomil, 2002]
The non-specific clinical waste is collected regularly from hospitals and other healthcare institutes, including doctors, dentists and veterinarians. The waste is collected in special 30- or 60-litre bins, which have been filled at the institutions and which do not need to be opened again. The waste is then incinerated, including the bins, which also act as an auxiliary fuel.

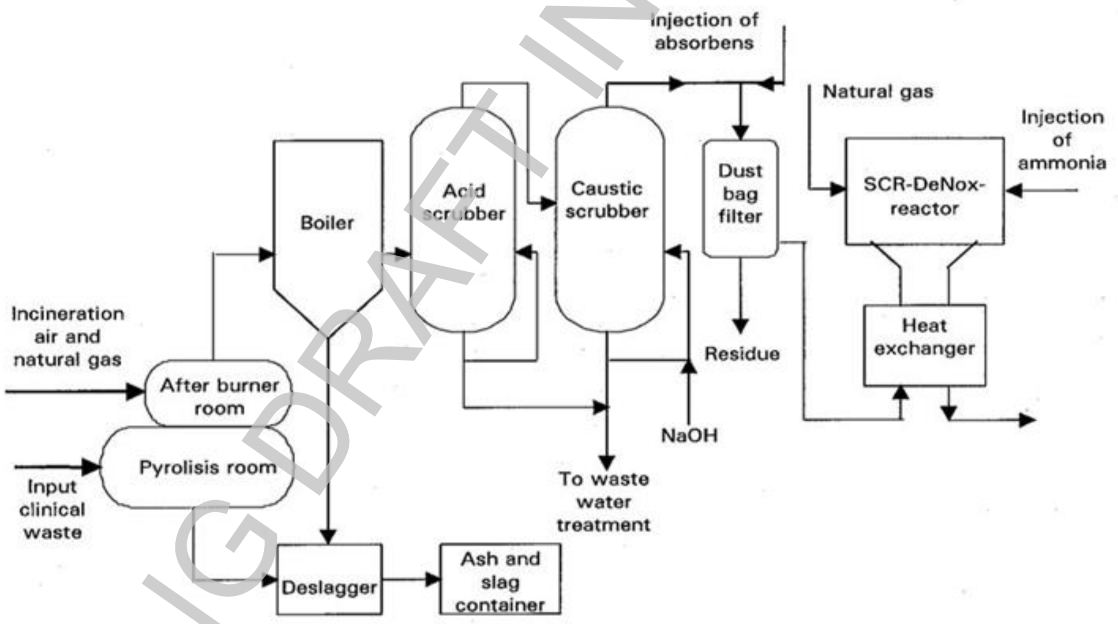
The non-clinical waste from hospitals and healthcare institutions is collected and treated as normal municipal waste.

The collected waste is stored in closed transport containers on site. The bins are collected and transported semi-automatically to the incineration unit, which is located in a closed building. The incinerator is fed through an airlock, in order to prevent the introduction of false incineration air.

Incineration takes place in a two-stage process (see Figure 2.23). In the lower incineration room, controlled pyrolysis occurs, followed by incineration with primary air as the waste progresses through the room. Finally, the waste ends in a water-filled ash discharger, from which the ash is removed by a chain conveyer system.

The flue-gases are incinerated with secondary air and, if required, with auxiliary fuel at a temperature of approximately 1 000 °C. Subsequently, they are cooled in a saturated steam boiler (steam temperature 225 °C, pressure 10 bar), a heat exchanger and a scrubber. Steam is supplied to the adjacent municipal waste incineration plant which uses the steam and returns the ~~related~~ boiler feed water.

The scrubber is a two-stage system for removing acid compounds. The treated flue-gas is heated up (in a heat exchanger and in a steam-flue-gas heat exchanger) before passing a dust bag filter with adsorbent injection (activated carbon and lime), for removal of dioxins, and a SCR-DeNO$_X$ unit. Emission concentrations of the emitted flue-gases comply with ~~are according to~~ Dutch standards. The flue-gas is emitted through a 55-metre high stack.



Source: [2, infomil, 2002]

Figure 2.23: Example of a clinical waste pyrolysis-incineration plant, ZAVIN, Netherlands

2.3.4.4.2 Pyrolysis-gasification

[For the TWG (especially Germany): This section is based on out-of-date information. Please comment on whether to keep it and if so please provide up-to-date information on this section.]

[1, UBA, 2001]
Two different types of pyrolysis-gasification processes can be distinguished:

- disconnected (pyrolysis with subsequent gasification = conversion process); and
- directly connected~~processes~~.

Conversion process

In the conversion process, metals and, if required, inert material may be removed after the pyrolysis step. As pyrolysis gas and pyrolysis coke require reheating in the gasification process, the technical and energetic requirements are higher than with connected processes. The condensed exhaust vapour is treated as waste water and discharged.

In the conversion process, the waste needs to be shredded and dried before it can be used in the first thermal stage. This stage more or less corresponds to that of the 'Smoulder-burn' process. The subsequent stages are:

- pyrolysis in the ~~drum~~ kiln;
- removal ~~withdrawal~~ of solid residues;
- separation of the fine fraction enriched with carbon;
- sorting of the metal and inert fraction.

The pyrolysis gas is cooled to condense exhaust vapour and pyrolysis oil. It is then supplied, together with the pyrolysis oil and the fine fraction, to the second thermal stage, which is a current flow gasifying reactor. The oil and the fine fraction are gasified in the current flow at high pressure and at a temperature of 1 300 °C. The resulting syn~~thesis~~-gas is cleaned and then combusted for energy recovery. Solid residues are withdrawn as melted granulate through a water bath. They correspond in type and quantity to those from the 'Smoulder-burn' process.

A conversion plant for the treatment of 100 000 tonnes/yr of municipal wastes and 16 000 tonnes/yr of dehydrated sewage sludge was approved at Northeim, Lower Saxony (DE).

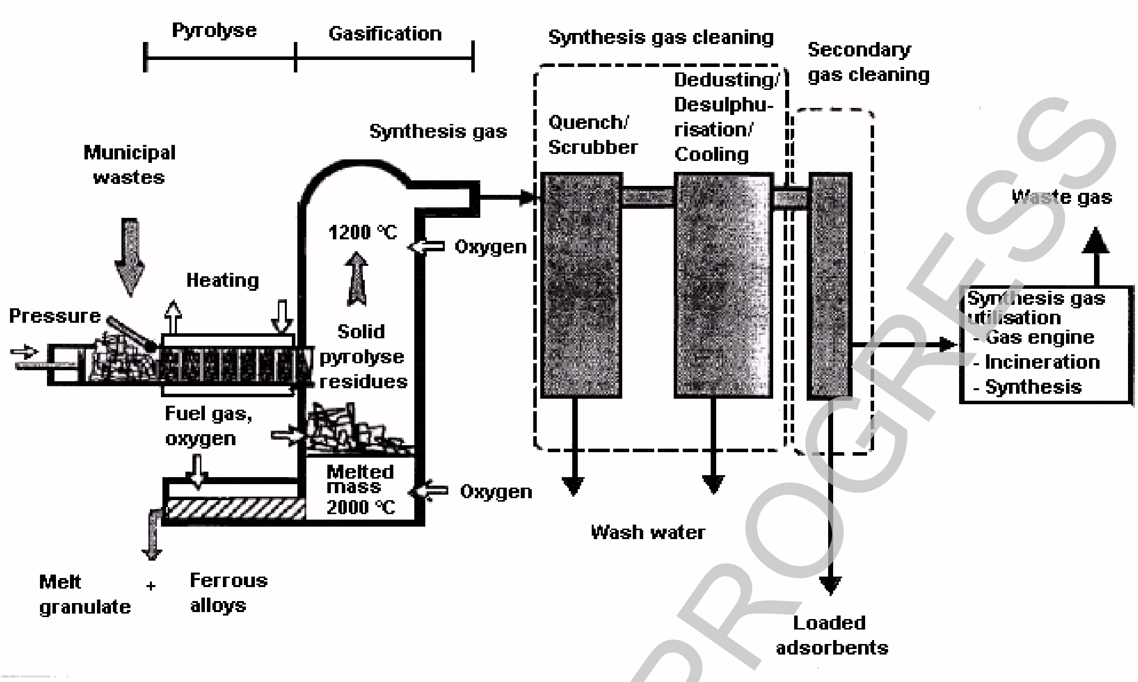
With direct connection, there may be improved electricity generation rates, but the metals and inert material go into a melt for which no use has been found to date.

Combined gasification-pyrolysis and melting process

In such processes, (see Figure 2.24) the unshredded wastes are dried in a push furnace and partially pyrolysed. From this furnace they are transferred directly and without interruption into a standing packed bed gasifier. Here they are gasified (in the lower part) at temperatures of up to 2 000 °C with the addition of oxygen. Pure oxygen is also added in the upper part of the gasification reactor to destroy the remaining organic components in the generated syn~~thesis-~~gas, through oxidation, gasification and cracking reactions.

Although reported to be capable of treating a wider range for wastes, this process is mainly used for municipal and non-hazardous industrial wastes. Wastes with a LCV of 6–18 MJ/kg and a moisture content up to 60 % may be treated. Automotive shredder residues with a chlorine content of up to 3.5 % have been treated with approximately equal amounts of MSW [69, Thermoselect, 2003].

The syn~~thesised~~ gas is subjected to a gas cleaning process and then combusted to utilise the energy value. The originally solid residues leave the reactor molten. During test operations, approximately 220 kg of bottom ash with approximately 30 kg metal accumulated per tonne of waste input.



Source: [1, UBA, 2001]

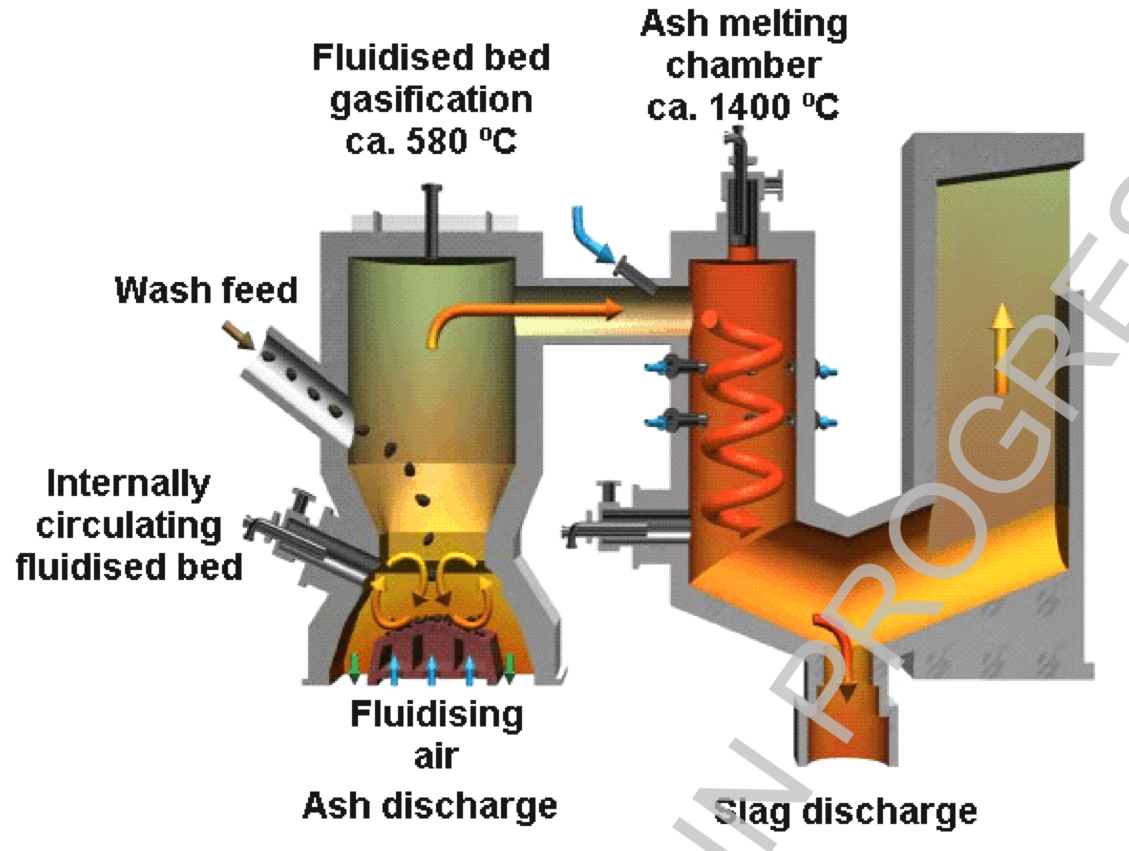
Figure 2.24: Schematic diagram of a push pyrolyser (example shown operated by Thermoselect)

A plant of this type with a municipal waste throughput of 108 000 tonnes/yr is currently under construction at Ansbach. Another plant with a throughput of 225 000 tonnes/yr has been built at Karlsruhe (DE), but has not yet achieved the design throughput. Two plants of this type are operated in Japan (2003).

2.3.4.4.3 Gasification-combustion

[*For the TWG: This section is based on out-of-date information. Please comment on whether to keep it and if so please provide up-to-date information on this section.*]

An example for the combination of gasification with combustion for ash melting is shown in Figure 2.25 below.



Source: [68, Ebara, 2003]

Figure 2.25: Combined fluidised bed gasification and high-temperature combustion process

Shredding residues, waste plastics or shredded MSW are gasified in an internally circulating bubbling fluidised bed, which is operated at about 580 °C. Larger inert particles and metals are discharged at the bottom and separated from the bed material. The bed material is returned to the gasifier. Fine ash, small char particles and combustible gas are transferred to the cyclonic ash melting chamber, where air is added to achieve the desired temperature for ash melting (normally 1 350–1 450 °C).

The ash melting chamber is an integrated part of the steam boiler, for energy recovery.

Products from this process – besides power or steam – are metal~~s~~ fragments ~~in pieces~~, a vitrified slag (low leaching and stable) and metal concentrates derived from the secondary ash.

In contrast to other gasification processes, this process is operated at atmospheric pressure and with air rather than oxygen. Pretreatment of MSW by shredding is necessary to reduce particle size to 300 mm in diameter. Wastes already within this specification can be treated without shredding. In the various plants in operation, other wastes like sewage sludge, bonemeal, clinical waste and industrial slags and sludges are treated in addition to MSW. [68, Ebara, 2003]

2.3.5 Other techniques

2.3.5.1 Stepped and static hearth furnaces

[*For the TWG: This section is based on out-of-date information. Please comment on whether to keep it and if so please provide up-to-date information on this section.*]

Static hearth furnaces consist of a refractory-lined box in which the wastes are burned at the base of the furnace, often with the injection of support fuels above the burning waste to help maintain temperatures. In some cases, the waste-loading mechanism is a simple door opening (although this is not common in modern plants due to the instability caused to the incineration process by the uncontrolled ingress of air that results) or is provided by a hydraulically operated ram, which also provides a measure of waste agitation. Such processes often operate on a batch basis, with de-ashing carried out in between batch loading. De-ash mechanisms are usually fairly simple drag systems – in older, smaller units, de-ashing was carried out manually using scrapers, although this causes difficulties with air ingress to the furnace. Such, very basic, technology has been widely applied, particularly to small incineration units (< 250 kg/h) but is less widely applied owing to the application of new air emission, ash burnout, etc. legislation, which such systems cannot ~~meet~~ comply with in the majority of circumstances. Such systems have been used in some cases to provide a means for the disposal of dead animals, animal parts, packaging wastes and some clinical wastes – but generally only at the low throughput rates noted above.

Stepped hearth systems are a development from static hearths. They usually consist of ~~a usually~~ two to four static hearths arranged as a series of steps. The waste is generally pushed forward through the furnace and over the steps using hydraulic rams. The pushing and tumbling of the waste provides agitation and allows improved burnout. Such systems continue to be applied, particularly at plants of below 1 t/h. Loading mechanisms are generally air-sealed hoppers or hydraulic batch loaders. De-ashing is generally continuous and may be via a water bath ~~batch~~ to ~~provide an air seal and~~ prevent air ingress to the furnace. Such systems are capable of meeting modern legislative requirements with some waste types. Burnout of the waste may be variable and highly dependent on the waste type – pretreatment of the waste by shredding usually assists in complying with required burnout standards.

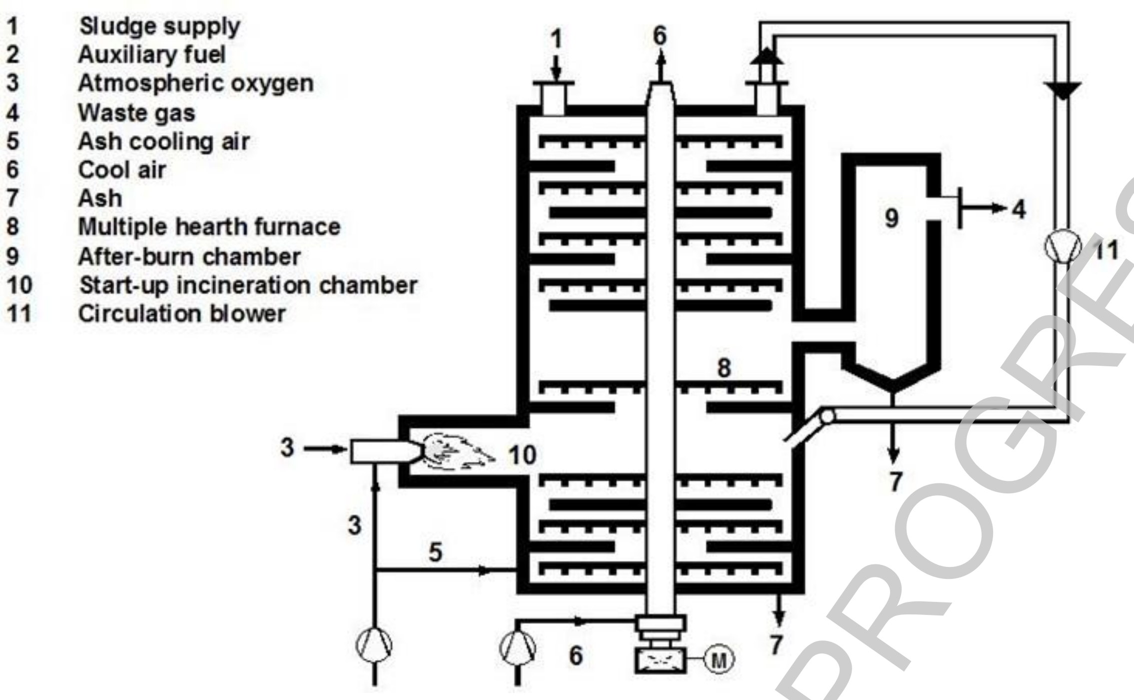
2.3.5.2 Multiple hearth furnaces

[*For the TWG (especially Germany): This section is based on out-of-date information. Please comment on whether to keep it and if so please provide up-to-date information on this section.*]

Multiple hearth incinerators are mainly applied to the incineration of sludges (e.g. sewage sludge).

The multiple hearth furnace (see Figure 2.26) consists of a cylindrical lined steel jacket, horizontal layers, and a rotating sleeve shaft with attached agitating arms. The furnace is lined with refractory bricks. The number of trays for drying, incineration and cooling is determined based on the residual material characteristics. The multiple hearth furnace is also equipped with a start-up burner, sludge-dosing mechanism, circulation-, sleeve shaft- and fresh air-blowers.

Sewage sludge is fed at the top of the furnace and moves downwards through the different hearths countercurrent to the combustion air, which is fed at the bottom of the furnace. The upper hearths of the furnace provide a drying zone, where the sludge gives up moisture while the hot flue-gases are cooled.



Source: [1, UBA, 2001]

Figure 2.26: ~~Principle function~~ Typical design of a multiple hearth furnace

The material to be incinerated is supplied at the highest furnace layer. It is captured by agitator sprockets, divided, and forced through the furnace layers through constant rotation. ~~In a counter-direction to the sludge, h~~Hot flue-gas is conducted, in the opposite direction to the sludge, from the highest incineration layer via the drying layers. The sludge is dried by the flue-gas and heated to ignition temperature. The circulating air is augmented with steam and volatile particles during the drying process. It is then led towards the lowest incineration layer.

The incineration mainly takes place on the central hearths. The incineration temperature is limited to 980 °C, as above this temperature the sludge ash fusion temperature will be reached and clinker will be formed. In order to prevent leakage of hot toxic flue-gases, multiple hearth furnaces are always operated at a slight vacuum ~~pressure~~.

The conversion of organic sludge particles to CO_2 and H_2O occurs at temperatures of between 850 °C and 950 °C. If the desired incineration temperature cannot be reached independently, a start-up burner is used for support incineration. As an alternative, solid auxiliary fuel can be added to the sludge. The ash is cooled to approximately 150 °C at the lower layers of the furnace with counter-flowing cool air and the ash is removed via the ash system. The flue-gas that is produced is fed through a post-reaction chamber with a guaranteed residence time of 2 seconds. Carbon compounds that have not been converted are oxidised here.

The multiple hearth furnace is employed with sludge where the ash forms such low eutectics with the fluidised bed material that it would cause operational problems in the fluidised bed furnace.

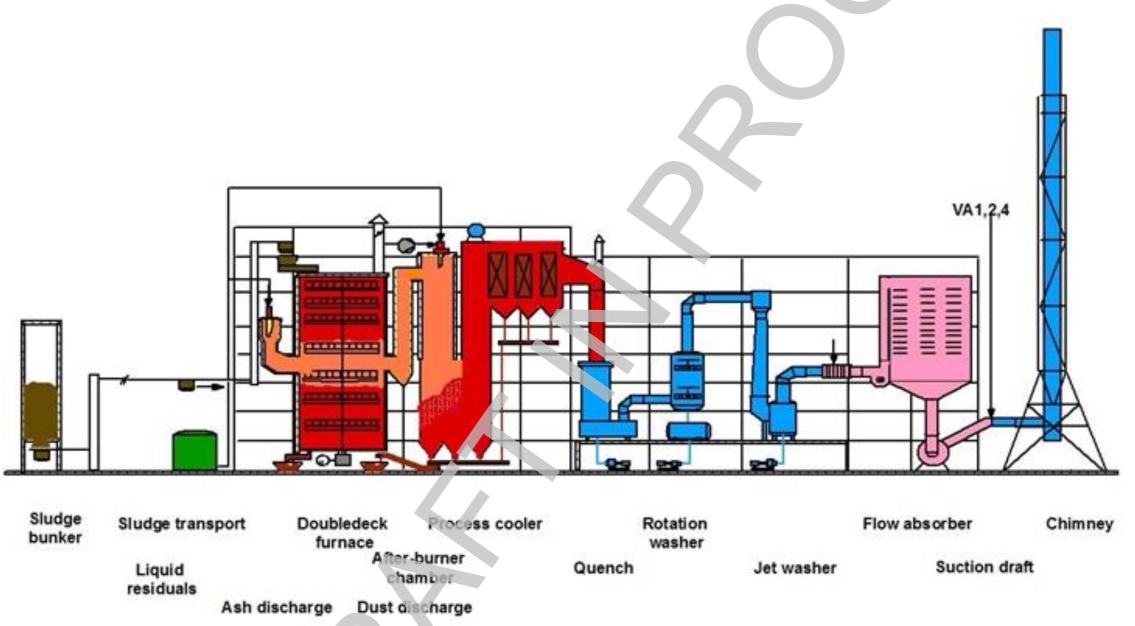
Multiple hearth furnaces can be operated by removing the flue-gases at the highest drying level and then feeding them to post-combustion (e.g. in an incineration chamber). This is advantageous at such locations where boiler plants are already available, facilitating the feeding of flue-gases into those plants. The afterburning process and the flue-gas cleaning occur at those plants.

The essential operational parameters are shown in the following table.

Table 2.10: Operational criteria for a multiple hearth furnace

Operational parameter	Unit	Value
Evaporation capacity	kg/m^2h	25–45
Heat conversion in incineration layers	GJ/m^2h	0.4–0.6
Incineration end temperature	°C	850–950
Residence time, free space, and after-burn zone	s	min. 2
Atmospheric oxygen preheating	°C	max. 600
Source: **[1, UBA, 2001]**		

Figure 2.27 below shows a practical example of a sewage sludge incineration plant with a capacity of 80 000 tonnes/yr.



Source: [1, UBA, 2001]

Figure 2.27: Example of a sewage sludge incineration plant with a multiple hearth furnace

The above plant essentially consists of the following parts:

- multiple hearth furnace;
- post-combustion chamber;
- waste water boiler for heat utilisation;
- multiple stage flue-gas cleaning.

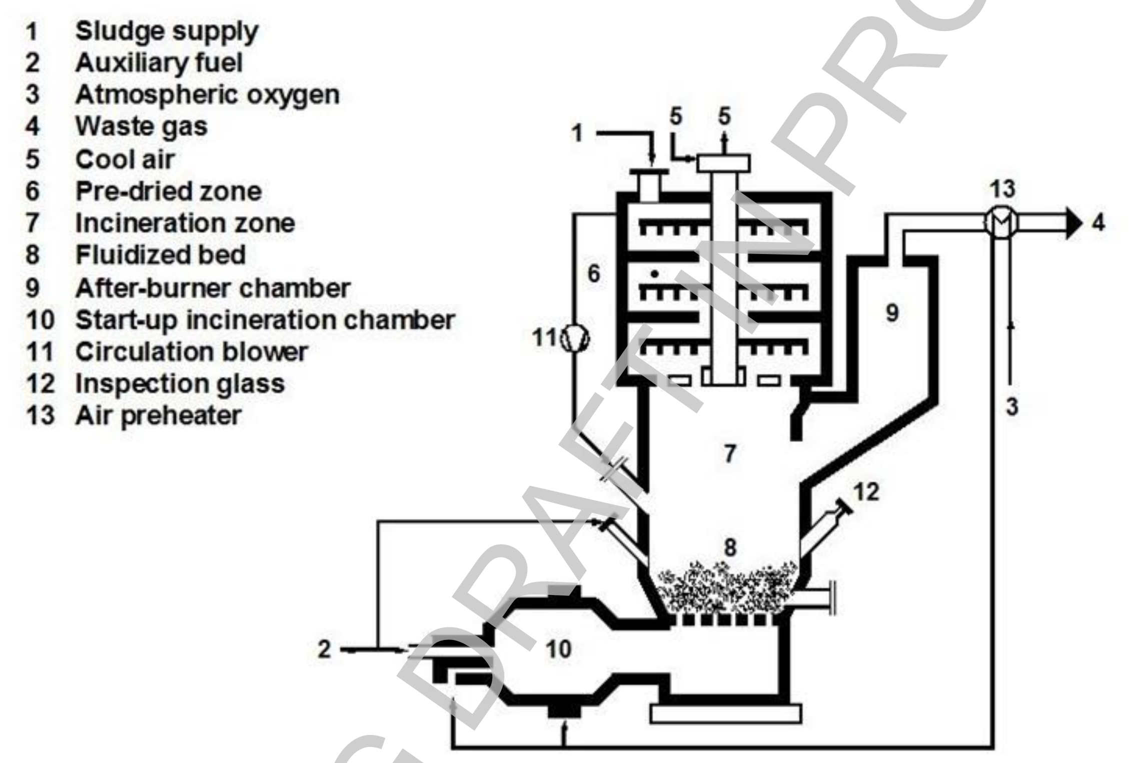
The accumulated sewage sludge is conditioned, meaning that it is converted into a form suitable for filtering using additives or other measures. The sludge is drained as much as possible in chamber filter presses and then temporarily stored in a bunker. From there, the press cake is deposited in buckets via a bucket loader. These buckets have a capacity of approximately 1.5 tonnes each. The sludge is loaded from the buckets into a filler container at the highest layer of the incineration plant and continuously fed into the furnace. Up to 12 tonnes of sewage sludge can be processed per hour. ~~This represents the contents of eight buckets.~~

2.3.5.3 Multiple hearth fluidised bed furnace

[*For the TWG (especially Germany): This section is based on out-of-date information. Please comment on whether to keep it and if so please provide up-to-date information on this section.*]

Several layers are installed into the freeboard of a stationary fluidised bed, enabling the sludge to be pre-dried with flue-gas. Using this pre-drying process, only a small amount of water must be evaporated in the actual fluidised bed, meaning that the grate surface and entire furnace can be reduced.

Uniform incineration is promoted in the multiple hearth fluidised bed furnace by optimising air supply, sand addition, and evaporation in the layers and in the fluidised bed. Higher temperatures (temperature differences between the furnace head and foot) can be avoided, leading to a lower formation of NO_X.



Source: [1, UBA, 2001]

Figure 2.28: ~~Principle function~~ Typical design of a multiple hearth fluidised bed furnace

2.3.5.4 Modular systems

[*For the TWG (especially Germany): This section is based on out-of-date information. Please comment on whether to keep it and if so please provide up-to-date information on this section.*]

[Bontoux, 1999 #7]
Waste incineration can occur in a selective manner in smaller facilities that are dedicated to:

- specific kinds of wastes; or
- specifically pretreated wastes.

These specialised forms of waste incineration are often performed in commercial or industrial tailor-made facilities that usually receive consistent waste streams. As a result, they usually benefit from optimised operating conditions and treat a much smaller tonnage of waste than mass burn facilities.

One of the designs used is the 'starved air' or 'two-stage' incinerator in which wastes are partially burned and partially pyrolysed at the front end of a hearth with the resulting char being fully burned out at the back end.

Depending on the furnace design, various wastes are treated in such systems. (Energos 2002) As well as dealing with specific industrial non-hazardous waste streams (e.g. packaging and paper wastes, fish industry wastes), modular semi-pyrolytic processes are also successfully applied to pretreated (shredded) municipal wastes. Plants in the range of 35 000–70 000 tonnes per year are operational in Europe. It is reported that these achieve NO_X emissions below 100 mg/m^3, without specific NO_X abatement, mainly through careful attention to combustion design and control. Whilst costs per unit disposal for mass burn facilities of this size are generally very high, the cost of systems dealing with specific waste streams is greatly reduced through a combination of:

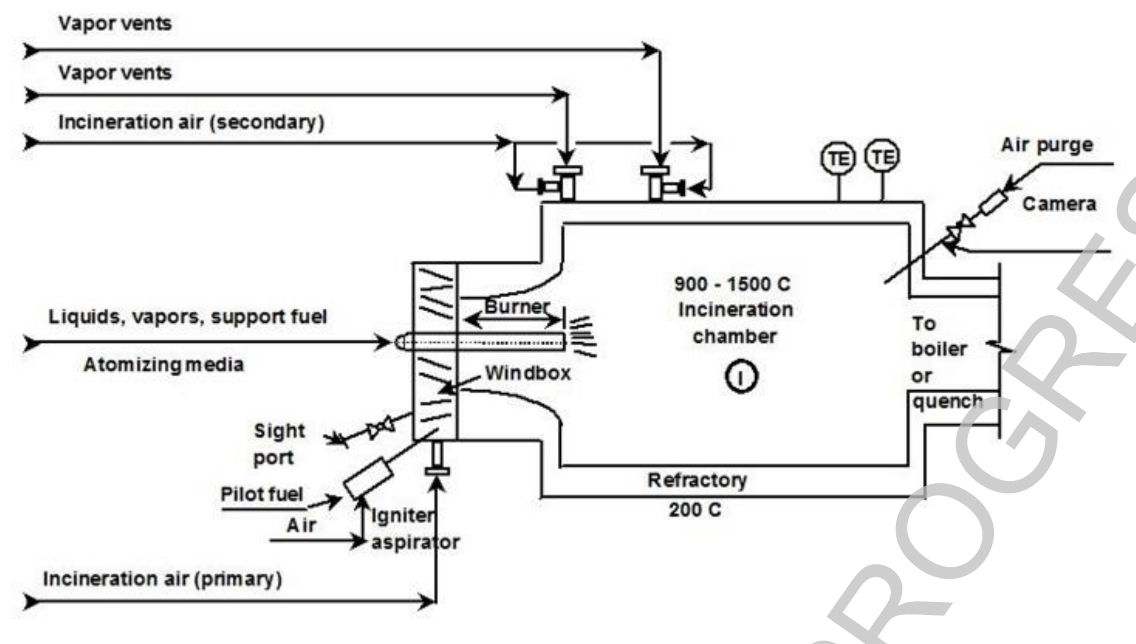
- simple small-scale gas cleaning systems which may be used as flue-gas variation is reduced;
- positioning of plants adjacent to heat users to increase energy supply and income which can then offset incoming disposal costs.

2.3.5.5 Incineration chambers for liquid and gaseous wastes

Incineration chambers are designed specifically for the incineration of liquid and gaseous wastes, as well as solids dispersed in liquids (see Figure 2.29) A common application of incineration chambers is in the chemical industry for the incineration of liquid and process off-gas. With chloride-containing wastes, HCl may be recovered for use.

All post-combustion chambers in hazardous waste incineration plants are essentially incineration chambers. In one plant (Ravenna, Italy), the post-combustion chamber is so large that the whole thermal process can occur there.

Operational temperatures are usually chosen to ensure good destruction of the wastes fed to the chamber. In some cases, catalytic systems are used for specific waste streams; these run at reduced temperatures of 400–600 °C. In general, temperatures in excess of 850 °C are selected for non-catalytic chambers. Support fuels are frequently used to maintain steady combustion conditions. Heat recovery may be used to supply hot water/steam via a boiler system.



Source: [1, UBA, 2001]

Figure 2.29: ~~Principle~~ Typical design of an incineration chamber for liquid and gaseous wastes

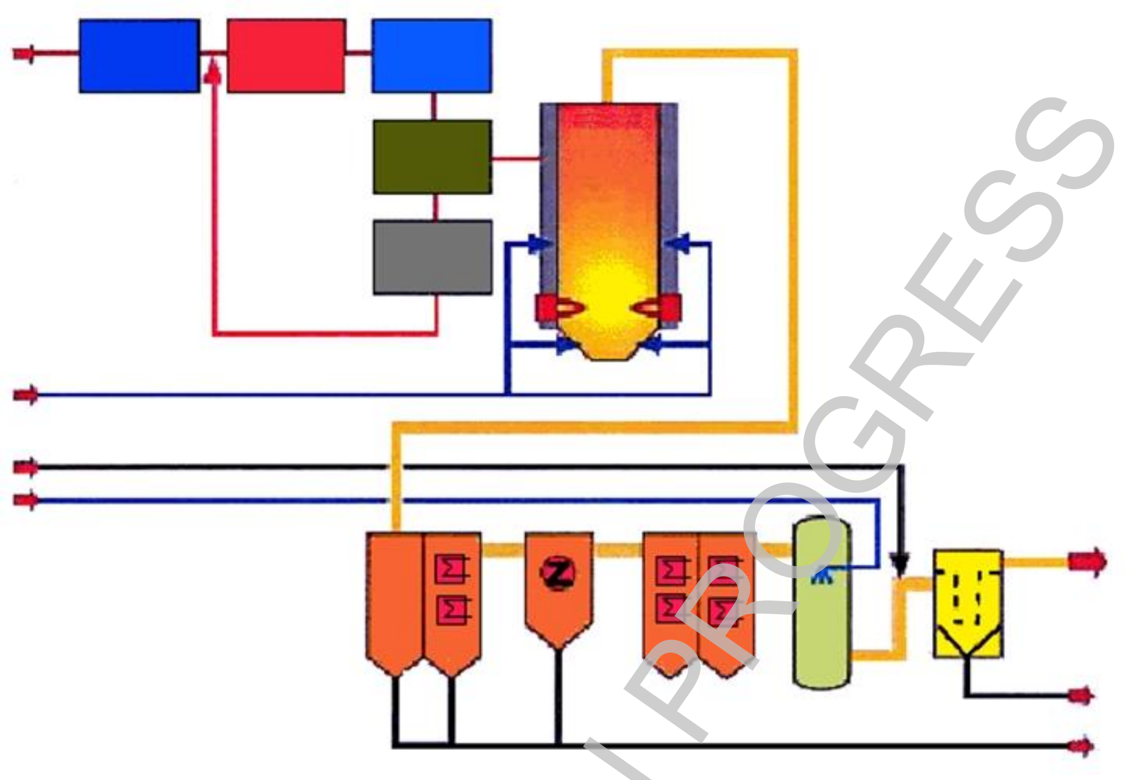
2.3.5.6 Cycloid incineration chamber for sewage sludge

[*For the TWG (especially Germany): This section is based on out-of-date information. Please comment on whether to keep it and if so please provide up-to-date information on this section.*]

The cycloid incineration chamber was originally developed for incinerating ~~old~~ coke derived from flue-gas cleaning at waste incineration plants but is now also used for the incineration ~~thermal disposal~~ of sewage sludge. The optimal particle size for fuel ignition lies between 1 mm and 5 mm. Therefore, only dried sewage sludge granules can be used.

The fuel granules are supplied gravimetrically via a radial chute into the lower part of the incineration chamber, which is designed as a metallic air-cooled hopper. Atmospheric oxygen is blown into the incineration chamber at various air levels: the primary air enters the furnace at an angle through the lower part of the hopper, and the secondary air is injected on different levels through tangentially placed jets above the fuel feed. The distribution of primary and secondary air varies according to the specific fuel characteristics.

The incineration of sewage sludge requires an even temperature distribution of between 900 °C and 1 000 °C throughout the entire incineration chamber. Using this method, the temperature of the ash is maintained below ~~under~~ its softening point. Fly ash ~~ing dust~~ is removed along with flue-gas from the incineration chamber. The coarse kernels circulate in the tangential flow field until they are incinerated to the point that they can be removed as fine kernels. ~~Crude~~ Bottom ash, remaining coke, or metallic parts will be removed in a downward direction via a lock system.



Source: [1, UBA, 2001]

Figure 2.30: Illustration of a cycloid furnace

2.3.5.7 ~~Example of process for the~~ Incineration of liquid and gaseous chlorinated wastes with HCl recovery

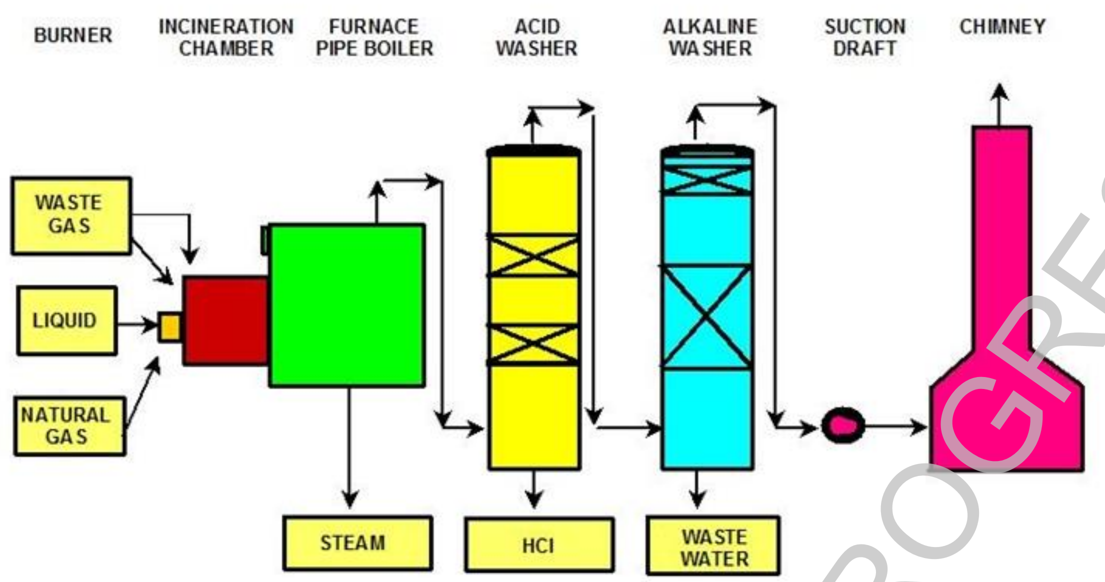
[1, UBA, 2001] The process includes:

- the incineration chamber;
- a steam generator;
- a flue-gas cleaner combined with hydrochloric acid recovery; and
- the flue-gas chimney (see Figure 2.31).

The plant treats liquid and gaseous chlorinated wastes using waste heat and produces hydrochloric acid.

Heat is converted into steam in the steam generator (212 °C, 20 bar) and transferred, for distribution. The particulate content of the flue-gases produced during incineration is separated, to produce the highest possible concentration of hydrochloric acid in the flue-gas cleaning plant. The removal and utilisation of hydrochloric acid normally occurs within the plant.

Gaseous residual substances (flue-gases) are fed to the recovery plant via transfer pipelines. Each flue-gas flow is conducted through a separate deposit container before incineration. Liquid particles are separated from the flue-gas flow in this deposit container. The feed lines are equipped with the appropriate flashback safety guards, according to the classification of the flue-gases. The number of feed lines depends on the control mechanisms. The volume flow is collected via flow measurements that are pressure- and temperature-compensated. The flue-gases are fed into the incineration chamber via a pressure regulator with a maximum pressure limit control. In addition, all flue-gas lines to the incineration chamber are equipped with automatic emergency shutdown valves.



Source: [1, UBA, 2001]

Figure 2.31: Diagram of a plant for HCl extraction from residual gases and liquid halogenated wastes

Transfer pipelines for the liquid wastes are also equipped with automatic emergency shutdown valves. All liquid wastes are conducted to a multi-material burner that is situated at the front side of the incineration chamber. Vaporisation of these liquids occurs via pressured air and/or steam that have been fed into the burner under a separate gas quantity control. In addition, various flue-gas flows are fed into the multi-material burner through lances. Each of these lances consists of concentric pipes. Several flue-gas flows can thus be fed separately into the incineration chamber. For cooling and to avoid corrosion, the lances are continuously sprayed with air through the outer circular gap.

Primary energy (natural gas) is required for the plant start-up and to maintain the desired temperature in the incineration chamber. It is also fed to the multi-material burner by a separate blast connection. The flow of natural gas is regulated via a quantity control computer system and is fed into the burner using a pressure regulator depending on the temperature in the incineration chamber. Natural gas is also required for the ignition flame that ignites the multi-material burner. Two automatic emergency shutdown valves with automatic gap releases can be found in the natural gas line to the multi-material burner and to the ignition flame.

Two independent flame-failure alarms (UV and IR) are installed to monitor the burner flame. In addition, the burner flame can be observed through inspection windows and with the help of a television camera installed on the back wall of the waste heat boiler. The amount of air is recorded with the appropriate gauges, as well as with pressure produced from a blower.

The cylindrical incineration chamber is designed in such a way that the wastes will have sufficient residence time to guarantee complete ~~flawless~~ incineration ~~in relation to~~ with an operational temperature higher than 1 100 °C during normal operation. The incineration chamber ~~has been~~ is designed for a temperature of 1 600 °C. The operational temperature is monitored continuously ~~by thermal elements~~. ~~Based on~~ To withstand this high temperature, the whole incineration chamber, up to the entrance to the steam boiler plant, is lined ~~exclusively~~ with refractory bricks. The incineration chamber shell is made of boilerplate. The wet cleaning of the flue-gases occurs in two wash towers with a simultaneous recovery of technically reusable hydrochloric acid of the highest concentration. The deployment of chlorinated wastes facilitates the recovery of approximately 5–20 % hydrochloric acid.

2.3.5.8 ~~Example of a process for the~~ Incineration of ~~highly~~ chlorinated liquid wastes with chlorine recycling

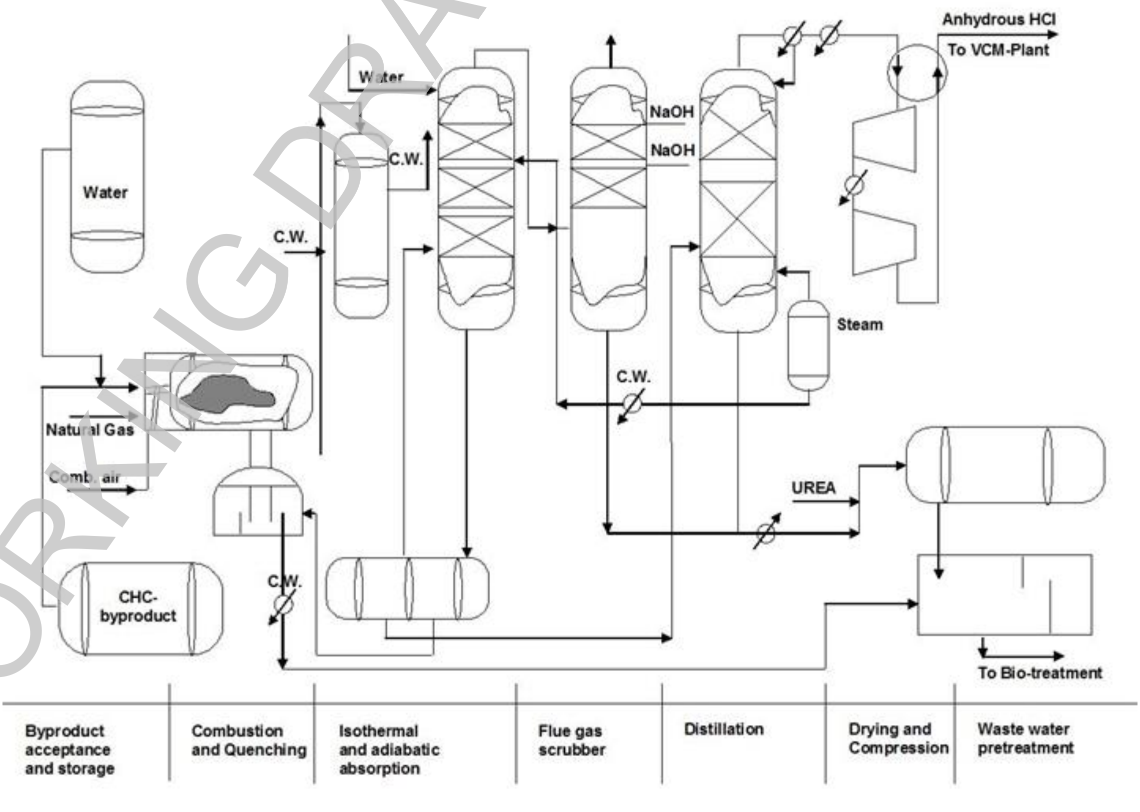
[2, infomil, 2002]
This incineration unit for highly chlorinated liquid wastes (chlorinated hydrocarbons) is located on an industrial site. The total plant capacity is approximately 36 000 t/yr. The processed waste originates on site, as well as from external customers. Wastes are limited in their content of solids (< 10 g/kg), fluorine, sulphur and heavy metals. PCBs are also treated.

Incineration takes place in two furnaces at a temperature of 1 450–1 550 °C (gas residence time 0.2–0.3 seconds). This temperature level can normally be maintained without auxiliary fuel. Water is injected in order to suppress the formation of Cl_2. After leaving the furnace, the flue-gas passes through a quench section, where the temperature is lowered to approximately 100 °C. Insoluble matter and heavy metal salts are removed from the circulating liquid in a quench tank. The flue-gas continues through an isothermal and an adiabatic absorber. The recuperated hydrochloric acid is distilled at elevated pressure and temperature, after which the gas is cooled down to −15 °C in order to reduce the water content to practically zero. The recovered anhydrous HCl is reprocessed in a vinyl chloride monomer plant.

Flue-gases pass through an alkaline scrubber and an activated carbon filter (for dioxin absorption). TOC, HCl, NO_X, O_2, CO and dust are continuously analysed. The concentration of dioxins and PCBs in emissions is below 0.1 ng TEQ/Nm^3. ~~Other emissions to air comply with Dutch emission limit values.~~

The effluent from the quench and the scrubber unit is treated in a physical/chemical unit and in a biological waste water treatment unit. The dioxin content is < 0.006 ng TEQ/l. PCBs are below the limit of detection (< 10 ng/l).

A scheme of the process is given in Figure 2.32.



Source: [2, infomil, 2002]

Figure 2.32: Process scheme of a chlorine recycling unit operated by Akzo Nobel

The main advantage of this dedicated incineration unit is that chlorine can be recovered. Also, in this case, overhead costs are reduced by the fact that it is part of a larger chemical plant.

2.3.5.9 Waste water incineration

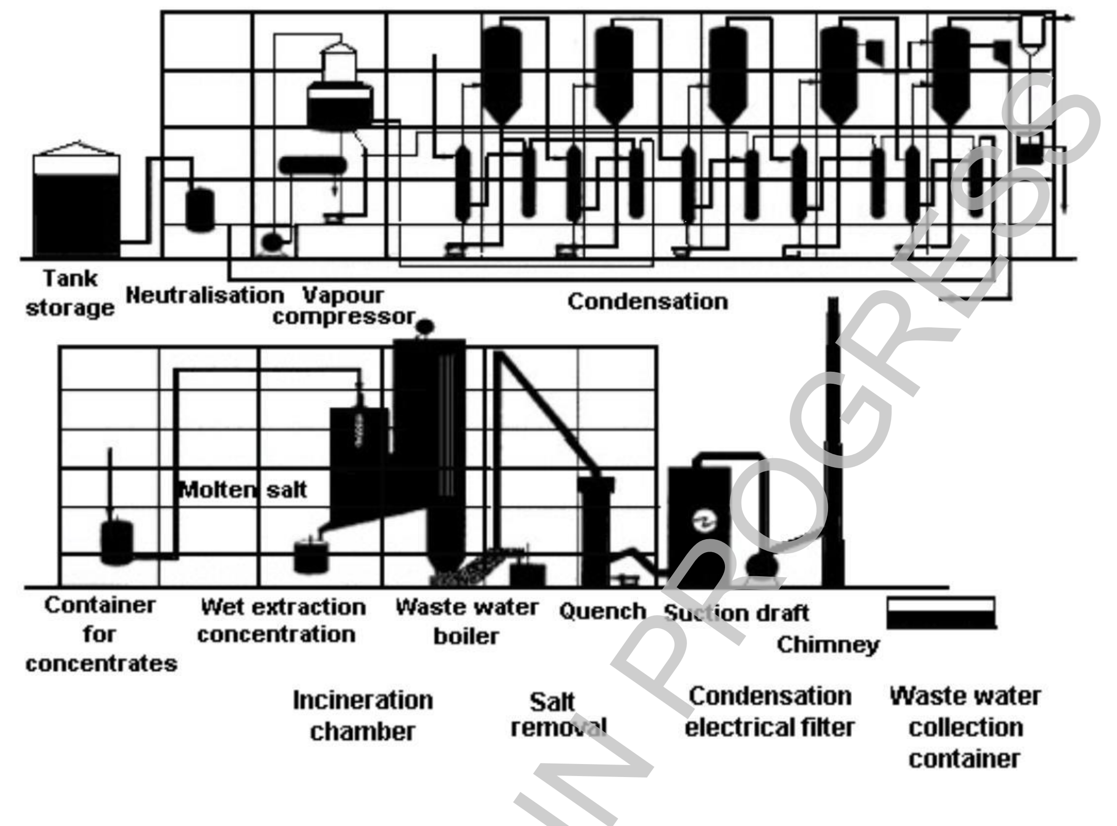
[1, UBA, 2001]
Waste water can be treated ~~cleaned~~ through incineration of the organic ~~content~~ materials. This is a special technology for the treatment of industrial waste water where organic and sometimes inorganic ~~waste water content~~ material is chemically oxidised with the help of atmospheric oxygen with the evaporation of the water, at high temperatures. The term 'gas phase oxidation' is used to differentiate this type of incineration from other technologies, such as wet oxidation. The process of gas phase oxidation is used if the organic substances in the water cannot be reused or if their recovery is not economical or another technique is not applied.

~~Waste water incineration is an exothermic process.~~ Unsupported ~~Independent~~ incineration can only take place if the organic load is sufficient to evaporate the water share independently and to perform superheating. The calorific value of the water is normally too low for unsupported incineration, in which case co-incineration or the use of supporting fuel will be necessary. ~~Therefore, waste water incineration plants normally require the use of support fuels for low organic load wastes.~~ Reduction of the requirement for additional energy can be achieved by reducing the water content. This can be achieved through deployment of a pre-connected, or multi-step, condensation plant. In addition, a heat recovery part (boiler) can be installed to recover steam for condensation from the furnace heat that is produced.

Depending on the individual organic and inorganic content of the waste water and the various local conditions, very different plant designs result.

Waste water and fuel are injected via burners or lances at several locations within the incineration chamber. Atmospheric oxygen is also supplied at several locations (primary air = atmospheric oxygen combined with fuel, secondary air = mixed air).

An example of a waste water incinerator with a waste water evaporation (concentration) unit is shown in the figure below [74, TWGComments, 2004]



Source: [1, UBA, 2001]

Figure 2.33: Example of a waste water incinerator with a waste water evaporation (concentration) unit

Example of an installation for the incineration of caustic waste water

[2, Infomil, 2002]
Caustic water is a specific waste water stream from MSPO (monostyrene propylene oxide) plants. This water is produced in several washing steps in the process. It contains approximately 10–20 % organic components and has a high sodium load (mainly NaCl).

Both the high organic fraction and the sodium make it difficult or even impossible to use biological water treatment. The calorific value of this water is too low for unsupported incineration, so co-incineration or the use of supporting fuel is necessary. The high sodium content, together with the large quantities, can cause problems for co-incineration in municipal waste incinerators.

Applicable treatment technologies are wet oxidation and incineration. For this purpose, four static vertical incinerators (total capacity approximately 350–400 kt/yr) are used in this example, which have been in operation since 1999/2000.

~~The incinerators are static vertical top-down incinerators~~. The low calorific value waste (caustic water with 10–20 % organics) can be passed ~~fed~~ through a falling film evaporator. This evaporator operates on excess low-pressure steam, which comes from the incinerator wall cooling, thus using less fuel in the incinerator.

The remaining liquid and the produced vapour are incinerated using static vertical top-down incinerators with natural gas and/or high calorific value liquid fuel (waste or fuel oil). The resulting flue-gases are partially cooled by a membrane wall, producing steam at ~~of~~ 27 bar. Subsequently, the flue-gases are quenched to clean the gases of sodium salts and other water-soluble impurities.

In the heat recovery section, recirculation water is sprayed over the flue-gases. This recirculation water flashes out in the flash chamber, generating approximately 30 t/h of steam per unit.

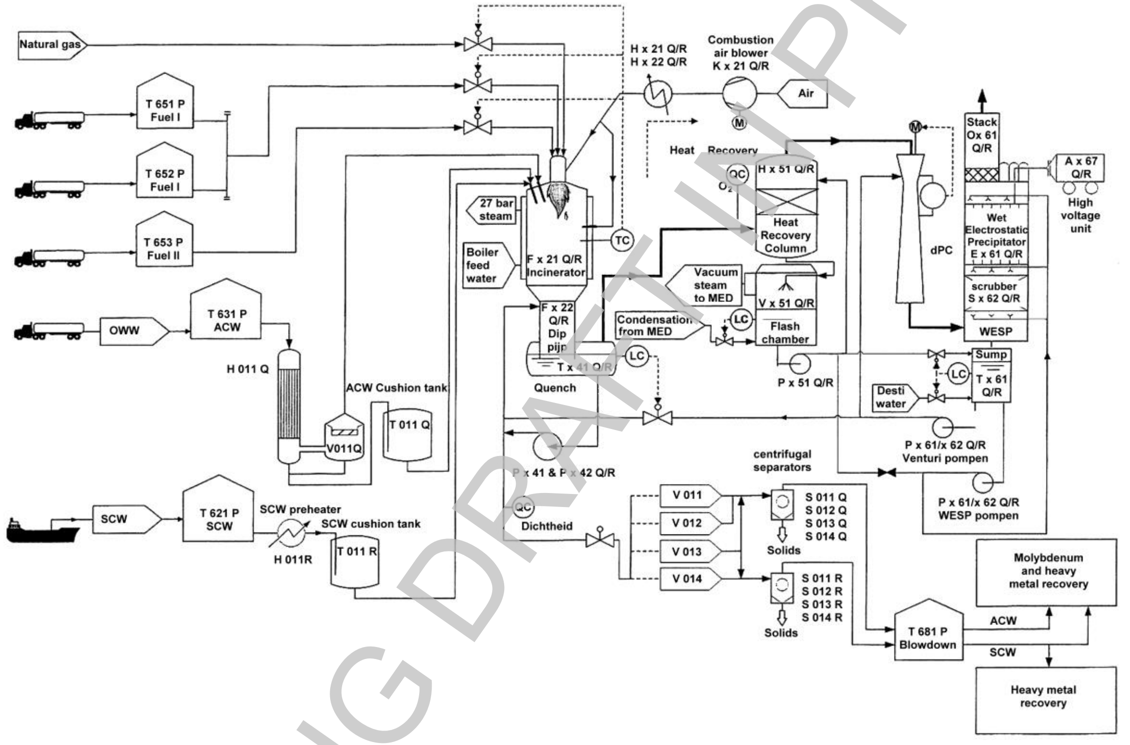
After the heat recovery, the flue-gases pass through a venturi ~~venture~~ scrubber and a wet electrostatic precipitator where aerosols and dust are removed.

The incinerators operate at a temperature of 930–950 °C, with low excess air (3–4 % O_2). Depending on the concentration of organics, the throughput of caustic water is 10–15 t/h per unit.

The water from the quench is treated in ion exchange beds to remove heavy metals. Special ion exchange beds concentrate the molybdenum (catalyst in the MSPO process) to a reusable grade.

The main advantage of these incinerators is their ability ~~the possibility~~ to incinerate large quantities of low calorific value waste with high salt concentrations.

The following diagram shows an example plant for this process.



Source: [2, Infomil, 2002]

Figure 2.34: Process scheme of a caustic water treatment plant operated by AVR

2.3.5.10 Plasma technologies

[For the TWG: This section is based on out-of-date information. Please comment on whether to keep it and if so please provide up-to-date information on this section.]

Plasma is a mixture of electrons, ions and neutral particles (atoms and molecules). This high-temperature, ionised, conductive gas can be created by the interaction of a gas with an electric or magnetic field. Plasmas are a source of reactive species, and the high temperatures promote rapid chemical reactions.

Plasma processes utilise high temperatures (5 000 °C to 15 000 °C), resulting from the conversion of electrical energy to heat, to produce a plasma. They involve passing a large electric current though an inert gas stream.

Under these conditions, hazardous contaminants, such as PCBs, dioxins, furans, pesticides, are broken into their atomic constituents, by injection into the plasma. The process is used to treat organics, metals, PCBs (including small-scale equipment) and ~~HCB~~ hexaclorobenzene. In many cases, pretreatment of wastes may be required.

~~An off-gas treatment~~ A waste gas cleaning system is normally required depending on the type of wastes treated ~~is required~~, and the residue is a vitrified solid or ash. The destruction efficiencies for this technology are quite high, > 99.99 %. Plasma is an established commercial technology, however the process can be very complex, expensive and operator-intensive.

Thermal plasmas can be generated by passing a DC or AC electric current through a gas between electrodes, by the application of a radio frequency (RF) magnetic field without electrodes, or by application of microwaves. Different kinds of plasma technologies are introduced below.

1. Argon plasma arc
This is an 'in flight' plasma process, which means that the waste mixes directly with the argon plasma jet. Argon was selected as the plasma gas since it is inert and does not react with the torch components.

The destruction and removal efficiency (DRE) is reported to exceed 99.9998 % for destroying ozone-depleting substances (ODS) at 120 kg/h and with 150 kW electrical power.

The advantage of this technology over some other plasma systems is that it has demonstrated high-efficiency destruction of both CFCs and halons on a commercial scale for several years. It has also demonstrated low emissions of PCDD/F. Mass emissions of pollutants are also low because of the relatively low volume of flue-gas produced by the process. Also, the very high energy density results in a very compact process that may easily be transported.

2. Inductively coupled radio frequency plasma (ICRF)
In ICRF applications, inductively coupled plasma torches are used, and energy coupling to the plasma is accomplished through the electromagnetic field of the induction coil. The absence of electrodes allows operation with a large range of gases, including inert, reducing or oxidising atmospheres and better reliability than plasma arc processes.

The ICRF plasma process has demonstrated a DRE exceeding 99.99 % while destroying CFCs at a rate of 50–80 kg/h.

The process is reported to have been demonstrated on a commercial scale to achieve high destruction of CFCs and low emission of pollutants. The ICRF plasma does not require argon and may therefore cost less to operate than other similar systems. In addition, the low volume of gas produced by the process results in low levels of mass emissions of pollutants.

3. AC plasma
The AC plasma is produced directly with 60 Hz high-voltage power but in other respects is similar to the inductively coupled RF plasma. The system is electrically and mechanically simple and is thus claimed to be very reliable. The process does not require argon and can tolerate a wide variety of working gases, including air or steam, as plasma gases and is claimed to be tolerant of oil contamination in ODS.

4. CO_2 plasma arc
A high-temperature plasma is generated by sending a powerful electric discharge into an inert atmospheric gas, such as argon. Once the plasma field has been formed, it is sustained with ordinary compressed air or certain atmospheric gases depending on the desired process outcomes.

The temperature of the plasma is well over 5 000 ºC at the point of generation into which the liquid or gaseous waste is directly injected. The temperature in the upper reactor is about

3 500 ºC and decreases through the reaction zone to a precisely controlled temperature of about 1 300 ºC.

A special feature of the process is the use of CO_2, which is formed from the oxidation reaction, as the gas to sustain the plasma.

The process has demonstrated high DREs with refractory compounds at a reasonably high demonstration rate. Mass emission rates of the pollutants of interest are low, primarily because of the low volume of flue-gas produced by the process.

5. Microwave plasma
This process feeds microwave energy at 2.45 GHz into a specially designed coaxial cavity to generate a thermal plasma under atmospheric pressure. Argon is used to initiate the plasma but otherwise the process requires no gas to sustain the plasma.

The DRE for the microwave plasma process is reported to exceed 99.99 % while destroying CFC-12 at a rate of 2 kg/h.

The process is reported to have a high destruction efficiency and to be capable of achieving the high operating temperatures in a very short time, thus providing operating flexibility and reduced downtime.

There is no need for an inert gas to operate the process, which improves the power efficiency, reduces operating costs and reduces the volume of flue-gas produced. In addition, the process is very compact.

6. Nitrogen plasma arc
This process uses a DC non-transferred plasma torch operating with water-cooled electrodes and using the nitrogen as the working gas to generate ~~generates~~ the thermal plasma. The process was developed in 1995 and there are commercial systems available.

The process is reported to achieve a DRE of 99.99 % while destroying CFCs, HCFCs and HFCs at a feed rate of 10 kg/h.

A key advantage of this technology is that the equipment is very compact in size. The system requires only 9 m x 4.25 m area for installation, which includes space for a precipitation and dehydration unit for the by-products ($CaCl_2$ and $CaCO_3$). Therefore, the system is capable of being carried on a truck to treat waste on the site where it is produced. ~~the waste generation spot, leading to an on-site treatment.~~

2.3.5.11 Various techniques for sewage sludge incineration

Typical process conditions applied to sewage sludge incineration
In addition to sewage sludge, other wastes from the waste water treatment process are often incinerated e.g. swim scum, screenings, and extracted fats.

Plants receiving partially dried sludge require less additional fuels than plants receiving raw sludges. The heat values of the sludge for auto-thermal incineration lie between 4.8 MJ/kg and 6.5 MJ/kg. Values between 2.2 MJ/kg and 4.8 MJ/kg sludge are seen where raw sewage is treated. Approximately 3.5 MJ/kg sludge is considered the limit for auto-thermal incineration. The need for additional fuel can be reduced by the use of efficient internal energy recovery systems, e.g. recovery of heat from flue-gases to heat incineration air and/or use of heat to provide for sludge drying.

~~Used~~ Waste oil is the most commonly used additional fuel in ~~mono-~~ dedicated sewage sludge incinerators. Heating oils, natural gas, coal, solvents, liquid and solid waste and contaminated air are also used. Contaminated gas is preferred for the incineration of digested sludge.

[*For the TWG: Please provide up-to-date information: is waste oil still used as the main fuel? What is contaminated air? Is contaminated gas the unrefined gas produced by anaerobic digestors in sewage treatment works*?]

The primary influences on the requirement for additional energy are the air preheating and degree of drainage needed. The influence of conditioning agents is relatively low.

Dedicated sewage sludge incinerators are generally designed and operated at temperatures between 850 °C and 950 °C. ~~Temperatures below 850 °C can result in odour emissions, while~~ Temperatures above 950 °C may result in ash fusion. ~~Gas residence times of in excess of 2 seconds are commonly employed.~~

The temperature ~~level~~ achieved during incineration depends mainly on the energy content and the amount of sewage sludge to be incinerated and on the ~~atmospheric~~ oxygen level.

~~There are some examples of sewage sludge incinerators (often fluidised bed processes) that operate at temperatures closer to 820 °C without a deterioration in incineration performance or increased emissions.~~

Comparison of furnace systems for sewage sludge incineration

~~The described furnace systems function according to different process technologies~~. The furnace structure, design, ~~and~~ operational technology, abatement equipment and material flows ~~of the incineration plant, the resulting post-connected cleaning equipment, as well as the transport of different material flows,~~ all have a significant influence on the resulting emissions. The characteristics of the various furnaces are shown in Table 2.9. ~~the following table:~~

Table 2.11: Comparison of furnace systems for sewage sludge incineration

	Fluidised bed furnace	Multiple hearth furnace	Multiple hearth fluidised bed furnace	Cycloid furnace
Main features of technique	• No mechanically moveable parts and low wear	• No separate pre-drying is necessary • Extensive furnace structure with moveable parts • Cooled hollow shaft	• No separate pre-drying is necessary • Moveable hollow shaft • Low fluidised bed volume	• No mechanically moveable parts and low wear • No fluidised bed material
Operational aspects	• Fast start-up and shutdown through short heating and cooling times, intermittent operation possible	• Long heating time, continuous operation necessary	• Medium heating and cooling time	• Comparable to the fluidised bed • Deployable for a wide range of wastes
Possible operational problems	• Agglomeration, de-fluidisation		• Possible emissions of organics, movable parts in the furnace	• Maintaining desirable temperature
Incineration stage main features	• Low excess air ~~surplus~~ required • Complete incineration only above the fluidised bed	• Incineration difficult to control • Immune to fluctuations in loads and coarse material	• Low excess air ~~surplus~~ required • Good incineration control • Incineration completed within the fluidised bed • Greater immunity to quality fluctuations in the sludge than fluidised bed furnaces	• Short residence times • Variable primary and secondary air supply on several levels
Ash content in flue-gas	• High	• Low	• High	• High
Ash removal	• Via flue-gas flow and sand removal	• Directly from the lowest level	• Via flue-gas flow and sand removal	• Via flue-gas flow • Crude ash at the bottom
Residues	• Ash • Fluidised bed material	• Ash	• Ash • Fluidised bed material	• Ash • Possibly coarse ash

Source: [1, UBA, 2001]

2.4 The energy recovery stage

2.4.1 Introduction and general principles

[28, FEAD, 2002]
Combustion is an exothermic (heat-generating) process. The majority of the energy produced during combustion is transferred to the flue-gases. Cooling of the flue-gas allows:

- recovery of the energy from the hot flue-gases; and
- cleaning of flue-gases before they are released to the atmosphere.

In plants without heat recovery, the gases are normally cooled by the injection of water, air, or both. ~~In the majority of cases a boiler is used. In waste incineration plants, the boiler~~

The majority of plants carry out heat recovery using a boiler, which has two interconnected functions:

- to cool the flue-gases;
- to transfer the heat from the flue-gases to another fluid, usually water which, most often, is transformed inside the boiler into steam.

The characteristics of the steam (pressure and temperature) or of the hot water are determined by the local energy requirements and operational limitations.

The design of the boiler will mainly depend on:

- the steam characteristics;
- the flue-gas characteristics (corrosion, erosion and fouling potential).

The flue-gas characteristics are themselves highly dependent upon the waste content. Hazardous wastes for example, tend to have very wide variations in composition and, at times, very high concentrations of corrosive substances (e.g. chlorides) in the raw gas. This has a significant impact on the possible energy recovery techniques that may be employed. In particular, the boiler can suffer significant corrosion at high temperatures, so it is usually designed to operate at a lower temperature which produces lower pressure steam. ~~and steam pressures may need to be reduced with such wastes.~~

Similarly, the thermal cycle (steam-water cycle) for each plant will depend on the relative importance of producing electricity, steam and/or hot water. ~~objective, for example:~~

- ~~the highest electrical outputs require the most sophisticated cycles, but~~
- ~~simpler cycles suit other situations e.g. supply of heat.~~

Water walls (the walls of the combustion chamber are made of water-filled heat exchange pipes - usually with a protective coating of some type) are widely used to cool the combustion gases in the empty (i.e. of heat-exchange bundles) boiler passes. The first pass generally needs to be empty as hot gases are too corrosive and particulate matter is too sticky for the effective use of heat-exchange tubes in this area.

Depending on the nature of the waste incinerated and the combustor design, sufficient heat may be generated to make the combustion process self-supporting (i.e. ~~external~~ non-waste fuels will not be required).

The principal uses of the energy transferred to the boiler are:

- production and supply of heat (as steam or hot water);

- production and supply of electricity;
- combinations of the above.

The energy transferred may be used on site (thus replacing imported energy) and/or off site. The energy supplied may be used for a wide variety of other processes. Commonly, heat and steam are used for industrial or district heating systems, industrial process heat and steam and occasionally as the driving force for cooling and air conditioning systems. Electricity is often supplied to national distribution grids and/or used within the installation.

2.4.2 External factors affecting energy efficiency

2.4.2.1 Waste type and nature

The characteristics of the waste delivered to the installation will determine the techniques that are appropriate and the degree to which energy can be effectively recovered. ~~Both chemical and physical characteristics are considered when selecting processes.~~

The chemical and physical characteristics of the waste actually arriving at plants or fed to the incinerator can be influenced by many local factors including:

- contracts with waste suppliers (e.g. industrial waste added to MSW);
- on-site or off-site waste treatments or collection/separation regimes;
- market factors that divert certain streams to or from other forms of waste treatment.

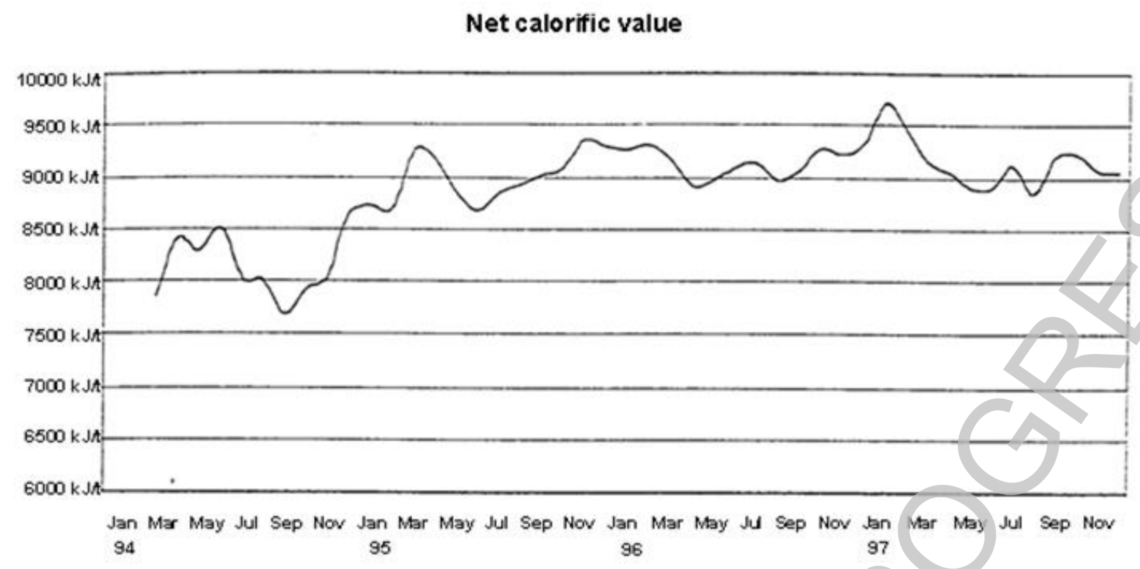
In some cases the operator will have very limited scope to influence the characteristics of the waste supplied, in other cases this is considerable.

~~The table below~~ Table 2.12 gives typical net calorific value ranges for some waste types.

Table 2.12: Ranges and typical net calorific values for some incinerator input wastes

Input type	Comments and examples	LHV in original substance (humidity included)	
		Range (GJ/t)	Average (GJ/t)
Mixed municipal solid waste (MSW)	Mixed household domestic wastes	6.3–10.5	9
Bulky waste	Furniture, etc. delivered to MSWIs	10.5–16.8	13
Waste similar to MSW	Waste of a similar nature to household waste but arising from shops, offices, etc.	7.6–12.6	11
Residual MSW after recycling operations	Screened out fractions from composting and material recovery processes	6.3–11.5	10
Commercial waste	Separately collected fractions from shops and offices, etc.	10–15	12.5
Packaging waste	Separately collected packaging	17–25	20
RDF (refuse-derived fuels)	Pellet or floc material produced from municipal and similar non-hazardous waste	11–26	18
Product specific industrial waste	e.g. plastic or paper industry residues	18 – 23	20
Hazardous waste	Also called chemical or special wastes	0.5–20	9.75
Sewage sludges	Arising from waste water treatment works	See below	See below
	Raw (dewatered to 25 % dry solids)	1.7–2.5	2.1
	Digested (dewatered to 25 % dry solids)	0.5–1.2	0.8

Source: (Energy sub-group 2003)



Source: For the TWG: please provide an updated source.

Figure 2.35: Graph showing recorded variation in waste LHV at a MSWI over 4 years

~~Waste net calorific value calculation:~~

~~When considering the efficiency of any combustion process it is important take into account the energy flows of the system. With waste incinerators it can be difficult to properly assess efficiencies owing to. uncertainties concerning the calorific value of the main energetic input i.e. the waste.~~

~~There are several calculation methods for the calorific value. Using the example calculation method outlined below, the following LHV results were obtained for 50 (mainly German) investigated MSW plants (2001 data):~~

~~Table 2.13: Calculated LHV values for waste treated at 50 European MSWI plants~~

~~LHV units~~	~~Minimum~~	~~Average~~	~~Maximum~~
~~MJ/kg~~	~~8~~	~~10.4~~	~~12.6~~
~~MWh/tonne~~	~~2.2~~	~~2.9~~	~~3.5~~
~~*Source:* [Energy subgroup, 2002 #29]~~			

~~Example of a calculation method:~~

~~A method allowing a very simple but reliable calculation (+/-5 %) of the LHV of the waste is shown in the following equation. The losses of heat etc. are taken into account. The data required for the calculation are generally available at incineration plants and are either measured or calculated from dimensioning figures such as steam parameters.~~

~~$\mathbf{LHV = (1.133 \times (m_{st\,w}/m) \times c_{st\,x} + 0.008 \times T_b)/ 1.085\ (GJ/tonne)}$~~

~~$\mathbf{LHV}$ **= lower calorific value (LHV) of the incinerated waste with** $\mathbf{m_{stw}/m \geq 1}$ **(GJ/tonne)**~~

~~where, $m_{st\,w} = m_{st\,x}\ (m_f x(c_{f\,/}c_{st\,x}) \times \eta_b)$~~

~~$m_{st\,w}$ = amount of the steam produced from the waste in the same time period to m_{st} e.g. per year (tonne/yr)~~
~~$m_{st\,x}$ = total amount of steam produced in a defined time period e.g. per year (tonne/yr)~~
~~m_x = amount of supplementary fuel used in the corresponding time period e.g. per year (tonne/yr)~~
~~m = mass of waste incinerated in the defined time period e.g. per year (tonne/yr)~~

~~$e_{st\,x}$ = net enthalpy of steam i.e. enthalpy of steam minus enthalpy of boiler water (GJ/tonne)~~
~~e_f = net calorific value of the supplementary fuel that add to steam production (GJ/tonne)~~
~~T_b = temperature of flue-gas after boiler at 4 – 12 % O_2 in flue-gas (°C)~~
~~0.008 = specific energy content in flue-gas (GJ/tonne x °C).~~
~~1.133 and 1.085 are constants derived from regression equations~~
~~η_b = efficiency of heat exchange to the boiler (approximately 0.80)~~

~~Note: This LHV calculation is only applicable to existing plants and not for the purposes of dimensioning new plants. It should also be noted that the formula can be applied within an operating range of 4 – 12 % O_2, when the original design point was 7 - 9 % O_2. Plants designed with O_2 concentrations outside the range of 7 - 9 % would require the use of modified coefficients to maintain accuracy.~~

2.4.2.2 Influence of plant location on energy recovery

In addition to waste quality and technical aspects, the possible efficiency of a waste incineration process is influenced to a large extent by the output options for the energy produced. Processes with the option to supply electricity, steam or heat will be able to use more of the heat generated during the incineration for this purpose and will not be required to cool away the heat, which otherwise results in reductions in efficiency.

The highest waste energy utilisation efficiency can usually be obtained where the heat recovered from the incineration process can be supplied continuously as district heat, process steam, etc., or in combination with electricity generation. However, the adoption of such systems is very dependent on plant location, in particular the availability of a reliable user for the supplied energy. The generation of electricity alone (i.e. no heat supply) is common, and generally provides a means of recovering energy from the waste that is less dependent on local circumstances.

~~The table below gives approximate ranges for the *potential* efficiencies at incineration plants in a variety of situations. The actual figures at an individual plant will be very site-specific. The idea of the table is therefore to provide a means to compare what might be achievable in favourable circumstances. Variations in calculation methods also make figures hard to compare – in this case the figures do not account for boiler efficiencies (typical losses ~ 20 %), which explains why figures approaching 100 % (figures exceeding 100 % are also quoted in some cases) are seen in some circumstances.~~

~~**Table 2.14: Energy potential conversion efficiencies for different types of waste incineration plants**~~

~~**Plant type**~~	~~**Reported potential thermal efficiency (%) ((heat + electricity)/energy output from the boiler)**~~
~~Electricity generation only~~	~~17–30~~
~~Combined heat and power plants (CHP)~~	~~70–85~~
~~Heating stations with sales of steam and/or hot water~~	~~80–90~~
~~Plant providing steam sales to large chemical plants~~	~~90–100~~
~~CHP and heating plants with flue-gas condensation~~	~~85–95~~
~~CHP and heating plants with flue-gas condensation and heat pumps~~	~~90–100~~

~~NB: The figures quoted in this table are derived from simple addition of the MWh of heat and MWh of electricity produced, divided by the energy output from the boiler. No detailed account is taken of other important factors such as: process energy demand (support fuels, electrical inputs); relative CO_2 value of electricity and heat supply (i.e. generation displaced).~~

~~*Source:* [RVF, 2002 #5]~~

~~The potential efficiencies are dependent on self-consumption of heat and electricity. Without taking the self-consumption into account, the calculated efficiencies of some facilities can lead to figures quoted of over 100 %. Distortions of efficiency figures are also common when boiler heat exchange losses are discounted (i.e. a boiler efficiency of 80 % means that 20 % of the flue-gas heat is not transferred to the steam, sometimes efficiency is quoted in relation to the heat transferred to the steam rather than the heat in the waste).~~

Where there is no external demand for the energy, a proportion is often used on site to supply the incineration process itself and thus to reduce the quantity of imported energy to very low levels. For municipal plants, such internal use may be in the order of 10 % of the energy of the waste incinerated.

Cooling systems are employed to condense boiler water for return to the boiler.

Processes that are conveniently located for connection to energy distribution networks (or individual synergistic energy users) increase the possibility that the incineration plant will achieve higher overall efficiencies.

2.4.2.3 Factors taken into account when selecting the design of the energy cycle

The following factors are reported to be taken into account when determining the local design of a new waste incineration plant [51, CNIM, 2003].

Table 2.15: Factors taken into account when selecting the design of the energy cycle for waste incineration plants

Factor to consider	Detailed aspects to consider
Waste feed	• Quantity and Quality • Availability, regularity, delivery variation with seasons • Prospect of change in both the nature and the quantity of waste • Effects of waste separation and recycling.
Energy sales possibilities	**Heat** • To communities, e.g. district heating • To private industries • Heat use, e.g. process use, heating use • Geographical constraints; delivery piping feasibility • Duration of the demand, duration of the supply contract • Obligations on the availability of the supply, i.e. is there another source of heat when the incinerator is shut down? • Steam/Hot water conditions: pressure (normal/minimum), temperature, flow rate, condensate return or not? • Season demand curve • Subsidies can influence economics significantly • Heat customer holdings in the plant financing, i.e. security of supply contract. **Electricity** • National grid or industrial network (rare), plant self-consumption, customer self-consumption (i.e. in a sewage sludge treating plant) • Price of electricity significantly influences investment • Subsidies or loans at reduced rates can increase investment • Technical requirements: voltage, power, availability of distribution network connection.
Local conditions	• Cooling medium selected: air or water • Meteorological conditions in time: temperature, hygrometry, (min., average, max., curves) • Acceptability of a 'plume' of water vapour (cooling tower) • Availability of cold water source: river or sea - Temperature, quality of water - Flow rate which can be pumped according to the season - Permitted temperature increase.

Combined heat and power	• Apportionment according to the season • Evolution of the apportionment in future.
Other	• Choice between: Increasing energy output, reducing investment cost, operational complexity, availability requirements, etc. • Acceptable noise level (air coolers) • Available space • Architectural constraints.
Source: [51, CNIM, 2003]	

2.4.3 Energy efficiency of waste incinerators

[Energy subgroup, 2002 #29]

In order to enable a comparison of energy performance between waste incinerators,~~ it is necessary to ensure that these comparisons are made in a consistent way. In particular~~ it is necessary to standardise:

- assessment boundaries, i.e. what parts of the process are included/excluded~~?~~;
- calculation methods;
- how to deal with different energy inputs and outputs, e.g. heat, steam, ~~primary~~ non-waste fuels, electricity production and internal electricity usage. ~~re-circulation of energy produced by the plant, etc.~~

The sections that follow describe the typical inputs and outputs seen at many waste incinerators.

~~See also appendix 8.4 for information regarding energy efficiency calculation.~~

2.4.3.1 Energy inputs to waste incinerators

[Energy subgroup, 2002 #29]
In addition to the energy in the waste, there are other inputs to the incinerator that need to be recognised when considering the energy efficiency of the plant as a whole.

Electricity inputs
Electricity is needed to run the process. The source can be external or circulated. ~~Electrical consumption is usually easily calculated. In situations where economic incentives are provided to support the production of electrical energy from incineration (e.g. as a renewable source) there may be a price differential between purchased and exported electricity. Plants may then choose (for economic reasons) to export all of the electricity generated by the incinerator, and import from the grid, that which is required to run the incineration process itself. Where this is the case, the incineration plant will often have distinct electricity flows for input and output.~~

Steam/heat/hot water inputs
Steam (heat or hot water) can be used in the process. The source can be external or circulated.

Non-waste fuels
~~They are required for several uses. For instance,~~ ~~conventional~~ Non-waste fuels are used to: ~~consumed in order to:~~

i. preheat the combustion air;
ii. increase the temperature in the combustion chamber to the required level during start-up before the plant is fed with waste; ~~(this contributes partially to steam production)~~
iii. ensure that the required combustion chamber temperatures are maintained during plant operation; ~~(this then contributes to steam production)~~
iv. maintain the temperature in the combustion chamber at the required level during shutdown, while there is still unburned waste in the plant;

v. heat up the flue-gas for treatment in specific devices, such as SCR or bag ~~fabric~~ filters;
vi. heat up the flue-gas ~~increase the flue-gas temperature~~ (e.g. after wet scrubbers) in order to avoid bag filter and stack corrosion, and to suppress plume visibility.

When considering the overall efficiency of energy recovery from the waste, it is important to note that some of these ~~primary~~ non-waste fuel uses can contribute to steam production whereas others, such as v. and vi. above, will not contribute because they are adding heat after the boiler. This needs to be taken into account when calculating energy efficiency figures. ~~and others will not~~. ~~A failure to consider this may result in misleading efficiency figures due to the incorrect attribution of energy derived from the burning of primary~~ fuels.

~~In the list above when fuel is used For example:~~

- ~~fuels used in auxiliary burners for i (fully) and ii (partially), will contribute to steam production (typically around 50 – 70 % of the additional non-waste fuel usage), whereas~~
- ~~fuels used for items ii (the remaining 30 – 50 % auxiliary fuel use), iii and v above will not contribute to steam production~~.

~~Fuel (e.g. coal/coke) inputs (in addition to the waste) can also be made at gasification plants~~ At waste gasification plants, non-waste fuels such as coal or coke may be added to the waste in order to produce a syngas with a desired chemical composition and calorific value.

2.4.3.2 Energy outputs from waste incinerators

Electricity
The electricity production is easily calculated. The incineration process itself may use some of the produced electricity.

Fuels
Fuel (e.g. syngas) is produced in gasification/pyrolysis plants and may be exported or combusted on site. ~~with (usually) or without energy recovery.~~

Steam/hot water
The heat released in the combustion of waste is often recovered for a beneficial purpose, e.g. to provide steam or hot water for industrial or domestic users, ~~for external electricity generation~~ or even as a driving force for cooling systems.

Combined heat and power (CHP) plants provide both heat and electricity. ~~Steam/hot water not used by the incineration plant can be exported.~~

2.4.4 Applied processes ~~techniques~~ for improving energy recovery

2.4.4.1 Waste feed pretreatment

There are two main categories of pretreatment techniques of relevance to energy recovery:

- homogenisation;
- extraction/separation.

Homogenisation of waste feedstock involves mixing, and sometimes shredding, ~~mixes~~ the wastes received at the plant ~~using the physical techniques (e.g. bunker mixing and sometimes shredding) outlined elsewhere in this document,~~ in order to supply a feed with consistent combustion qualities.
The main benefits achieved are the improved process stability and more consistent steam quality ~~that results, which thus allows smooth downstream process operation. Steadier steam~~

~~parameters result from the boiler,~~ which can allow for increased electricity generation. The overall energy efficiency benefits are thought to be limited but cost savings and other operational benefits may arise.

Extraction/separation involves the removal of certain fractions from the waste before it is sent to the combustion chamber.

Techniques range from extensive physical processes for the production of refuse-derived fuels (RDF) and the blending of liquid wastes to meet specific quality criteria, to the simple spotting and removal by crane operators of large items that are not suitable for combustion, such as concrete blocks or large metal objects. The main benefits achieved are:

- increased homogeneity, particularly where more elaborate pretreatments are used (see comments above for homogeneity benefits);
- removal of bulky items – thus reducing the risks of obstruction and ~~thus of~~ unscheduled shutdowns;
- possible use of fluidised beds or other techniques that could improve combustion efficiency.

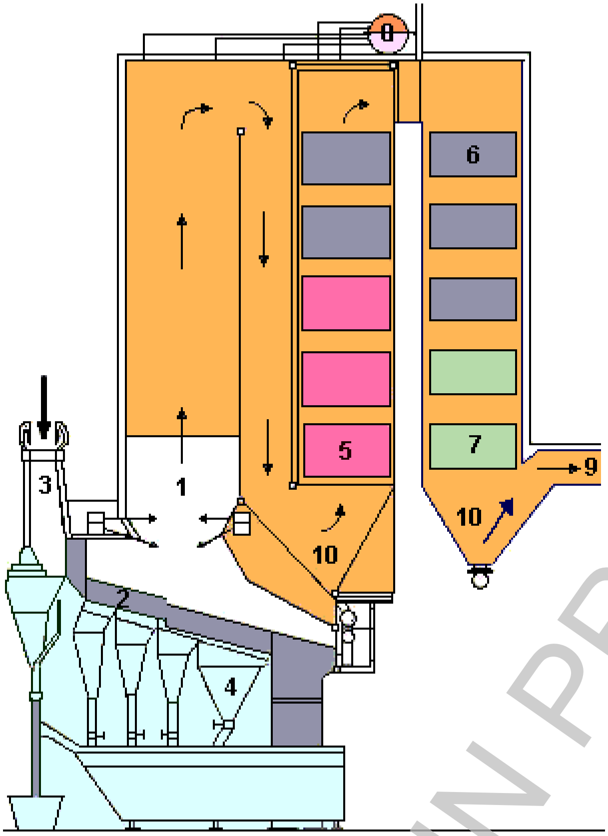
Extraction, separation and homogenisation of the waste can significantly improve the energy efficiency of the incineration plant itself. This is because these processes can substantially change the nature of the waste that is finally delivered to the incineration process, which can then allow the incineration process to be designed around a narrower input specification, and lead to optimised (but less flexible) performance. However, for a wider assessment (beyond the scope of this document), it is important to note that the techniques that are used in the preparation of this different fuel, themselves require energy and will result in additional emissions.

~~(Note: The scope of this BREF does not extend to recommending the upstream systems that can influence the combustion characteristics and energy content of the waste received. It does however recognise that these upstream issues have a key influence on the characteristics of the waste finally received at the plant and hence what is achievable.)~~

2.4.4.2 Boilers and heat transfer

Tubular water boilers are generally used for steam and hot water generation from the energy potential of hot flue-gases. The steam or hot water is generally produced in tube bundles in the flue-gas path. The envelopment of the furnace, the following empty passes and the space where evaporator and superheater tube bundles are located are generally designed with water-cooled membrane walls.

In steam generation, it is usually possible to differentiate between the three heat surface areas shown in Figure 2.36.



KEY:
5. Superheater, producing superheated steam (usually bundled or bulkhead heating surfaces).
6. Evaporator, producing saturated steam (bundled heating surface, envelopment wall of the incineration chamber).
7. Economiser, preheating the feed water (bundled heating surface).
Source: [1, UBA, 2001]

Figure 2.36: Illustration of individual heat surface areas in a steam generator

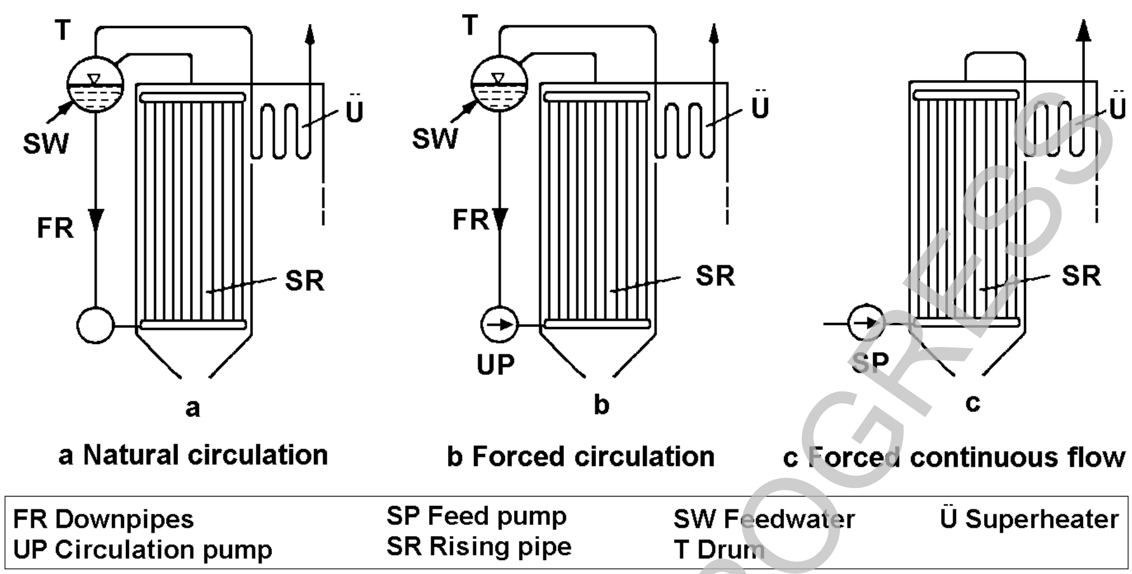
~~Key to some of the features shown in Figure 2.36 (above):~~

~~7 Feed-water preheating (Economiser):~~
~~In this area, the boiler feed water is heated by flue-gases to a temperature close to the boiling point (designed as a bundled heating surface).~~

~~6 Evaporation:~~
~~In this area, the water coming from the economiser is heated until it reaches the saturated steam temperature (designed as a bundled heating surface, envelopment wall of the incineration chamber).~~

~~5 Superheating:~~
~~In this area, the saturated steam coming from the evaporator is superheated to the end temperature (as a rule, bundled heating surfaces or bulkhead heating surfaces).~~

The following traditional evaporation systems can be differentiated (see Figure 2.37):



Source: [1, UBA, 2001]

Figure 2.37: Basic boiler flow systems

- **Natural circulation**: The water/steam mass flow in the evaporator is maintained due to the different density of the medium in heated and unheated pipes. The water/steam mixture flows into a steam separator drum~~. Here, steam and water are separated. The~~ and the saturated steam then passes through a ~~reaches the post-connected~~ superheater.
- **Forced circulation**: This is similar to ~~principle corresponds with the~~ natural circulation, but ~~is expanded by~~ a circulation pump is used to increase ~~supporting~~ ~~the~~ circulation in the evaporator.
- **Forced continuous flow (once-through boiler)**: In this system, the feed water is pumped ~~pressed~~ in a continuous flow through the economiser, the evaporator and the superheater.

Spray coolers and surface coolers are used in circulation boilers in order to maintain the exact required steam temperature. It is their function to balance the fluctuations of the steam temperature, caused by changes in ~~these fluctuations being the consequences of~~ load, ~~fluctuations, changes in the~~ waste quality and excess ~~the surplus~~ air, as well as contamination of the heat-exchange surfaces.

The preparation of boiler feed water and make-up water is essential for effective operation and to reduce corrosion inside the tubes ~~or~~ and the risk of turbine damage. The quality of boiler water must be higher when increased steam parameters are used.

A compromise is required when determining steam parameters from waste-fired boilers. ~~This is because, while the~~ The selection of high steam temperatures and pressures will better utilise the energy contained in the waste, ~~these higher steam parameters~~ but can lead to significantly increased corrosion problems, especially at the superheater surfaces and in the evaporator. In municipal waste incinerators, it is common to ~~use generate~~ operate at steam parameters of ~~at~~ 40 bar and 400 °C when~~ there is~~ electricity is produced,~~ production~~ although higher values are used, especially with pretreated MSW and prepared RDF (values of 60 bar and 520 °C are in use when combined with special measures to prevent corrosion). In the case of heat production, steam with lower parameters ~~conditions~~ or superheated water may be produced. ~~Based on these rather low (compared to most primary fuel power stations) steam parameters, almost exclusively, natural circulation steam boilers are selected.~~ These steam parameters are relatively low compared to most primary fuel power stations which means that incinerators almost exclusively use natural circulation steam boilers.

~~A~~ An important feature of waste incineration is the high dust load in flue-gases. Gravity separation of dust can be enhanced by designing the boiler areas with low flue-gas speeds and bends in the gas flow path.

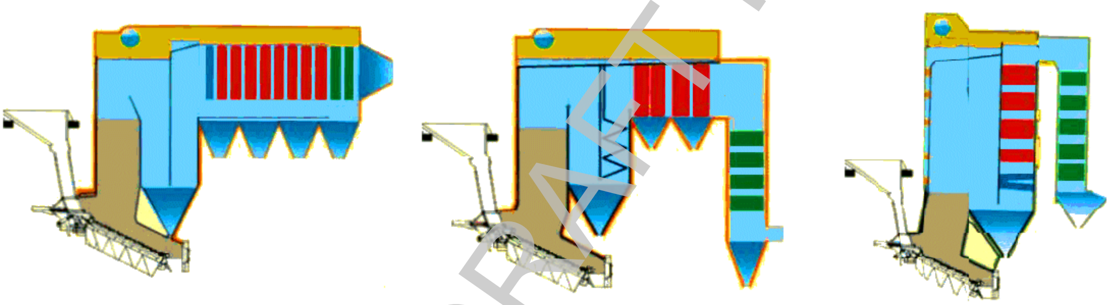
~~Measures that can assist dust removal in the boiler areas by gravity separation of fly ash, are:~~

- ~~low flue-gas speeds, and~~
- ~~turns in the gas flow path.~~

~~The high proportion of ash in flue-gas causes a risk of a correspondingly high contamination of the heat transfer surfaces. This leads to a decline in heat transfer and therefore a performance loss~~. The high dust load in the flue-gases causes dust contamination of the heat transfer surfaces, reducing heat transfer and overall plant performance. Thus, heat transfer surface cleaning plays an important role. This cleaning can be accomplished manually or automatically with lances (compressed air or water jet), ~~with~~ agitators, ~~with~~ soot blowers using steam, ~~with~~ a hail of pellets (sometimes shot cleaning), ~~with~~ sound and shock waves, or with tank cleaning devices.

Different boiler concepts can be used in waste incineration plants. They are from left to right (see Figure 2.38):

- horizontal boilers;
- combination of vertical and horizontal boilers;
- vertical boilers.



Source: [1, UBA, 2001]

Figure 2.38: Overview of various boiler systems: horizontal, combination and vertical

In horizontal and vertical systems, usually a number of empty passes with evaporation walls are followed by an arrangement of bundles of heat transfer surfaces, i.e. superheater, evaporator and economiser. The selection of the system to be deployed depends on the given building concept, the selected steam parameters, and the customer specifications.

2.4.4.2.1 Corrosion in boilers

[1, UBA, 2001] ~~With the introduction of minimum temperature, residence times and oxygen content requirements, corrosion has increased in steam generators at waste incineration plants.~~

Corrosion is caused by the chemical attack of flue-gas and ash particles from the furnace. The incineration chamber, the water walls of the first blank (empty) passes, and the superheater are the boiler components that are most in danger of corrosion.

Erosion, which is the abrasion of surface material through vertical wear-and-tear, is caused primarily by the ash particles present in flue-gas. Erosion appears mostly in the area of gas redirection.

Tube wear is caused by a combination of corrosion and abrasion. Corrosion appears on clean metallic surfaces. If the corrosion products deposit themselves as film on the pipe surface (oxide layer), they function as a protective layer and slow down corrosion. If this protective layer wears out through erosion, and if the metallic surface reappears, the entire process starts anew.

Coherent consideration of the corrosion processes is difficult, as physical, chemical, incineration technical, metallurgical and crystallographic parameters interact.

Various types of flue-gas corrosion exist:

- Tinder process: High-temperature corrosion.

- Initial corrosion: Time-limited ferrous chloride formation before the first oxide layer formation ~~at~~ on 'blank' steel during start-up. This reaction occurs continuously after film removal through erosion.

- Oxygen-deficiency corrosion: Through $FeCl_2$ formation under a deoxygenated flue-gas atmosphere, e.g. under films (such as oxides, contamination or fireproof material) and in the furnace area. $FeCl_2$ is sufficiently volatile in the temperatures used in WI and is therefore mobilised. An indicator for such corrosion is the appearance of CO (this explains the often ~~falsely~~ wrongly-used term CO corrosion). The microscopic situation at the border between material and film is, however, decisive. This corrosion is observed in individual cases with steam pressures above 30 bar, but more usually above 40 bar. The corrosion rate increases with the metal temperature. The corrosion products appear in flaky layers.

- ~~Chloride~~ High-temperature-chloride corrosion: Corrosion by chloride, which is released during the sulphating of alkaline chlorides and attacks iron or lead hydroxides. This corrosion mechanism is observed in waste incineration plants with flue-gas temperatures > 700 °C and at pipe wall temperatures above 400 °C. The corrosion products can be recognised as a black firmly bonded cup that includes a hygroscopic red $FeCl_3$ layer in thicker films.

- Molten salt corrosion: The flue-gas contains alkali and similar components, which can form ~~eutectics. E~~ eutectic compounds that have a lower melting point than the original individual ~~single~~ components. ~~which form the eutectic system.~~ These molten systems are highly reactive and can cause severe corrosion of steel. They can react with the refractory lining and lead to the internal formation of compounds like kalsilite, leucite and sanidine which destroy the refractory mechanically. ~~It~~ They can also form low viscous melts on the surface consisting of deposited material and refractory material (refractory corrosion). [64, TWGComments, 2003] [74, TWGComments, 2004]

- Electrochemical corrosion: This is based on the electrical potential equalisation of different metals. The conductor can be aqueous or a solid that shows sufficient electrical conductivity at the temperatures seen. The conductivity can arise from the water dew point to the sulphuric acid dew point to molten salt.

- Standstill corrosion: Based on its high chloride content (especially $CaCl_2$), the deposits are hygroscopic. The humidity in the air dissolves these compounds and causes chemical dissolution appearances in the material.

- Dew point corrosion: When the temperature falls below ~~beneath~~ the acid dew point, wet chemical corrosion appears on cold surfaces. This damage can be avoided by raising the temperature or by selecting an appropriate material.

In reality, from a thermodynamic perspective, a degree of corrosion is unavoidable. Countermeasures only help to reduce corrosion damage to an acceptable level. The causes of corrosion require constructive and operational countermeasures. Improvement possibilities are mainly found in the steam generator. Low steam parameters, long reaction times before the flue-gas comes into contact with ~~entry into~~ the heat surfaces, lowering the flue-gas ~~speed~~ velocity, and levelling of the speed profile could all be successful. Protective shells, tooling, stamping, and deflectors can also be used to safeguard heat surfaces.

A compromise must be found in determining the boiler cleaning intensity between the best possible heat transfer (metallic pipe surface) and optimal corrosion protection.

2.4.4.3 Combustion air preheating

Preheating the combustion air is particularly beneficial for assisting the combustion of high-moisture-content wastes. The pre-warmed air supply dries the waste, thus facilitating its ignition. The supply heat can be taken from the combustion of the waste by means of heat-exchange systems.

Preheating of primary combustion air can have a positive influence on overall energy efficiency in the case of electricity production.

2.4.4.4 Water-cooled grates

Water cooling of grates is used to protect the grate. Water is used as a cooling medium to capture heat from the burning waste bed and use it elsewhere in the process. It is common that the heat removed is fed back into the process for preheating the combustion air (primary and/or secondary air) or heating the condensate. Another option is to directly integrate the water-cooling into the boiler circuit, operating it as an evaporator.

These grates are applied where the net calorific value of the waste is higher, typically above 10 MJ/kg. At lower calorific values their application is more limited. Increases in the calorific value of municipal waste seen in Europe have increased the application of this technique.

There are other reasons for the use of water-cooled grates – these are discussed in Section 2.3.1.2.5.

2.4.4.5 Flue-gas condensation

[5, RVF, 2002]
Water in the flue-gas ~~from combustion~~ comprises evaporated free water from the fuel and reaction water from the oxidation of hydrogen, as well as water vapour in the combustion air. When burning wastes, the water content in the flue-gas after the boiler and economiser normally varies between 10 vol-% and 20 vol-%, corresponding to water dew points of about 50–60 °C. During the cleaning of the boiler with steam the water content in the flue-gas increases to about 25 %.

The minimum possible dry gas temperature at this point is 130–140 °C using normal boiler construction materials. This temperature is mostly determined ~~in order~~ by the need to be above the acid dew point, which is linked to the SO_3 and water ~~content and the H_2O~~ content in the flue-gas.

Lower temperatures result in corrosion. The boiler thermal efficiency (steam or hot water from waste) will, under these conditions, be about 91 ~~85~~%, as calculated based on the calorific value of the waste input. However, if there is more available energy in the flue-gas, a water vapour will result which has a latent specific energy of about 2 500 kJ/kg and dry gas with a specific heat of about 1 kJ/(kg °C).

Return water from district heating at a temperature of 40–70 °C (system configuration-dependent) can be used directly to cool and condense the water vapour in the flue-gas. This system is common at plants burning biofuel, which is normally very wet and gives water dew points of 60–70 °C in the flue-gas.

Examples moved to Section 4.3.16

Condensation can be effective only if there is a comparatively big temperature difference between the water dew point in the flue-gas and the cooling water (normally district heating return water). If this condition is not fulfilled, heat pumps can be installed (see Section 2.4.4.6).

It should be noted that, in this case, it is the cold district heating water return that provides the energetic driver for the condensation of the flue-gases. This situation is only likely to exist in regions with the lower ambient temperatures found mostly in Northern Europe.

2.4.4.6 Heat pumps

[RVF, 2002 #5]
The main purpose of heat pumps is to transform energy from one temperature level to a higher level. There are three different types of heat pumps in operation at incineration installations. These are described below with examples.

2.4.4.6.1 Compressor driven heat pumps

This is the most well-known heat pump. It is, for instance, installed in refrigerators, air conditioners, chillers, dehumidifiers, ~~and~~ ground source heat pumps and air source heat pumps. ~~used for heating with energy from rock, soil, water and air.~~ An electrical motor normally drives the pump, but for big installations steam turbine-driven compressors can be used.

In a closed circuit, a refrigerant substance (e.g. R134a) is circulated through a condenser, expander, evaporator and compressor. The compressor compresses the substance, which condenses at a higher temperature and delivers the heat to the district heating water. There the substance is forced to expand to a low pressure, causing it to evaporate and absorb heat from the water from the flue-gas condenser at a lower temperature. Thus the energy at a low temperature in the water from the flue-gas condenser has been transformed to the district heating system at a higher temperature level. In typical incineration conditions, the ratio between output heat and compressor power (heat to power ratio) can be as high as 5. The compressor-driven heat pump can utilise a very hich proportion ~~very much~~ of the energy ~~from~~ of the flue-gas.

2.4.4.6.2 Absorption heat pumps

Similar to the compressor-type pump, absorption heat pumps were originally developed for cooling. Commercial heat pumps operate with water in a closed loop through a generator, condenser, evaporator and absorber. Instead of compression, the circulation is maintained by water absorption in a salt solution, normally lithium bromide, in the absorber. The diluted water/salt solution is pumped to the generator. There the water is evaporated by hot water or low-pressure steam and is then condensed in the condenser at a higher temperature. The heat is transferred to the district heating water. The concentrated salt solution is circulated back to the absorber. The process is controlled by the pressure in the system, in relation to the vapour pressure of the liquids, water and lithium bromide.

Electrical power consumption is very low, limited to a small pump between the absorber and generator, and there are few moving parts. The ratio between the output heat and absorber power is normally about 1.6.

2.4.4.6.3 Open heat pumps

~~The third heat pump is sometimes called open heat pump.~~ The principle of an open heat pump is to decrease the water content of the flue-gas downstream of the condenser using a heat and humidity exchanger with air as intermediate medium.

The higher water content in the flue-gas in the condenser means a higher water dew point, and a bigger difference between the water dew point and the dew point of the return water from the district heating system.

2.4.4.6.4 Example data of different heat pumps

The following table has been collated from data from three different plants in Sweden, each using a different type of heat pump, as described above.

As can be seen from the table, the use of heat pumps consumes electricity; therefore the net electrical output is reduced. However, the thermal heat output is increased.

Table 2.16: Example data showing the variation in heat and electricity output at three different plants in Sweden when using various different types of heat pumps

	Example 1	**Example 2**	**Example 3**
Heat pump type	**Compressor-driven**	**Absorption heat pump**	**Open heat pumps**
Net heat output using heat pump	82	80	81
Net heat output **without** heat pump	60	63	70
Variation in heat output	**+37 %**	**+28 %**	**+16 %**
Net electricity output using heat pump	15	15	0
Net electricity output without heat pump	20	19	0
Variation of electricity production	**-25 %**	**-21 %**	**0**
NB: Data refer to an energy input of 100, therefore all numbers are percentages. Example 3 does not produce electricity			
Source: [5, RVF, 2002]			

2.4.4.7 Flue-gas recirculation

A proportion (approximately 10–20 vol-%) of the (usually cleaned) flue-gases is recirculated, normally after pre-dedusting, to replace secondary air feeds in the combustion chamber.

This technique is reported to reduce heat losses with the flue-gas and to increase the process energy efficiency by around 0.75–2 %. Additional benefits of primary NO_X reduction are also reported.

Lagging of the recirculation ducting is reported to provide an effective remedy for corrosion concerns in this area.

2.4.4.8 Recovery of the heat used for reheating ~~of~~ flue-gases to the operating temperature FGC devices

Some air pollution control equipment requires the flue-gases to be reheated to enable their effective operation. Examples include SCR systems and bag filters that generally require temperatures in the region of 250 °C and 120 °C respectively.

The energy for heating the gases can be obtained from:

- external energy sources (e.g. electrical heating, gas or oil burners);
- use of process-generated heat or power (e.g. steam bleeds from the turbine).

The use of heat exchangers to recapture the heat after the equipment reduces the need for external energy input. This is carried out where the next stage of the process does not require the flue-gas temperature to be as high as that emitted from the earlier equipment.

~~2.4.4.9 Plume visibility reduction~~

For the TWG: this technique does not improve the amount of recovered energy.

~~In some locations sensitivity to visible plumes is high. Certain techniques (e.g. wet scrubbing) also give rise to higher levels of moisture in the flue-gas and therefore increase the possibility of high visibility plumes. Lower ambient temperature and higher humidity levels increase the risk of plume condensation, and hence visibility.~~

~~Increasing the temperature of the flue-gases provides one way of reducing plume visibility, as well as improving dispersion characteristics of the release. Dependent on flue-gas moisture content and atmospheric conditions, plume visibility is greatly reduced above stack release temperatures of 140 °C.~~

~~Reducing the moisture content of the flue-gases also reduces the plume visibility. This can be achieved by selecting alternative flue-gas treatment (i.e. avoiding wet systems) or by the use of condensing scrubbers to remove water from the flue-gas (see Section 2.4.4.5).~~

2.4.4.10 Steam-water cycle improvements: effect on efficiency and other aspects

The selection of the steam-water cycle will generally have a much greater impact on the energy efficiency of the installation than improving individual elements of the system, and therefore provides the greatest opportunity for increased use of the energy in the waste.

The following table provides examples of ~~information concerning~~ techniques ~~or actions that are~~ used for improving energy recovery at a municipal waste-to-energy plant ~~incinerator~~, along with an estimation of their effectiveness, advantages and disadvantages ~~'weight'~~. The figures given were calculated for one example plant that only generated electricity [50, CNIM, 2003].

Table 2.17: Steam-water cycle improvements: effect on efficiency and other aspects

Technique	Net power output increase (approx.) and other advantages	Disadvantages
Increase steam pressure	3 % for 60 bar instead of 40 bar	I. Increase in investment cost II. Corrosion risk slightly increased
Decrease vacuum at turbine outlet (e.g. a hydro-condenser may be used to improve vacuum)	1–2 % for 20 mbar reduction	III. Significant increase in investment cost (air condenser area: + 10 % between 120 mbar and 110 mbar at an air temperature of 15 °C) IV. Size and noise increase V. Uncertainties on suppliers' commitments for very low pressure
Heat secondary air	0.7–1.2 %	VI. Complexity and cost increase if there are 2 air fans
Air heater in 2 stages (i.e. 2 bleeds on the turbine)	1–1.5 %	VII. Cost increase VIII. Space requirement increase
Increase de-aerator temperature	0.9 % for 140 °C instead of 130 °C	IX. Increase in the size and the cost of the economiser
Add a condensate heater	0.5–1.2 %	X. Cost of the equipment and piping XI. Not necessarily applicable for small TG sets XII. Corrosion problem may occur in particular during transitory phases (start-up, shutdown, etc.)
Recycle a part of the flue-gas	0.75–2 % for a decrease of 1 % of dry O_2 ------ Decrease of NO_X level by approx. 100 mg/Nm^3	XIII. Increase in investment cost XIV. Decreasing the O_2 by other means reduces the interest of flue-gas recycling XV. Corrosion problem may occur in particular during transitory phases (start-up, shutdown, etc.)
Reduce the flue-gas temperature at boiler outlet	0.4–0.7 % for 10 °C lower between 190 °C and 140 °C	XVI. The boiler outlet temperature is determined according to the FGC system type
Use SNCR de-NO_X instead of SCR	3–6 % depending on the processes used	XVII. See discussions about SCR and SNCR de-NO_X
Optimise the choice of the TG set	1 to 2 % instantaneous, but much higher difference over a long period of time if low availability	XVIII. Some TG sets have higher efficiency at nominal conditions but lower reliability, availability and/or flexibility at partial load
Reduce O_2 content in flue-gas by 1 % (in range 6–10 %)	1–2 % increase	XIX. With a lower O_2 content, CO may increase XX. Low oxygen content may increase corrosion risk
Source: [50, CNIM, 2003]		

2.4.5 Steam generators ~~and quench cooling~~ for hazardous waste incinerators

For the TWG: the quench is not a technique for to recover energy

~~In Europe there are two main approaches adopted for cooling the combustion gases from hazardous waste incinerators.~~ The~~ir~~ principle advantages and disadvantages of using a heat recovery boiler when hazardous wastes are incinerated are described in Table 2.18. ~~are described in the table below:~~

Table 2.18: **Advantages and disadvantages of using a Summary of the main differences between quench cooling and heat recovery boiler**

Gas cooling system	Advantages	Disadvantages
Heat recovery boiler	- High energy recovery efficiency possible (70–80 % can be converted to steam) - Lower water consumption and water treatment volumes	- Possible increased risk of dioxin reformation in boiler - Additional capital and maintenance costs of boiler system
~~Rapid quench cooling~~	~~- reduced risk of dioxin re-formation~~ ~~- need for additional dioxin controls on emissions to air may be reduced~~ ~~- it may be possible to treat wastes with a more variable range and higher halogen or salts loading if this technique is used.~~	~~- very limited energy recovery~~ ~~- water consumption may be higher~~ ~~- water treatment volumes may be higher.~~
Source: adapted from [Cleanaway, 2002 #46], [EURITS, 2002 #41]		

Heat recovery boilers in hazardous waste incineration installations
[EURITS, 2002 #41]
The hot combustion gases are cooled in a **steam generator** (or **boiler**) with a capacity of between 16 MW and 35 MW depending on the installation. The steam that is produced has a pressure of 13 bar to 40 bar with a temperature between 207 °C and 385 °C. As a guideline, a fully equipped installation normally produces an average of 4–5 tonnes of steam per tonne of incinerated waste, thereby attaining a thermal efficiency of 70–80 % (energy in steam versus energy in waste). Most installations are equipped with an **economiser device** and a **superheater** if electricity is produced. A range of factors influence the efficiency of the steam generators used in hazardous waste incinerators, including the composition of the gas and the potential for deposition to occur on the heat-exchange surfaces. This has a significant influence on the construction materials used and on the design, as well as on the operational life and performance of the equipment.

For some installations, the steam is used in **a turbine** to produce electricity. The electricity is used by the incineration plant for its own purposes or exported. Alternatively steam may be transported for direct use in industrial processes, e.g. the production of chemicals, or to other waste treatment processes or fed into a district heating system. Combinations of these are also applied.

~~Rapid quench cooling:~~
~~Some installations are not equipped with a boiler, but the combustion gases are reduced in temperature by means of **very quick quench cooling** (e.g. 1 100 °C to 100 °C in less than 1 second). This is performed to prevent the formation of dioxins and to avoid the installation of an extra end-of-pipe dioxin removal technique. These installations are referred to as *'quenchers'*, and have been adopted in some plants where a very wide range of highly halogenated wastes inputs have to be treated. This limits the potential options for energy recovery.~~

2.4.6 Examples of energy recovery from fluidised bed incinerators

For the TWG: is there an update on the data reported below?

The different designs and sizes of fluidised bed incinerators influence the behaviour of the boiler and the amount and type of energy produced [33, Finland, 2002]. The following two examples give approximate figures for different sizes of incinerators:

1. 15–30 MW heat and low-pressure steam-producing boilers

This size of fluidised bed boiler uses approximately 35 000–40 000 tonnes of RDF per year ~~ready made recovered fuel~~. If it is made up of commercial waste, demolition waste and separately collected packages from households, the incinerator ~~it~~ can use all of ~~this kind of~~ the material generated by a city of about 150 000 inhabitants. The heat produced is about 150 GWh, which could be used by industry or for district heating.

~~Boilers of this size are very similar to operate to normal power plant boilers of 50 - 100 MW. Its behaviour is steady and uniform, because of the ready made controlled fuel made of sorted waste, and the heavy bed.~~ The operation of fluidised bed boilers of this size is very similar to the operation of conventional 50–100 MW power plant boilers. Their behaviour is steady and uniform because the waste feed has a consistent composition.

When a suitable energy user is available, an energy efficiency range of 70–90 % can be achieved.

Rotating fluidised bed incinerators have been designed for thermal capacities ~~from~~ of 10–55 MW (thermal) and corresponding waste throughputs of 22 000–167 000 tonnes/year per line. Energy is recovered by steam generators and used for electricity production and/or heating purposes depending on local requirements. The thermal efficiency is ~~can be~~ about 80 % and the electrical efficiency typically around 25 %. [64, TWGComments, 2003]

2. 50–100 MW electricity-producing power plants

If the size of the waste-to-energy boiler is > 30 MW, it may be more difficult to find a suitable customer for such a large quantity of heat energy. Whenever electricity is also produced, the economics of the waste-to-energy boiler is mostly dependent on the price of the electricity, not on the price of the heat.

The electrical efficiency with well-defined, quality-controlled feeds can be relatively high, up to level of 30–35 % with typical steam temperatures ~~from~~ of 450–500 ºC.

2.5 Applied flue-gas cleaning ~~treatment~~ and control systems

2.5.1 Summary of the application of FGC~~T~~ techniques

Flue-gas cleaning ~~treatment~~ systems are constructed from a combination of individual process units that together provide an overall treatment system for the flue-gases. The balance of applied systems is different with different waste streams. A description of the individual process units, organised according to the substances upon which they have their primary effect, is given in this chapter. ~~A description of each of the techniques listed in the table is given later in this section.~~

Some flue-gas cleaning ~~treatment~~ techniques are also explained in detail in the ~~horizontal BREF~~ 'Best Available Techniques Reference Document for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector' (the CWW BREF), published in July 2016.

Table 2.19 below gives a summary of the application of some systems in the municipal waste incineration sector.

Table 2.19: Summary of the main applied FGC systems for ~~MS~~WI plants in Europe in 2014 ~~2000/2003~~

	Number of ~~MS~~WI plants with various flue-gas cleaning ~~treatment~~ systems									
	Dry with BF	**Semi-wet ~~dry~~ with BF**	**Wet**	**Dry and Wet**	**Semi-wet and Wet**	**ESP only**	**BF only**	**SNCR de-NO$_X$**	**SCR de-NO$_X$**	**SNCR and SCR**
Austria	1	0	5	7	0	4	1	0	14	0
Belgium	0	2	4	6	1	7	1	10	8	0
Czech Republic	0	0	0	0	0	0	0	2	0	0
Denmark	2	0	1	4	0	0	0	7	0	0
Finland	3	1	0	4	0	0	0	7	1	0
France	30	10	18	8	4	19	0	33	30	3
Germany	19	15	41	30	0	39	2	43	53	0
UK	13	5	4	6	0	1	0	25	0	0
Hungary	0	2	0	0	0	0	0	2	0	0
Italy	26	0	2	5	0	0	0	9	11	13
Netherlands	1	0	2	3	0	1	0	2	5	0
Norway	4	0	0	6	0	2	0	5	0	0
Poland	5	0	1	1	0	1	0	5	0	3
Portugal	0	7	0	0	0	0	0	7	0	0
Spain	4	13	1	0	0	1	0	8	10	0
Sweden	0	0	2	4	0	1	0	5	1	0
Total plants	**105**	**55**	**81**	**84**	**5**	**76**	**4**	**170**	**133**	**19**

NB: Dry = dry sorbent injection; ~~SW and~~ Semi-wet = semi-wet scrubber; wet = wet scrubber; BF = bag filter.
~~1. All figures (except SCR data) are derived from data provided to TWG in [42, ISWA, 2002] – Tables 1 and 2 and TWG Comments~~
2. Other combinations of FGC unit operations are applied but not included in the table.
~~3. Data supplied to EIPPCB by FEAD suggests 43 of around 200 surveyed MSWI use SCR~~
~~4. Belgium data only represents Flemish region and Brussels only~~
~~5. *applied* indicates that the technique is applied – data for blanks was not provided~~
Source: [81, TWG 2016] ~~adapted from [42, ISWA, 2002, 64, TWG Comments, 2003]~~

2.5.2 Overview of overall combined FGC system options

The individual components of a FGC system are combined to provide an effective overall system for the treatment of the pollutants that are found in the flue-gases. There are many individual components and designs, and they may be combined in many ways. The diagram below shows an example of the options and their possible combination. It can be seen that in this assessment there are a total of 408 different combined systems.

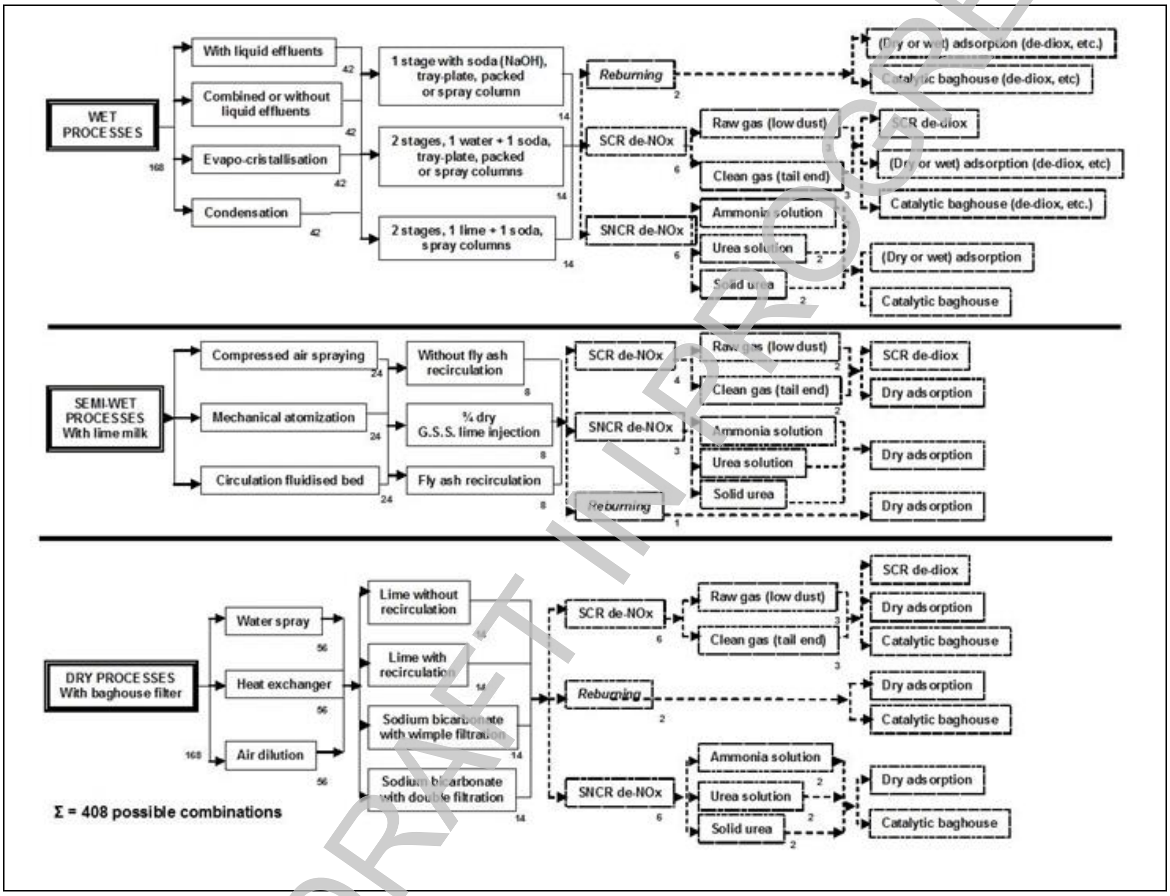


Figure 2.39: Overview of potential combinations of FGC systems

2.5.3 Techniques for the reduc~~ing~~tion of dust ~~particulate~~ emissions

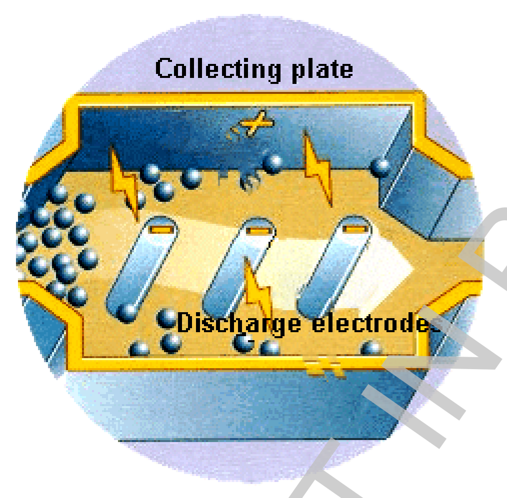
[1, UBA, 2001] The selection of gas cleaning equipment for ~~particulates~~ dust from the flue-gas is mainly determined by:

- ~~particle~~ dust load in the gas stream;
- average particle size;
- particle size distribution;
- flow rate of gas;
- flue-gas temperature;
- compatibility with other components of the entire FGC system (i.e. overall optimisation);
- required outlet concentrations.

Some parameters are rarely known (such as particle size distribution or average size) and are empirical figures. Available treatment or disposal options for the deposited substances may also influence FGC system selection, i.e. if an outlet exists for treatment and use of fly ash, this may be collected separately rather than ~~the fly ash~~ being collected with FGC residues.
[74, TWGComments, 2004]

2.5.3.1 Electrostatic precipitators

[1, UBA, 2001]
Electrostatic precipitators are sometimes also called electrostatic filters. The efficiency of dust removal of electrostatic precipitators is mostly influenced by the electrical resistivity of the dust. If the dust layer resistivity rises to values above approximately 10^{11} to 10^{12} Ωcm, removal efficiencies are reduced. The dust layer resistivity is influenced by waste composition. It may thus change rapidly with a changing waste composition, particularly in hazardous waste incineration. Sulphur in the waste (and water content at operational temperatures below 200 °C [64, TWGComments, 2003]) often reduces the dust layer resistivity as SO_2 (SO_3) in the flue-gas and therefore facilitates deposition in the electric field.



Source: [1, UBA, 2001]

Figure 2.40: Operating principle of an electrostatic precipitator

For the deposition of fine dust and aerosols, installations that maintain the effect of the electric field by drop formation in the flue-gas (pre-installed condensation and wet electrostatic precipitators, condensation electrostatic precipitators, electro-dynamic venturi scrubbers, ionised spray coolers) can improve removal efficiency.

Typical operational temperatures for electrostatic precipitators are 160–260 °C. Operation at higher temperatures (e.g. above 250 °C) are generally avoided as this may increase the risk of PCDD/F formation ~~(and hence releases)~~.

2.5.3.2 Wet electrostatic precipitators

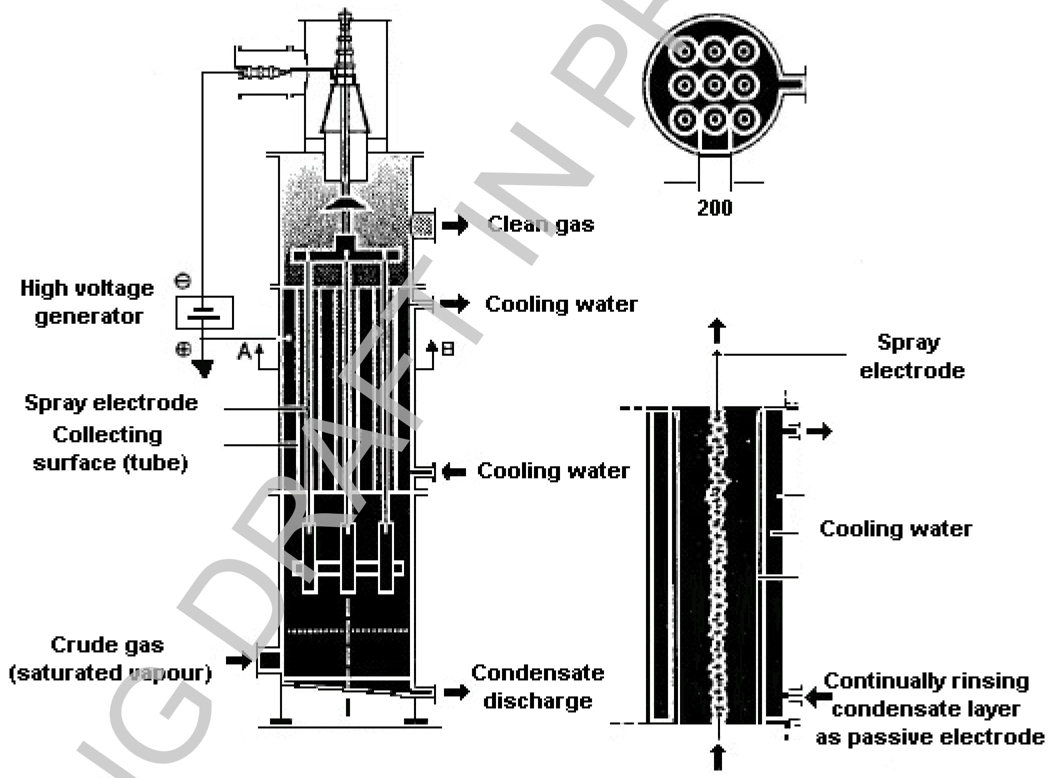
[1, UBA, 2001] Wet electrostatic precipitators are based upon the same technological working principle as electrostatic precipitators. With this design, however, the precipitated dust on the collector plates is washed off using a liquid, usually water. This may be done continuously or periodically. This technique operates satisfactorily in cases where moist or cooler flue-gas enters the electrostatic precipitator.

2.5.3.3 Condensation electrostatic precipitators

[1, UBA, 2001] The condensation electrostatic precipitator is used to deposit very fine, solid, liquid or sticky particles, for example, in the flue-gas from hazardous waste incineration plants. Unlike conventional wet electrostatic precipitators, the collecting surfaces of condensation electrostatic precipitators consist of vertical plastic tubes arranged in bundles, which are externally water-cooled.

The dust-containing flue-gas is first cooled down to dew-point temperature in a quench by direct injection of water and then saturated with vapour. By cooling the gases in the collecting pipes further down, a thin, smooth liquid layer forms on the inner surface of the tubes as a result of condensation of the vapour. This is electrically earthed and thus serves as the passive electrode.

Particles are deposited by the influence of the electric field between the discharge electrodes suspended in the tube axes and the condensation layer in continuous flow. At the same time the condensation layer also causes continuous removal of deposited particles from the deposition area. Even water-insoluble dust and poorly wettable soot are washed off. The constantly renewed wetting prevents dry spots and sticking, which can cause sparking (electrical discharges between the electrodes). Avoiding sparking allows for a higher deposition voltage, which in turn leads to an improved and consistent high deposition performance (see Figure 2.41).



Source: [1, UBA, 2001]

Figure 2.41: Condensation electrostatic precipitator

2.5.3.4 Ionisation wet scrubbers

[1, UBA, 2001] The purpose of the ionisation wet scrubber (IWS) is to remove various pollutants from the flue-gas flow. The IWS combines the principles of:

- electrostatic charging of particles, electrostatic attraction and deposition for aerosols (smaller than 5 µm);
- vertical deposition for coarse, liquid and solid particles (larger than 5 µm); and
- absorption of hazardous, corrosive and ~~mal~~odorous gases.

The IWS system is a combination of an electrostatic filter and a packed scrubber. It is reported to require little energy and has a high deposition efficiency for particles in the submicron as well as the micron range.

A high-voltage zone is installed before each packed tower stage. The function of the high-voltage zone is to ionise the particles (dust, aerosols, submicron particles) contained in the flue-gas. The negatively charged particles induce opposing charges on the neutral surface of the wetted packing material and the falling water drops. ~~Because of this~~ As a result, they are attracted onto the liquid surfaces and are then washed out in the packed section. This is referred to as Image/Force attraction (IF attraction), i.e. attraction through electron shift. Hazardous, corrosive and ~~mal~~odorous gases are also absorbed in the same scrubber fluid and chemically combined to be discharged with the scrubber effluent.

Another type of ionisation wet scrubber includes a venturi. The pressure changes that occur through the venturi allow the fine particles to grow and the electrode charges them. They are then collected by the dense layer of water droplets projected by a nozzle, serving as a collecting electrode. [74, TWGComments, 2004]

2.5.3.5 Bag ~~Fabric~~ filters

Bag ~~Fabric~~ filters, also called fabric ~~bag~~ filters, are very widely used in waste incineration plants. Filtration efficiencies are very high across a wide range of particle sizes. At particle sizes below 0.1 microns, efficiencies are reduced, but the fraction of these that exist in the flue-gas flow from waste incineration plants is relatively low. Low dust emissions are achieved with this technology. It can also be used following an ESP and wet scrubbers. [74, TWGComments, 2004]

The compatibility of the filter medium with the characteristics of the flue-gas and the dust, and the process temperature of the filter are important for effective performance. The filter medium should have suitable properties for thermal, physical and chemical resistance (e.g. hydrolysis, acid, alkali, oxidation). The gas flow rate determines the appropriate filtering surface, i.e. filtering velocity.

Mechanical and thermal stress on the filter material determines service life, energy and maintenance requirements.

In continuous operation, there is gradual loss of pressure across the filtering media due to the deposit of particles. When dry sorption systems are used, the formation of a cake on the media helps to provide the acid removal. In general, the differential pressure across the filter is used to monitor the need for cleaning. Periodic replacement is required when the residual lifetime is achieved or in the case of irreversible damage (e.g. an increasing loss of pressure may be caused by an irreversible deposit of fine dust on the filter material). Several parameters help to control the lifetime of the bags: pressure drop drift, visual, microscopic analysis, etc. Potential leaks in the bag filter will also be detected by the increased emissions or by some process disturbance. [64, TWGComments, 2003]

~~It is not unusual for systems to be sized to achieve performance with n-1 sections in service, to facilitate on-load maintenance and reduce downtime. However, there will still be constraints on how much repair work can be completed with the unit on-line, due for instance to safety considerations for personnel access (high temperature due to adjacent sections in service).~~

Bag filter systems are usually composed of several chambers where sections can be isolated one by one for maintenance. It is common practice to design the system to operate at full capacity with one section is out of service to facilitate on-load maintenance and reduce downtime. However, there may still be constraints on how much repair work can be completed with the incinerator on-line, for example the outside of the off-line section may be too hot to allow safe personnel access due to the adjacent sections being in service.

The application of dry deposition is limited for dusts that are hygroscopic at high temperatures (300–600 °C) and become sticky at these temperatures. This type of dust forms deposits in the deposition equipment, which cannot be extracted sufficiently by conventional cleaning techniques during operation but may need to be removed by ultrasound vibration. These may be dusts from complex salts, e.g. from wastes containing phosphorus, sulphur or silicon.

Source: [1, UBA, 2001]

Figure 2.42: An example of a bag filter

Selection of filter bag material

The filter material is selected to be suited to the physical and chemical conditions under which it will operate.

The key characteristics of fabrics for use in gas filtration include maximum operational temperature and resistance to acids, alkalis and flexing (due to bag cleaning). Gas humidity can also affect the strength and dimensional stability of the fabrics, due to hydrolysis. Several basic fibre properties are summarised below; some may be coated or impregnated with special chemicals (e.g. sulphur). [74, TWGComments, 2004]

Table 2.20: Operational information for different bag filter materials

Fabric	Maximum temperature (°C)	Resistance		
		Acid	Alkali	Physical flexibility
Cotton	80	Poor	Good	Very good
Polypropylene	95	Excellent	Excellent	Very good
Wool	100	Fair	Poor	Very good
Polyester	135	Good	Good	Very good
Nylon	205	Poor to fair	Excellent	Excellent
PTFE	235	Excellent	Excellent	Fair
Polyimide	260	Good	Good	Very good
Fibreglass	260	Fair to good	Fair to good	Fair

NB:

1. Not all of these materials are commonly used in incineration – see operational data below.
2. Some operational experiences suggest a common maximum operational temperature to be 200 °C.

Source: [2, infomil, 2002] [67, Inspec, 2004]

Increasing the temperature may lead to the melting of any plastic components in the fabric material, and the potential for fires. High humidity in the flue-gas may cause the filter materials to stick together and lead to shutdowns. [74, TWGComments, 2004] PTFE covering of sheets/foils can be used to improve the removal of such sticky salts and solid particles from the bags. Operational improvements in semi-wet systems (see also Section 2.5.4) are reported to have been achieved by using PTFE in a MSWI facility in Prague (CZ) and in Schwandorf (Germany).

Several filtration media are reported to not be commonly used in MSWI, e.g. cotton, wool, propylene. In MSWI, the main media are polyimide (known as P84), PPS (rarely), and PTFE, fibreglass (with or without PTFE coating). Some fibres may be combined (e.g. P84 and PTFE for higher resistance at high temperatures).

Chemical reactions in the absorbent media may affect the operational temperature. The quality of the scrim is also of importance, as well as the fibre quality. [2, infomil, 2002], [64, TWGComments, 2003]

Special filter bags may include catalytic elements for the reduction of NO_X and/or for the destruction of PCDD/F (see Sections 4.5.4.2 and 4.5.5.4).

2.5.3.6 Cyclones and multi-cyclones

[64, TWGComments, 2003]

Cyclones and multi-cyclones use centrifugal forces to separate particulate matter from the gas stream. Multi-cyclones differ from single cyclones in that they consist of many small cyclone units. The gas flow enters the separator tangentially and leaves from a central port. Solids are forced to the outside of the cyclone and collected at the sides for removal.

~~In general,~~ Cyclones on their own cannot achieve the required dust emission levels ~~now applied to modern waste incinerators~~. They can, however, an play important role, where applied as a pre-deduster before other flue-gas treatment stages, in reducing the dust load to be finally treated. Energy requirements are generally low as there is almost no pressure drop across the cyclone.

A major advantage of cyclones is ~~are~~ their wide operational temperature range and robust construction. Erosion of cyclones, particularly at the point of impingement of dirty flue-gases, can be an issue where the flue-gas is more heavily loaded with particulate, and particularly where bed material escapes from fluidised bed plants. Circulating fluidised beds usually incorporate a cyclone for the removal and recirculation of the bed material to the furnace.

2.5.3.7 Venturi scrubbers

A venturi scrubber consists of three sections: a converging section, a throat section, and a diverging section. The inlet gas stream enters the converging section and, as the area decreases, the gas velocity increases. Liquid is introduced either at the throat or at the entrance to the converging section. The inlet gas, forced to move at extremely high velocities in the small throat section, shears the liquid from its walls, producing a great number of very small droplets.

Particle and gas removal occur in the throat section as the inlet gas stream mixes with the fog of tiny liquid droplets. The inlet stream then exits through the diverging section, where it is forced to slow down.

While venturis can be used to reduce both particles and gaseous pollutants, they are mainly effective in removing fine particles.

The design can be based on a single venturi for a complete flue-gas stream or on several venturi nozzles. The pressure drop and performance can be controlled by injecting scrubbing liquid upstream of the venturi or into the venturi throat, and/or by mechanically adjusting the opening in the venturi throat.

The position of the venturi stage within a ~~multistep~~ multistage wet scrubbing system can be at the inlet (venturi quench), intermediate (e.g. downstream of the quench / packed bed stage) or at the end as a last polishing stage.

Venturi scrubbers are normally combined with dry dust pre-separation (e.g. with an ESP) and/or with activated carbon injection upstream of the wet scrubber (for dioxin/mercury removal).

[77, ESWET, 2015]

2.5.4 Techniques for the reduction of acid gases (e.g. HCl, HF and SO_X emissions)

These substances are generally cleaned from the flue-gas using alkaline reagents. The following flue-gas cleaning processes are applied:

- **Dry processes:** A dry sorption agent (e.g. lime, sodium bicarbonate) is added to the flue-gas flow. The reaction product is also dry.
- **Semi-wet processes:** Also called semi-dry. The sorption agent added to the flue-gas flow is an aqueous solution (e.g. lime milk) or suspension (e.g. as a slurry), or dry hydrated lime with separate water injection. The water solution evaporates and the reaction products are dry. The residue may be recirculated to improve reagent utilisation. ~~A sub-set of this technique are *flash-dry* processes which consist of injection of water (giving fast gas cooling) and reagent at the filter inlet~~

- **Wet processes:** The flue-gas flow is fed into water, hydrogen peroxide, and/or a washing solution containing part of the reagent (e.g. sodium hydroxide solution). The reaction product is aqueous.

2.5.4.1 Removal of acid gases ~~sulphur dioxide and halogens~~

[1, UBA, 2001] Acid gases such as sulphur dioxide and gaseous halogenides are cleaned from flue-gases by the injection of chemical or physical sorption agents, which are brought into contact with the flue-gas. Depending on the technique, the reaction products are dissolved or dry salts.

Dry systems

In dry sorption processes, the absorption agent (usually lime or sodium bicarbonate) is fed into the reactor as a dry powder. The dose rate of reagent may depend on the temperature as well as on the reagent type. With lime, this ratio is typically two or three times the stoichiometric amount of the substance to be removed ~~deposited~~; with sodium bicarbonate, the ratio is lower. This is required to ensure emission limits are complied with over a range of inlet concentrations. The reaction products generated are solid and need to be deposited from the flue-gas as dust in a subsequent stage, normally a bag filter.

The overdose of lime (or other reagent) leads to a corresponding increase in the amount of residues, unless reagent recirculation is carried out, when the unreacted fraction can be recirculated and the stoichiometric ratio reduced accordingly.

If there is no pre-deposition stage (e.g. electrostatic precipitator), particles are removed with the used reagent and reaction products. The cake of reagent that forms on fabric filters ~~gives~~ provides for effective contact between flue-gas and absorbent.

Plumes are rarely visible with this technique.

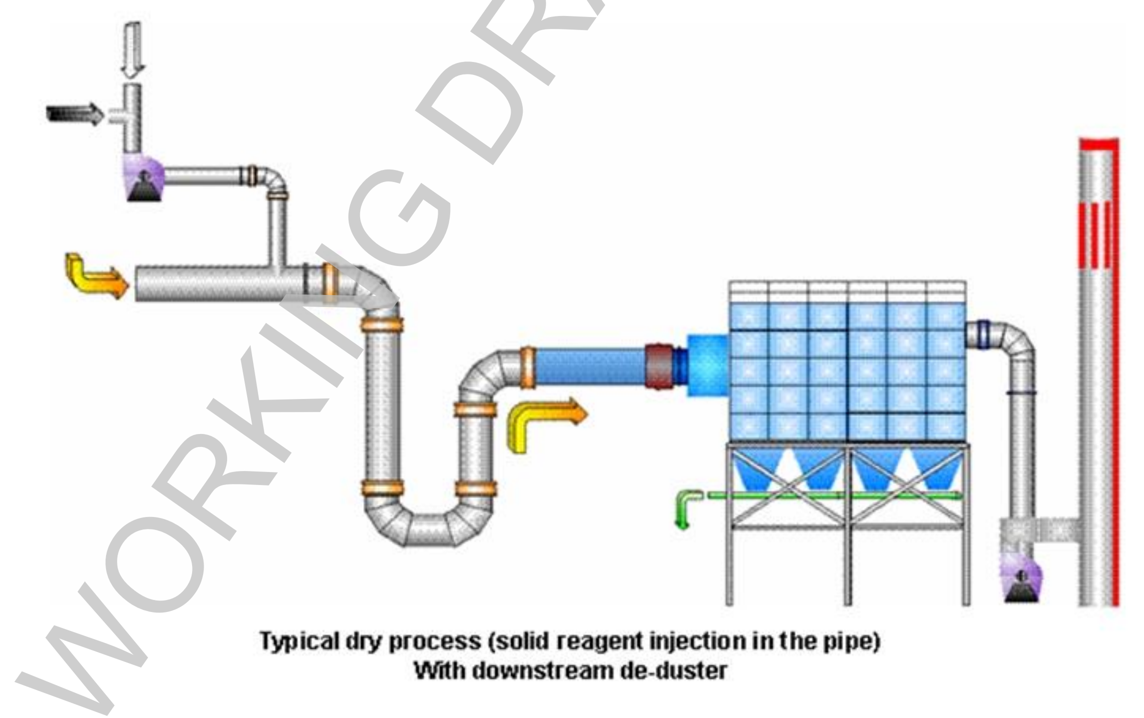


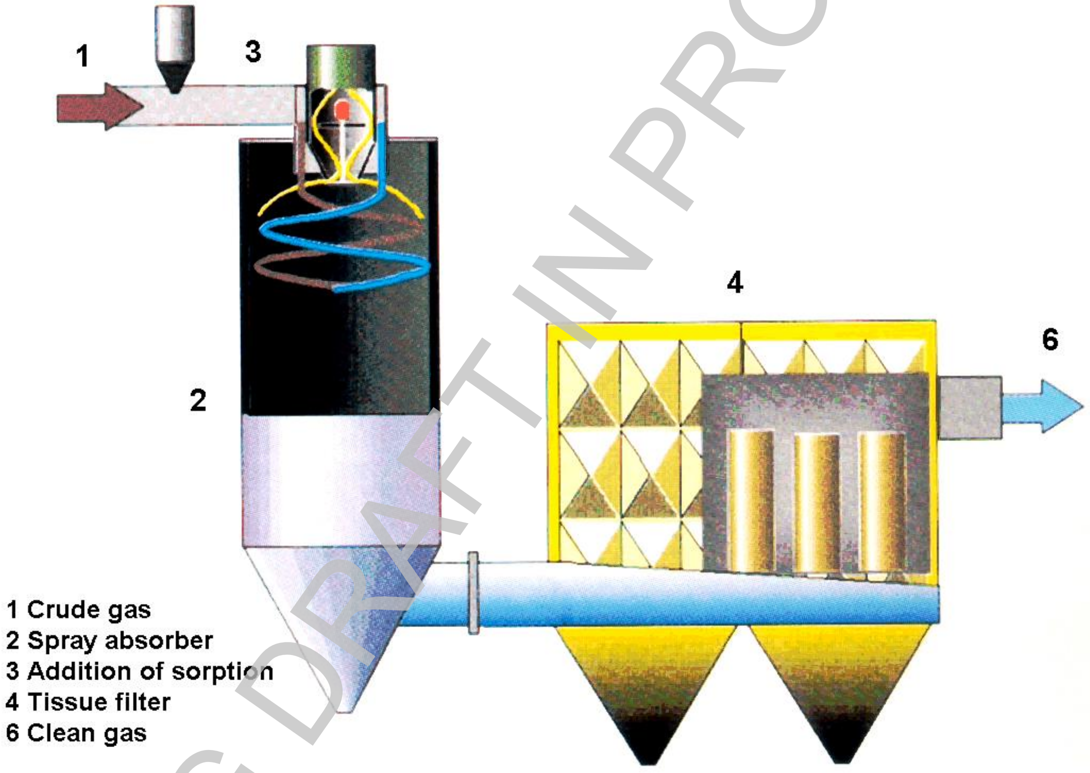
Figure 2.43: Schematic diagram of a dry FGC system with reagent injection into the FG duct ~~pipe~~ and downstream bag filtration

Semi-wet systems

These are also called semi-dry processes if water and hydrated lime are injected separately. In the spray absorption, the absorption agent is injected either as a suspension or solution into the hot flue-gas flow in a spray reactor (see Figure 2.44).

This type of process utilises the heat of the flue-gas for the evaporation of the solvent (water). The reaction products generated are solid and need to be deposited from the flue-gas as dust in a subsequent stage, e.g. bag filter. These processes typically require overdoses of the sorption agent of 1.5 to 2.5 stoichiometric equivalents.

Here, the bag ~~fabric~~ filter is also an important part of the process. Plumes are also rarely visible with this technique.



Source: [1, UBA, 2001]

Figure 2.44: Operating principle of a spray absorber

A system which falls between the normal dry and semi-wet systems is also applied. This is sometimes known as a flash-dry system~~.~~ (Alstom 2003) or semi-dry with CFB (circulating fluidised bed) reactor. These systems re-inject into the inlet flue-gas a proportion of the solids collected in the bag filter. Water is added at a controlled rate either directly to the collected fly ash and reagent or into the reactor upstream of the filter in such a way as to ensure that solids ~~it~~ remain~~s~~ free-flowing and not prone to stickiness or scaling. The reactor design might be as a circulating fluidised bed (CFB) reactor or a simple plug-flow reactor (duct). No ~~contact tower or~~ slurry handling is required (in contrast to semi-wet systems) and no effluents are produced (in contrast to wet systems).

The recycling of reagent reduces the demand for reagent and the amount of solid residue produced. Stoichiometric ratios in the range of 1.5 to 2 are common. Recycling of reagent can also be applied to dry and semi-wet systems.

Another system that is not completely dry or semi-wet or semi-dry uses the condensation effect on solid particles recirculated into the flue-gas upstream of the fabric filter. This effect can be achieved by steam injection or by cooling the solids prior to re-feeding.
[78, ESWET, 2015]

Wet systems

Wet flue-gas cleaning processes use different types of scrubber design, for example:

- jet scrubbers;
- rotation scrubbers;
- venturi scrubbers;
- dry tower scrubbers;
- spray scrubbers;
- packed tower scrubbers.

The scrubber solution is (in the case of water only injection) strongly acidic (typically pH 0–1) due to acids forming in the process of deposition. HCl and HF are mainly removed in the first stage of the wet scrubber. The effluent from the first stage is recycled many times, with little fresh water addition and a bleed from the scrubber to maintain acid gas removal efficiency. In this acidic medium, deposition of SO_2 is low, so a second stage scrubber is required for its removal.

Removal of sulphur dioxide is achieved in a washing stage controlled at a pH close to neutral or alkaline (generally pH 6–7) in which caustic soda solution or lime milk is added. For technical reasons this removal takes place in a separated washing stage, in which, additionally, there occurs further removal of HCl and HF.

If the treated waste contains bromine and iodine, these elements can be deposited from the flue-gas flow if waste containing sulphur is combusted simultaneously. In addition to sulphur compounds, water-soluble salts of bromine and iodine will form, which can be deposited through the wet SO_2 flue-gas cleaning processes. Additionally, the deposition of elementary bromine and iodine may be improved by specific employment of reductive washing stages (sulphite solution, bisulphite solution). In any case, it is important to be aware of which wastes contain iodine or bromine.

If lime milk or limestone is used as a neutralising agent in the wet flue-gas cleaning stages, sulphate (as gypsum), carbonates and fluorides will accumulate as water-insoluble residues. These substances may be removed to reduce the salt load in the waste water and hence reduce the risk of encrustation within the scrubbing system. Residues of the cleaning process (e.g. gypsum) can be recovered. When using a caustic soda solution there is no such risk because the reaction products are water-soluble. If NaOH is used, $CaCO_3$ may form (depending upon water hardness), which will again lead to deposits within the scrubber. These deposits need to be removed periodically by acidification.

The diagram below shows a typical two-stage wet scrubbing system. The number of scrubbing stages usually varies between one and four with multiple stages being incorporated in each vessel.

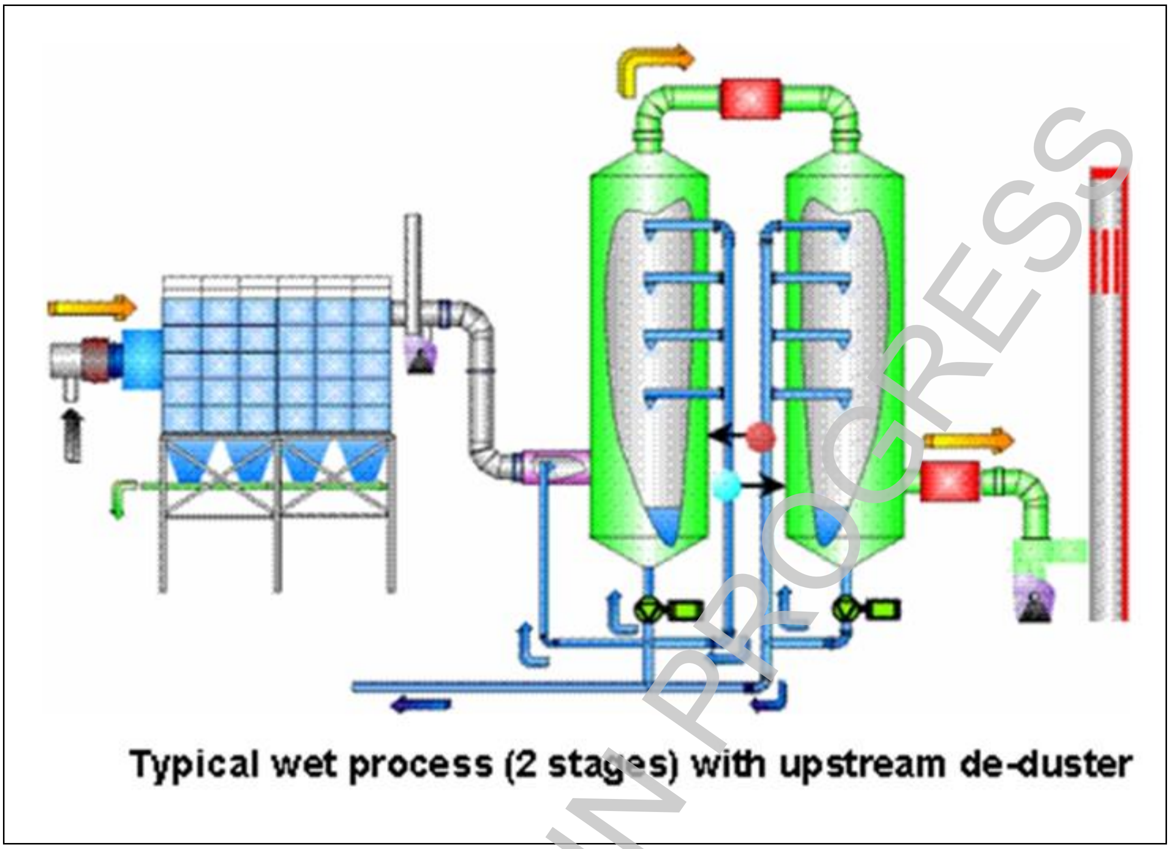


Figure 2.45: Diagram of a two-stage wet scrubber with upstream dedusting

Waste water from wet scrubbers

To maintain scrubbing efficiency and prevent clogging in the wet scrubber system, a portion of the scrubber liquor must be removed from the circuit as waste water. This waste water must be subjected to special treatment (neutralisation, precipitation of heavy metals), before discharge or use internally. Mercury removal is given special attention. Volatile mercury compounds, such as $HgCl_2$, will condense when flue-gas is cooled, and dissolve in the scrubber effluent. The addition of reagents for the specific removal of mercury provides a means for removing it from the process.

In ~~some~~ many plants fitted with wet abatement systems, the waste water produced is evaporated in the incineration plant by spraying it back into the flue-gas as a quench in combination with a dry dust abatement system ~~filter~~. This avoids waste water emissions from the flue-gas treatment system and avoids waste water treatment costs.

2.5.4.2 Selection of alkaline reagent

Various alkaline reagents (and combinations) are used in FGC systems of waste incineration plants.

Lime is used in all types of FGC systems, although most often with wet and semi-wet systems. It is used as hydrated lime in dry systems, as slaked lime in semi-wet systems, and also as high specific surface (HSS) lime [74, TWGComments, 2004]. Sodium bicarbonate is applied to a range of mainly dry systems. Sodium hydroxide and limestone are generally only applied to wet FGC systems.

The advantages and disadvantages of the different reagents, usually strongly influenced by the overall technology selection, are summarised in the following table.

Table 2.21: Comparison of features of various alkaline reagents

Reagent	Advantages	Disadvantages	Comments/other data
Sodium hydroxide	• Highly reactive with acid gases • Low consumption rates • Low solid waste production	• Higher cost/kg reagent • Variable cost (quarterly) • Soluble salts formed • Highly corrosive material • Odour if in contact with humidity	• Only used in wet systems • Well suited to variable inlet concentrations, e.g. HWI
Lime	• Medium reactivity (higher reactivity with HSS lime) • Possibility to operate at higher temperature with HSS lime • Lower cost/kg reagent • Low solubility residues • Can allow gypsum recovery from wet scrubbers	• Handling can be problematic and recycling difficult	• Residues from lime-based dry, intermediate and semi-dry systems are highly alkaline
Limestone	• Medium reactivity • Lower cost/kg reagent • Low solubility residues • Can allow gypsum recovery from wet scrubbers	• Releases CO_2, which must be stripped off by bleeding from an HCl scrubber	• Not widely applied in MSWI • Mainly used in wet systems • Sometimes used in fluidised bed systems
Sodium bicarbonate	• Highly reactive both on SO_2 and HCl • Low consumption rates (stoichiometric ratio ~1.25) • Low residue production depending on the stoichiometric ratio • Purification and reuse of residue possible and applied • Effective over wide FGC operational temperature range (140–300 °C) • High operational temperature range and high efficiency on SO_2 may increase compatibility with SCR • No water injection/humidity control required	• Higher soluble part in residue • Soluble solid residues formed can be problematic for disposal (but use in chemicals industry is possible) • Higher cost than lime/kg reagent • Size reduction device is required and may cause problems of availability due to fouling	• 10–15 kg/t MSW incinerated without fly and boiler ash

Source: [64, TWGComments, 2003] [74, TWGComments, 2004]

The temperature range which is adequate for the dry sodium bicarbonate process is linked to the transformation of sodium bicarbonate to sodium carbonate; this phenomenon increases the surface area and porosity of the reagent and hence its reactivity. The phenomenon is observable from temperatures around 100 ºC, but higher temperatures are required to ensure reaction kinetics are acceptable. From 140 ºC the kinetics are generally fast enough, with experience of further increases in reactivity at temperatures of 160–180 ºC.

In some cases, mixed FGC systems are implemented: they can operate either with HSS lime or sodium bicarbonate. Although less operationally optimised, reagent costs may thus be better controlled. [74, TWGComments, 2004]

The co-injection of hydrated lime with sodium bicarbonate is also possible, as recently applied in plants in Germany and in the Netherlands, to make up for the lower reactivity of sodium bicarbonate with HF and thus improve the continuous control of HF emissions. The co-injection of hydrated lime has been reported to also potentially reduce the overall use of reagents and associated operating costs [99, EuLA 2015].

The overall reagent cost is determined both by the unit cost per kilogram of reagent and the amount required (stoichiometric ratio), as well as by the availability and cost of residue treatment/disposal options. For example, for dry FGC systems, lime has the lowest reagent cost per kilogram of reagent, but the lower dose rates (kg of reagent per tonne of waste treated) required with sodium bicarbonate mean that the overall reagent cost per unit of waste treated will be similar. The relative prices and availability of residue treatment/disposal options may then become a determining factor.

~~Some additional cost information and estimates are given in the annex to this document (see Section 8.2.4).~~

Lime, sodium hydroxide, limestone and sodium bicarbonate are all used in a wide variety of incineration plants throughout Europe and elsewhere.

2.5.4.3 Direct desulphurisation

[1, UBA, 2001] Desulphurisation in fluidised bed processes can be carried out by adding absorbents (e.g. calcium or calcium/magnesium compounds) directly into the incineration chamber. Additives such as limestone dust, calcium hydrate and dolomitic dust are used. The system can be used in combination with downstream flue-gas desulphurisation.

The arrangement of the jets and the injection speed influence the distribution of the absorbents and thus the degree of sulphur dioxide deposition. Part of the resulting reaction products are removed in filter installations downstream; however, a significant proportion remains with the bottom ashes. Therefore, direct desulphurisation may impact on bottom ash quality [64, TWGComments, 2003].

Ideal conditions for direct desulphurisation exist in a cycloid furnace due to the constant temperature.

~~It is reported that,~~ On its own, this technique does not lead to compliance with the required SO_2 emission levels ~~ELV requirements of the Directive 2000/76/EC. [1, UBA, 2001]~~. However, it is useful as a pretreatment and contributes to meeting the lowest emission levels when applied in combination with other techniques.

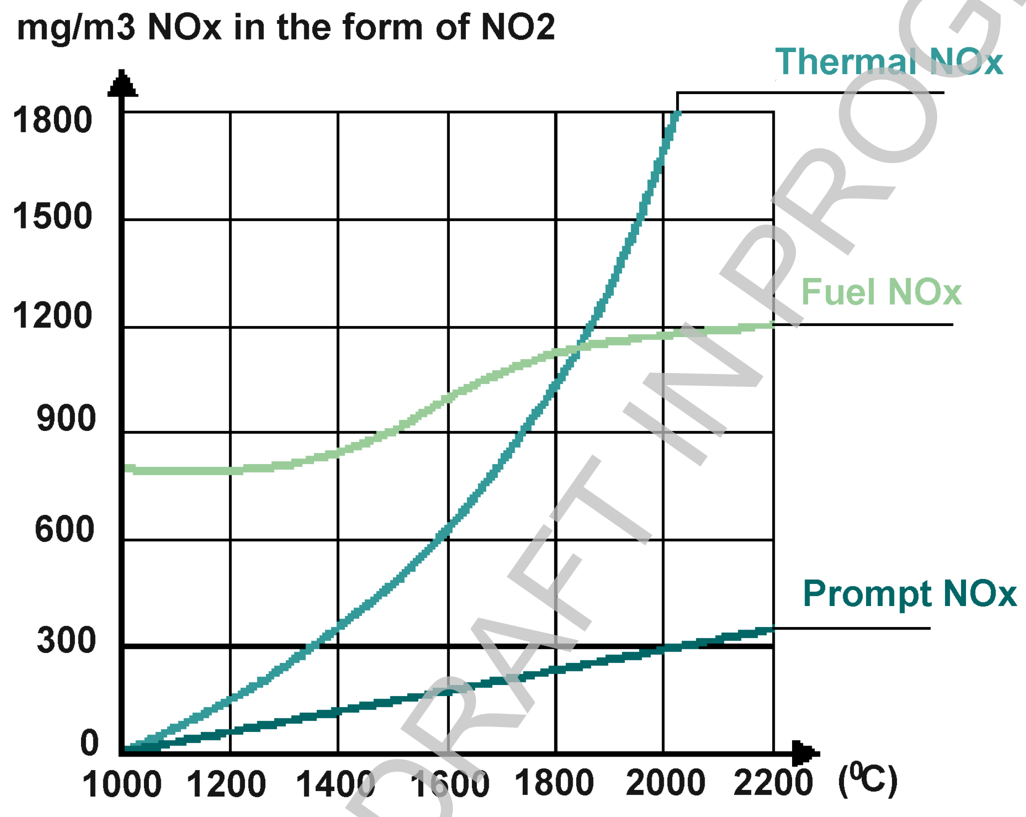
The amount of residue from the flue-gas cleaning ~~treatment~~ system itself can be reduced, resulting in lower disposal costs.

Absorption (and adsorption) of pollutants can also be performed in a (circulating) fluidised bed reactor into which residues and reagents are recirculated in the combustor at a high rate. Recirculation of flue-gas keeps the gas flow above a minimum level in order to maintain fluidisation of the bed. The bed material is separated in a bag filter. Injection of water reduces the consumption of absorbents (and hence the production of residues) significantly.
[74, TWGComments, 2004]

2.5.5 Techniques for the reduction of emissions of oxides of nitrogen

[3, Austria, 2002]
Nitrogen oxides (NO_X) may be formed in three ways:

- Thermal NO_X: During combustion a part of the air nitrogen is oxidised to nitrogen oxides. This reaction only takes place significantly at temperatures above 1 300 °C. The reaction rate depends exponentially on the temperature and is directly proportional to the oxygen content.
- Fuel NO_X: During combustion a part of the nitrogen contained in the fuel (including in the waste) is oxidised to nitrogen oxides.
- Formation of NO_X via radical reaction (prompt NO_X): Atmospheric nitrogen can also be oxidised by reaction with CH radicals and intermediate formation of HCN. This mechanism of formation is of relatively low importance in waste incineration.



Source: [3, Austria, 2002]

Figure 2.46: Temperature dependence of various NO_X formation mechanisms in waste incineration

2.5.5.1 Primary techniques for NO_X reduction

[1, UBA, 2001] NO_X production can be reduced using furnace control measures that:

- prevent oversupply of air (i.e. prevention of the supply of additional nitrogen);
- prevent the use of unnecessarily high furnace temperatures (including local hot spots).

2.5.5.1.1 Air supply, gas mixing and temperature control

The use of a well-distributed primary and secondary air supply to avoid the uneven temperature gradients that result in high-temperature zones and, hence, increased NO_X production is a widely adopted and important primary measure for the reduction of NO_X production.

Although sufficient oxygen is required to ensure that organic materials are oxidised (giving low CO and VOC emissions), the oversupply of air can result in additional oxidation of atmospheric nitrogen, and the production of additional NO_X.

Achieving effective gas mixing and temperature control are important elements.

2.5.5.1.2 Flue-gas recirculation (FGR)

This technique involves replacement of around 10–20 % of the secondary combustion air with recirculated flue-gases. NO_X reduction is achieved because the supplied recirculated flue-gases have a lower oxygen concentration and therefore lower flue-gas temperature which leads to a decrease of the nitrogen oxide levels. [74, TWGComments, 2004]

2.5.5.1.3 Oxygen injection

The injection of either pure oxygen or oxygen-enriched air provides a means to supply the oxygen required for combustion, while reducing the supply of additional nitrogen that may contribute to additional NO_X production.

2.5.5.1.4 Staged combustion

Staged combustion has been used in some cases. This involves reducing the oxygen supply in the primary reaction zones and then increasing the air (and hence oxygen) supply at later combustion zones to oxidise the gases formed. Such techniques require effective air/gas mixing in the secondary zone to ensure CO (and other products of incomplete combustion) are maintained at low levels.

2.5.5.1.5 Natural gas injection (reburn)

[70, USEPA, 1994]
Natural gas injection into the over-grate region of the furnace can be used to control NO_X emissions from the combustor. For MSWIs, two different natural-gas-based processes have been developed:

- reburning – a three-stage process designed to convert NO_X to N_2 by injecting natural gas into a distinct reburn zone located above the primary combustion zone;
- methane de-NO_X – this technique injects natural gas directly into the primary combustion unit to inhibit NO_X formation.

2.5.5.1.6 Injection of water into furnace/flame

A properly designed and operated injection of water either into the furnace or directly into the flame can be used to decrease the hot spot temperatures in the primary combustion zone. This drop in peak temperature can reduce the formation of thermal NO_X.
[74, TWGComments, 2004]

2.5.5.2 Secondary techniques for NO_X reduction

[1, UBA, 2001] ~~Directive 2000/76/EC requires a daily average NO_X (as NO_2) clean gas value of 200 mg/Nm³~~. In order to achieve compliance with NO_X emission limits ~~at this level~~, it is common for secondary measures to be applied. For most processes, the application of ammonia or derivatives of ammonia (e.g. urea) as a reduction agent has proved successful. The nitrogen oxides in the flue-gas basically consist of NO and NO_2 and are reduced to N_2 and water vapour by the reduction agent.

Reaction equations:

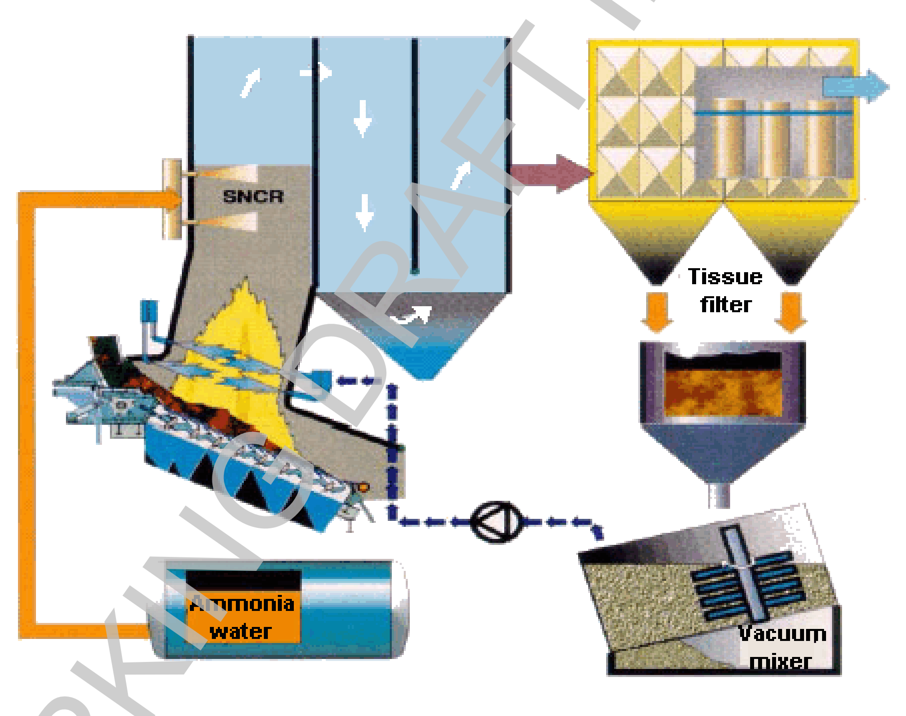
$$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O$$
$$2\ NO_2 + 4\ NH_3 + O_2 \rightarrow 3\ N_2 + 6\ H_2O$$

Two processes are important for the removal of nitrogen from flue-gases - ~~the~~ selective non-catalytic reduction (SNCR) and ~~the~~ selective catalytic reduction (SCR).

Both NH_3 and urea are applied in aqueous solutions. For safety reasons, NH_3 is normally supplied ~~delivered~~ as a 25 % solution.

2.5.5.2.1 Selective non-catalytic reduction (SNCR) process

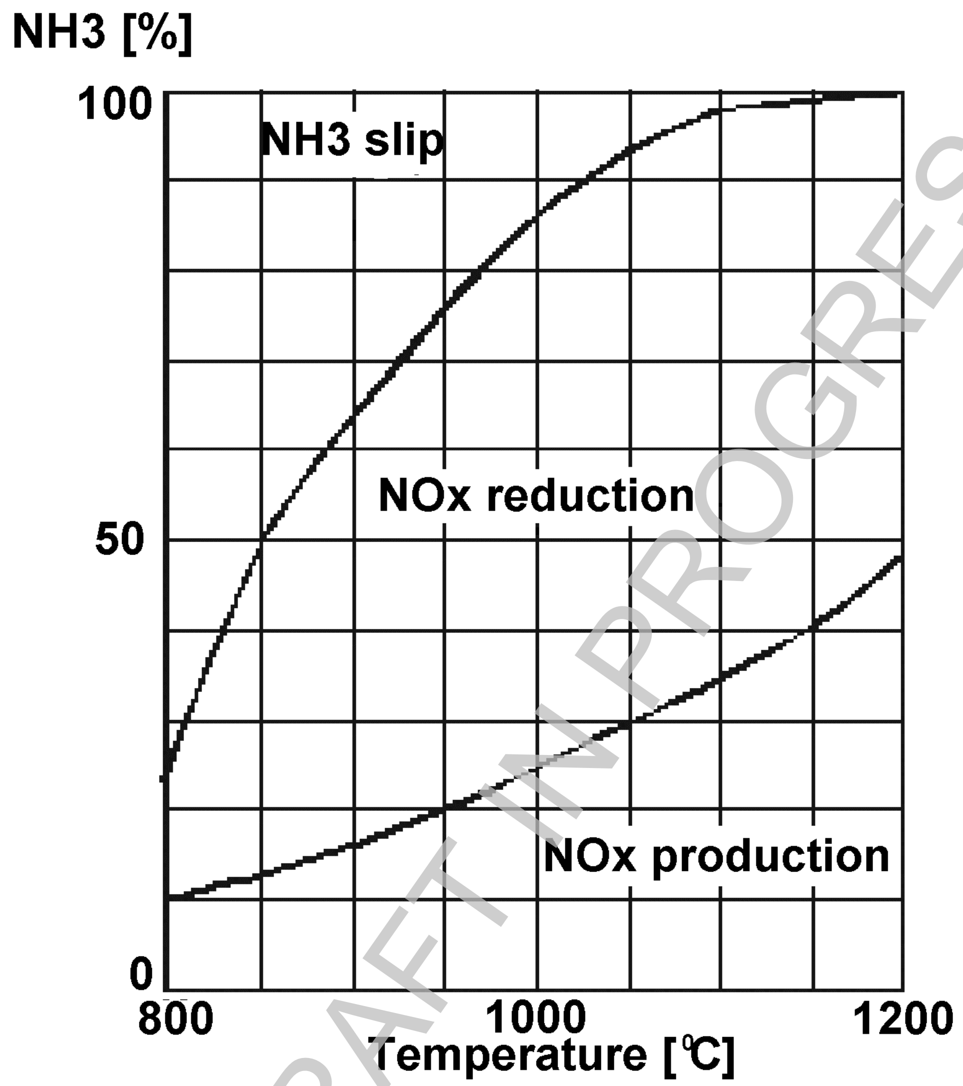
In the selective non-catalytic reduction (SNCR) process, nitrogen oxides ($NO + NO_2$) are removed by ~~selective non-catalytic reduction. With this type of process~~ injecting the reducing agent (typically ammonia or urea) ~~is injected~~ into the furnace ~~and reacts with the nitrogen oxides~~. The reactions occur at temperatures between 850 °C and 1 000 °C, with zones of higher and lower reaction rates within this range.



Source: [1, UBA, 2001]

Figure 2.47: SNCR operating principle

Reducing NO_X levels by ~~SNCR~~ more than 60–80 % using SNCR requires a higher addition of the reducing agent. This can lead to emissions of ammonia, also known as ammonia slip. The relationship between NO_X reduction, ammonia slip and the reaction temperature is given in Figure 2.48 below.



Source: [Austria, 2002 #3] [64, TWGComments, 2003]

Figure 2.48: Relationship between NO_X reduction, production, ammonia slip and reaction temperature for the SNCR process

~~In~~ Figure 2.48~~, it is shown~~ shows that, at a reaction temperature of~~, for example,~~ 1 000 °C, the reduction of NO_X would be about 85 %, with ~~and there would be~~ an ammonia slip of about 15 %. In addition, at this temperature there would be a production of NO_X, from the incineration of the injected NH_3, of about 25 %.

Figure 2.48 also shows that, at higher temperatures (with ammonia), the percentage of NO_X reduction is higher, and, while the ammonia slip is lower, the NO_X produced from the ammonia rises. At high temperatures (> 1 200 °C), NH_3 itself oxidises and forms NO_X. At lower operating temperatures, the NO_X reduction is less efficient and the ammonia is slip higher

Application of urea instead of ammonia in SNCR leads to relatively higher N_2O emissions in comparison with ammonia reduction. [64, TWGComments, 2003]

In order to ensure an optimum utilisation of ammonia at varying ~~degrees of~~ loads, which cause varying temperatures in the combustion chamber, NH_3 can be injected at several layers.

When used with wet scrubbing systems, the excess ammonia may be removed in the wet scrubber. The ammonia can then be recovered from the scrubber effluent using an ammonia stripper and fed back to the SNCR feed system.

The effective mixing of flue-gases and NO_X reduction reagent is important for optimisation of the SNCR process and there must be sufficient gas residence time to allow the NO_X reduction reactions to occur.

In the case of pyrolysis and gasification processes, optimisation of SNCR is achieved by injecting the reagent into the syngas combustion zones with a well-controlled temperature and effective gas mixing.

Selection of reagents for SNCR
The reagents used for SNCR are ammonia and urea.

Obtaining a good understanding of temperature profiles in the combustion chamber is fundamental to the selection of the reagent.

New plants ~~processes~~ can be specifically designed to achieve ~~the~~ stable and predictable combustion conditions, ~~and select the~~ allowing for optimal injection locations for the reagent, ~~that then allow~~ thus making it possible to use ammonia with the most ~~the~~ benefits ~~of ammonia~~ (i.e. highest peak NO_X reduction at lowest N_2O emissions) ~~to be secured~~. ~~Those~~ This also applies to existing plants ~~processes~~ that have stable and well-controlled combustion and temperature profiles in the furnace ~~will also be able to maximise this benefit~~.

Existing plants ~~processes~~ that experience difficulties in stabilising combustion conditions (e.g. for design, control or waste type reasons) are less likely to be in a position to optimise the reagent injection (location, temperature, mixing) and may therefore benefit from the use of urea. However, if temperatures above 1 000 °C are anticipated, the N_2O production rate with urea becomes more significant.

In cases where the advantages and disadvantages are finely balanced, storage and handling hazards may have a greater impact on the final reagent selection.

The relative advantages and disadvantages of ~~their selection~~ ammonia and urea are outlined in the table below. The reagent selection needs to take account of a variety of process operational, cost and performance factors to ensure that the optimal one is selected for the installation concerned.

Table 2.22: Advantages and disadvantages of urea and ammonia use for SNCR

Reagent	Advantages	Disadvantages
Ammonia	• Higher peak NO_X reduction potential (if well optimised) • Lower N_2O emissions (10–15 mg/Nm^3)	• Narrower effective temperature range (850–950 °C) therefore greater optimisation is required • Handling and storage hazards higher • Higher cost per tonne of waste • ~~ammonia slip approx. 10 mg/Nm³~~ • Odour of residues if in contact with humidity
Urea	• Wider effective temperature range ~~wider~~ (540–1 000 °C) makes ~~therefore~~ temperature control less critical • Lower hazard storage and handling • Lower cost per tonne of waste	• Lower peak NO_X reduction potential (compared to ammonia when optimised) • Higher N_2O emissions (25–35 mg/Nm^3) and hence GWP • ~~ammonia slip approx. 1 mg/Nm³~~

For the TWG: the data gathered do not show any significant correlation between the ammonia slip concentration and the reagent used (ammonia or urea)

~~NB: The lower cost of~~ associated with ~~urea is most significant at relatively small plants. For larger plants, the higher storage cost of ammonia may be fully compensated by the lower chemical cost.~~

Source: [62, Tyseley, 2001] [64, TWGComments, 2003]

The urea/N_2O reaction is very dependent on temperature, with as much as 18 % of the NO_X removed appearing as N_2O at 1 000 °C, while it is ~~(although~~ negligible at 780 °C~~)~~.

Ammonia is reported to be marginally more expensive to use than urea. Handling and storage requirements for ammonia liquid, gas and solutions are generally more stringent and, hence, more expensive than for urea, which can be stored as a solid - this contributes to the cost differential between the two reagents.

Storage of gaseous or liquefied ammonia is subject to stringent safety requirements, which may cause extra costs. In most cases ammonia is used as a solution, as in this case the safety requirements are less onerous.

The use of urea is only cheaper for relatively small plants. For larger plants the higher storage cost of ammonia may be fully compensated by the lower chemical cost.

2.5.5.2.2 Selective catalytic reduction (SCR) process

In the selective catalytic reduction (SCR) ~~is a catalytic~~ process, ~~during which~~ an ammonia-~~mixed with~~ air mixture (the reduction agent) is added to the flue-gas and passed over a catalyst, usually a mesh (e.g. platinum, rhodium, TiO_2, zeolites). [74, TWGComments, 2004] When passing through the catalyst, ammonia reacts with NO_X to give nitrogen and water vapour.

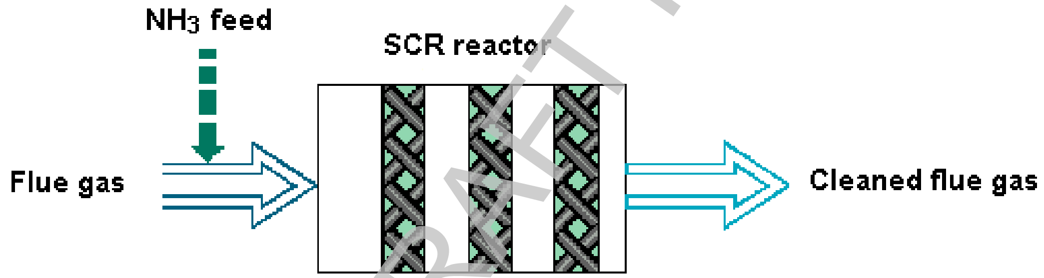
To be effective, the catalyst usually requires a temperature of between 180 °C and 450 °C. The majority of systems used in waste incinerators currently operate in the range of 230–300 °C. Below 250 °C, more catalyst volume is necessary and there is a greater risk of fouling and catalyst poisoning. In some cases, catalyst-temperature-regulated bypasses are used to avoid damage to the SCR unit. [74, TWGComments, 2004]

~~The~~ SCR ~~process~~ gives high NO_X reduction rates (typically over 90 %) at close to stoichiometric additions of the reduction agent. For waste incineration, SCR is mainly applied in the clean gas area, i.e. after dedusting and acid gas removal. For this reason, the flue-gases generally require reheating to the effective reaction temperature of the SCR system. This adds to the energy requirements of the flue-gas treatment system. However, when SO_X levels in the flue-gas have already been reduced to a very low value at the inlet of the SCR section, reheating may be reduced substantially or even omitted. Heat exchangers are used to reduce additional energy demand.

After a wet FGC system, droplets may be removed to prevent salt deposits inside the catalyst. Due to risk of ignition [*For the TWG: Is the risk due to the catalyst or to the use of ammonia/urea? This sentence does not say what the cause is.*], safety measures are of importance, e.g. bypasses, CO control. [74, TWGComments, 2004]

Low-temperature SCR requires catalyst regeneration due to the formation of salts (especially ~~ammonium chloride and~~ ammonium sulphate). The thermal regeneration should be carefully controlled ~~may be critical~~ because ~~of~~ the salt sublimation may lead to ~~exceedences of the applied ELV for~~ peaks in the releases to air for some pollutants, e.g. ~~HCl,~~ SO_2, NO_X, NH_3, which can be avoided by recirculation of the exhaust gas from regeneration or by controlling the heating rate. [74, TWGComments, 2004]

SCR is sometimes positioned directly after the ESP, to reduce or eliminate the need for reheating ~~in~~ the flue-gas. When this option is used, the additional risk of PCDD/F formation in the ESP (typically when the ESP is operated at temperatures above 220–250 °C) must be considered. Such operation can result in increased PCDD/F emissions ~~to ESP residues and higher concentrations~~ in the gas stream leaving the ESP and in the ESP residues. ~~passing to the SCR unit.~~ However, since SCR can also be used for PCDD/F destruction, PCDD/F emissions downstream of the SCR are generally low. Multi-layer SCR systems are used to provide combined NO_X and PCDD/F control.



Source: [3, Austria, 2002]

Figure 2.49: SCR operating principle

The flue-gases discharged from ~~by~~ the reactor may be directed through a gas-gas heat exchanger to preheat the entering gases in order to maintain the operating temperature of the catalyst and to save ~~a part~~ some of the imported energy (see diagrams in Section 4.5.4.1).

2.5.6 Techniques for the reduction of mercury emissions

2.5.6.1 Primary techniques

Mercury is highly volatile and therefore almost exclusively passes into the flue-gas stream.

~~The limit value set in the waste incineration directive is 0.05 mg/m^3. Limit values as low as 0.03 mg/m^3 as a daily average value (with continuous monitoring) have been set in some European Member States [1, UBA, 2001]. Continuous measurement is also prescribed in some national waste incineration legislation (e.g. Austria, Germany).~~
~~The majority of installations cannot meet these limit values, particularly for peak loads, without the addition of special gas cleaning measures for Hg.~~

The only relevant primary techniques for preventing emissions of mercury to air are those which prevent or control, if possible, the inclusion of mercury in the waste:

- efficient separate collection of waste that may contain heavy metals, e.g. cells, batteries, dental amalgams;
- notification of waste producers of the need to segregate mercury;
- identification and/or restriction of receipt of potential mercury-contaminated wastes:
  - by sampling and analysis of wastes where this is possible;
  - by targeted sampling/testing campaigns;
- where such wastes are known to be received - controlled addition to avoid overload of the abatement system capacity.

2.5.6.2 Secondary techniques

[1, UBA, 2001] Mercury vaporises completely at a temperature of 357 °C and remains gaseous in the flue-gas after passing through the furnace and boiler. Inorganic mercury (mainly Hg^{2+} as a chloride) and elemental mercury are ~~e~~affected differently by FGC systems and detailed consideration of the fate of both is required.

The selection of a process for mercury abatement depends on the mercury content and the chlorine content of the feed material. ~~upon the load fed in and upon the chlorine content of the burning material.~~ At higher chlorine contents, mercury in the crude flue-gas will be increasingly in the ionic form which can be deposited in wet scrubbers. This is a particular consideration at sewage sludge incineration plants where raw gas chlorine levels may be quite low. If, however, the chlorine content in the (dry) sewage sludge is 0.3 % by mass or higher, only 10 % of the mercury in the flue-gas ~~clean gas~~ is elemental~~; and the elimination of only the ionic mercury may achieve a total Hg emission level of 0.03 mg/Nm^3~~. [74, TWGComments, 2004]

Metallic mercury can be removed from the flue-gas stream by the following:

- Transformation into ionic mercury by adding oxidants and then deposition in ~~the~~ a wet scrubber - the effluent can then be fed to waste water treatment plants with heavy metal deposition, where the mercury can be converted to a more stable form (e.g. HgS), ~~thus~~ which is more suitable for final disposal [74, TWGComments, 2004].
- The alternative option is direct deposition on sulphur-doped activated carbon, hearth furnace coke, or zeolites. Adsorption on activated carbon can take place in a fixed-bed absorber or on activated carbon injected into the gas flow. In the latter case the carbon accumulates on the bag filters used to collect it, where it forms a filter cake. The contact time and mixing with the sorbent increase when the flue-gas passes through the filter cake, enhancing mercury capture.

Tests have shown that sulphur dioxide neutralisation in the furnace by adding limestone can reduce the proportion of metallic mercury, making overall mercury removal from the gas stream more efficient.

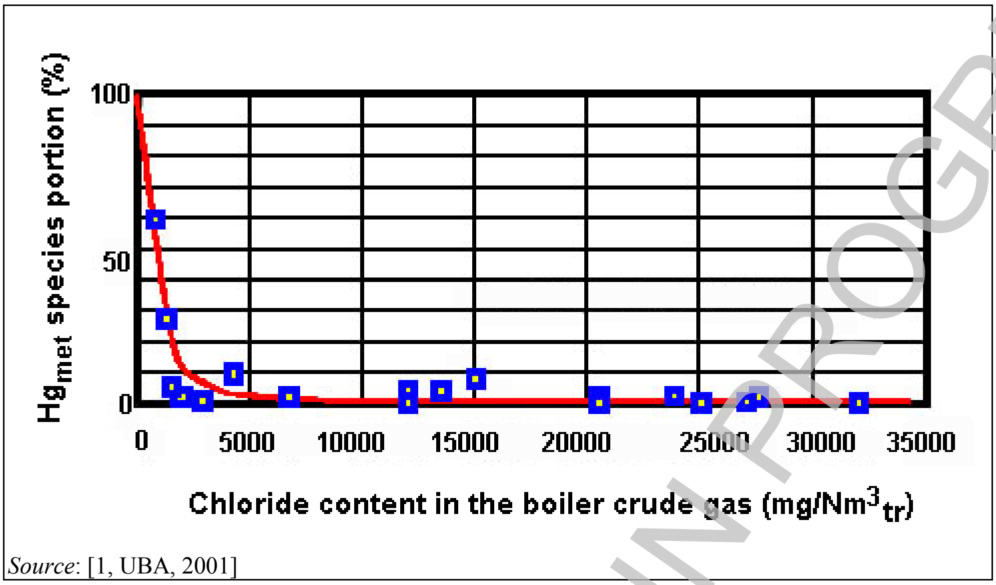
In incineration plants for municipal and hazardous wastes, the chlorine content in the ~~average~~ waste is usually high enough~~, in normal operating states,~~ to ensure that mercury is present mainly in the ionic form. However, specific inputs of certain waste may change the situation and metallic mercury may need to be deposited, as mentioned above.

High-mercury wastes

For the incineration of waste with a high mercury content in hazardous waste incineration plants, mercury deposition ~~degrees~~ of 99.9 % can only be ensured when highly chlorinated waste is also incinerated in an appropriate proportion to the mercury load. Multistage wet scrubbing processes are typical of this type of plant~~. High proportions of ionic Hg (e.g.>99.9 %)~~

~~in the boiler crude flue-gas before wet gas cleaning are caused by including highly chlorinated waste. This assists~~ and these can achieve almost total mercury removal from the flue-gas.

High chlorine total loads (approximately 4 wt-% ~~w/w~~ input) and a therefore high interim Cl_2 supply lead to high mercury chlorination levels and mercury deposition of close to 100 %. With lower chlorine loads, the mercury deposition ~~degree~~ reduces rapidly.



Source: [1, UBA, 2001]

Figure 2.50: Relationship between fraction of mercury present in metallic form ~~emissions~~ and the raw gas' chloride content at a hazardous waste incineration plant

2.5.7 Techniques for the reduction of ~~other~~ emissions of other ~~heavy~~ metals

[1, UBA, 2001] Other heavy metals in incineration are converted mainly into non-volatile oxides and deposited with fly~~ue~~ ash. Thus, the main techniques of relevance are, therefore, those applicable to dust removal (see Section 2.5.3).

Activated carbon is also ~~reported to be~~ used for reducing the emissions of other ~~heavy~~ metals emissions. [74, TWGComments, 2004]

2.5.8 Techniques for the reduction of emissions of organic carbon compounds

Effective combustion provides the most important means of reducing emissions to air of organic carbon compounds.

[1, UBA, 2001] Flue-gas from waste incineration plants can contain trace quantities of a very wide range of organic species including:

- halogenated aromatic hydrocarbons;
- polycyclic aromatic hydrocarbons (PAHs);
- benzene, toluene and xylene (BTX);
- polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF), (PCDD/F).

PCDD/F may form after the furnace from precursor compounds such as ~~. Precursor compounds are, for example,~~ polychlorinated biphenyls (PCBs), polychlorinated diphenylmethanes

(PCDM), chlorobenzenes and chlorohydroxybenzenes. ~~PCDD and PCDF~~ PCDD/F may also form in catalytic reactions of carbon or carbon compounds with inorganic chlorine compounds over metal oxides, e.g. copper. These reactions will occur especially on fly ash or filter dust at temperatures between 200 °C and 450 °C.

The following ~~three~~ mechanisms are believed to lead to the formation of PCDD/F ~~dioxin/furan~~ in waste incineration:

1. formation ~~of PCDD/F~~ from chlorinated hydrocarbons already in, or formed in, the furnace (such as chlorohydrobenzene or chlorobenzene);
2. *de novo* synthesis in the low temperature range (typically seen in boilers, dry ESPs);
3. incomplete destruction of the PCDD/F supplied with the waste.

Optimum flue-gas incineration largely destroys the precursor compounds. The formation of PCDD/F from the precursor compounds is therefore suppressed.

~~The emission limit value for the total of dioxins and furans in Directive 2000/76/EC is 0.1 ng I-TEQ/m³.~~ Adsorption processes and oxidising catalysts can be used to reduce PCDD/F emissions. ~~are available, amongst others, for achieving this value.~~ Oxidising catalysts are reported to also reduce NH_3 slip and CO emissions. [74, TWGComments, 2004]

Emissions of organic hydrocarbon compounds can also be reduced by further dust and aerosol deposition, since these pollutants preferably adsorb onto the fine fraction of dust, and by enforced flue-gas cooling (condensation).

2.5.8.1 Adsorption on activated carbon reagents in an entrained flow system

Activated carbon is injected into the gas flow. The carbon is filtered from the gas flow using bag filters. The activated carbon shows a high absorption efficiency for mercury as well as for PCDD/F.

Different types of activated carbon have different adsorption efficiencies. This is believed to be related to the specific nature of the carbon particles, which are, in turn, influenced by the manufacturing process.

2.5.8.2 SCR systems

SCR systems are used for NO_X reduction (see description in Section 2.5.5.2.2). They also destroy gaseous PCDD/F (not particle-bound) through catalytic oxidation; however, in this case, the SCR system must be designed accordingly, since it usually requires a bigger, multi-layer, SCR system than for just the de-NO_X function. Destruction efficiencies for PCDD/F of 98 % to 99.9 % are seen.

The main reactions involved are: [74, TWGComments, 2004]

$$C_{12}H_nC_{l8}\ nO_2 + (9 + 0.5\ n)\ O_2 => 12CO_2 + (n\text{-}4)H_2O + (8\text{-}n)HCl \text{ and}$$
$$C_{12}H_nC_{l8}\ nO + (9.5 + 0.5\ n)\ O_2 => 12CO_2 + (n\text{-}4)H_2O + (8\text{-}n)HCl$$

2.5.8.3 Catalytic bag filters

(Belgium 2002) Filter bags are either impregnated with a catalyst, or the catalyst is directly mixed with organic material in the production of fibres. Such filters have been used to reduce PCDD/F emissions as well as, in combination with a source of NH_3, to reduce NO_X.

Gaseous PCDD/F can be destroyed on the catalyst rather than adsorbed in carbon (as with carbon injection systems). The particle-bound PCDD/F fraction ~~can be~~ is removed by filtration. The catalyst has no effect on mercury and therefore it is generally necessary to implement additional techniques (such as activated carbon or sulphur reagent) to remove mercury ~~in order to meet the modern Emission Limit Value in air~~. [74, TWGComments, 2004]

The gas temperature entering the filter bags should be above 170–190 °C in order to have effective destruction of the PCDD/F and to prevent adsorption of PCDD/F in the media; the reference operating temperature for de-NO$_X$ is 180–210 °C. [74, TWGComments, 2004]

2.5.8.4 Reburning of carbon adsorbents

[55, EIPPCBsitevisits, 2002] Carbon is used to adsorb both PCDD/F ~~dioxins (~~and mercury~~)~~ at many waste incinerators. ~~Where processes have another outlet for the mercury that provides an adequate removal rate, (i.e. a greater rate than the input rate to avoid circulation and hence emission breakthrough) it is possible for the net dioxin emissions from the plant to be reduced by re-burning the adsorbed PCDD/F by re-injection into the furnace.~~ The net PCDD/F emissions from the incinerator can be reduced by feeding the spent carbon into the furnace which will reburn the adsorbed PCCD/F. However, this technique will also recycle the mercury so it can only be used where the FGC system has another means of mercury removal. Usually the additional mercury removal is provided by a low pH wet scrubbing system, but this will only be effective when the chlorine content in the waste is consistently high enough to ensure that mercury is present mainly in the ionic form. ~~Gas streams with low HCl concentration may not find there are sufficient mercury removal rates to use this process.~~

Examples of the application of this technique include the reburning of:

- static coke bed adsorbents;
- entrained flow activated carbon adsorbents;
- carbon-impregnated inserts used to adsorb dioxins in wet scrubbers and prevent ~~memory effects.~~ the emission of PCDD/F that has accumulated in the cold parts of the boiler and FGC system, especially during a cold start.

In some MS, local regulations do not allow reburning.

2.5.8.5 Use of carbon-impregnated plastics for PCDD/F adsorption

[58, Andersson, 2002] Plastics are widely used in the construction of flue-gas cleaning equipment due to their excellent corrosion resistance. PCDD/F is adsorbed on these plastics in wet scrubbers, where the typical operational temperature is 60–70 °C. If the temperature is increased by only a few degrees Celsius, or if the dioxin concentration in the gas is reduced, the absorbed PCDD/F can be desorbed to the gas phase, leading to increased ~~and increase~~ emissions to air. Lower chlorinated PCDD/F are subject to the highest desorption rate increase with respect to temperature rise. ~~These can lead to increased TEQ values downstream of wet scrubbers.~~

The addition of a tower packing in the scrubber that contains polypropylene embedded with carbon provides a means of selectively absorbing PCDD/F (mercury is not absorbed in the packing). This material becomes saturated after a certain period of time. Therefore the charged material can periodically be removed for disposal or, if permitted, burned in the furnace. [74, TWGComments, 2004]

With inlet concentrations of 6–10 ng TEQ/Nm^3, gas phase removal efficiencies in the range of 60–75 % are reported across a wet scrubber. This compares with 0–4 % without the impregnated packing material. The absorption efficiency is reported ~~not to decline~~ not to have declined over the test period (1 year). [58, Andersson, 2002]. [74, TWGComments, 2004]

This techniaque alone may have problems achieving the required PCDD/F emissions levels. However, it is useful to control the emissions coming from the PCDD/F wet scrubber desorbtion.

~~An installation, like the one reported above, achieves outlet concentration of 2 – 3 ng TEQ/Nm^3. which do not, on their own, comply with the 0.1 ng/Nm^3 requirement of Directive 2000/76/EC.~~ The technique can also be used in a more extensive tower packing installation and/or in combination with other PCDD/F removal processes. ~~subsequent up-stream or downstream dioxin FGT to provide overall PCDD/F compliance (also for start-up and with FGT devices in bypass).~~ [74, TWGComments, 2004]

2.5.8.6 Static bed filters

[1, UBA, 2001] Activated coke moving bed filters are used as a secondary FGC ~~cleaning~~ process in ~~the flue-gas of~~ municipal and hazardous waste incineration. ~~Using this adsorption system, it is possible to deposit~~ These filter beds can adsorb substances contained in the flue-gas at extremely low concentrations with high efficiency. Lignite coke produced in the hearth furnace coke process is used in moving bed absorbers.

Wet and dry coke beds are used in waste incineration. Wet systems have the addition of a countercurrent flow of water that washes the coke. In doing so, the reactor temperature is lowered and some of the accumulated pollutants are washed from the filter. When activated lignite is used in the place of coke/coal, it does not require the preheating of the flue-gas above the acid dew point and can even be effectively operated with 'wet' or water-saturated flue-gas. For this reason, an ~~the~~ activated lignite filter ~~absorber~~ can be placed directly downstream of ~~behind~~ a wet flue-gas scrubber. [64, TWGComments, 2003]

The flue-gases pass through a filling of grained hearth furnace coke (HFC – a fine coke of 1.25 mm to 5 mm). The HFC's depositing effect is essentially based upon mechanisms of adsorption and filtration. It can remove ~~is thus possible to deposit~~ residual quantities of almost all emission relevant flue-gas components~~, in particular, residual contents of~~ (e.g. hydrochloric acid, hydrofluoric acid, sulphur oxides and heavy metals (mercury)), ~~to~~ sometimes down to below the lower limit of detection ~~limit~~.

An essential feature of the moving bed system is its high efficiency with all emissions due to the large bulk of activated coke, so that variations from incineration and upstream flue-gas cleaning caused by operation will not cause disadvantageous effects.

The flue-gas is guided to the activated coke filling over a distributor bed equipped with a multitude of double funnels. The gas flows through them from the bottom to the top, while the HFC passes through the absorber from the top to the bottom. By this, an ideal distribution of the flue-gas over the whole cross-section of the absorber and an optimal utilisation of the absorber capacity are achieved with a minimum consumption of activated coke.

~~Operating results from plants of an industrial scale (municipal and hazardous waste incineration) have shown that the emission values, in particular for dioxins/furans, are well below the limit values of Directive EC 2000/76/EC~~.

Care is required with such processes, to ensure temperature and CO are well monitored and controlled, to prevent fires in the coke filter. ~~This~~ The filter may become saturated after a certain period of time and should then be disposed of and replaced.

2.5.8.7 Rapid quenching of flue-gases

This technique involves the use of a single stage or multistage water scrubber to cool flue-gases directly from their combustion temperature to below 100 ºC. The technique is used in some HWI. ~~The action of~~ Rapid quenching reduces the residence time of flue-gases in high temperature zones that may otherwise give rise to additional *de novo* PCDD/F synthesis.

The scrubber must be designed to cope with the high particulate (and other pollutant) loads that will be transferred to the scrubber water and ~~The scrubbers used are single or multi stage, with~~ the later stages are sometimes cooled to reduce evaporative water losses with the flue-gas.

A boiler is not used and energy recovery is limited to heat transfer from the hot scrubber liquors.

2.5.9 Reduction of greenhouse gases (CO_2, N_2O)

[1, UBA, 2001] There are essentially two ways of reducing greenhouse gas emissions:

- increase the efficiency of energy recovery and supply (see Sections 2.4 and 4.4);
- control CO_2 emissions using flue-gas treatment.

Production of sodium carbonate by reacting CO_2 in the flue-gases with NaOH is possible. This technique is discussed further in Section 6.5 on emerging techniques.

2.5.9.1 Prevention of nitrous oxide (N_2O) emissions

Emissions of nitrous oxide (N_2O) from waste incineration can arise from:

- use of lower combustion temperatures – typically this becomes significant ~~of interest~~ below 850 ºC;
- the use of SNCR for NO_X reduction (particularly where urea is the reagent chosen).

[71, JRC(IoE), 2003] The optimum temperature for the simultaneous minimisation of both NO_X and N_2O production is reported to be in the range of 850–900 °C. ~~Under conditions where the temperature in~~ When the post-combustion chamber temperature is above 900 ºC, the N_2O emissions are reported to be low. N_2O emissions from the use of SCR are also low. Thus, provided combustion temperatures are above 850 °C, in general, SNCR represents the only significant source of N_2O emissions at ~~modern~~ waste incinerators.

If not properly controlled, SNCR, especially with urea, can give rise to increased N_2O emissions ~~of nitrous oxide~~. Similarly, it is possible for N_2O ~~nitrous oxide~~ to be emitted from processes with sub-stoichiometric oxygen supply levels (e.g. gasification and pyrolysis ~~process~~) and also from fluidised bed furnaces operated under certain conditions. [74, TWGComments, 2004]

To avoid N_2O ~~nitrous oxide~~ emissions, the following techniques are used:

- reduction of SNCR reagent dosing by SNCR process optimisation;
- selecting optimised temperature window for SNCR reagent injection;
- utilisation of ammonia instead of urea in SNCR;
- use of flow modelling methods to optimise injection nozzle locations;
- designing to ensure effective gas/reagent mixing in the appropriate temperature zone;
- over-stoichiometric burnout zones to ensure oxidation of N_2O ~~nitrous oxide~~

~~2.5.10 Overview of flue-gas treatments applied at hazardous waste incinerators~~

[For the TWG: This and the following section are deleted as this information is in Chapter 3 (updated)]

~~This section provides an overview of the flue-gas treatment techniques that are applied in the Merchant HWI sector in Europe. For detailed descriptions of the FGC techniques themselves see earlier in this chapter.~~

~~[EURITS, 2002 #41]~~
~~After the steam generator or quench cooling, the flue-gases pass through the flue-gas cleaning section. In almost 40 % of the installations, this section starts with a **spray dryer** or a similar technique to cool the gases further, and to evaporate the waste water (in those installations that do not have water discharges). Other installations just have an **intermediate quench** step in order to reduce the flue-gas temperature for further treatment (e.g. 250 °C to 60 °C).~~

~~Different techniques are used to reduce the concentrations of polluting components in the flue-gases; these are described below.~~
~~Scrubber systems are used to reduce the acid components (e.g. as below Cl, S) in the flue-gases. Almost 80 % of the installations are equipped with an acidic and an alkali **wet scrubber** system, of which 30 % have an additional scrubber system for removal of specific components (e.g. Br, I, Hg). The remaining 20 % use a **dry scrubber** with lime injection or the injection of bicarbonate.~~

~~To decrease the amount of dust and heavy metals in the flue-gas, **Electrostatic Precipitators (ESPs)** and **bag-house filters** are used:~~

- ~~54 % of the installations are equipped with a dry ESP (one installation with a wet ESP)~~
- ~~70 % of the installations are equipped with a bag-house filter~~
- ~~25 % of the installations combine these two techniques~~
- ~~one installation is equipped with two bag-house filters installed.~~

~~ESPs systems are normally installed in the front end of wet scrubbers to reduce the solid input to the washing liquid, but not generally for dry or semi-dry treatment systems where bag filters are used. The bag filters themselves provide a dust control system.~~

~~To reduce the release of dioxins to air, the following techniques are used:~~

- ~~**activated carbon** (or an alternative reagent such as brown coal cokes) is injected before the bag-house filter (67 % of installations)~~
- ~~a **fixed-bed activated carbon filter** is used (17 % of installations); this can be either a dry or wet system and alternatively brown coal cokes can be used as a reagent~~
- ~~one installation uses a **Selective Catalytic Reduction (SCR)** specifically to reduce dioxins, as well as other organics and NO_X.~~

~~Installations with very quick quench cooling and no boiler system do not use additional dioxin abatement measures (8 %). The amount of dioxins in the flue-gases is very low due to the fast cooling process. If the flue-gases are fed to an ESP after the quench step, the temperature must be less than 220 °C in order to avoid dioxin reformation.~~

~~In order to reduce NO_X emissions:~~

- ~~29 % of the installations use **Selective Catalytic (SCR) or Selective Non Catalytic (SNCR) Reduction** (almost all in Germany)~~
- ~~three installations use an SNCR, and~~

- ~~four installation use an SCR.~~

~~58 % of installations already comply with the requirement in Directive 2000/76/EC for an ELV of 200 mg/Nm³ without applying a specific NO_X abatement technique. The remaining 42 % installations are not currently equipped with a dedicated NO_X removal system and do not yet comply with this ELV.~~

~~2.5.11 Flue-gas treatment for sludge incinerators~~

~~[2, infomil, 2002] The type of FGC systems used depends largely upon the composition of the waste, and will often be similar to those applied to municipal waste incinerators. However, special attention may be required for removing nitrogen oxides (NO_X) and mercury.~~

~~In two Dutch fluidised bed incineration plants, NO_X emissions are reduced by the injection of ammonia during the incineration process (SNCR). By using this system, it is possible to reduce a normal emission concentration level of NO_X emissions from 100 – 200 mg/Nm³ to less than 70 mg/Nm³.~~

~~During the sludge incineration process, mercury is mainly released in the metallic state. In municipal waste incineration, due to the larger concentration of chloride in municipal waste mercury is largely in the ionic state (mainly chloride).~~
~~Metallic mercury is more difficult to remove from the flue-gases than mercury in an ionic state. Techniques for the reduction of Hg emissions are described in Section 2.5.6.~~

2.6 Waste water treatment and control techniques

~~2.6.1 Potential sources of waste water~~

For the TWG: Information moved to Section 3.3.1 and to Section 3.3.2

~~[2, infomil, 2002]~~
~~Potential emissions sources to water from waste incineration plants are as follows:~~

- ~~**process waste water**~~

~~The process waste water from generally only arises to any significant degree from wet FGC systems. Other types of flue-gas cleaning systems (dry and semi-dry) do not usually give rise to any effluent. Measures can also be taken with wet systems so that the effluent arising is not discharged from the installation (see later).~~

- ~~**waste water from collection, treatment and (open air) storage of bottom ash**~~

~~This type of Waste water can be used as the water supply for de-slaggers, and therefore, normally so it will not need to be discharged. It is, however, important to have sufficient storage (and treatment) capacity, in order to be able to cope with fluctuations in storage levels, caused by rainfall. Generally, the treatment options for excess water are: discharge to an available process waste water treatment system; discharge to the local sewerage system; and/or special disposal. This type of waste water can be reused in the FGC system if the quality is suitable, generally after treatment by sedimentation, filtration etc.~~

- ~~**Boiler water other less specific process**~~

~~For example, Waste water from the water/steam cycle (resulting from the preparation of boiler feed-water, boiler drainage, and cooling water discharge). In many practical situations, these water flows can be reused in the incineration and flue-gas treatment process FGC system. (e.g. as make-up water) and therefore will not lead to emissions to the environment. However, the recycling of waste water to the FGC system is only possible in the case of semi-wet or wet system if the quality of waste water is suitable; otherwise the waste water is discharged (mainly due to the high salt content).~~

- ~~**sanitary waste water**~~

~~This originates from toilets, kitchens and cleaning. It is normally discharged to the sewerage system, for treatment in a communal waste water treatment plant. A septic tank may be used if. here is no other possibility. As this category of waste water is not specific for waste incineration, it is not discussed in this document.~~

- ~~**clean rainwater**~~

~~This arises from rain falling on non-polluted surfaces, such as roofs, service roads and parking places, etc. Normally this water is collected discharged by a "clean" water collection system and is discharged directly to the local surface water or via soakaways. Pretreatment may be required for rainwater from roads or parking areas.~~

- ~~**polluted rainwater**~~

~~This arises from rain falling on polluted surfaces, such as unloading activities etc). It is usually segregated from clean water and may be treated before use or discharge.~~

- ~~**used cooling water**~~

~~By far, the largest cooling capacity is required where water condenser cooling is used, i.e. for electricity production with a steam turbine. Depending on the design of the plant, various types of cooling water streams will need to be disposed of,:~~
~~These include:~~

- ~~water from convection cooling of the condenser, which is connected with the steam turbine~~
- ~~water drained off from an evaporation cooling water system, as used for condenser cooling~~
- ~~water from various other equipment parts which require cooling; waste chute, hydraulic systems, strippers, etc.~~

~~Because These cooling water streams are not specific for waste incineration, they are described in the discussed in the European 'Reference document on the application of Best Available Techniques to Industrial Cooling.~~

- ~~**condensed waste water from the partial pre-drying of sewage sludge**~~

~~This type of waste water is specific to sewage sludge incineration, although it does not arise in all cases as the steam generated during drying is sometimes evaporated with the incinerator flue-gas instead of being condensed. It generally has a high Chemical Oxygen Demand (COD) and contains substantial concentrations of N (mainly NH_3), as well as other pollutants that were originally present in the treated sludge. The high nitrogen content can form a bottleneck for treatment; in this case stripping of nitrogen may be used, although there may be a risk of fouling and additional energy requirements for its operation. A solution in this case may be recycling into the furnace, when the recovered ammonia solution (concentration approximately 10 %) can be used for SNCR de-NO_X feed.~~

2.6.2 ~~Basic~~ Design principles for waste water control

[2, infomil, 2002]
The following ~~basic~~ principles are applied to incineration waste water control:

1. Application of optimal incineration technology

Running an optimised incineration process, important in terms of stability of the incineration process, also provides an effective control of emissions to water where wet processes are used ~~(it is not relevant to other processes in respect of water releases because water releases do not generally arise from non-wet processes)~~. Incomplete incineration has a negative effect on the flue-gas and fly ash composition, by increasing the presence of organic compounds with a polluting and/or toxic character. This, in turn, can impact on the content of the scrubber effluent.

2. Reduction of water consumption and discharge of waste water

~~Some examples of~~ Measures which can be taken include: ~~to achieve this are:~~

- ~~maximisation of~~ recirculation of polluted waste water in wet or semi-wet FGC ~~flue-gas treatment~~ systems (~~the~~ e.g. wet scrubbers), ~~or semi-wet flue-gas treatment systems,~~ including effective process control ~~of process parameters, in order~~ to minimise ~~reduce the amount of~~ waste water ~~for~~ discharges;
- ~~additional~~ cooling of polluted waste water from wet FGC ~~flue-gas treatment~~ systems (see also condensing scrubbers in Section 2.4.4.5) which results in lower water losses to flue-gases and therefore ~~in~~ reduced water consumption; this design can eliminate cooling water consumption;
- application of waste-water-free FGC ~~flue-gas treatment~~ technology (e.g. semi-dry or dry sorption systems);
- use of boiler drain water as water supply for the scrubber;

- treatment of laboratory waste water in the scrubber;
- application of a waste-water-free bottom ash discharger; ~~de-slaggers~~
- use of leachate from ~~of~~ open-air bottom ash storage areas ~~for supply of~~ as feed water to the bottom ash discharger; ~~de-slaggers~~
- use of segregated drainage to enable direct discharge of clean rainwater from roofs and other clean surfaces;
- ~~use of segregated drainage and~~ use of roofed enclosures to reduce the exposed surface areas used for waste storage and handling ~~(i.e. roofed enclosures)~~.

3. Compliance with relevant water emission standards

Some process options will be greatly affected by local factors. An example ~~of this~~ is the discharge of salt effluent from scrubbers. While such discharges may be acceptable to marine environments, discharges to fresh watercourses require the consideration of dilution factors, etc. Such decisions may therefore cause fundamental changes to incineration process design, particularly the FGC system and effluent treatment selection.

4. Optimal operation of the water treatment systems

~~Discharges can only be reduced through the optimal operation of the treatment system.~~

Having sufficient storage capacity for the buffering of waste water storage can allow time for operators to react to disturbances in the process conditions and ensure an optimal operation of the waste water treatment system.

2.6.3 Influence of flue-gas cleaning ~~treatment~~ systems on waste water

[2, infomil, 2002]
The production of waste water depends on the type of FGC ~~flue-gas treatment~~ system selected. The following main FGC options are used:

1. dry flue-gas treatment;
2. semi-wet flue-gas treatment;
3. wet flue-gas treatment:
   a) with physical/chemical scrubber effluent treatment;
   b) with in-line scrubber effluent evaporation;
   c) with separate scrubber effluent evaporation;

Of these options, only option 3(a) has a waste water stream for discharge. Treatment options for the scrubber effluent from system 3(a) are discussed in the following sections, along with the techniques used to evaporate effluent (options 3b and 3c).

2.6.4 Processing of waste water from wet flue-gas treatment systems

The process waste water resulting from wet FGC ~~flue-gas treatment~~ contains a wide variety of polluting components. The amounts of waste water and concentrations depend on the composition of the waste and on the design of the wet flue-gas system. The recirculation of waste water in wet FGC systems can result in a substantial reduction in the amount of waste water, and as a consequence, in higher concentrations of pollutants.

Three main methods are applied, for treatment of the waste water from wet FGC ~~flue-gas treatment~~ systems:

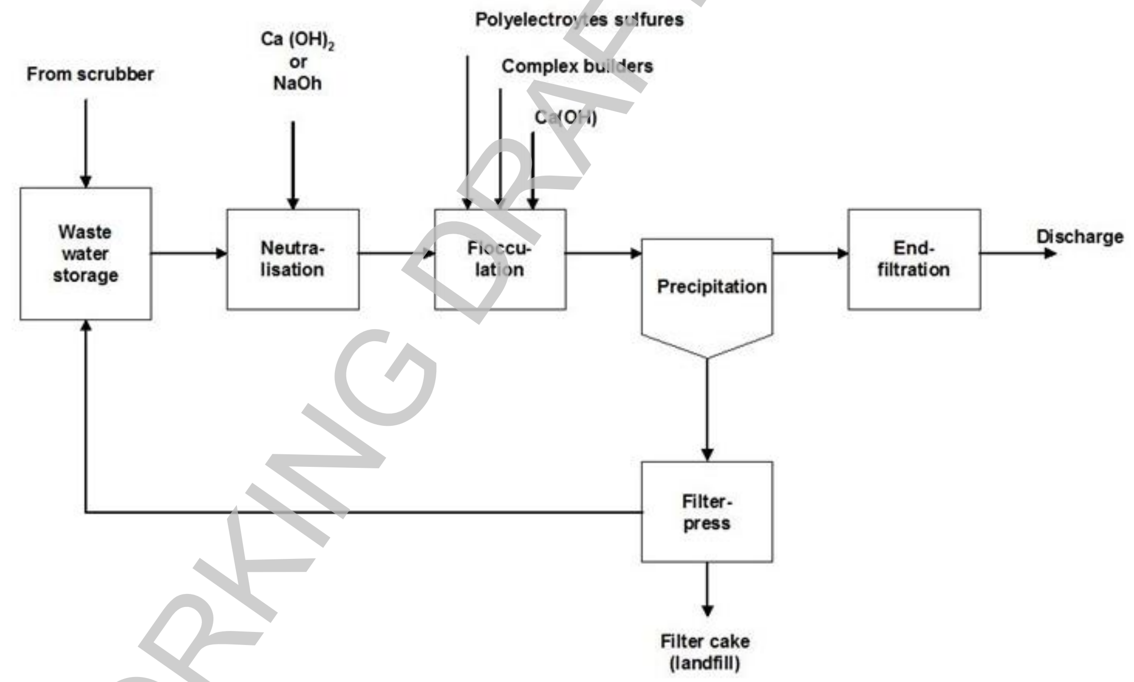
- **Physico-chemical treatment** based on pH correction and sedimentation. With this system, a treated waste water stream containing dissolved salts is produced and, if not evaporated (see below), requires discharge.
- **Evaporation in the waste incineration process line** by means of a spray dryer, into a semi-wet FGC system, or other system that uses a bag filter. In this case, the dissolved salts are incorporated in the residue of the FGC ~~flue-gas treatment~~ system. There is no emission of waste water, ~~other than that evaporated with the flue-gases~~ (for more detail on in-line evaporation see Section 2.6.4.7.1).
- **Separate evaporation** of waste water. In this case, the evaporated water is condensed, but as it is generally very clean can it often be discharged (or reused) without special measures. (for more detail on separate evaporation see Section 2.6.4.7.2).

These are discussed further in the following sections. Some of these techniques are also described in ~~the 'Best Available Techniques Reference Document for Common Waste and Waste Gas Treatment/Management Systems in the Chemical Sector' (the~~ CWW BREF~~),~~ published in 2016.

If SNCR is used for NO_X control with a downstream wet FGC system, the waste water will contain high levels of NH_3, which may require treatment by NH_3 stripping. [74, TWGComments, 2004]

2.6.4.1 Physico-chemical treatment

A typical set-up of a physico-chemical treatment unit for process waste water is given in Figure 2.51 below:



Source: [2, infomil, 2002]

Figure 2.51: Process scheme for physico-chemical treatment of waste water from a wet flue-gas treatment system

The processes ~~shown consists of the following~~ steps that can be used are: ~~some or all of these may be in use~~:

- pH control (neutralisation); ~~of the polluted waste water~~
- temperature control;
- flocculation of pollutants;
- settlement of the formed sludge;
- dewatering of the sludge;
- precipitation (e.g. of heavy metals);
- coagulation;
- filtration of the effluent (‘polishing’).

~~Other steps can also be included~~

- ~~precipitation (e.g. of heavy metals)~~
- ~~coagulation~~
- ~~pH and temperature control.~~

~~For the neutralisation,~~ Lime is often used for neutralisation and this results in the precipitation of sulphites and sulphates (gypsum). Where discharging of sulphites/sulphates to surface water is allowed (e.g. some marine environments), caustic soda (NaOH) can be used instead of lime, resulting in a substantially lower production of filter cake.

Removal of heavy metal compounds is based on flocculation, followed by precipitation. Heavy metal compounds have a very low solubility within a pH range of 9–11. Above a pH of 11 heavy metals can redissolve again. The optimal pH is different for various heavy metal compounds. In particular, the optimal pH for nickel and cadmium deviates from other heavy metals.

Two-step (or more) neutralisation improves the stability and control of discharge acidity (pH). The first step is a coarse neutralisation, especially in the case of waste water from the first acid step of the scrubber system. The second step is a fine neutralisation. The provision of sufficient waste water storage capacity helps to maintain a steady operating regime ~~reduce process variations in time,~~ by providing a buffering capacity.

The flocculation of heavy metal hydroxides takes place under the influence of flocculation agents (polyelectrolytes) and $FeCl_3$. The additional removal of mercury and other heavy metals can be achieved if complex-builders are added.

The precipitation of fluorides requires a pH range between 8 and 9. [74, TWGComments, 2004]

Precipitation generally takes place in settling tanks or in lamellar separators.

The resulting sludge is normally dewatered in filter presses. Dry solids contents of 40–60 % can be achieved, depending on the chemicals used and on other conditions.

If required, for filtration of the resulting effluent ('polishing'), sand filters and/or active carbon filters can be used. The direct effect of sand filters is mainly a reduction of suspended solids, but this also results in a reduction of heavy metal concentrations. Filtration with active carbon is especially effective for a reduction of PCDD/F ~~compounds~~, PAHs, etc. The active carbon needs to be replaced regularly. Other filtration systems are also used (e.g. disc filters).

Physico-chemical waste water treatment units require special operational attention, as they are ~~quite~~ sensitive systems.

2.6.4.2 Application of sulphides

In order to carry out flocculation, organic agents (e.g. polyelectrolytes) are commonly used. The addition of complex-builders and sulphides (e.g. Na_2S, tri-Mercaptan - TMT) allows further reductions in mercury and other heavy metal discharges.

The use of sulphides requires special safety regulations because of their toxicity. One advantage of their use is the lower costs of sulphides in comparison with other complex-builders.

2.6.4.3 Application of membrane technology

One option for treatment of waste water polluted with salts and micro-pollutants is membrane filtration. This technique is especially efficient for large water flows with relatively low salt concentrations. With higher salt concentrations, energy consumption increases rapidly.

The salt content of the process waste water of waste incineration is high (up to 10 wt-%). Therefore, this option usually requires significant additional energy consumption.

The remaining water with high solute concentration has to be removed ~~in~~ via an appropriate outlet. [74, TWGComments, 2004]

2.6.4.4 Stripping of ammonia

For the application of SNCR de-NO_X, the waste water from the wet scrubber contains ammonia compounds. The actual ammonia concentration depends on the process conditions of the SNCR de-NO_X unit. Depending on the actual ammonia concentration, stripping of ammonia from the effluent may be an option.

An ammonia-stripping unit consists mainly of a heated distillation column. The vapours are condensed, resulting in an ammonia solution. Though the ammonia concentration is normally below the original concentration of the trade product, the solution can be reused in the SNCR process.

Stripping of ammonia requires an increase in the pH to 11–12.5 and the use of steam. Fouling risks are reported when used with lime neutralisation.

2.6.4.5 Separate treatment of waste water from the first and ~~the~~ last steps of the scrubber system

The first step(s) of wet scrubber systems are typically operated at a very low pH level. Under these process conditions, specifically HCl is removed from the flue-gas stream. The removal of SO_2 takes place in the final step, at a neutral pH.

If these two effluent streams are dealt with separately, the waste water treatment process can be optimised for each stream and recyclable gypsum can be recovered from the SO_2 scrubber effluent.

The waste water from the first step of the scrubber is neutralised with lime, followed by removal of heavy metal compounds by ~~normal~~ flocculation and precipitation. The treated waste water, containing mainly $CaCl_2$, is mixed with the waste water from the final step, mainly containing $Na_2SO_{3/4}$. This results in the formation of gypsum and a liquid effluent, mainly consisting of NaCl.

Depending on local conditions, this salty waste water is either discharged or evaporated. Evaporation results in the production of NaCl~~, household salt~~.

Because the salt is separated from other flue-gas treatment residues contained in the effluent, this results in a very substantial reduction in the mass of residues - the precipitated sludge of heavy metal compounds is the only residue which remains.

2.6.4.6 Anaerobic biological treatment (conversion of sulphates into elementary sulphur)

One of the problems with discharging the treated waste water may be the remaining content of sulphates. Sulphates can affect concrete sewerage systems. To solve this problem, a system has been developed for anaerobic biological treatment of waste water from waste incineration.

The sulphates in the waste water can be reduced to sulphides in a reactor, by the activity of anaerobic bacteria. The effluent of this reactor, which has a high content of sulphides, is treated in a second reactor. In this second reactor, the sulphides are biologically oxidised in an aerobic atmosphere into elemental sulphur. Care must be taken to ensure that adequate oxygen is available in the aerobic stage, otherwise thiosulphate will be produced instead of elemental sulphur and this will restrict disposal of the waste water.

Subsequently the sulphur is removed from the waste water in a laminated separator. The collected sludge is dewatered in a decanter, resulting in a sulphur cake, which can be used. The remaining waste water can be reused in the scrubber and/or discharged.

It is reported that this technology may be difficult to apply in hazardous waste incineration ~~field~~ [64, TWGComments, 2003]. [*For the TWG: please provide more information on these difficulties*]

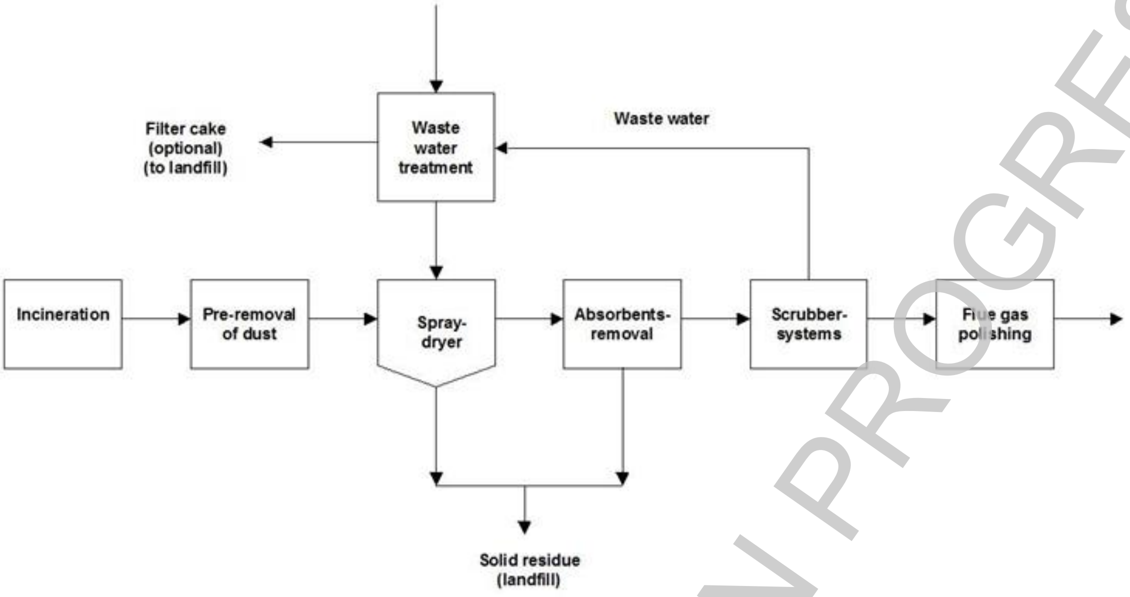
2.6.4.7 Evaporation systems for process waste water

If the discharge of soluble salts (chlorides) is not acceptable, the process waste water needs to be evaporated. For this purpose two main options exist:

- in-line evaporation;
- separate evaporation.

2.6.4.7.1 In-line evaporation

In this configuration, the waste water is recycled in the process by means of a spray dryer. Figure 2.52 below gives an overview of the process configuration.



Source: [2, infomil, 2002]

Figure 2.52: In-line evaporation of waste water from wet scrubbing

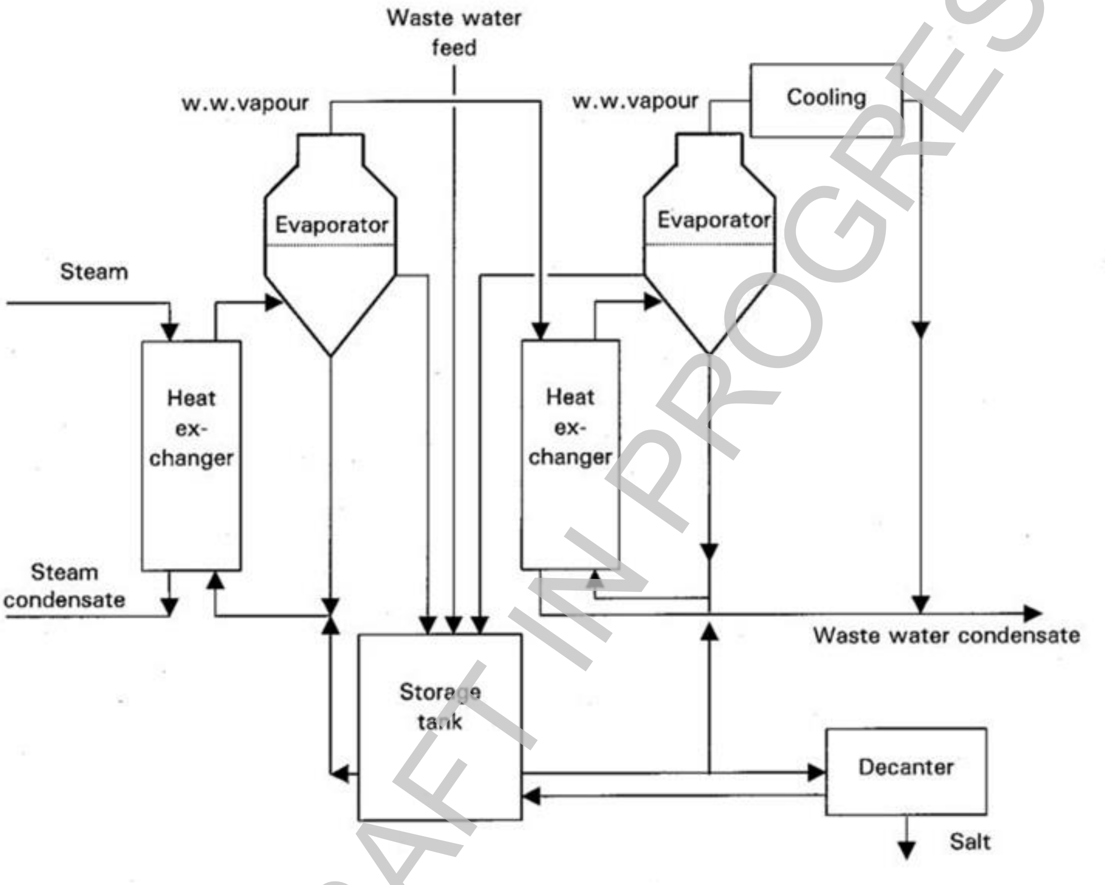
The spray dryer is comparable with the spray absorber used in the semi-wet FGC system. The difference is that, in the case of semi-wet treatment, lime is injected and, for in-line evaporation, the waste water from the scrubber is used for injection after a neutralisation step. This neutralisation step can be combined with flocculation and the settling of pollutants, resulting in a separate residue (filter cake). In some applications, lime is injected in the spray absorber for gas pre-neutralisation.

The neutralised waste water, containing soluble salts, is injected in the flue-gas stream. The water evaporates and the remaining salts and other solid pollutants are removed in a dust removal step (e.g. ESP or bag filter). This flue-gas treatment residue consists of a mixture of fly ash, salts and heavy metals.

Due to the application of a wet scrubbing system, the consumption of chemicals is approximately stoichiometric and consequently residue production is lower than in semi-dry FGC systems.

2.6.4.7.2 Separate evaporation

Separate evaporation is based on evaporation in steam-heated evaporation systems. Figure 2.53 below gives an example of a process scheme.



Source: [2, infomil, 2002]

Figure 2.53: Separate evaporation of scrubber effluent from wet scrubbing

The waste water, containing soluble salts, is fed into a storage tank containing a mixture of waste water and already partially evaporated liquid. Subsequently, the water is partly evaporated in a reactor under low pressure. The required heat is supplied by (low-pressure) steam and transferred to the liquid in a heat exchanger. The surplus liquid flows back to the storage tank. The vapours are cooled down, resulting in a clean condensate, which is then discharged.

Due to the increasing salt concentrations in the liquid, crystallisation of salts begins. Subsequently, the salt crystals are separated in a decanter and collected in a container.

Figure 2.53 shows a two-stage process, where two evaporators are installed. The input of heat for the second evaporator is from the first evaporator, thus reducing the specific energy consumption. Additionally, if not used for some other purpose (e.g. district heating), the effective energy consumption may be reduced as low-pressure steam can be used.

This technique requires energy and there may be operational risks such as fouling of the crystallisation. [64, TWGComments, 2003]

2.6.4.8 ~~Example of process producing~~ Stripping or evaporation of hydrochloric acid ~~with downstream cleaning~~

[1, UBA, 2001]
When wastes containing chlorine are combusted, hydrogen chloride is formed. Hydrogen chloride is absorbed in water, forming hydrochloric acid. The resulting hydrochloric acid ~~produced like this~~ is a colourless liquid and free of impurities after treatment. It is an aqueous solution with ~~has~~ a concentration of approximately 19 wt-% HCl and can be used as a raw material in different consumer installations, e.g. for pH control in chlorine-producing plants.

In the production of hydrochloric acid, the flue-gases leaving the steam boiler are first discharged into a quench and cooled down. The quench unit lining contains jets through which hydrochloric acid from the downstream washing column is sprayed into the flue-gas. A portion of the hydrochloric acid is then evaporated, which causes the flue-gases to cool down.

The hydrochloric acid is transferred from the quench to the washing column together with the cooled flue-gas. In the washing column, hydrogen chloride and other acid gases contained in the flue-gas are absorbed. The hydrochloric acid is then transferred to a temporary storage tank. The flue-gas, now stripped of hydrogen chloride, leaves the acid washing column via a mist eliminator installed at the head of the column and enters the ionisation wet scrubber.

The hydrochloric acid generated in the acid washing column of the flue-gas washing system is stripped of dissolved salts and solids in an evaporator system. This cleaning step can enable the hydrochloric acid to be used as feedstock in a variety of production plants.

From the temporary storage tank, a pump transfers the hydrochloric acid to an evaporator. Here, the raw acid is upgraded in a vacuum to become an azeotropic mixture. The excess water and small amounts of hydrogen chloride pass into the vapour phase and are condensed with water in an adsorption tower.

From the vacuum unit, the process liquid is pumped into the waste water plant together with the excess water. The raw acid, upgraded to an azeotrope, will evaporate and then condense again. The remaining acid containing solids and heavy metals is drawn from the evaporator and pumped into a mixer for neutralisation purposes.
[64, TWGComments, 2003]

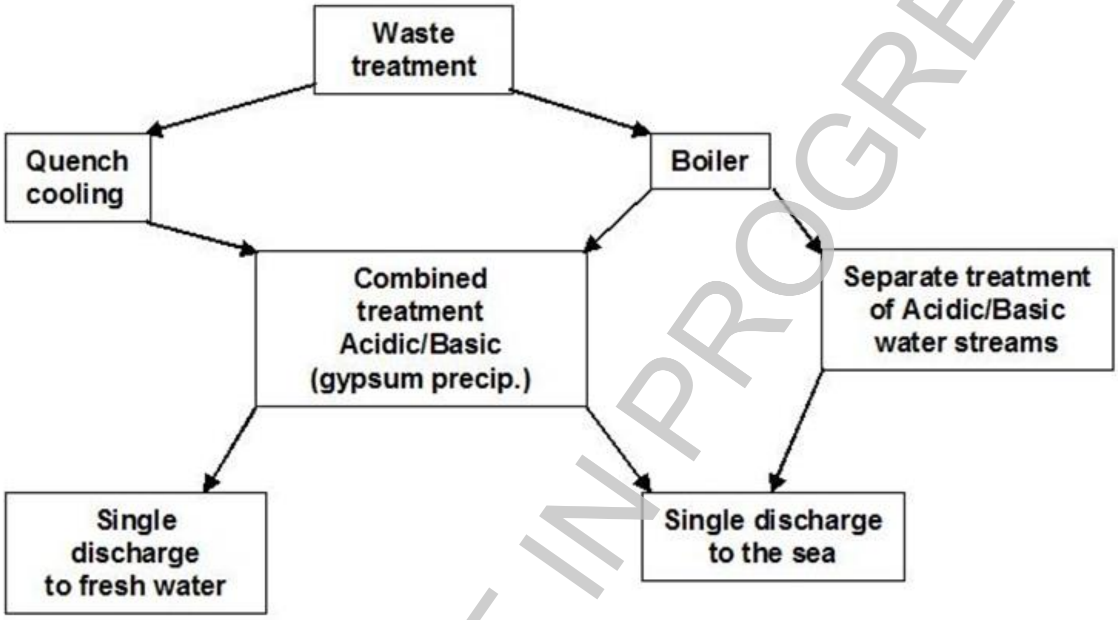
2.6.5 Waste water treatment at hazardous waste incinerators

Of the European HWI installations, 55 % do not discharge waste water; they either use systems that do not generate waste water (e.g. dry or semi-dry FGC) or evaporate the water via the stack by means of spray dryers or in a separate evaporation plant, sometimes after treating the waste water to remove mercury [74, TWGComments, 2004] [*to the TWG: please update if necessary*]

The remaining 45 % of the HWI installations have a waste water treatment facility, typically as ~~The current situation is~~ described in Figure 2.54 below, and can be summarised as follows.

A general distinction can be made between the incinerators equipped with a boiler and ~~the other HWI installations~~ those equipped with a quick quench-cooling system, with the flow of discharged effluent being greater for the latter due to technical reasons. (Note: some HWI installations are equipped with both a quick quench-cooling system and a boiler) [74, TWGComments, 2004]. Installations equipped with a boiler discharge between < 1 l/kg and 5 l/kg incinerated waste. Installations with only quench-cooling systems discharge between 10 l/kg and 20 l/kg incinerated waste, although they can reduce their water flow to 5 l/kg by recirculating the effluent of the waste water treatment plant or recycling within the quench unit itself.

Normally the effluents of the acidic section of the wet gas cleaning (containing NaCl, $CaCl_2$, Hg, CaF_2 and SO_3) are mixed with the effluent of the alkaline section (containing Na_2SO_4) in order to precipitate part of the gypsum (and to decrease the sulphate content of the effluent to less than 2 g/l, which is the solubility concentration of gypsum) before further treatment. There is, however, one installation where the effluents of acidic and alkali scrubbers are treated separately.



Source: [EURITS, 2002 #41]

Figure 2.54: Overview of applied waste water treatment systems at merchant HWIs

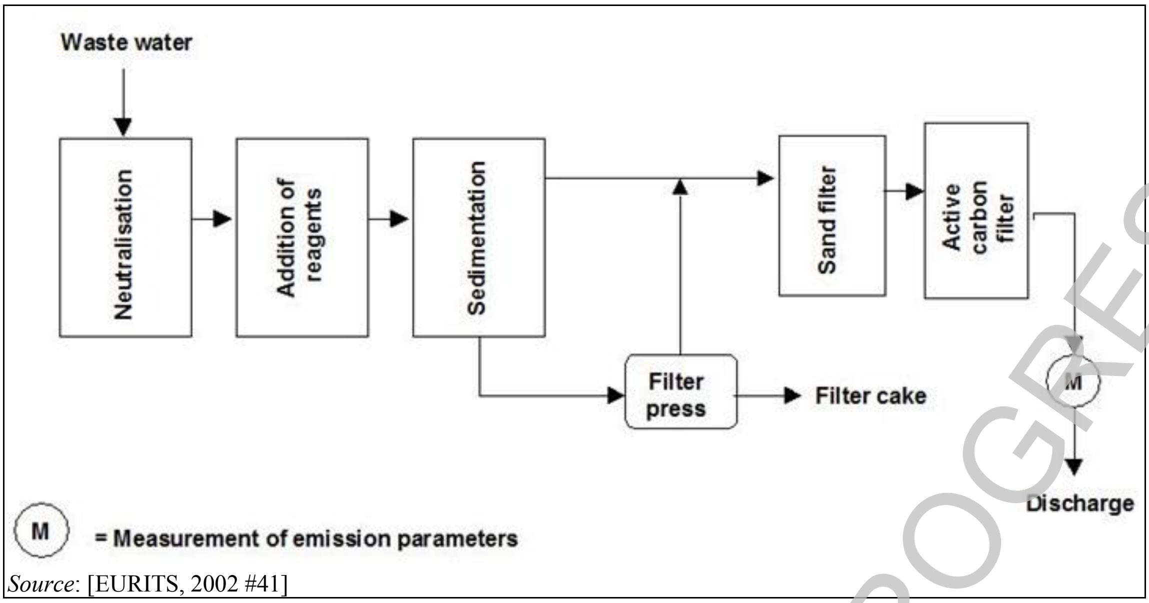
Whether an installation has an on-site waste water treatment plant or transfers the waste water to an external treatment plant depends on its location.

Figure 2.55 below gives a typical set-up of a waste water treatment plant for the treatment of effluents from the wet flue-gas cleaning section of hazardous waste incineration.

The main elements of these facilities are:

- neutralisation (e.g. addition of lime, NaOH/HCl);
- the addition of reagents specifically for the precipitation of metals as hydroxides or metal sulphides (e.g. flocculation agents, tri-mercapto-tri-azine, sulphides, polyelectrolytes);
- the removal of sediment: either using sedimentation by gravity and decantation, or using mechanical techniques such as filter press, centrifuge.

In some waste water treatment plants, the waste water is polished by passing it through **a sand filter**, followed by an **activated carbon filter**.



Source: [EURITS, 2002 #41]

Figure 2.55: Example of a waste water treatment facility in the merchant HWI sector

2.7 Solid residue treatment and control techniques

2.7.1 Types of solid residues

Waste incineration creates ~~results in~~ various types of solid residues:

- **bottom ash** is the solid residue removed from the combustion chamber after the waste has been incinerated;
- **fluidised bed ash** is the solid residue removed from the fluidised bed after the waste has been incinerated;
- **slag** is the solid melted residue removed from the combustion chamber after the waste has been incinerated;
- **fly ash** is the particles from the combustion chamber or formed within the flue-gas stream that is transported in the flue-gas;
- **boiler ash** is the part of the fly ash that is removed from the boiler;
- **exhausted catalyst** is the used catalyst that has been replaced;
- **sludge** is the solid residue remouved from the wet scrubber or from the waste water treatment plant.

~~, some of which have uses in~~ certain ~~different countries to varying degrees. A distinction can be made between those residues directly resulting from the incineration process and those resulting from the Flue-gas Cleaning (FGC) system. The FGC residues may be fine fly ash and/or reaction products and unreacted additives from the FGC system (or associated waste water treatment system). The term Flue-gas Cleaning (FGC) residues is used in this BREF, but elsewhere they are The latter category is often called Flue-gas Treatment (FGT) or Air Pollution Control (APC) residues. The solid residues from (wet) scrubber effluent treatment processes are often pressed to form a solid filter cake. called a *filter cake* or mixed with fly ash to minimise volume or for better dewatering with gypsum from the plant. [74, TWGComments, 2004] In addition gypsum and salt may be recovered from wet flue-gas~~ cleaning ~~treatment systems if specific processes are used (see below and Section 2.6). [64, TWGComments, 2003]~~

2.7.1.1 Residues arising directly from the incineration process ~~from the combustion stage of the incinerator are:~~

These residues are as follows:

<u>Municipal waste incineration</u>

- **Bottom ash**. ~~resulting from grate incineration~~ This is an important residue of municipal waste incineration because of the large volume produced. ~~of municipal waste. Because of its large volume, this is an important type of residue, Options for its use are discussed in Section 0.~~ Most MWIs use a wet discharge system for bottom ash. It is referred to as fresh bottom ash when first removed from the incinerator, raw bottom ash while awaiting treatment and aged bottom ash when it has been treated, then stored for a period of time. [75, FEAD, 2014]
- **Siftings** (or riddlings) are particles that have fallen through the grate during incineration. Usually they are fed again to the furnace.
- **Fly ash.** ~~It is collected in a dust removal step in municipal waste incineration and is discussed further below under FGC residues.~~ This type of waste is generally disposed of, often after pretreatment, but has been used as a filling material for bitumen-bound applications in civil construction, in countries where this practice is permitted. [74, TWGComments, 2004] Treatment and disposal are further discussed below.
- **Boiler ash** is ~~collected in the boiler of municipal waste incineration plants and may be~~ often treated together with fly ash. [74, TWGComments, 2004]

Hazardous waste and specific clinical waste incineration

- **Slag** ~~resulting from rotary kiln incineration of hazardous wastes. In general, this type of residue~~ is disposed of by landfill without further treatment, or may be recycled if locally permitted.
- ~~**other**~~ **Fly ash** is ~~are~~ similar to those from MSWI but because ~~in as they~~ it may contain higher levels of pollutants it is generally been disposed of. ~~general the practice has been mostly for their disposal.~~

Sewage sludge incineration

- **Fly ash** ~~resulting from fluidised bed incineration of sewage sludge. This type of waste~~ can be used without further treatment as a filling material for bound applications in civil construction, in countries where this practice is permitted. In Germany it is also used ~~as a filling material~~ for back filling of mines ~~in Germany, both applications without further treatment~~. Unused fly ash ~~which is not used~~ is landfilled.
- **Fluidised bed-ash** ~~resulting from fluidised bed incineration of sewage sludge. This is a relatively small category. It~~ The quantity produced is relatively small and is often added to the fly ash or landfilled without further treatment.

RDF

- **Fluidised bed ash** ~~resulting from fluidised bed incineration of RDF~~. Depending on the specific characteristics of the material, fluidised bed ash amounts may be substantially higher than for sewage sludge incineration. There is little experience of its reuse.
- **Fly ash** resulting from small- and medium-scale incineration of waste wood. ~~This concerns relatively small quantities~~ The quantity produced is relatively small and is not discussed further.

Some installations operate at especially high temperatures (e.g. > 1 400 °C) with the specific aim of melting the bottom ash ~~in order~~ to form a slag which has ~~. Such slags may have~~ improved use options owing to lower leachability, etc. High-temperature slagging rotary kilns and combined gasification-combustion process provide examples of such systems. The latter is used in Japan, where very strict leachability criteria are applied to MSWI residues, specifically to increase residue reuse and reduce the need for landfill.

Both within and beyond Europe there are variations in policy and procedures regarding the reuse of residues from incinerators. [74, TWGComments, 2004]

2.7.1.2 Residues arising from the FGC system~~: The second category of residues are the FGC residues:~~

FGC residues are a mixture of the pollutants originally present in the flue-gas and the substances that are used to remove those pollutants. FGC residues contain concentrated amounts of pollutants (e.g. hazardous compounds and salts) and therefore are not normally considered suitable ~~appropriate~~ for recycling ~~purposes~~. The main objective is then to find an environmentally safe final disposal option. The following types of flue-gas cleaning ~~treatment~~ residues can be distinguished:

- **Residues from dry and semi-wet flue-gas treatment**~~. These residue~~ are a mixture of calcium and/or sodium salts, mainly as chlorides and sulphites/sulphates. There are also some fluorides and unreacted reagent chemicals (e.g. lime or sodium carbonate). This mixture also includes some fly ash that has not been removed by any preceding dust removal step. It can, therefore, also include polluting heavy metals and PCDD/F. The normal way of disposal is landfilling as hazardous waste, often in big bags. ~~(e.g. *big bags*).~~ The leachability of the residues is an important parameter for ~~aspect for subsequent~~ landfill disposal. ~~, therefore~~ Various treatments can be applied to lower the leachability ~~of these residues~~ prior to landfilling and these are described in the WT BREF. ~~is currently used in Europe (e.g. Austria, the Netherlands, Portugal, France)~~. The FGC residues coming from the dry sodium bicarbonate process can be purified and recycled ~~in an industrial process, e.g.~~ ~~asraw material in the chemical industry, this can require segregation of fly ash and salt residues using (e.g. two stages of flue-gas filtration) in order to reduce the inert content. The transport to the end-user can be a critical factor for economies~~. [74, TWGComments, 2004]

- ~~improvement of the properties for landfilling by cold solidification~~
- **Sludge** ~~**filter cake**~~ from the physico-chemical treatment of waste water from wet flue-gas treatment~~. This material~~ is characterised by a very high heavy metals content, but can also include salts of limited solubility, such as gypsum. The normal way of disposal is landfilling (as hazardous waste). These residues may contain high levels of ~~be concentrated in~~ PCCD/F and are therefore sometimes pretreated before landfilling.
- **Gypsum** may also be recovered with or without cleaning depending on the process parameters and quality requirements. Recovery ~~of gypsum~~ is possible when limestone or hydrated lime is used in a two stage wet scrubber with an efficient droplet separator. [74, TWGComments, 2004] The recovered gypsum can be recycled in some circumstances. (*to the TWG: please provide more information*)
- **Salts** resulting from in-line evaporation of waste water. This residue is comparable with the residue from (semi-)dry flue-gas treatment
- **Salts** resulting from separate evaporation of waste water. Salt use or disposal depends on the composition of the residue. It is usually purer than where in-line evaporation has been carried out.
- **Residues from dry sorbent injection** ~~**flue-gas polishing**~~. Options for use depend on the adsorbent used (activated carbon, cokes, lime, sodium bicarbonate, zeolite). The residue of (activated) carbon from fixed bed reactors is sometimes ~~permitted to be~~ incinerated ~~in the~~ a waste incineration plant ~~itself~~, if the incineration plant is able to destroy and/or retain the pollutants contained ~~certain process conditions are fulfilled~~. The residue of entrained bed systems can also be incinerated, if the applied adsorbent is activated carbon or oven cokes only. If a mixture of other reagents and activated carbon is used, the residue is generally sent for external treatment or disposal, since there might be risks of corrosion. ~~If zeolite is used, there are in principle possibilities to recover the mercury, but these techniques are not yet available in practice. [2, infomil, 2002] [64, TWGComments, 2003]~~
- ~~use as filler material in salt mines – in some MSs FGC residues of various types are used as fill material in mines.~~

2.7.2 Treatment and recycling of solid residues

The high mineral content of incineration ash residues can make them potentially suitable for use as road or other construction material. Use is possible if the material complies with a set of environmental and technical criteria. This requires an optimisation of the ash quality through primary or secondary measures. The general parameters of concern are:

- burnout;
- mineral reactivity;
- metal leaching;
- salt content;
- particle size and particle size distribution.

After suitable treatment, residues from many modern waste incineration plants fulfil the environmental and technical requirements for these quality parameters. Regulatory and political barriers sometimes provide the main barriers to the use of (in particular) bottom ashes from suitably designed/operated installations.

Residue treatment methods generally aim to optimise one or more of these parameters in order to mimic primary construction material quality. Due to its large production volume, lower hazardous character and leachability, treatment for recycling is mainly applied to MSW bottom ash. Bottom ash use is promoted in the Netherlands (> 90 % used), Denmark (90 %), Germany (80 %), France (> 70 %), Belgium and the UK (21 %). Bottom ash treatment techniques are described in Section 4.7. Bottom ash can be used above ground as a building material. There are strong seasonal and regional variations in the volumes that can be used for different building applications. Bottom ash can also be used underground as backfilling material to provide long-term safe support in old mine workings.
[Vehlow, 2002 #38], [Vrancken, 2001 #39], [56, UKEnvAgency, 2002], [64, TWGComments, 2003], [74, TWGComments, 2004]. [82, Germany 2014]
[*For the TWG: Please provide up-to-date information on bottom ash use in Member States*]

~~Filter~~ Fly and boiler ash treatment is performed in only a few installations in Europe. In the Netherlands, fly ash from MSWI and SSI plants is applied as filling material for road construction materials (asphalt) without any pretreatment at the incineration plant. About a third of the total fly ash from MSWI plants and 80 % of the fly ash from SSI plants (approximately 80 000 tonnes yearly in total) has been used in this way. [74, TWGComments, 2004]. Fly and boiler ash treatment techniques are covered in the WT BREF.
[*For the TWG: Please provide up-to-date information*]

Primary measures for controlling residue outputs involve optimising control of the combustion process in order to [Vehlow, 2002 #38]:

- guarantee an excellent burnout of carbon compounds;
- promote the volatilisation of heavy metals such as mercury and cadmium out of the fuel bed; and
- fix lithophilic elements in the bottom ash, thus reducing their leachability.

Secondary treatment systems involve one or more of the following actions:

- size reduction, to allow metal segregation and improve technical quality;
- segregation of ferrous and non-ferrous metals, which may be recycled in the metals industry;
- separation of unburned elements and returning them to the incinerator;
- washing, in order to remove soluble salts;
- ageing (carbonatation), to stabilise the matrix structure and reduce the reactivity;
- treatment with a hydraulic or hydrocarbon binder, for reuse as road base;
- thermal treatment, to make and contain inert metals in a glassy matrix.

Both primary and secondary measures will be discussed in more detail in Section 4.7.

2.7.3 Treatments applied to flue-gas cleaning ~~treatment~~ residues

The treatments that can be applied to FGC residues are described in the WT BREF.

The thermal treatment of incineration residues takes place extensively in a few countries, mainly to reduce the volume of the residues, but also to reduce its organic and heavy metal content and to improve the leaching behaviour before landfilling. Sometimes FGC residues and bottom ash are mixed together for thermal treatment. [74, TWGComments, 2004]

The three categories of thermal treatment are vitrification, melting and sintering. The differences between these processes are chiefly related to the characteristics and properties of the final product. The flue-gas produced from thermal treatment of solid residues may contain high levels of pollutants such as NO_X, TOC, SO_X, dust and heavy metals so appropriate flue-gas treatment is required. Sometimes the flue-gas produced is fed into the FGC system of the incinerator if it located nearby. [74, TWGComments, 2004]

~~The information in this section is taken from [48, ISWA, 2003]. Further details of the techniques that fall within each of the categories of treatment given below can be found in Section 4.7~~

~~2.7.3.1 Solidification and chemical stabilisation of FGC residues~~

~~The main purpose of solidification is to produce a material with physical and mechanical properties that promote a reduction in contaminant release from the residue matrix. An addition of cement, for example, generally decreases hydraulic conductivity and porosity of the residue, and, on the other hand increases durability, strength and volume. In addition, it usually increases the alkalinity of the mixture, therefore improving the leaching behaviour of the product, although the solubility of amphoteric metals, such as lead and zinc, may be result increased.~~

~~The solidified product is usually cast into blocks (e.g. 1 m^3) or landfilled directly. A major consideration here is to reduce the interaction between the water and the residue. According to Swiss studies, this only influences the leaching behaviour of landfilled products over the first few years of storage.~~

~~Solidification methods commonly make use of several, mostly inorganic, binder reagents: cement, lime and other pozzolanic materials such as coal fly ash, blast furnace bottom ash or cement kiln dust, although some organic binders such as bitumen/asphalt or paraffin and polyethylene can also be used. Combinations of binders and various types of proprietary or non-proprietary additives are used as well. The most prevalent solidification technique is by far cement stabilisation.~~

~~The main concept of chemical stabilisation is to bind the heavy metals in more insoluble forms than they are present in the original untreated residues. These stabilisation methods make use of both the precipitation of metals in new minerals as well as the binding of metals to minerals by sorption. This process includes the solubilisation of the heavy metals in the residues and a subsequent precipitation in, or sorption to, new minerals.~~

~~Several of the stabilisation methods incorporate an initial washing step where a major part of soluble salts and to some extent metals are extracted before chemical binding of the remaining metals. These methods can be completed by dewatering the stabilised product and removal of organic compounds.~~
~~[74, TWGComments, 2004]~~

~~2.7.3.2 Thermal treatment of FGC residues~~

~~The thermal treatment of incineration residues (sometimes FGC residues and bottom ash are mixed together for treatment) takes place extensively in a few countries, mainly to reduce volume of the residues, but also to reduce its organic and heavy metal content and to improve the leaching behaviour before landfilling. [74, TWGComments, 2004]~~
~~Thermal treatment can be grouped into three categories: vitrification, melting and sintering. The differences between these processes are chiefly related to the characteristics and properties of the final product:~~

- ~~**Vitrification** is a process where residues are treated at high temperature (currently 1300 to 1500 °C and then quickly quenched (with air or water) to obtain an amorphous glassy matrix. After cooling down, the melt forms a single phase product called a vitrificate. The vitrificate can be a glass like or stone like product depending on the melt composition.~~

~~Additives are sometimes used added to the residues to favour the formation of the glassy matrix [64, TWGComments, 2003]~~

- ~~**Melting** is similar to vitrifying, but the quenching step is controlled to allow crystallisation of the melt as much as possible. It results in a multi-phase product. Temperatures and the possible separations of specific metal phases are similar to those used in vitrifying. It is also possible to use add specific additives to favour the crystallisation of the matrix. [64, TWGComments, 2003]~~

- ~~**Sintering** involves the heating of residues to a level where bonding of particles occurs and the chemical phases in the residues reconfigure. This leads to a denser product with less porosity and a higher strength than the original product. Typical temperatures are around 900 °C. When MSW is incinerated, some level of sintering will typically take place in the incineration furnace. This is especially the case if a rotary kiln is used. as part of the incineration process.~~

~~Regardless of the actual process, the thermal treatment of residues in most cases results in a more homogeneous, denser product with improved leaching properties. Vitrifying also adds the benefits of physical containment of contaminants in the glass matrix.~~

~~The energy requirements of stand alone treatments of this type, are generally very high. The main problem is the heat transfer transport into the melting reactor. [74, TWGComments, 2004] In some cases residue melting is achieved within the installation (i.e. not in a separate melting process) using a higher temperature combustion stage (see 2.3.4.4.3). In such cases the energy demand is partially met by the use of the flue-gas thermal energy and external energy input requirements may be reduced.~~

~~The flue-gas produced issued from thermal treatment of solid residues may contains high levels of pollutants such as $\mathrm{NO_X}$, TOC, $\mathrm{SO_X}$, dust and heavy metals etc. Therefore appropriate flue-gas treatment is required. Sometimes the flue-gas produced is fed into the FGC of the incinerator if nearby. [74, TWGComments, 2004]~~

~~The high salt concentrations in FGC residues can cause corrosion problems in the flue-gas treatment from such processes. Sintering is not used as a dedicated treatment option for FGC residues, although some combined treatments do involve this.~~

~~2.7.3.3 Extraction and separation of FGC residues~~

~~Treatment options using extraction and separation processes can, in principle, cover all types of processes extracting specific components from the residues. However, most emphasis has been put on processes involving an extraction of heavy metals and salts with acid.~~

~~Several techniques have been proposed both in Europe and in Japan. Most of these techniques make use of the acidic solution from the first scrubber in wet FGC systems.~~

~~2.7.3.4 Chemical stabilisation of FGC residues~~

~~The main concept of chemical stabilisation is to bind the heavy metals in more insoluble forms than they are present in the original untreated residues. These stabilisation methods make use of both the precipitation of metals in new minerals as well as the binding of metals to minerals by sorption. This process includes the solubilisation of the heavy metals in the residues and a subsequent precipitation in, or sorption to, new minerals.~~

~~Several of the stabilisation methods incorporate an initial washing step where a major part of soluble salts and to some extent metals are extracted before chemical binding of the remaining metals. These methods are completed by dewatering the stabilised product.~~

~~2.7.3.5 Other methods or practices for FGT residues~~

~~A commonly used management option at incinerators with wet cleaning systems is to combine the fly ash with the sludge produced by treating the scrubber solutions; the resulting product is called a Bamberg cake~~ ~~*Bamberg cake*. Sulphides in the sludge used in the waste water treatment facility to precipitate heavy metals can further help decrease leachability of heavy metals from the Bamberg cake in a landfill. This method has been used for more than a decade to improve residue properties before landfilling.~~

~~It is also possible to contact the fly ash with the acidic waters of a scrubber. It is reported that this can achieve very significant extraction of the heavy metal and organic components. [74, TWGComments, 2004]~~

~~2.8 Monitoring and control techniques~~

For the TWG: This section has been deletetd because techniques used to monitor emissions to air and water are described in the JRC Reference Report on Monitoring of Emissions to Air and Water from IED installations (ROM). Information on how the emissions are monitored (AMS, Spot sampling) is in Chapter 3. Information related to the PCDD/F and Hg monitoring costs has been moved to Annex 8.2 and the information contained in Section 2.8.1 "Incineration control systems" is already in Section 4.3.6.

~~2.8.1 Incineration control systems~~

~~[2, infomil, 2002]~~
~~One of the main challenges with waste incineration results from the often is the wide variation in waste composition, including differences in some properties that have a significant effect on the incineration process. Because of these wide differences, incineration processes have been developed to cope with large variations in process conditions. However, when unfavourable process conditions occur, interventions in the operation are still required.~~

~~The introduction of sophisticated control systems is, therefore, an important development. These systems result in an incineration process that has less variations in time (improved stability) and space (more homogeneous). The improved process control has many potential advantages, such as (note: the main reason(s) for the improvement are given in parentheses):~~

- ~~better bottom ash quality (due to sufficient primary air distribution and a better positioning of the incineration process on the grate)~~
- ~~less fly ash production (due to less variations in the amount of primary incineration air)~~
- ~~better fly ash quality (less unburned material, due to more stable process conditions in the furnace)~~
- ~~less CO and C_xH_y formation (due to more stable process conditions in the furnace; i.e. no 'cold' spots)~~
- ~~less NO_X formation (due to more stable process conditions in the furnace; i.e. no 'hot' spots)~~
- ~~better utilisation of the capacity (because the loss of thermal capacity by variations is reduced)~~
- ~~better energy efficiency (because the average amount of incineration air is reduced)~~
- ~~better boiler operation (because the temperature is more stable, there are fewer less temperature 'peaks' and thus less risk of corrosion and clogging fly ash formations)~~
- ~~better operation of the flue-gas treatment system (because the amount and the composition of the flue-gases is more stable)~~
- ~~the indicated advantages also result in less maintenance and better plant availability.~~

~~In order to be able to control the incineration process, detailed process information is required, a control system ('philosophy') must be designed, and it is necessary to be able to intervene in the process. Design of the overall control system depends on the specific grate and furnace design of each supplier. Therefore, this section only provides an overview of potential process information, control philosophy systems and process interventions.~~

~~Process information may include:~~

- ~~grate temperatures for various positions~~
- ~~thickness of waste layer on the grate~~
- ~~pressure drop over the grate~~
- ~~furnace and flue-gas temperatures at various positions~~
- ~~determination of temperature distribution over the grate surface by optic or infrared measurement systems~~
- ~~CO-, O_2-, CO_2- and/or H_2O-measurements (at various positions)~~

- ~~steam production.~~

~~The control philosophy may be a classic control system, which is part of the process control computer. Additionally, fuzzy control systems are applicable.~~

~~Control interventions include:~~

- ~~the dosing system for the waste~~
- ~~frequencies and speed of grate movements in various parts of the grate~~
- ~~amount and distribution of primary air at the various grate compartments~~
- ~~temperature of the primary air (if preheating facilities are available)~~
- ~~amount and distribution of secondary air in the furnace (and, if available, of recirculated flue-gas).~~

~~2.8.2 Overview of emissions monitoring carried out~~

~~General information on emissions monitoring is presented in the BREF "Reference Document on the General Principles of Monitoring" (MON code).~~

~~[1, UBA, 2001]~~
~~The recent EU directive (2000/76/EC) on the incineration of waste includes requirements for emissions measurement.~~

~~The following emission compounds are to be measured on a continuous basis:~~

- ~~dust~~
- ~~HCl~~
- ~~SO_2~~
- ~~CO~~
- ~~C_xH_y~~
- ~~NO_X (if emission standards apply)~~
- ~~HF (but not if the process ensures adequate HCl removal)~~

~~Continuous measurements are not imperative for HCl, HF and SO_2, where the process is such that it is not possible that emission standards to be exceeded. (Art.11 (6) of EU Directive 2000/76/EC).~~

~~Additionally, the following process parameters need to be monitored continuously:~~

- ~~furnace temperature~~
- ~~O_2~~
- ~~pressure~~
- ~~flue-gas outlet temperature~~
- ~~water vapour content (unless emission measurements are executed in dried flue-gas).~~

~~Other emission compounds to be measured on a regular basis base (minimum of 2 – 4 times per year) are:~~

- ~~heavy metals~~
- ~~PCDD/F.~~

~~Measurement techniques for Mercury (Hg) and dioxins (PCDD/F's) are relatively complicated and expensive.~~

~~Measurements of mercury are more complicated than measurements of other heavy metals, as a substantial part of the emitted mercury is in the gaseous state. Some analysers measure only elemental mercury, and others can measure total mercury (e.g. ionic and elemental mercury). In the last decade, measurement systems for mercury have become more sophisticated. Older measurements were often unreliable, as the gaseous part of the mercury emission was neglected. Continuous measurement of Hg has proven to be a reliable method within certain borders and it is prescribed in some national legislations (e.g. in Germany and in Austria).~~

~~While there is not currently a continuous measurement system for dioxins. However, a continuous sampling system is available. This system is operational in some waste incineration plants in Austria and Belgium and has been operated for six months in a Dutch hazardous waste incineration plant. Samples can be analysed as frequent as necessary or desirable.~~

~~In some cases actual impacts of the emissions may be assessed by bio-monitoring (e.g. with lichen). Although it may be difficult to attribute impacts to individual sources, such monitoring may make a useful contribution in respect of the assessment of combined impacts where there are multiple sources.~~
~~[74, TWGComments, 2004]~~

~~2.8.3 Experiences with continuous sampling of dioxin PCDD/F emissions~~

~~(Belgium 2002)~~
~~According to the EN1948 standard, dioxin emissions from waste incinerators are sampled during 6 to 8 hours. This measurement is generally carried out once or twice a year, although at much greater frequencies in some cases.~~

~~Continuous sampling has proven to be useful for the assessment of dioxin emissions during unfavourable process conditions. The technique has been used to demonstrate low PCDD/F emissions over the entire range of operational conditions. The results can also be used to guide technological improvements, revised monitoring requirements, or other changes.~~

~~Cost data for continuous sampling of dioxins (from Indaver):~~

~~Investment:~~	~~EUR 110 000 - 140 000~~
~~Testing of the system:~~	~~EUR 4 900 (estimation)~~
~~Analysis (26 samples/yr):~~	~~EUR 20 000/yr~~
~~Maintenance by the supplier (preventive):~~	~~EUR 2 500/yr~~

~~2.8.4 Experiences with continuous measurement of mercury emissions~~

~~Continuous measurement and recording of emissions of mercury and its compounds has been required by law for waste incineration installations in Germany since 1999, except those installations where it can be reliably proven that mercury levels are less than 20 % of the defined limits.~~

~~Continuous monitoring of a HWI is also reported to have been carried out since 1992 using a reduction unit and cold vapour instrument.~~

~~The standard reference method for comparative measurements during calibration is the potassium permanganate method in accordance with EN 13211. It should be noted that this method determines the total mercury content (i.e. metallic/elemental Hg + ionic Hg), while some Hg analysers only detect the proportion of metallic mercury.~~

~~During the test, the instrument is calibrated using test gases. The test gases must be produced immediately before being used (e.g. by setting the required gas pressure in the gas phase over a mercury reactor). When using test gas, it may be necessary to take the cycle time of the~~

~~measuring device into consideration. In the same way, the sampling interval for the comparative measurements must be adjusted to the enrichment phase for the measurement device.~~

~~Examples of suitability-tested continuous working measuring devices for emission measurements of mercury are listed in the table below:~~

~~**Suitable measurement devices**~~		~~**Announcement in the GMBl**~~		
~~**Type**~~	~~**Manufacturer/Distribution**~~	~~**Year**~~	~~**No.**~~	~~**Page**~~
~~OPSIS AR 602 Z~~	~~OPSIS AB~~	~~1994~~	~~289~~	~~869~~
		~~1996~~	~~42~~	~~882~~
~~HG MAT II~~	~~Seefelder Messtechnik~~	~~1995~~	~~7~~	~~101~~
~~HGMAT 2.1~~	~~Seefelder Messtechnik~~	~~1998~~	~~20~~	~~418~~
~~HM 1400~~	~~VEREWA~~	~~1996~~	~~28~~	~~592~~
~~HG 2000~~	~~SEMTECH AB~~	~~1996~~	~~28~~	~~592~~
~~MERCEM~~	~~Bodenseewerk Perkin-Elmer~~	~~1996~~	~~28~~	~~592~~
~~SM 3 Quecksilbermonitor~~	~~Mercury Instrument und IMT Innovative Messtechnik~~	~~1999~~	~~33~~	~~720~~
~~Hg 2010~~	~~SEMTECH AB~~	~~2000~~	~~60~~	~~1193~~
~~Hg-CEM~~	~~Seefelder Messtechnik~~	~~2000~~	~~60~~	~~1193~~
~~HM 1400 TR~~	~~VEREWA~~	~~2001~~	~~19~~	~~386~~
~~MERCEM~~	~~SICK UPA~~	~~2001~~	~~19~~	~~386~~

~~**Table 2.23: Tested continuous working measuring devices for emission measurements of mercury**~~

~~**[64, TWGComments, 2003]**~~

~~Cost data for continuous measurement of mercury (estimated):~~
~~Investment: EUR 30 000~~
~~Testing of system: EUR 5 000~~

2.8 ~~Overview of~~ Safety devices and measures

This section deals with safety in the sense of preventing accidents that could give rise to pollutant emissions.

[64, TWGComments, 2003]
Plant safety is an important aspect in the planning, establishment and operation of waste incineration plants. To ensure a high level of plant safety and operational safety, the safety-relevant parts of the installation are equipped with protective systems. These are to prevent, as far as possible, the occurrence of malfunctions or accidents with the potential to cause negative effects on the environment in the vicinity of the plant, or to reduce such effects if a malfunction or accident occurs.

Safety-relevant parts of waste incineration plants and, therefore, potential sources of danger include, in particular, areas in which certain substances are present or can be formed in safety-relevant quantities.

These are, in particular:

- the waste bunker and other areas for the storage of potentially hazardous waste;
- the combustion and flue-gas purification plants; and
- storage facilities for necessary auxiliaries (e.g. ammonia, activated carbon).

Protective systems used to control risks include:

- systems for controlling the release of pollutants, such as retention systems for used fire-fighting water, bunding of tanks for substances constituting a hazard to water;
- fire protection systems and devices such as fire walls, fire detectors, fire extinguishing systems;
- systems for protection against explosions, such as pressure relief systems, bypasses, arrangements for avoiding sources of ignition, inert gas systems, earthing systems.
- systems for protection against sabotage (e.g. building security, access control and surveillance measures);
- fire dividing walls to separate the transformers and retention devices;
- fire detection and protection where low-voltage power distribution panels are located;
- pollutant detection (ammonia, gas etc.) near corresponding storage, distribution etc.;
- ~~systems for protection against lightning strike~~
- systems for protection against environmental hazards (e.g. flooding, strong winds, lightning strikes and extreme hot and cold weather).

Other plant components required for operational safety:

- Machines and equipment designed to ensure input and output of energy (e.g. emergency power generator).
- Components for the discharge, removal or retention of hazardous substances or mixtures of hazardous substances, such as holding tanks, emergency relief and emptying systems.
- Warning, alarm and safety systems, which trigger when there is a disruption of normal operations, prevent a disruption of normal operations or restore normal operations. This includes all instrumentation and control systems of a plant. In particular, it includes all instrumentation and control systems for the various process parameters which are essential to secure normal operations, on the one hand, and which, in the event of a disturbance, bring the affected plant components to a safe condition and inform the operating personnel of the disturbance in good time, on the other.

The response of a protective device to a malfunction or an accident may cause a temporary increase in pollutant emissions. The aim of all safety measures must be to keep this time span to a minimum and to restore the safety of the plant.
[64, TWGComments, 2003]

3 CURRENT EMISSION~~S~~ AND CONSUMPTION~~S~~ LEVELS

This chapter provides information on the current ranges of consumption and emission levels from the WI sector covering the scope of processes described in Chapter 2. The information is detailed, where considered relevant and subject to data availability, by the main types of incinerated waste that are taken into consideration. The environmental issues already described in Chapter 2 are further supported by data in this chapter, and key environmental issues are identified.

The main environmental issues for the sector are emissions to air and recovery of energy. Emissions to water are a less prominent issue.

Emission and consumption data in this chapter are mainly derived from the general data collected at individual sites in 15 Member States and in Norway and provided to support this document. Other sources of aggregated data and site-specific data were received from Member States and Industry and are also included in this chapter. Data presented in this chapter are intended to illustrate the current emission levels found in the sector, with the related consumption levels for energy and water, and including data and details on the wastes used as well as the residues produced.

3.1 Introduction

Emissions and consumption at waste incinerators are mainly influenced by:

- waste composition and content;
- furnace technical measures (design and operation);
- design and operation of flue-gas cleaning equipment.

Emissions to air
Emissions of HCl, HF, SO_2, NO_X and ~~heavy~~ metals depend mainly on the structure of the waste and the flue-gas cleaning quality. CO and VOC emissions are determined primarily by furnace technical parameters and the degree of waste heterogeneity when it reaches the combustion stage. The furnace design and operation also affect NO_X to a large extent. Dust emissions are very dependent upon flue-gas cleaning ~~treatment~~ performance. PCDD/F emissions to air depend on waste structure, furnace (temperature and residence times) and plant operating conditions (reformation and *de novo* synthesis ~~are possible~~ ~~under certain conditions~~) and flue-gas cleaning performance.

Municipal waste incineration plants generally produce flue-gas volumes (at 11 % oxygen) of between 4 500 m^3 and 6 000 m^3 per tonne of waste. For hazardous waste incineration plants, this value (at 11 % oxygen) is generally between 6 500 m^3 and 10 000 m^3, depending mainly on the average thermal value of the waste. Plants using pyrolysis, gasification or oxygen-enriched air supply produce lower flue-gas volumes per tonne of waste incinerated.

The emission levels to air noted in this document are reported over specified averaging periods – usually yearly ~~annual~~, daily and half-hourly averages. Some installations, particularly those that treat highly heterogeneous wastes, may experience transient conditions that give rise to instantaneous emission concentrations that are outside of the numerical range of the averaged levels. [64, TWGComments, 2003]

Emissions to water
Depending on the type of flue-gas cleaning applied, emissions ~~in~~to ~~the medium water~~ may also occur. Wet flue-gas cleaning is the main source of effluents, although in some cases this effluent is also eliminated by evaporation.

Some other waste water streams may arise from storage, boilers, etc. These have already been described in Section 2.6.1.

Solid residues

Solid residues that may arise are:

- bottom ash or slag~~ – mainly the incombustible fraction of the waste~~;
- ~~boiler ash – the ash that accumulates and is removed from the boiler~~
- fly ash~~ – the light ash that travels with the flue-gas and is then removed by FGT equipment~~;
- flue-gas cleaning ~~air pollution control~~ residues ~~accumulated, reacted and un-reacted that are accumulated in the FGT equipment~~;
- waste water treatment residues.

(For longer descriptions see Chapter 2.7.1.)

[64, TWGComments, 2003]

The production and content of these solid residues is influenced by:

- waste content and composition, e.g. different ash contents influence ~~vary~~ the amount of bottom ash arising, ~~or different~~ and the content of substances such as chlorine or sulphur ~~that will end up in~~ will have an influence on the flue-gas cleaning residues;
- furnace design and operation, e.g. pyrolysis plants deliberately produce a char in place of the ash, and higher temperature furnaces may sinter or vitrify the ash and volatilise some fractions;
- flue-gas treatment design and operation, e.g. some systems separate dusts from chemical residues, wet systems produce an effluent for treatment to extract solids.

Energy output from the installation

The major influences on the achieved export levels are:

- availability of an energy user (particularly for heat/steam supply);
- installation design (particularly for electrical output where the steam parameters chosen for electricity generation have a significant influence on electricity generation rates).

The energy output system design adopted is often heavily influenced by the income to be derived from the sales of the energy supplied. Relative and absolute prices of heat, steam and electricity all have an influence on the final design and hence the energy output and efficiency levels achieved.

Energy consumption by the installation itself

The main influences are as follows:

- The waste composition - some wastes require the use of a support fuel to ensure complete combustion while ~~addition of fuels to assist their treatment~~ others are auto-thermal, i.e. they generate sufficient heat to support the combustion without additional support fuel input.
- The design of the installation, e.g. varying energy requirements of different flue-gas cleaning ~~treatment~~ equipment designs. In general, the lower the required emissions to air the higher the energy consumption by the FGC system.

Other consumption

The consumption of chemical reagents is mainly associated with the design and operation of flue-gas cleaning equipment – which, to a large degree, is dependent upon the waste type and the desired air emission levels – lower emissions to air generally require higher reagent dosing rates.

3.1.1 Substance partitioning in waste incineration

[1, UBA, 2001]
As a result of their chemical properties, the different elements contained in the waste are distributed differently in the incineration process. Table 3.1 gives an example of this distribution on the basis of Austrian studies ~~examinations~~ at the waste incineration plant of Spittelau, Vienna.

This distribution varies from plant to plant, depending on the flue-gas cleaning method used, waste type and other factors, but these figures provide a guide to the percentage distribution of various substances in a MSWI. The installation concerned uses an ESP as a pre-deduster, before wet FGC, with a~~n~~ WWTP ~~ETP~~ treating the scrubber effluent.

Table 3.1: Distribution of various substances in an example MSWI installation (in mass %)

Substance	Cleaned flue-gas discharge	ESP dust	Waste water	Filter cake from waste water treatment	Bottom ash (2)(3)
Carbon (%)	98 (+/-2)	< 1	< 1	< 1	1.5 (+/-0.2)
Chlorine (%)	< 1	35	54	< 1	11
Fluorine (%)	< 1	15 (+/-1)	<1	< 1	84 (+/-1)
Sulphur (%)	< 1	38 (+/-6)	8 (+/-1)	6 (+/-1)	47 (+/-7)
Phosphor (%)	< 1	17 (+/-1)	< 1	< 1	83 (+/-1)
Iron (1) (%)	< 1	1 (+/-0.5)	< 1	< 1	18 (+/-2)
Copper (%)	< 1	6 (+/-1)	< 1	< 1	94 (+/-1)
Lead (%)	< 1	28 (+/-5)	< 1	< 1	72 (+/-5)
Zinc (%)	< 1	54 (+/-3)	< 1	< 1	46 (+/-3)
Cadmium (%)	< 1	90 (+/-2)	< 1	< 1	9 (+/-1)
Mercury (%)	< 1	30 (+/-3)	< 1	65 (+/-5)	5 (+/-1)

(1) The remaining approx. 80 % are sorted out as scrap.
(2) The bio-availability of materials that remain in the bottom ash depends on leachability in situ during subsequent use/disposal.
(3) The risk associated with the reuse of bottom ash is not necessarily indicated by the presence or absence of the substances indicated – the chemical and physical form of the substance as well as the nature of the environment where the material will be used is also important. [64, TWGComments, 2003]
Sources: [1, UBA, 2001], [64, TWGComments, 2003]

[*For the TWG: Please provide up-to-date information for Table 3.1.*]

Additional differences result from different contents of waste, especially in the case of hazardous waste incineration facilities.

Table 3.2 gives the percentage distribution of six ~~heavy~~ metals, mercury, cadmium, arsenic, lead, copper and zinc, averaged over a test period in a HWI. The table also gives the mass fraction of the following solid residues: slag, fly ash and sludge ~~filter cake~~, related to the amount of waste incinerated during the test.

Table 3.2: Percentage (%) distribution of heavy metals in a hazardous waste incineration process

Heavy metal	Solid residues for disposal					Release to environment				
	Slag	Fly ash	Sludge ~~Filter-cake~~	Sum	Act. carbon	To air	Water effluent	~~Water landfill~~	~~To land~~	Sum
% Mass fraction	30	3	4							
Hg	< 0.01	< 0.01	99.88	99.88	0.05	< 0.01	0.07	~~0~~	~~0~~	0.07
Cd	1.3	94.2	4.49	99.99	< 0.01	< 0.01	< 0.01	~~0~~	~~0~~	< 0.01
As	14.6	80.0	5.39	99.99	< 0.01	< 0.01	< 0.01	~~0~~	~~0~~	< 0.01
Pb	41.2	56.0	2.75	99.95	< 0.01	0.03	0.02	~~0~~	~~0~~	0.05
Cu	75.9	22.4	1.69	99.99	< 0.01	< 0.01	0.01	~~0~~	~~0~~	0.01
Zn	41.9	56.9	1.17	99.97	< 0.01	0.01	0.02	~~0~~	~~0~~	0.03
Source: [41, EURITS, 2002]										

The most important parameters that influence the behaviour of metals are:

- kiln temperature;
- O_2 excess in the kiln;
- the chlorine and sulphur contents of the waste; and
- the mass transfer of fine particles in the flue-gas.

The average conditions during the tests on a HWI that gave rise to the data inTable 3.2 are given below in Table 3.3.

Table 3.3: Average operational conditions during partitioning tests on a HWI installation

Parameter	Test data
Kiln temperature	1 120 ± 40 °C
PCC temperature	1 100 ± 20 °C
Oxygen content (in the kiln)	11.9 ± 1.3 %
Cl content (in the waste)	5.1 ± 1.0 %
S content (in the waste)	1.0 ± 0.2 %
Source: [41, EURITS, 2002]	

From Table 3.2, the following observations regarding the metals studied can be made:

- about 99.6 % of the pollutants are concentrated in the solid residues;
- about 70–80 % of the pollutants are concentrated and immobilised in the fly ash and sludge ~~filter-cake~~ fraction; both residues amount in weight to approximately 7 % of the original waste input;
- the removal of mercury from the flue-gas is (in this case) mainly the result of the low pH of the first flue-gas cleaning stage.

3.1.2 Examples of the dioxin balance for MSWI

[1, UBA, 2001]
PCDD/F is contained in the input (municipal waste) as well as the output (outgoing air, waste water and residues) of municipal waste incineration plants. Most of the PCDD/F input is destroyed during the incineration process but ~~it~~ can also be reformed.

The balance below is for a typical plant in Germany, operating free of process water releases and complying with German emission limit values.

Table 3.4: PCDD/F balance for a municipal waste incineration plant in Germany

Output streams	Amount per kg of waste input	Specific load	Stream-specific load ~~account stream~~ per kg of waste input
Flue-gas	6.0 m^3	0.08 ng/m^3	0.48 ng/kg
Bottom ash	0.25 kg	7.0 ng/kg	1.75 ng/kg
~~Waste water~~	~~0~~	~~n/a~~	~~0~~
Filter dust and other residues from flue-gas cleaning	0.07 kg	220 ng/kg	15.40 ng/kg
Total output to all media:	17.63 ng TEQ/kg of waste		
NB: Estimated input with the waste: 50 ng TEQ/kg of waste. *Sources:* [1, UBA, 2001], [64, TWGComments, 2003]			

[For the TWG: Please provide up-to-date information for Table 3.4.]

From Table 3.4 above it can be seen that, for the example given, the estimated output released to air is approximately 1 % of the input (0.48 ng TEQ/kg out of 50 ng TEQ/kg). The estimated output released to all media is 17.63 ng TEQ/kg of incoming waste. This corresponds to 35.3 % of the estimated input (i.e. a net destruction of 64.7 % of the PCDD/F originally contained in the waste). It can therefore be concluded that, in this case, the installation acts as a net sink for PCDD/F. [64, TWGComments, 2003]

Other data from a 1997 study (French Ministry of Environment/TIRU) of eight MSWIs and two HWIs showed significant variation in residue PCDD/F content:

bottom ash:	0.3–300 ng I-TEQ/kg;
boiler ash:	40–700 ng I-TEQ/kg;
fly ash:	60–5 000 ng I-TEQ/kg;
filter cake (wet FGC):	600–30 000 ng I-TEQ/kg;
semi-wet FGC residues:	800 ng I-TEQ/kg (approximately).

Where data show variation to the extent indicated in the bullets above, it is more difficult to draw conclusions regarding the overall mass balance of PCDD/F.
[64, TWGComments, 2003]

The following data are an example of a MSWI (in France) operating with a release to water.

Table 3.5: Example PCDD/F load data for an MSWI in France

Output stream	Specific Load
Flue-gas	0.1 ng I-TEQ/Nm^3
Bottom ash	7 ng I-TEQ/kg
FGC residues	5 200 ng I-TEQ/kg
Waste water	< 0.3 ng I-TEQ/l
NB: Example ~~given is~~ for a MSWI ~~with FGC of~~ fitted with ESP + wet scrubber (2-stage) + SCR. *Source:* [64, TWGComments, 2003]	

3.1.3 Composition of crude flue-gas in waste incineration plants

The composition of crude flue-gas in waste incineration plants depends on the structure of the waste and on furnace technical parameters.

Table 3.6 provides an overview of typical crude flue-gas concentrations after the boiler and before the flue-gas treatment.

Table 3.6: Flue-gas concentrations after the boiler (crude flue-gas) at various waste incineration plants (O_2 reference value 11 %)

Components	Units	Incineration plants for		
		Municipal waste	Hazardous waste	Industrial sewage sludge (fluidised bed)
Dust	mg/Nm^3	1 000–5 000	1 000–10 000	30 000–200 000
Carbon monoxide (CO)	mg/Nm^3	5–50	< 30	5–50
TOC	mg/Nm^3	1–10	1–10	1–10
PCDD/F	ng TEQ/ Nm^3	0.5–10	0.5–10	0.1–10
Mercury	mg/Nm^3	0.05–0.5	0.05–3	0.2
Cadmium + thallium	mg/Nm^3	< 3	< 5	2.5
Other heavy metals (Pb, Sb, As, Cr, Co, Cu, Mn, Ni, V, Sn)	mg/Nm^3	< 50	<100	800
Inorganic chlorine compounds (as HCl)	mg/Nm^3	500–2 000	3 000–100 000	NI
Inorganic fluorine compounds (as HF)	mg/Nm^3	5–20	50–550	NI
Sulphur compounds, total of SO_2/SO_3, counted as SO_2	mg/Nm^3	200–1 000	1 500–50 000	NI
Nitrogen oxides, counted as NO_2	mg/Nm^3	250–500	100–1500	<200
Nitrous oxide	mg/Nm^3	< 40	< 20	10–150
CO_2	%	5–10	5–8	NI
Water steam (H_2O)	%	10–20	6–20	NI

NB:
Sewage sludge plants are those for the incineration of industrial sewage sludge.
This information refers to German plants. The values seen at older plants can be considerably higher, especially in the case of emissions influenced by furnace technical parameters, e.g. CO, TOC.
Hazardous waste values refer to mixed HW merchant plants rather than dedicated stream plants.
NI: No information provided
Source: [1, UBA, 2001], [64, TWGComments, 2003]

<u>Municipal waste</u>

In the case of municipal waste, the structure depends, among other things, on the systems used for the collection of different waste fractions and on the use or absence of pretreatment. For example, the separate collection of different municipal waste fractions can influence the thermal value of municipal waste in the following way:

- glass and metal - reduction of the ash content, resulting in an increase in the thermal value;
- paper - reduction of the thermal value;
- light packaging - reduction of the thermal value;
- clinical/hospital waste - increase in the thermal value.

Parameters such as the chlorine content and heavy metals content are also influenced, but the changes remain within the typical range of variations. The provision of separate collections of various fractions of household waste can have a significant influence over the average composition of the waste received at MSWIs. For example, separate collection of some batteries and dental amalgam can significantly reduce mercury inputs to the incineration plant. [64, TWGComments, 2003]

Commercial non-hazardous waste
In the case of non-hazardous waste from commercial enterprises, the ranges of variations can be considerably greater than MSW. When incinerated with other MSW, mixing in the bunker and shredding may be used to limit these variations.

Hazardous waste
The composition of hazardous waste may vary within a considerably greater range. In the case of hazardous waste, fluorine, bromine, iodine and silicon can be significant. Unlike municipal waste, however, the structure of hazardous waste is usually verified at the incineration plants by means of a check analysis of all essential parameters. Due to the possible variations, a hazardous waste incineration plant is designed with regard to an average waste structure (menu), in some cases with considerable additional reserves for flue-gas cleaning.

Such an incineration menu can then be created by intentionally mixing the incoming waste in bulk tanks or the bunker, or by individually feeding the waste to the furnace in separate pipes in hourly amounts corresponding to the design of the plant. This is also to be taken into account if waste is fed in barrels, which can themselves exert sudden shock loads. Incineration plants specifically designed for recovering HCl and SO_2 from waste streams containing chlorine or sulphur, respectively, may have very different raw gas structures.

Sewage sludge
[64, TWGComments, 2003]
Variations in the raw gas at sewage sludge incineration plants correspond to changes in the waste composition of the incinerated waste. This, in turn, is influenced by the presence or absence of pretreatment, and the composition of the sludge received. The composition of sewage sludge is strongly dependent upon the nature of the drainage catchment served by the sewage treatment works (STW) where the sludge arises, and the treatments applied at the STW.

Where sewage sludge is incinerated with other wastes, variations in sewage sludge quality may have a less pronounced effect on raw gas quality owing to the buffering effect of the other wastes. The water content of the sewage sludge may indeed provide benefits at some MSWI installations as, when sprayed through special nozzles in selected locations above the waste bed (often in the gas burnout zone), it provides an additional means of controlling temperature and may assist with primary NO_X control.

Clinical waste
[64, TWGComments, 2003]
Variations in the raw gas at clinical incineration plants correspond mainly to changes in the waste composition of the incinerated waste. Physical pretreatments that may limit the range of variation of raw gas composition are not often used for clinical wastes because of concerns regarding the infectivity of the waste.

Categorising incoming waste streams according to their source and probable combustion characteristics (mainly relating to CV, moisture content and calorimetric throughput rate), and feeding them to the incineration process so as to comply with an appropriate input *recipe*, may be used to reduce the range of combustion-related raw gas composition variations.

3.1.4 Emissions of gases relevant to climate change

Sources and total emissions relevant to climate change

The total emissions relevant to climate change in Germany in the year 1999 and the emissions from waste incineration (related to the fossil portion of the waste that is considered relevant to climate change in Germany) are summarised in Table 3.7.

Table 3.7: Total emissions relevant to climate change in Germany in the year 1999 compared with those arising form waste incineration

Pollutants in 1999	Total emissions (kt/yr)	Global warming potential (GWP) CO_2 equivalents (kt/yr)	Waste incineration (fossil portion) of the total emissions (kt/yr)
Carbon dioxide (CO_2)	858 511	858 511	8 685
Nitrous oxide (N_2O)	141	43 710	0.81 (252)*
Methane (CH_4)	3 271	68 691	n/a
Fluorinated hydrocarbons	3 284	4 290	
CF_4 (perfluorinated hydrocarbons)	0.186	1 209	
C_2F_6 (perfluorinated hydrocarbons)	0.046	423	
C_3F_8 (perfluorinated hydrocarbons)	0.011	77	
SF_6 (sulphur hexafluoride)	0.229	5 473	
Total GWP		**982 384**	**(c. 9 000)***
Indirectly effective greenhouse gases			
Nitrogen oxide (NO_X as NO_2)	1 637		15.2 (122.24)*
Carbon monoxide (CO)	4 952		3.82 (11.46)*
NMVOC (non-methane volatile organic compounds)	1 651		0.76 (8.36)*
Ammonia (NH_3)	624		0.3
Aerosol formers			
Sulphur dioxide SO_2	831		n/a

(..)* in brackets: the converted emission value in CO_2 equivalents for comparison with the GWP.
Source: [1, UBA, 2001]

This table indicates that in 1999, in Germany, waste incineration accounted for approximately 1 % of GHG emissions.

3.2 Emissions to air

3.2.1 Substances emitted to air

[1, UBA, 2001] [64, TWGComments, 2003].

Carbon monoxide
CO is an odourless toxic gas. Carbon monoxide (CO) in the flue-gas of incineration plants is the product of the incomplete combustion of carbon-based compounds. CO is produced when there is insufficient oxygen locally and/or an insufficiently high temperature of combustion to carry out full oxidation to carbon dioxide. In particular, this can occur if spontaneously evaporating or rapid-burning substances are present, or when combustion gas mixing with the supplied oxygen is poor. Continuous measurement of the CO level can be used to check the efficiency of the incineration process. CO is a measure of the quality of combustion. If the CO emissions are very low then the gas burnout quality is very high and TVOC emissions are also low (and vice versa). [74, TWGComments, 2004]

After its release to the atmosphere, CO is oxidised to CO_2, after some time. Particularly high concentrations of CO (above the lower explosion limit) must be avoided as they can create explosive mixtures in the flue-gas. In particular, at hazardous waste incineration plants, increased CO emissions can occur with some drummed wastes.

CO in ~~the plants~~ is measured continuously. ~~Daily averages of CO emissions below 50 mg/~~Nm^3 ~~are achieved; at some plants, the daily averages are well below this figure [64, TWGComments, 2003]~~

It is reported that NO_X treatment with SCR may increase CO emission levels. [74, TWGComments, 2004]

Total volatile organic carbon (TVOC)
This parameter includes a number of gaseous organic substances, the individual detection of which is generally complex or not possible. During the incineration of organic waste, a large number of chemical reactions take place, some of which are incomplete. This leads to an extremely complex pattern of compounds ~~of the~~ in trace amounts. A complete account of every substance within the TVOC parameter is not available; however, incineration generally provides high destruction efficiencies for organic substances.

TOC is ~~can be~~ measured continuously ~~in the flue-gas~~. Low TVOC levels are key indicators for the quality of combustion in an incineration process. ~~Emissions in the range of 0.1 mg/Nm^3 to 10 mg/Nm^3 are seen. [64, TWGComments, 2003]~~

Hydrogen chloride
Many wastes contain chlorinated organic compounds or chlorides. In municipal waste, typically approximately 50 % of the chlorides come from PVC [64, TWGComments, 2003]. In the incineration process, the organic component of these compounds is destroyed and the chlorine is converted to HCl. Part of the HCl may react further ~~to metal chlorides on~~ with inorganic compounds which are also contained in the waste to form metal chlorides.

HCl is highly soluble in water and has an impact on plant growth. It is measured continuously ~~with emissions in the range of 0.1 - 10 mg/Nm^3~~. ~~[74, TWGComments, 2004]~~

The formation and emission of Cl_2 is of minor importance under normal incineration conditions. However, it is essential for ~~the~~ fouling and corrosion. So it is worthwhile to control the formation so that the process mentioned takes place in the gas phase and not after deposition on boiler tubes. [74, TWGComments, 2004]

Hydrogen fluoride

The formation mechanism of HF in incineration plants corresponds to that of HCl. The main sources of HF emissions in municipal waste incineration plants are probably fluorinated plastic or fluorinated textiles and, in individual cases, the decomposition of CaF$_2$ in the course of the incineration of sludge.

HF~~Cl~~ is highly soluble in water and can have an impact on plant growth. It ~~can be~~ is measured continuously or discontinuosuly~~ with emissions in the range of 0.1 - 1 mg/Nm^3~~. ~~[74, TWGComments, 2004]~~

Various kinds of fluorinated waste are treated in hazardous waste incineration plants.

Hydrogen iodide and iodine, hydrogen bromide and bromine

Municipal waste usually contains very small quantities of bromine or iodine compounds. Bromine or iodine emissions are, therefore, of minor importance to municipal waste incineration plants.

In hazardous waste incineration plants, organic and inorganic wastes containing bromine or iodine are sometimes treated. For example, bromine compounds can still be found in some electronic devices as flame protection agents. Iodine can be contained in medicines or may be used for the treatment of metal surfaces. On the whole, however, their quantity is small in relation to chlorinated compounds. Bromine and iodine help to oxidise mercury and decrease the mercury content in the clean gas by improving the ~~retaining~~ retention capacity of wet scrubbers. [74, TWGComments, 2004]

Where present, the chemical properties of elementary iodine and bromine can result in colouration of chimney plumes. Special measures can be taken for the incineration of such waste in order to prevent the formation and release of elemental bromine or iodine. These substances can also have toxic and irritant effects. [64, TWGComments, 2003]

Sulphur oxides

If the waste contains sulphur compounds, mainly SO$_2$ will be created during the incineration of the waste. Under appropriate reaction conditions, SO$_3$ can also be created. For MSW, the proportion of SO$_3$ can be around 5 % at the inlet to the FGC (the SO$_3$ content is important to determine the acid dew point). Common sources of sulphur in some waste streams are: waste paper, plasterboard (calcium sulphate), and sewage sludges. [64, TWGComments, 2003].

SO$_2$ ~~gives rise to~~ causes acidification and is a precursor of secondary aerosols. ~~and~~ It is ~~can be~~ measured continuously~~ with emissions in the range of 1 - 50 mg/Nm^3 (stp; 11 % O$_2$)~~. ~~[74, TWGComments, 2004]~~

Nitrogen oxides

Various oxides of nitrogen are emitted from incineration plants and, in many cases, they are measured using continuous emission monitors. Oxides of nitrogen ~~They~~ can have toxic~~,~~ ~~acidic~~ and global warming effects, cause acidification and eutrophication, and form secondary aerosols depending on the oxide concerned.

The NO and NO$_2$ emitted from waste incineration plants originate from the conversion of the nitrogen contained in the waste (so-called fuel NO$_X$) and from the conversion of atmospheric nitrogen from the combustion air into nitrogen oxides (thermal NO$_X$). Production of thermal NO$_X$ generally becomes more significant at temperatures above 1 000 °C, so, in MSWI ~~plants,~~ the proportion of thermal NO$_X$ is usually very low due to the lower temperatures in the afterburner chamber. In MSWI, the amount of thermal NO$_X$ can also critically depend on the quantity, and manner, of injection of secondary air into the afterburner chamber – with higher NO$_X$ seen with higher nozzle temperatures (i.e. above 1 400 °C).

The mechanisms for the formation of NO_X from the nitrogen contained in the waste are very complicated. Amongst other reasons, this is because nitrogen can be contained in the waste in many different forms, which, depending on the chemical environment, can react either to NO_X or to elementary nitrogen. A conversion rate of approximately 10–20 % of the fuel nitrogen is usually assumed depending on waste type. High chlorine and sulphur concentrations, O_2 content and temperature may have ~~great~~ a significant influence. The proportion of NO/NO_2 in the total NO_X stack emissions is usually about ~~approx.~~ 95 % NO and 5 % NO_2.

Nitrous oxide (N_2O) is not usually measured as a part of the NO_X estimation. ~~Nitrous oxide (N_2O)~~ It can be emitted if the temperature is insufficient for complete combustion ~~insufficient temperature for the combustion process is applied~~ (e.g. less than 850 °C) and there is ~~an~~ insufficient oxygen ~~concentration~~. The N_2O emissions from incineration processes are, therefore, often correlated with CO emissions.

Where SNCR is applied for $deNO_X$, the formation of N_2O may increase, dependent upon reagent dose rates and temperature. Values of 20–60 mg/m^3 have been measured~~, but especially~~ where ~~low NO_X values are sought (i.e. N_2O can increase when~~ higher SNCR dose rates are used to achieve ~~secure~~ lower NO_X emission levels, in particular ~~targets). This is particularly the case~~ when urea is used as the reagent, rather than ammonia ~~(ammonia is the alternative reagent)~~.

For municipal waste incineration, N_2O emissions of 1–12 mg/Nm^3 (for individual measurements) and averages of 1–2 mg/Nm^3 are seen. For the incineration of MSW in fluidised bed plants, the measured N_2O emission values (individual measurements) are usually higher.

Individual measurements in hazardous waste incineration plants have resulted in N_2O emission values of 30–32 mg/Nm^3 [64, TWGComments, 2003]

Normal N_2O emission levels for fluidised bed sludge incineration can be as low as 10 mg/Nm^3, though some values up to 500 mg/Nm^3 have been reported. ~~with some values reported up to 500 mg/Nm^3.~~

Whilst incineration is a minor ~~low (in terms of anthropogenic emissions)~~ contributor of emissions of nitrous oxide (compared to anthropogenic emissions), they add to the global warming impact of releases from incineration processes.

NO_X ~~gives rise to acidification and eutrophication and can be~~ is measured continuously. ~~and emissions at modern plants are reported to be generally in the range between 30 and 200 mg/Nm^3 (daily average, stp, 11 % O_2). [74, TWGComments, 2004] Some installation may give rise to daily average NO_X levels of up to 400 mg/Nm^3 — in general these are already in the process of closing down or upgrading to the daily average levels of 200 mg/Nm^3 required by Directive 2000/76/EC.~~

Dust

Dust emissions from waste incineration plants mainly consist of the fine ash from the incineration process that is entrained in the gas flow. Depending on the reaction balance, other elements and compounds are concentrated in this airborne dust. The separation of dust from the flue-gas using air pollution control devices removes the majority of the dust and entrained inorganic and organic substances (e.g. metal chlorides, PCDD/F).

Air pollution control equipment greatly reduces emissions of total particulate matter from waste incineration plants. In common with all combustion processes, the type of air pollution control equipment used effects the particle size distribution of the emitted dust. The filtration equipment is generally more effective on the larger particles, and therefore changes the proportion of finer particulate in the resulting emissions to air, whilst reducing the total particulate emission.

Dust is ~~normally~~ measured continuously~~ with reported emissions of between <0.05 and 15 mg/Nm^3 (stp, 11 % O_2). [74, TWGComments, 2004]~~

Mercury and mercury compounds

Mercury can currently still be found in municipal waste, notably in the form of batteries, thermometers, dental amalgam, fluorescent tubes or mercury switches. Separate collection of these can help reduce overall loads in mixed MSW but collection rates of 100 % are not achieved in practice.

Mercury is a highly toxic metal. Without adequate air pollution controls, the incineration of mercury-containing wastes can give rise to significant emissions.

Mercury emissions ~~can be~~ are measured continuously or discontinuously (in some cases using long-term sampling [80, DK, 2015]). ~~measured and abated levels have been reported to be generally in the range between 0.0014 and 0.05 mg/Nm^3 (11 % O_2). [74, TWGComments, 2004] Short-term higher emission levels are reported where inlet concentration vary greatly~~.

In hazardous waste incineration, there are several specific streams that may contain increased concentrations of mercury in the received waste:

- tars from coking plants;
- waste from chlorine alkaline electrolysis (amalgam process);
- caustic oil sludge from refineries;
- chemicals containing mercury.

The form of the mercury emissions depends strongly on the chemical environment in the flue-gas. A balance between metallic mercury (Hg^o) and $HgCl_2$ normally develops. Where there is a sufficiently high concentration of HCl in the flue-gas (in relation to the reduction agent SO_2), mercury will mainly be contained in the flue-gas as $HgCl_2$. This can be separated from the flue-gas significantly more easily than metallic mercury. If, however, HCl is contained in the flue-gas at lower concentrations (e.g. in sewage sludge incineration plants), mercury exists in the flue-gas mainly in metallic form and is then more difficult to control.

The combustion temperature also influences $HgCl_2$ formation.

In wet scrubbers (only), the $HgCl_2$ removed can be reduced if SO_2 is also present (the separation of these substances is one reason why distinct wet scrubber stages are operated for the removal of $HgCl_2$ and SO_2). The Hg_2Cl_2 formed when this happens can ~~itself~~ in turn disproportionate to $HgCl_2$ and metallic Hg. These reactions can be prevented by adjusting the pH in wet scrubbers to low values and by ~~withdrawing~~ removing mercury from the scrubber effluent.

Metallic mercury is virtually insoluble in water (59 µg/l at 25 °C). Mercuric (II) chloride is much more soluble at 73 g/l. Mercury (II) chloride can therefore be separated in wet scrubbers, whereas the separation of metallic mercury requires further flue-gas treatment stages (see Section 2.5.6 for further details).
[64, TWGComments, 2003]

Cadmium and thallium compounds

Common sources of cadmium in municipal waste incineration plants are electronic devices (including accumulators), batteries, some paints and cadmium-stabilised plastic. Thallium is virtually non-existent in municipal waste.

Hazardous wastes may contain high concentrations of cadmium and thallium compounds. Effluent treatment sludges and drummed wastes from metal plating and treatment may be significant sources.

Cadmium is highly toxic and can accumulate in the soil. ~~The range of emissions have been reported to be 0.0002 to 0.2 mg/Nm^3. (11 % O_2). [74, TWGComments, 2004]~~
Cadmium and thallium emissions are measured discontinuously

Other ~~heavy~~ metal compounds

This term comprises the ~~heavy~~ metals antimony, arsenic, lead, chromium, cobalt, copper, manganese, nickel, vanadium, tin and their respective compounds. European and many national regulations, thus, group them together for emission measurement requirements. This group contains carcinogenic metals and metal compounds such as arsenic and chromium (VI) compounds, as well as metals with toxicity potential.

The retention of these metals depends largely on an effective separation of dust as they are bound in dust due to the vapour pressures of their compounds, as contained in the flue-gas (mainly oxides and chlorides).
Metal emissions are measured discontinuously.

Polychlorinated biphenyls

Low quantities of polychlorinated biphenyls (PCBs) are found in most municipal waste streams and also in some industrial wastes. Wastes with large proportions of PCBs, however, generally only arise from specific PCB collection and destruction programmes, when concentrations of PCBs in such waste can be very high.

In hazardous waste incineration plants, wastes with a PCB content as high as 60–100 % are combusted. The same applies to special plants for the incineration of highly chlorinated hydrocarbons. PCBs are more efficiently destroyed if higher incineration temperatures are used (e.g. above 1 200 °C); however, lower temperatures (e.g. 950 °C) together with appropriate conditions of turbulence and residence time have also been found to be effective for PCB incineration. [74, TWGComments, 2004] PCBs contained in the crude flue-gas of waste incineration plants can be the result of incomplete destruction.

PCB emissions are classified as potentially toxic by some international organisations (e.g. WHO). A toxicity potential (similar to that of dioxins and furans) is ascribed to some of the PCBs (coplanar PCBs).

Polyaromatic hydrocarbons

Polyaromatic hydrocarbons are well known as products of incomplete combustion. They are toxic and have carcinogenic and mutagenic properties. [74, TWGComments, 2004]

Polychlorinated dibenzo-dioxins and furans (PCDD/F)

Dioxins and furans (PCDD/F) are a group of compounds, some of which are extremely toxic, and are considered to be carcinogens. ~~Dioxins and furans~~ They have played a ~~main part~~major role in the debate about waste incineration for many years. Their production and release is not specific to waste incineration but occurs in all thermal processes under certain process conditions.

[64, TWGComments, 2003] Significant advances in PCDD/F emission control have been achieved in recent years in the WI sector. Improvements in the design and operation of combustion and flue-gas cleaning ~~treatment~~ systems have resulted in ~~systems~~ plants that can reliably achieve very low emission limit values. ~~National [44, RVF, 2001] and regional emissions inventories confirm that, where compliance with Directive 2000/76/EC is secured, incineration represents a low contributor to overall emissions to air of dioxins and furans [45, FEAD, 2002].~~

[64, TWGComments, 2003] In well-designed and -operated incineration plants, material balances have shown that incineration effectively removes PCDD/F ~~dioxins~~ from the environment (see Section 3.1.2). The dioxin ~~is~~ balance is made most favourable by ensuring that:

- input~~coming~~ dioxins and precursors are effectively destroyed using appropriate combustion conditions;
- the use of conditions that may give rise to PCDD/F formation and reformation including *de novo* synthesis is reduced.

~~Dioxins and furans~~ PCDD/F entering the process with the waste are destroyed very efficiently if sufficiently high incineration temperatures and appropriate process conditions are used. ~~Standards for operating conditions are stated in existing European legislation on incineration (i.e. Directive 2000/76/EC). The dioxins and the furans~~ The PCDD/F found in the crude flue-gas of waste incineration plants are the result of ~~a~~ recombination reactions of carbon, oxygen and chlorine. Suitable precursor substances (e.g. from chlorophenols) can also react to form dioxins and furans. ~~In the formation of the substances, certain catalysers in the form of transitional metal compounds (e.g. copper) also play an important part.~~ Some transitional metal compounds (e.g. copper compounds) can act as catalysts for the reformation of PCDD/F. PCDD/F emissions are monitored discontinuously also using the long term sampling.

Ammonia

Ammonia has a significant impact on eutrophication and acidification of the environment. Ammonia emissions can arise from the overdosing or poor control of NO_X reduction reagents that are used for NO_X control.~~The emissions normally range from 1 to 10 mg/Nm^3, with an average of 4 mg of NH_3/Nm^3. [64, TWGComments, 2003]~~

Carbon dioxide ~~(CO_2)~~

~~If one~~ For every tonne of municipal waste ~~is~~ combusted, approximately 0.7–1.7 tonnes of CO_2 are generated. ~~This CO_2 is released directly into the atmosphere and, as a result, the climate relevant share of CO_2, (resulting from the fossil origin) contributes to the greenhouse effect. [64, TWGComments, 2003]~~

Because municipal waste is a heterogeneous mixture of biomass and fossil material, the portion of CO_2 from MSWIs of fossil origin (e.g. plastic) which is considered relevant to climate change is generally in the range of 33 % to 50 %.

Methane ~~CH_4~~

It can be assumed that, if combustion is carried out under oxidative conditions, methane levels in the flue-gas will be almost zero~~ and consequently not emitted to air~~. Methane is measured with the VOC component. [64, TWGComments, 2003]

Methane can also be created in the waste bunker if there are low oxygen levels and subsequent anaerobic processes in the waste bunker. This is only the case where wastes are stored for long periods and not well agitated. Where the storage area gases are fed to the incineration chamber air supply, they will be incinerated and emissions will be reduced to insignificant levels.

3.2.2 Emissions to air from waste incineration plants ~~Municipal waste incineration plants~~

This section presents the range of emissions achieved by the waste incineration plants that participated in the data collection for the review of the WI BREF. Emission data are presented in graphs alongside the techniques and, where relevant, the type of reagents in use in each of the plants, as well as additional complementary information, such as the age and size of each plant. A separate graph is presented for each pollutant, and the accompanying selection of techniques is adapted to the pollutant addressed (e.g. the use of SCR and SNCR is shown in the graph on NO_X and NH_3 emissions, while the use of ESP and bag filter is shown in the graph on dust emissions).

A single data point refers to a monitored point of release for air emissions (reference line), and may refer to either one or a group of individual incineration lines. All reference lines, along with some of their key characteristics, are lised in Annex 8.6. *[To the TWG: A much more comprehensive description of the graphs and of the accompanying data files is available in the document WI BREF D1 data compilation and presentation GUIDE 2017]*

Emission data are presented as follows:

For continuously monitored data

The graphs show emissions as yearly averages and as yearly maxima of daily averages calculated on the basis of reported half-hourly averages and obtained using a 'base' and a 'fine' data filtering options. Data filtering is used to exclude from a daily average the emissions measured during half-hourly periods that are associated with some specific operating conditions. In particular:

- The 'base' data filter excludes the emissions measured when:
    - The furnace temperature is below the minimum incineration temperature required, and/or the measured flow rate is very low;
    - The plant is under maintenance, in breakdown, or in stoppage;
    - The plant is only combusting support fuels (pre-heating before the first waste is introduced in the furnace or shutdown operation after the last waste remaining in the furnace has been incinerated);
    - The automated monitoring systems is in maintenance or malfunctioning.
- Additionally, the 'fine' data filter also excludes the emissions measured when:
    - The plant is in start-up while waste is already being incinerated, or in shutdown while waste is still being incinerated;
    - The abatement system is being bypassed;
    - There is a failure, malfunction or leak in the abatement system or in the process;
    - One of the half-hourly ELVs established in the plant´s permit is being exceeded;
    - Other exceptional conditions reported by the plant operator.

Further, with the 'fine' data filter the daily average is discounted when more than 5 half-hourly periods are fileterd out by any of the conditions above. To be noted that the data filtering relies on detailed information reported by the plant operators, and the data is not fully comparable across plants where information is missing or was misreported.

The graphs also report the daily ELV in the permit of each plant and, where relevant, the amount of reagent used per tonne of waste incinerated; in the case of alkaline reagents the amount is normalised to a lime-weight equivalent by stoichiometry.

All emission data are corrected for standard pressure and temperature conditions and normalised for a reference oxygen level of 11 %, but otherwise are presented as measured, without adding or subtracting the measurement uncertainty or taking into account the specific rules applied for compliance.

For discontinuously monitored data

The graphs show the following data points for emission levels:

- Maximum emission level among all the data reported;
- Maximum emission level among the measurement taken with long sampling period;
- Maximum emission level among the reported 2014 data that do not exceed the ELV set in the permit;
- Average of all the reported emission levels.

The graphs also report the daily ELV in the permit of each plant and, where relevant, the amount of reagent used per tonne of waste incinerated; in the case of alkaline reagents the amount is normalised to a lime-weight equivalent by stoichiometry.

The following subsections show this information for plants combusting different types of waste, separately for: municipal solid waste (MSW); other non-hazardous waste (ONHW); hazardous waste (HW); sewage sludge (SS); clinical waste (CW). In reality, different types of waste may be processed in the same plant. The allocation of plants to one waste type or another is based therefore on the predominant type of waste, in mass terms, incinerated by each plant in the reference year 2014.

3.2.2.1 ~~Summary data for e~~Emissions to air from ~~MSWI~~ the incineration of municipal solid waste and other non-hazardous waste

~~Table 3.8 gives the range of values for emissions to air from some European MSWI plants. Thirty minute, daily and annual averages are shown. It is important to note that data that are the result of non-continuous (or spot) measurements are also included in the Table. They are indicated (N) in the *type of measurement* column. Furthermore, where non-continuous measurements appear in an *averaging* column, the values presented for non-continuous measurements are not collected over the stated averaging period for that column, and should only be interpreted as non-continuous measurements:~~

~~**Table 3.8: Range of clean gas operation emissions levels reported from some European MSWI plants**~~

~~**Parameter**~~	~~**Type of Measurement**~~	~~**Daily averages (where continuous measurement used) in mg/m³**~~		~~**Half hour averages (where continuous measurement used) in mg/m³**~~		~~**Annual averages mg/m³)**~~
	~~**C: continuous N: non-cont.**~~	~~**Limits in 2000/76/EC**~~	~~**Range of values**~~	~~**Limits in 2000/76/EC**~~	~~**Range of values**~~	~~**Range of values**~~
~~Dust~~	~~C~~	~~10~~	~~0.1 – 10~~	~~20~~	~~<0.05 – 15~~	~~0.1 – 4~~
~~HCl~~	~~C~~	~~10~~	~~0.1 – 10~~	~~60~~	~~<0.1 – 80~~	~~0.1 – 6~~
~~HF~~	~~C/N~~	~~1~~	~~0.1 – 1~~	4	~~<0.02 – 1~~	~~0.01 – 0.1~~
~~SO_2~~	~~C~~	~~50~~	~~0.5 – 50~~	~~200~~	~~0.1 – 250~~	~~0.2 – 20~~
~~NO_X~~	~~C~~	~~200~~	~~30 – 200~~	~~400~~	~~20 – 450~~	~~20 – 180~~
~~NH_3~~	~~C~~	~~n/a~~	~~<0.1 - 3~~		~~0.55 – 3.55~~	
~~N_2O~~		~~n/a~~				
~~VOC (as TOC)~~	~~C~~	~~10~~	~~0.1 – 10~~	~~20~~	~~0.1 – 25~~	~~0.1 – 5~~
~~CO~~	~~C~~	~~50~~	~~1 – 100~~	~~100~~	~~1 – 150~~	~~2 – 45~~
~~Hg~~	~~C/N~~	~~0.05~~	~~0.0005 – 0.05~~	~~n/a~~	~~0.0014 – 0.036~~	~~0.0002 – 0.05~~
~~Cd~~	~~N~~	~~n/a~~	~~0.0003 – 0.003~~	~~n/a~~		
~~As~~	~~N~~	~~n/a~~	~~<0.0001 – 0.001~~	~~n/a~~		
~~Pb~~	~~N~~	~~n/a~~	~~<0.002 – 0.044~~	~~n/a~~		
~~Cr~~	~~N~~	~~n/a~~	~~0.0004 – 0.002~~	~~n/a~~		
~~Co~~	~~N~~	~~n/a~~	~~<0.002~~	~~n/a~~		
~~Ni~~	~~N~~	~~n/a~~	~~0.0003 – 0.002~~	~~n/a~~		
~~Cd and Tl~~	~~N~~	~~0.05~~		~~n/a~~		~~0.0002 – 0.03~~
~~Σ other metals 1~~	~~N~~	~~0.5~~		~~n/a~~		~~0.0002 – 0.05~~
~~Σ other metals 2~~	~~N~~	~~n/a~~	~~0.01 – 0.1~~	~~n/a~~		
~~Benz(a)pyrene~~	~~N~~	~~n/a~~		~~n/a~~		~~<0.001~~
~~Σ PCB~~	~~N~~	~~n/a~~		~~n/a~~		~~<0.005~~
~~Σ PAH~~	~~N~~	~~n/a~~		~~n/a~~		~~<0.01~~
~~PCDD/F (ng TEQ/m³)~~	~~N~~	~~0.1 (ng TEQ/m³)~~		~~n/a~~		~~0.0002 – 0.08 (ng TEQ/m³)~~

~~1. In some cases there are no emission limit values in force for NO_X. For such installations a typical range of values is 250 – 550 mg/Nm³ (discontinuous measurement).~~
~~2. Other metals 1 = Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V~~
~~3. Other metals 2 = Sb, Pb, Cr, Cu, Mn, V, Co, Ni, Se and Te~~
~~4. Where non-continuous measurements are indicated (N) the averaging period does not apply. Sampling periods are generally in the order of 4 – 8 hours for such measurements.~~
~~5. Data is standardised at 11 % Oxygen, dry gas, 273K and 101.3kPa.~~
~~*Source:* [1, UBA, 2001], [2, infomil, 2002], [3, Austria, 2002], [64, TWGComments, 2003]~~

~~Table 3.9 below gives emissions to air for various substances per tonne of MSW incinerated. The data given is average data for 12 MSWI in the Flanders Region of Belgium in 1999 and average data for three MSWI plants in Austria **[3, Austria, 2002]**.~~

~~Table 3.9: Operational emission levels to air from MSWI expressed per tonne of MSW incinerated~~

~~Parameter~~	**~~Average Value (g/tonne incinerated)~~**	
	~~12 Belgian plants~~	~~3 Austrian plants~~
~~Dust~~	~~165~~	~~7~~
~~HCl~~	~~70~~	~~4~~
~~HF~~	~~2.2~~	~~0.36~~
~~SO_2~~	~~129~~	~~24.8~~
~~NO_X~~	~~2 141~~	~~189~~
~~CO~~	~~126~~	~~101~~
~~TOC~~	~~19~~	-
~~Hg~~	~~0.048~~	~~0.1~~
~~Cd + Tl~~	~~0.095~~	-
~~Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn~~	~~1.737~~	-
~~PCDD/F~~	~~250 ng TEQ/tonne incinerated~~	~~44.4 ng TEQ/tonne incinerated~~
~~*Source:* [64, TWGComments, 2003] [3, Austria, 2002] [74, TWGComments, 2004]~~		

~~3.2.2.2 European air emissions survey data for MSWI~~

~~The data presented here are based on the results of a survey of 142 European non-hazardous waste incineration plants submitted to the TWG [45, FEAD, 2002], with additional information from comments made by the TWG [64, TWGComments, 2003]~~

~~The information relates to process lines rather than individual plants. The size of the data set may therefore, in some cases, exceed the number of plants surveyed. The data set is not a complete survey of European MSWIs - most of the plants that were complying only with the earlier 1999 Waste Incineration Directives, were excluded from this survey.~~

Hydrogen chloride and hydrogen fluoride

~~Different national emission limit values apply.~~

~~Most of the data presented are based on continuous measurements.~~

~~Table 3.10: HCl emissions survey of European MSWIs~~

~~Level of annual averages~~	**~~Number of plants/lines~~**
~~>50 mg/Nm^3~~	~~0~~
~~>30 <50 mg/Nm^3~~	~~10~~
~~>10 <30 mg/Nm^3~~	~~24~~
~~>5 <10 mg/Nm^3~~	~~35~~
~~<5 mg/Nm^3~~	~~73~~
~~NB: For German plants only some representative examples have been taken into account. All the other incinerators (about 50 plants) not mentioned here also operate below 10 mg/Nm^3.~~ ~~*Source:* [45, FEAD, 2002]~~	

~~Basically~~ Three main types of flue-gas cleaning systems are in use for HCl and HF:

1. wet systems using different types of scrubbers in which ~~the~~ HCl is taken out by water, working normally at a pH < 1;
2. semi-wet systems~~, which use~~ using lime in water, or semi-dry systems;
3. dry systems, which use lime or sodium bicarbonate (usually in combination with activated carbon), often combined with a bag ~~house~~ filter.

[74, TWGComments, 2004]

The emissions will depend, among other factors, on the amount of ~~additives~~ reagents used and the operational/design set point of the plant.

HCl emission data, based on continuous measurements, are shown in the following figures:

- Figure 3.1, for small plants incinerating predominantly MSW;
- Figure 3.2 and Figure 3.3, for medium-size plants incinerating predominantly MSW; the graph is divided into two figures for readability, due to the large number of plants represented;
- Figure 3.4, for large plants incinerating predominantly MSW;
- Figure 3.5, for plants incinerating predominantly ONHW.

The emission levels range between close to the limit of quantification and 13 mg/Nm^3 as a yearly average and 17 mg/Nm^3 as a maximum daily average. In some cases higher emission peaks may be recorded, generally related to OTNOC.

The graphs show that plants fitted with a wet scrubber generally achieve lower emission levels (mostly below 2 mg/Nm^3 as a yearly average and 4 mg/Nm^3 as a maximum daily average) than plants fitted with DSI or with semi-wet techniques.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used, the age and size of the plant, or the furnace type.

The data on hydrogen fluoride (HF) are mainly based on discontinuous measurement. HF is reduced by the same techniques ~~tools~~ as HCl, meaning that an effective flue-gas cleaning system for HCl will also deal with HF. Since the chemical behaviour of HF is not exactly the same as that of HCl, ~~so~~ the efficiency of HF removal will differ slightly from system to system.

HF emission data are shown in the following figures:

- Figure 3.6, for small plants incinerating predominantly MSW and monitoring HF discontinuously;
- Figure 3.7, for medium-size plants incinerating predominantly MSW and monitoring HF discontinuously;
- Figure 3.8, for large plants incinerating predominantly MSW and monitoring HF discontinuously;
- Figure 3.9, for plants incinerating predominantly MSW and monitoring HF continuously;
- Figure 3.10, for plants incinerating predominantly ONHW and monitoring HF discontinuously;
- Figure 3.11, for plants incinerating predominantly ONHW and monitoring HF continuously.

The emission levels range between close to the limit of quantification and 0.4 mg/Nm^3 as a yearly average and 1.6 mg/Nm^3 as a maximum daily average, with the exception of one plant reaching 0.7 mg/Nm^3 as a yearly average and one exceeding 3 mg/Nm^3 as a maximum daily average. Discontinuously monitored emissions are between close to the limit of quantification and 0.6 mg/Nm^3 with the exception of six plants that report emissions between 1 mg/Nm^3 and 4 mg/Nm^3.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed, the type and amount of reagent used, the age and size of the plant, or the furnace type.

~~Table 3.11: HF emissions survey of European MSWIs~~

~~Level of annual averages~~	~~Number of plants/lines~~
~~>5 <10 mg/Nm^3~~	~~0~~
~~>2 <5 mg/Nm^3~~	~~1~~
~~>1 <2 mg/Nm^3~~	~~1~~
~~<1 mg/Nm^3~~	~~53~~
~~*Source:* [45, FEAD, 2002]~~	

Sulphur dioxide

~~Different national emission limit values are applied.~~

~~Most of the data are from continuous measurement.~~

~~Table 3.12: Sulphur dioxide emissions survey of European MSWIs~~

~~Level of annual averages~~	~~Number of plants/lines~~
~~>200 mg/Nm^3~~	~~3~~
~~>100 <200 mg/Nm^3~~	~~5~~
~~>50 <100 mg/Nm^3~~	~~16~~
~~>25 <50 mg/Nm^3~~	~~25~~
~~<25 mg/Nm^3~~	~~123~~
~~*Source:* [45, FEAD, 2002]~~	

The types of flue-gas cleaning systems in use are the same as those ~~mentioned~~ for HCl, with the main difference ~~being~~ that~~, for~~ wet scrubbers~~, they~~ are operated at a slightly basic pH (usually 7–8).

SO_2 emission data, based on continuous measurements, are shown in the following figures:

- Figure 3.12, for small plants incinerating predominantly MSW;
- Figure 3.13 and Figure 3.14, for medium-size plants incinerating predominantly MSW; the graph is divided into two figures for readability, due to the large number of plants represented;
- Figure 3.15, for large plants incinerating predominantly MSW;
- Figure 3.16, for plants incinerating predominantly ONHW.

The emission levels range between close to the limit of quantification and 45 mg/Nm^3 as a yearly average and 90 mg/Nm^3 as a maximum daily average.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed, the type and amount of reagent used, the age and size of the plant, or the furnace type.

Dust

~~Most of the data are from continuous measurement. They show the values of total dust.~~

For dust, ~~mainly~~ three main types of flue-gas cleaning systems are in use:

1. dry electrostatic precipitator (dry ESP);
2. wet electrostatic precipitator (wet ESP) (note: the wet ESP is not often used in MSWI);
3. bag ~~house~~ filter (BF).

In several cases ~~(mainly in NL and D)~~, two of these techniques ~~tools~~ have been combined ~~with each other~~, for example a dry electrostatic precipitator ~~directly~~ for pre-dedusting after the boiler with a bag ~~house~~ filter ~~directly~~ before the stack. This allows the separation of fly ash from FGC residues and separate recycling/disposal.

~~Recent new plants have been built with a bag house filter only.~~

Wet scrubbers and fixed adsorprion beds can also ~~significantly~~ contribute to dust removal. ~~Typically about 50 % efficiency is observed for dust (with additional selected heavy metal) removal.~~

Some plants also use cyclones or multi-cyclones for pre-dedusting. Although this is not a common configuration, there are example plants where the flue-gas cleaning system does not include a bag filter or an ESP but combines wet scrubbing with a (multi-)cyclone.

Interdependencies between different parts of the system are frequently seen in the overall flue-gas cleaning system design. For instance, ~~An important point to note is that, all tools are connected and generally have an influence on each other.~~ in the case of dry and semi-wet systems ~~processes~~, bag filters also act as a reactor for acid gas removal. In addition, they can enable the removal of PCDD/F and metals (including mercury and cadmium) if a suitable reagent is used (e.g. activated carbon).

Dust emission data, based on continuous measurements, are shown in the following figures:

- Figure 3.17, for small plants incinerating predominantly MSW;
- Figure 3.18 and Figure 3.19, for medium-size plants incinerating predominantly MSW; the graph is divided in two figures for readability, due to the large number of plants represented;
- Figure 3.20, for large plants incinerating predominantly MSW;
- Figure 3.21, for plants incinerating predominantly ONHW.

The emission levels range between close to the limit of quantification and 6 mg/Nm^3 as a yearly average and 17 mg/Nm^3 as a maximum daily average. In some cases higher emission peaks may be recorded, generally related to OTNOC.

The graphs show that the plants fitted with a bag filter generally achieve emission levels below 2.5 mg/Nm^3 as a yearly average; only a few plants report yearly average levels between 3 mg/Nm^3 and 6 mg/Nm^3, and, with the exception of UK7-1 and UK7-2, they are plants fitted with an ESP. As a maximum daily average, the great majority of plants achieve levels below 7 mg/Nm^3, and below 5 mg/Nm^3 for plants fitted with a well-maintained bag filter except in cases where the daily average emission level is substantially affected by occurrences such as filter bag failures or a start-up where the bag filter is being bypassed.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used, the age and size of the plant, or the furnace type.

~~**Table 3.13: Dust emissions survey of European MSWIs**~~

~~Level of annual averages~~	~~Number of plants/lines~~
~~>50 mg/Nm^3~~	~~3~~
~~>30 <50 mg/Nm^3~~	~~1~~
~~>10 <30 mg/Nm^3~~	~~8~~
~~>5 <10 mg/Nm^3~~	~~29~~
~~<5 mg/Nm^3~~	~~103~~
~~*Source:* [45, FEAD, 2002]~~	

Nitrogen oxides

~~Most of the data presented are from continuous measurements. In some countries there are currently no limit values for NO_X from municipal waste incinerators.~~

~~Many plants already achieve results below 200 mg/Nm^3. In some cases emissions of less than 70 mg/Nm^3 are achieved.~~

A variety of combustion control techniques are used to reduce NO_X formation. SCR and ~~or~~ SNCR are the main secondary techniques in use for the further abatement of NO_X emissions in MSWIs. ~~Emission values below 100 mg/Nm^3 normally require the use of SCR. The use of SNCR can also lead to emissions below 150 mg/Nm^3 and exceptionally below 100 mg/Nm^3 (e.g. when primary NO_X reduction measures are also implemented) [74, TWGComments, 2004]~~

~~**Table 3.14: Nitrogen oxides emissions survey of European MSWIs**~~

~~Level of annual averages~~	~~Number of plants/lines~~
~~>400 mg/Nm^3~~	~~9~~
~~>300 <400 mg/Nm^3~~	~~35~~
~~>200 <300 mg/Nm^3~~	~~22~~
~~>100 <200 mg/Nm^3~~	~~48~~
~~<100 mg/Nm^3~~	~~11~~
~~NB: the 11 plants (not lines) below 100 mg/Nm^3 are in NL – all comply with applied ELVs of 70 mg/Nm^3. Other plants operating below 100 but not included here are found in Europe (commonly in D, A, B).~~ ~~*Source:* [45, FEAD, 2002], [64, TWGComments, 2003]~~	

NO_X emission data, based on continuous measurements, are shown in the following figures:

- Figure 3.22, for small plants incinerating predominantly MSW;
- Figure 3.23 and Figure 3.24, for medium-size plants incinerating predominantly MSW; the graph is divided into two figures for readability, due to the large number of plants represented;
- Figure 3.25, for large plants incinerating predominantly MSW;
- Figure 3.26, for plants incinerating predominantly ONHW.

The emission levels range between 18 mg/Nm^3 and 275 mg/Nm^3 as a yearly average and between 22 mg/Nm^3 and 350 mg/Nm^3 as a maximum daily average. In some cases higher emission peaks may be recorded in OTNOC, but for the majority of cases little difference is observed between the 'base' and 'fine' data filtering for daily averages, and – especially for plants fitted with SCR – the maximum daily average is in most cases within 125 % of the yearly average.

The graphs show that plants fitted with SCR generally achieve substantially lower emission levels (down to a mimumum of 20 mg/Nm^3 and generally below 100 mg/Nm^3 as a yearly average and 130 mg/Nm^3 as a maximum daily average) than plants fitted with SNCR. The best performing plants fitted with SNCR achieve levels down to 54 mg/Nm^3 as a yearly average and 76 mg/Nm^3 as a maximum daily average.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used, the age and size of the plant, or the furnace type.

Ammonia

Ammonia emissions are related to reactant slip from SCR or SNCR. The main technique in use to control such emissions is process optimisation as well as good maintenance of the catalyst in the case of SCR. SCR can also be implemented as slip catalyst to further react the unreacted ammonia after the main reduction has taken place in a SNCR system.

Ammonia emission data, based on either continuous or discontinuous measurements, are shown in the following figures:

- Figure 3.27, for small plants incinerating predominantly MSW and monitoring NH_3 discontinuously;
- Figure 3.28, for medium-size plants incinerating predominantly MSW and monitoring NH_3 discontinuously;
- Figure 3.29, for large plants incinerating predominantly MSW and monitoring NH_3 discontinuously ;
- Figure 3.30, for small plants incinerating predominantly MSW and monitoring NH_3 continuously;
- Figure 3.31, for medium-size plants incinerating predominantly MSW and monitoring NH_3 continuously;
- Figure 3.32, for large plants incinerating predominantly MSW and monitoring NH_3 continuously
- Figure 3.33, for plants incinerating predominantly ONHW and monitoring NH_3 discontinuously;
- Figure 3.34, for plants incinerating predominantly ONHW and monitoring NH_3 continuously.

The emission levels range between close to the limit of quantification and 10 mg/Nm^3 as a yearly average and 37 mg/Nm^3 as a maximum daily average or average over the sampling period. In some cases higher emission peaks are observed, generally related to OTNOC.

The graphs show that plants fitted with SCR generally achieve substantially lower ammonia emission levels (generally well below 5 mg/Nm^3 as a yearly average and 10 mg/Nm^3 as a maximum daily average or average over the sampling period) than plants fitted with SNCR. The best performing plants fitted with SNCR achieve very low levels down to the limit of quantification.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used, the age and size of the plant, or the furnace type.

TVOC ~~(Total organic carbon)~~

TVOC is an important measure of the efficiency of combustion. The achieved ~~levels of the~~ TVOC emission~~s~~ levels are mainly a result of the design of the firing system and the afterburning chamber, as the possibilities to decrease those emissions by flue-gas cleaning are limited. The same equipment used for the abatement of dust will also reduce solid organic particles. Some of the organic compounds will be reduced by the use of activated carbon.

~~**Table 3.15: Total organic carbon emissions survey of European MSWIs**~~

~~**Level of annual averages**~~	~~**Number of plants/lines**~~
~~>10 mg/Nm^3~~	4
~~>5 <10 mg/Nm^3~~	~~7~~
~~<5 mg/Nm^3~~	~~79~~
~~*Source:* [45, FEAD, 2002]~~	

TVOC emission data are based on continuous measurements and are shown in the following figures:

- Figure 3.35, for small plants incinerating predominantly MSW;
- Figure 3.36 and Figure 3.37, for medium-size plants incinerating predominantly MSW; the graph is divided into two figures for readability, due to the large number of plants represented;
- Figure 3.38, for large plants incinerating predominantly MSW;
- Figure 3.39, for plants incinerating predominantly ONHW.

The emission levels range between close to the limit of quantification and 3 mg/Nm^3 as a yearly average and 17 mg/Nm^3 as a maximum daily average, although for the great majority of plants the maximum daily average is below 6 mg/Nm^3. While even the maximum daily levels are generally very low, the difference with respect to the yearly average tends to be substantial. This reflects the variability of TVOC emissions, which can show peaks when the combustion conditions in the furnace are not stable, e.g. at start-ups and shutdowns, and is also related to the occasionally large differences between the maxima of daily averages obtained with 'base' and 'fine' data filtering.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed, the type and amount of reagent used, the age and size of the plant, or the furnace type.

Carbon monoxide

Like TVOC, CO also provides a measure of the quality of combustion. Low levels of CO emissions are associated with high-quality gas burnout.

CO emission data are based on continuous measurements and are shown in the following figures:

- Figure 3.40, for small plants incinerating predominantly MSW;
- Figure 3.41 and Figure 3.42, for medium-size plants incinerating predominantly MSW; the graph is divided into two figures for readability, due to the large number of plants represented;
- Figure 3.43, for large plants incinerating predominantly MSW;
- Figure 3.44, for plants incinerating predominantly ONHW.

The emission levels range between 0.5 mg/Nm^3 and 31 mg/Nm^3 as a yearly average and between 4 mg/Nm^3 and 53 mg/Nm^3 as a maximum daily average, with the exception of two plants showing negligibly low levels and one plant showing a level of 81 mg/Nm^3 as a maximum daily average ('fine' data filtering). Similarly to TVOC emissions, the difference between the maximum daily average and the yearly average tends to be substantial, reflecting the variability of CO emissions when the combustion conditions in the furnace are not stable, e.g. at start-ups and shutdowns. This is also reflected by typically large differences between the maxima of daily averages obtained with 'base' and 'fine' data filtering.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed, the type and amount of reagent used, the age and size of the plant, or the furnace type.

PCDD/F, PCBs and PAHs

~~The data on PCDD/PCDF emissions from MSWI do not represent the whole range of plants currently operating. Data from Denmark and Italy were not available. Data from France are also not included, although the data for these showed emission above 0.1ng/m^3 in many cases.~~

~~PCDD/PCDF emissions reported here are all based on discontinuous measurements, mainly twice a year. There is experience on continuous collection of dioxin measurements especially for MSWI in Flanders (B) and in Austria.~~

For reaching low levels of PCDD/F emissions, primary as well as secondary measures are important. In the firing system, effective mixing of the gases (high turbulence) improves the destruction of PCDD/F and similar compounds already present in the waste. Avoiding the temperature window for the recombination of PCDD/F and similar compounds in the boiler and flue-gas treatment system avoids the *de novo* synthesis ~~breeding~~ of new PCDD/F.

For further reduction, ~~mainly~~ three main types of techiques ~~flue-gas cleaning~~ are in use:

1. static activated carbon filter;
2. bag ~~house~~ filter with injection of activated carbon (usually mixed with other reagents);
3. ~~catalyst~~ destruction of ~~for~~ gaseous PCDD/F on a catalyst.

~~Both~~ The use of activated carbon ~~systems above~~ has ~~ve~~ the advantage of also reducing mercury emissions. ~~The~~ Catalysts ~~systems~~ are mainly used to reduce NO_X emissions ~~and PCDD/F~~.

PCDD/F emission data are based on discontinuous measurements, with 24 % of the reference lines using long-term sampling, and are shown in the following figures:

- Figure 3.45, for small plants incinerating predominantly MSW;
- Figure 3.46 and Figure 3.47, for medium-size plants incinerating predominantly MSW; the graph is divided into two figures for readability, due to the large number of plants represented;
- Figure 3.48, for large plants incinerating predominantly MSW;
- Figure 3.49, for plants incinerating predominantly ONHW.

The emission levels range between close to the limit of quantification and 0.24 ng I-TEQ/Nm^3, with the great majority of reference lines showing levels below 0.06 ng I-TEQ/Nm^3 both as an average over the sampling period and as a long-term sampling average. All plants fitted with fixed adsorption bed reported emission levels below 0.05 ng I-TEQ/Nm^3.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used, the age and size of the plant, or the furnace type.

~~Table 3.16: PCDD/F (TEQ) emissions survey of European MSWIs~~

~~Level of annual averages~~	~~Number of plants/lines~~
~~>2 ng/Nm^3~~	~~3~~
~~>1 <2 ng/Nm^3~~	~~11~~
~~>0.5 <1 ng/Nm^3~~	4
~~>0.1 <0.5 ng/Nm^3~~	~~7~~
~~>0.05 <0.1 ng/Nm^3~~	~~22~~
~~<0.05 ng/Nm^3~~	~~72~~
~~*Source:* [45, FEAD, 2002], [64, TWGComments, 2003]~~	

Polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs) are removed by the same techniques as PCDD/F, meaning that an effective flue-gas cleaning system for PCDD/F will also deal with PCBs and PAHs.

PCB emission data, based on discontinuous measurements, are shown in the following figures:

- Figure 3.50, for plants incinerating predominantly MSW;
- Figure 3.51, for plants incinerating predominantly ONHW.

Figure 3.52 shows PCDD/F and PCB emissions together, for the cases where both goups of substances were measured in the same sample, irrespective of the predominant type of waste incinerated.

The emission levels are mostly at levels that are low and below the levels of PCCD/F. However, there are a substantial number of plants reporting much higher emissions, up to 3 ng WHO-TEF for MSW and up to 56 ng WHO-TEF for ONHW. However, these high values are possibly misreported (e.g. not normalised for the TEF). *To the TWG: please check if the high values have been TEF-normalised.*

PAH and BaP emission data are based on discontinuous measurements and are shown in the following figures:

- Figure 3.53, PAH emissions from plants incinerating predominantly MSW;
- Figure 3.54, PAH emissions from plants incinerating predominantly ONHW;
- Figure 3.55, BaP emissions from plants incinerating predominantly MSW;
- Figure 3.56, BaP emissions from plants incinerating predominantly ONHW.

Emission levels range from 0.01 ng/Nm^3 to 50 µg/Nm^3 for PAHs and from 0.004 ng/Nm^3 to 1 µg/Nm^3 for BaP.

Mercury

~~The data include results from continuous measurement (used in Germany for over two years and Austria for over one year) and from discontinuous measurements (minimum twice a year). Therefore, comparability of data between these two types of measurement may be not very high. Continuous measurements will also include events with elevated emissions due to higher loads in the waste feed, which have been reported by some plants.~~

~~Table 3.17: Mercury emissions survey of European MSWIs~~

~~Level of annual averages~~	~~Number of plants/lines~~
~~>200 µg/Nm^3~~	~~0~~
~~>100 <200 µg/Nm^3~~	~~1~~
~~>50 <100 µg/Nm^3~~	~~3~~
~~>30 <50 µg/Nm^3~~	~~7~~
~~<30 µg/Nm^3~~	~~83~~
~~*Source:* [45, FEAD, 2002]~~	

~~For several plants in France, mercury measurements are not given alone but in combination with Cd (the ELV being given as a sum of the two). As the distribution of the two is not necessarily predictable, these results are presented in the following additional table:~~

~~Table 3.18: Combined Cd and Hg emissions of selected MSWIs in France~~

~~Level of annual averages~~	~~Number of plants/lines~~
~~>200 µg/Nm^3~~	~~0~~
~~>100 <200 µg/Nm^3~~	~~1~~
~~>50 <100 µg/Nm^3~~	~~5~~
~~>30 <50 µg/Nm^3~~	~~8~~
~~<30 µg/Nm^3~~	~~18~~
~~*Source:* [45, FEAD, 2002]~~	

~~The plants from which data are included in this report are equipped with, amongst others, the following types of flue-gas cleaning systems. The Hg emission levels reported are also shown:~~

~~Table 3.19: Emission results and techniques applied for Hg control at European MSWIs~~

~~System identifier~~	~~Dry ESP~~	~~Wet acid scrubber~~	~~Wet ESP~~	~~Bag house filter~~	~~Activated carbon injection~~	~~Activated carbon filter~~	~~Emission of Hg (µg/Nm^3)~~
~~1~~	~~✓~~	~~✓~~	~~✓~~	~~✓~~	~~✓~~		~~0.1~~
~~2~~		~~✓~~		~~✓~~		~~✓~~	~~0.1~~
~~3~~				~~✓~~	~~✓~~		~~1.77 and 1.93 and 3.16~~
4	~~✓~~	~~✓~~				~~✓~~	~~3~~
~~5~~		~~✓~~		~~✓~~	~~✓~~		~~3 and 6~~
~~6~~		~~✓~~		~~✓~~			~~2 and 7.3 and 10~~
~~7~~				~~✓~~			~~22 and 50~~
~~*Source:* [45, FEAD, 2002]~~							

~~The lowest results are seen where~~ The great majority of plants use activated carbon~~ is used~~, either as a ~~static~~ fixed-bed system~~,~~ or in an entrained flow activated carbon injection system with a bag filter. The consumption rate as well as the quality of activated carbon (e.g. sulphur impregnation) directly affect the emission levels. Other less frequently used techniques are the use of zeolites or the capture of mercury in the acidic wet scrubber, ~~The techniques in Table~~ 3.19~~ correspond to different ELVs requirements and to different costs. The wet acidic scrubber~~ which can serve as a sink for mercury if ~~the mercury~~ it is present in the Hg(II) chloride form. The mercury that has been transferred from the gas stream to the scrubber liquor can then be removed by a waste water treatment plant~~ or captured by spray drying of the waste water in the flue-gas. In the second case mercury recycles can occur unless there is an adequate rate Hg removal step~~.

~~Additional treatment may be required~~ If mercury is present in metallic form, the use of other techniques is needed (see mercury removal techniques). [74, TWGComments, 2004]

Under certain conditions (e.g. high input rate of mercury), the removal capacity limits of the FGC systems may be exceeded, leading to temporarily elevated mercury emissions. MSW usually contains low quantities of mercury. However, some short-term high loads may be observed if the buffer capacity or the ability to respond to peak concentrations of the flue-gas cleaning system is exceeded~~ have been noted~~. These are generally associated with the inclusion in the MSW of batteries, electrical switches, thermometers, laboratory wastes, etc. This may be reflected by cases where the performance levels of a reference line for different averaging periods show large differences.

Mercury emission data are based either on continuous or discontinuous measurement and are shown in the following figures:

- Figure 3.57, for small plants incinerating predominantly MSW and monitoring mercury discontinuously;
- Figure 3.58, for medium-size plants incinerating predominantly MSW and monitoring mercury discontinuously;
- Figure 3.59, for large plants incinerating predominantly MSW and monitoring mercury discontinuously;
- Figure 3.60, for plants incinerating predominantly MSW and monitoring mercury continuously;
- Figure 3.61, for plants incinerating predominantly ONHW and monitoring mercury discontinuously;
- Figure 3.62, for plants incinerating predominantly ONHW and monitoring mercury continuously.

Additionally, maximum half-hourly levels shown in the following figures:

- Figure 3.63, maximum half-hourly levels for plants incinerating predominantly MSW;
- Figure 3.64, maximum half-hourly levels for plants incinerating predominantly ONHW.

For half-hourly levels, the 'fine' data filtering is the same as the 'base' filtering but excludes the levels recorded in the 30 hours of highest emissions in the year. For monthly levels, which are hardly affected by short-term peaks, only the 'base' filtering mode is presented.

The emission levels range between close to the limit of quantification and 0.01 mg/Nm^3 as a yearly average, 0.018 mg/Nm^3 as a maximum monthly average, and 0.036 mg/Nm^3 as a maximum daily average ('fine' data filtering). In certain cases the maximum daily average obtained with 'base' data filtering may be substantially higher (up to 0.09 mg/Nm^3), which may reflect not only high mercury input episodes, but also OTNOC situations where the daily average typically includes only a few half-hourly periods and where the mercury levels measured are elevated. Plants that measure mercury discontinuously report averages over the sampling period generally below 0.025 mg/Nm^3, with a few exceptions that include plants not reporting the use of reagents to control mercury emissions.

The plants fitted with fixed adsorption bed generally report emission levels that are stable with maximum daily averages relatively insensitive to data filtering, mostly below 0.01 mg/Nm^3 and in all cases below 0.025 mg/Nm^3. These levels are also maintained as averages over the sampling period reported by plants that measure mercury discontinuously.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used, the age and size of the plant, or the furnace type.

Antimony, arsenic, chromium, cobalt, copper, lead, manganese, nickel and vanadium

The techniques used to remove dust are the main ones also used to reduce the emissions of dust-bound metals. [Sb+As+Cr+Co+Cu+Pb+Mn+Ni+V] emission data are based on discontinuous measurements and are shown in the following figures:

- Figure 3.65, for small plants incinerating predominantly MSW;
- Figure 3.66 and Figure 3.67, for medium-size plants incinerating predominantly MSW; the graph is divided into two figures for readability, due to the large number of plants represented;
- Figure 3.68, for large plants incinerating predominantly MSW;
- Figure 3.69, for plants incinerating predominantly ONHW.

The emission levels range between close to the limit of quantification and 0.3 mg/Nm^3 with the exception of six reference lines showing levels between 0.3 mg/Nm^3 and 0.5 mg/Nm^3 as a maximum of the averages over the sampling period; one reference line reported a maximum level of around 5 mg/Nm^3.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed, the age and size of the plant, or the furnace type.

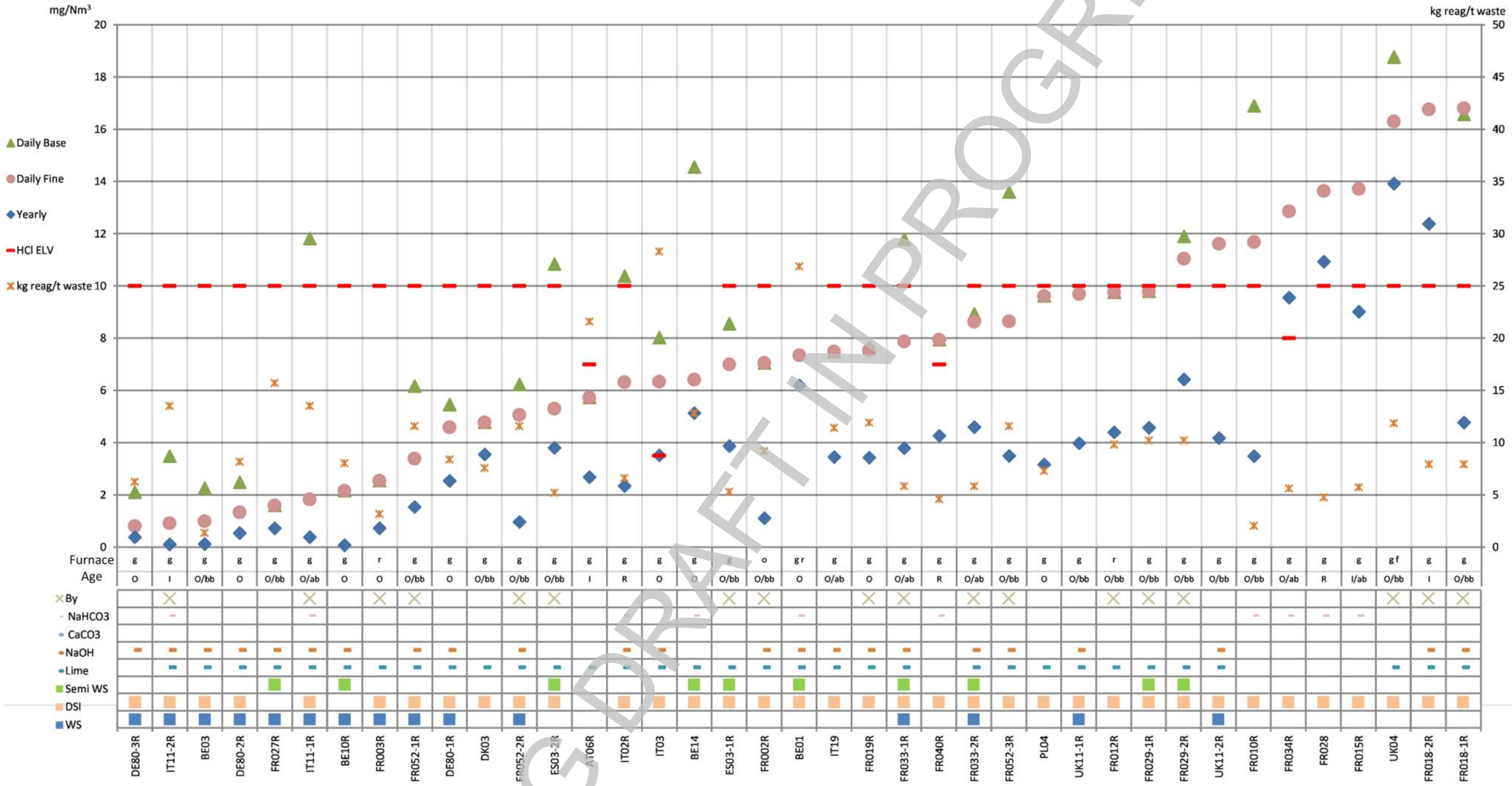
Cadmium and thallium

The techniques used to remove dust are the main ones also used to reduce the emissions of dust-bound metals. [Cd+Tl] emission data are based on discontinuous measurements and are shown in the following figures:

- Figure 3.70, for small plants incinerating predominantly MSW;
- Figure 3.71 and Figure 3.72, for medium-size plants incinerating predominantly MSW; the graph is divided into two figures for readability, due to the large number of plants represented;
- Figure 3.73, for large plants incinerating predominantly MSW;
- Figure 3.74, for plants incinerating predominantly ONHW.

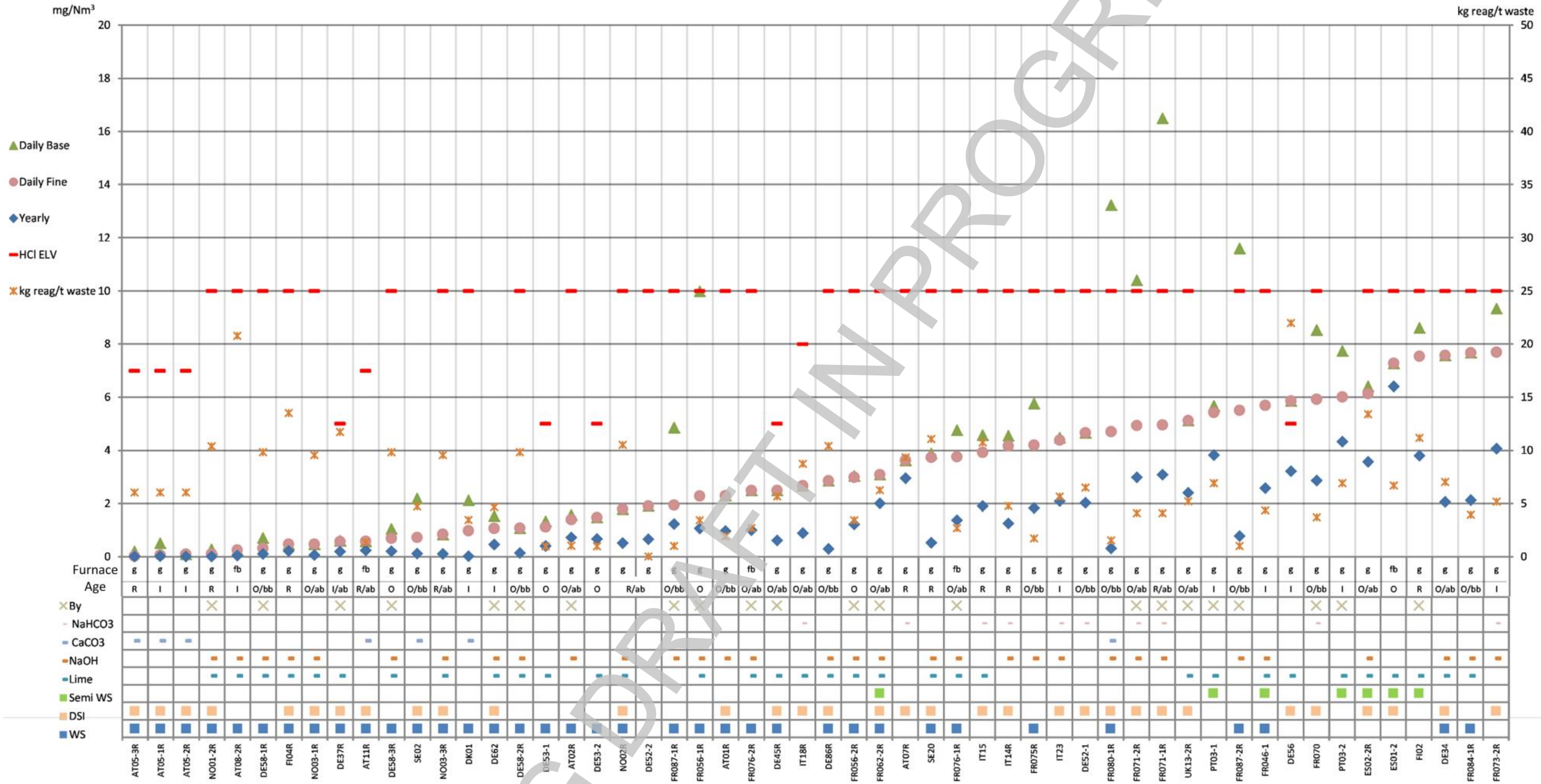
The emission levels are almost always very low and range between close to the limit of quantification and 0.02 mg/Nm^3,with the exception of six reference lines showing levels between 0.02 mg/Nm^3 and 0.1 mg/Nm^3 as a maximum of the averages over the sampling period; one reference line reported a maximum level above 1 mg/Nm^3.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed, the age and size of the plant, or the furnace type.



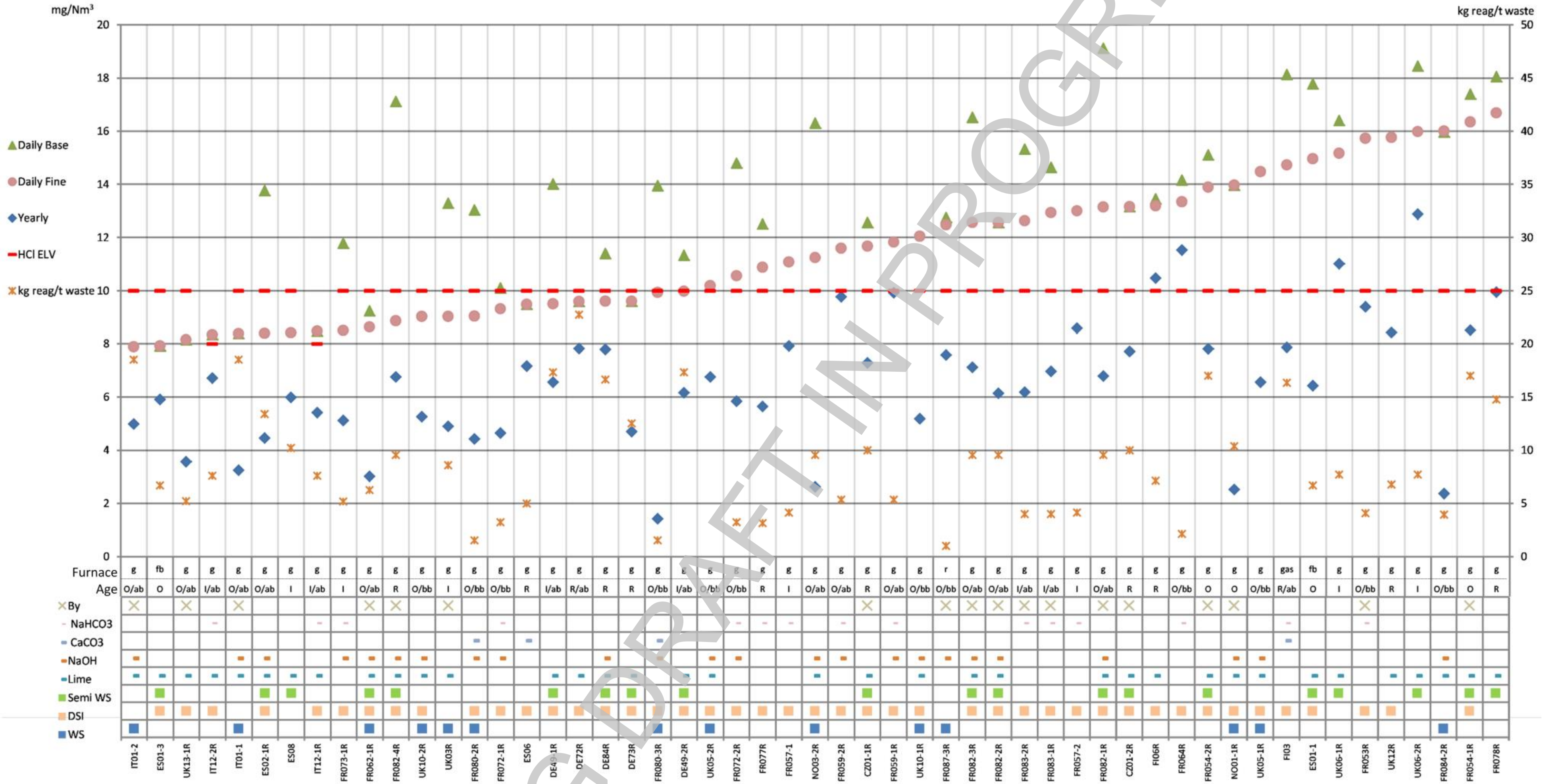
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.1: Continuously monitored HCl emissions to air from small plants incinerating predominantly municipal solid waste



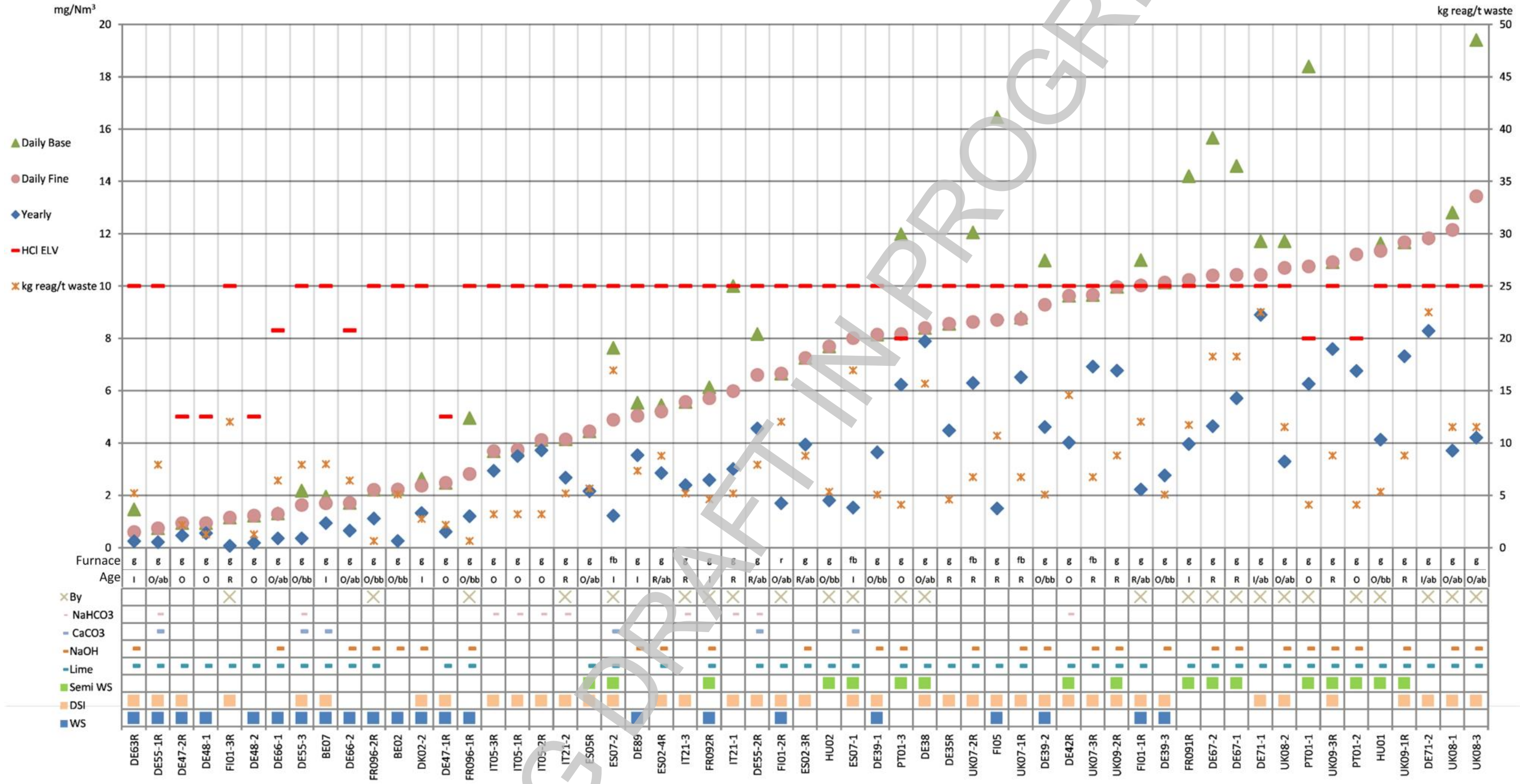
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.2: Continuously monitored HCl emissions to air from medium-size plants incinerating predominantly municipal solid waste (1/2)



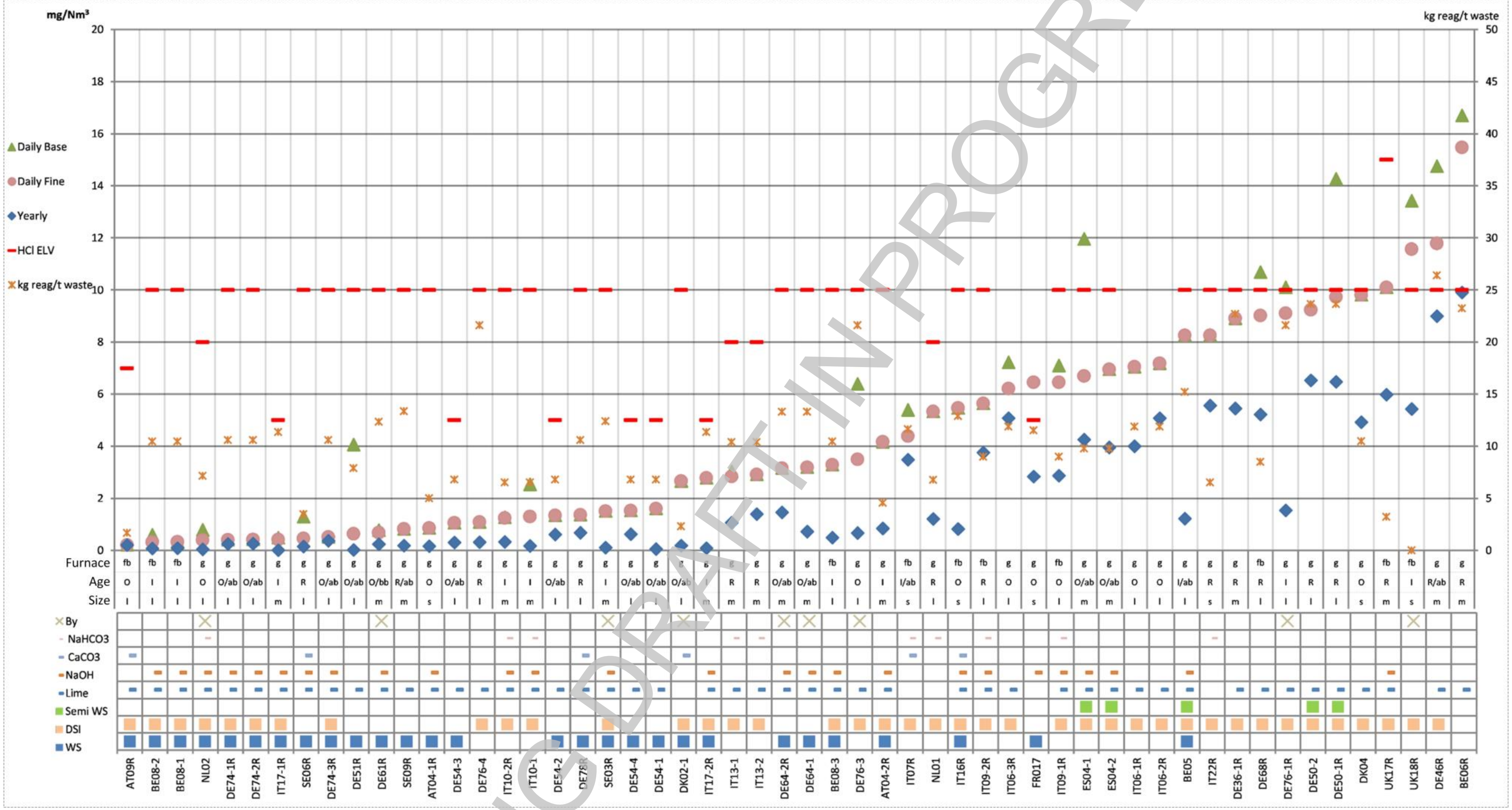
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.3: Continuously monitored HCl emissions to air from medium-size plants incinerating predominantly municipal solid waste (2/2)



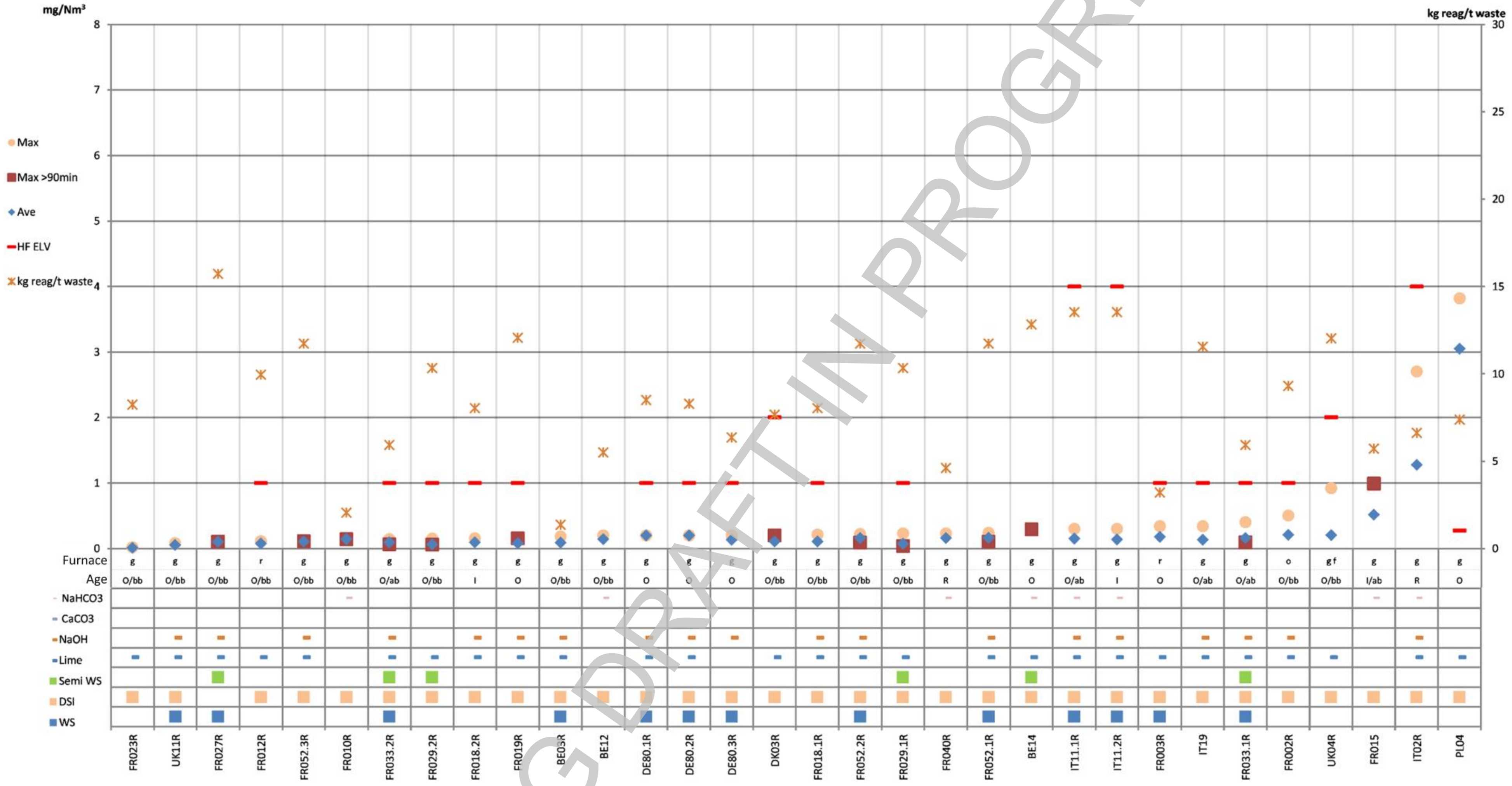
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.4: Continuously monitored HCl emissions to air from large plants incinerating predominantly municipal solid waste



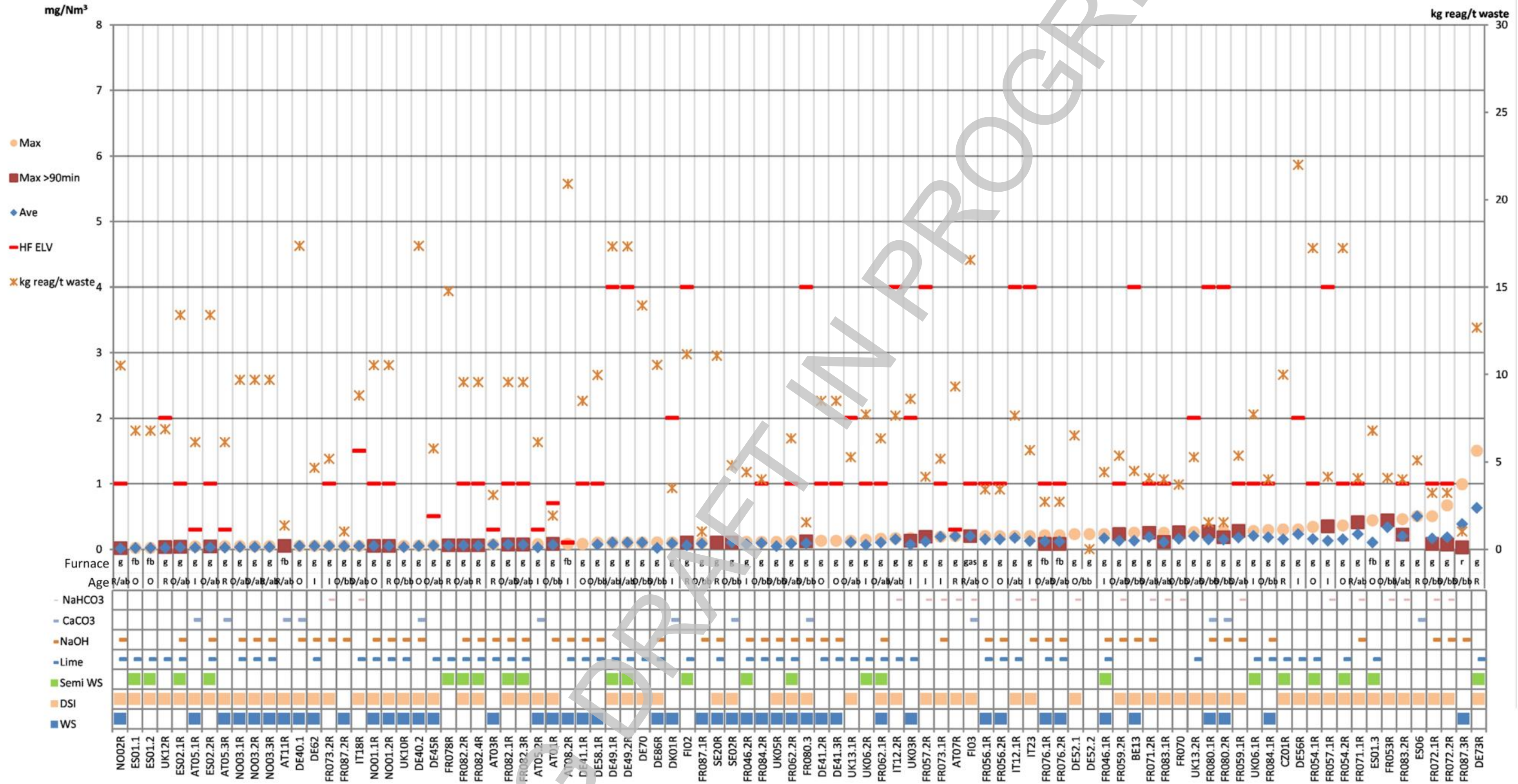
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Plant size: s = small; m = medium; l = large.
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.5: Continuously monitored HCl emissions to air from plants incinerating predominantly other non-hazardous waste



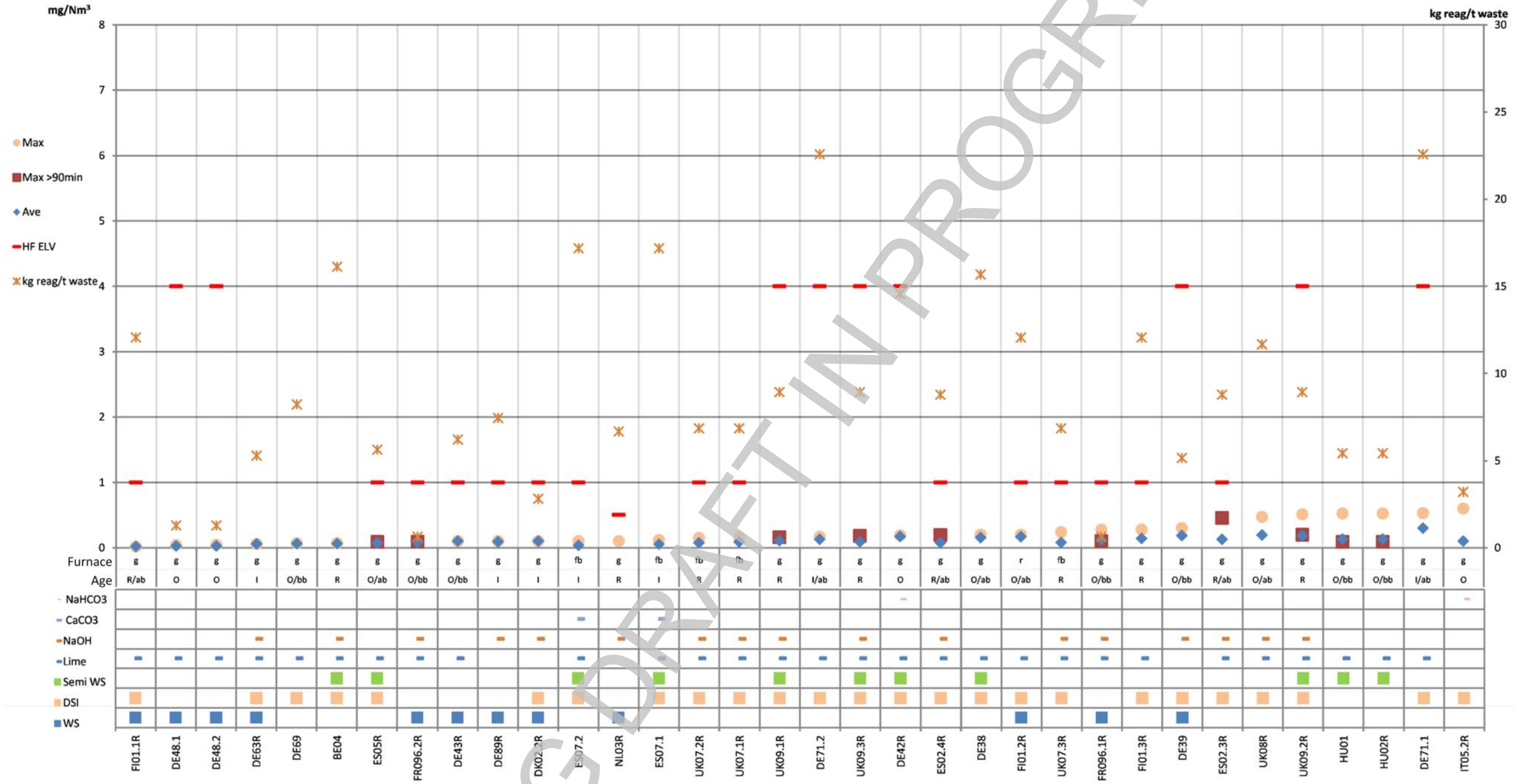
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.6: Discontinuously monitored HF emissions to air from small plants incinerating predominantly municipal solid waste



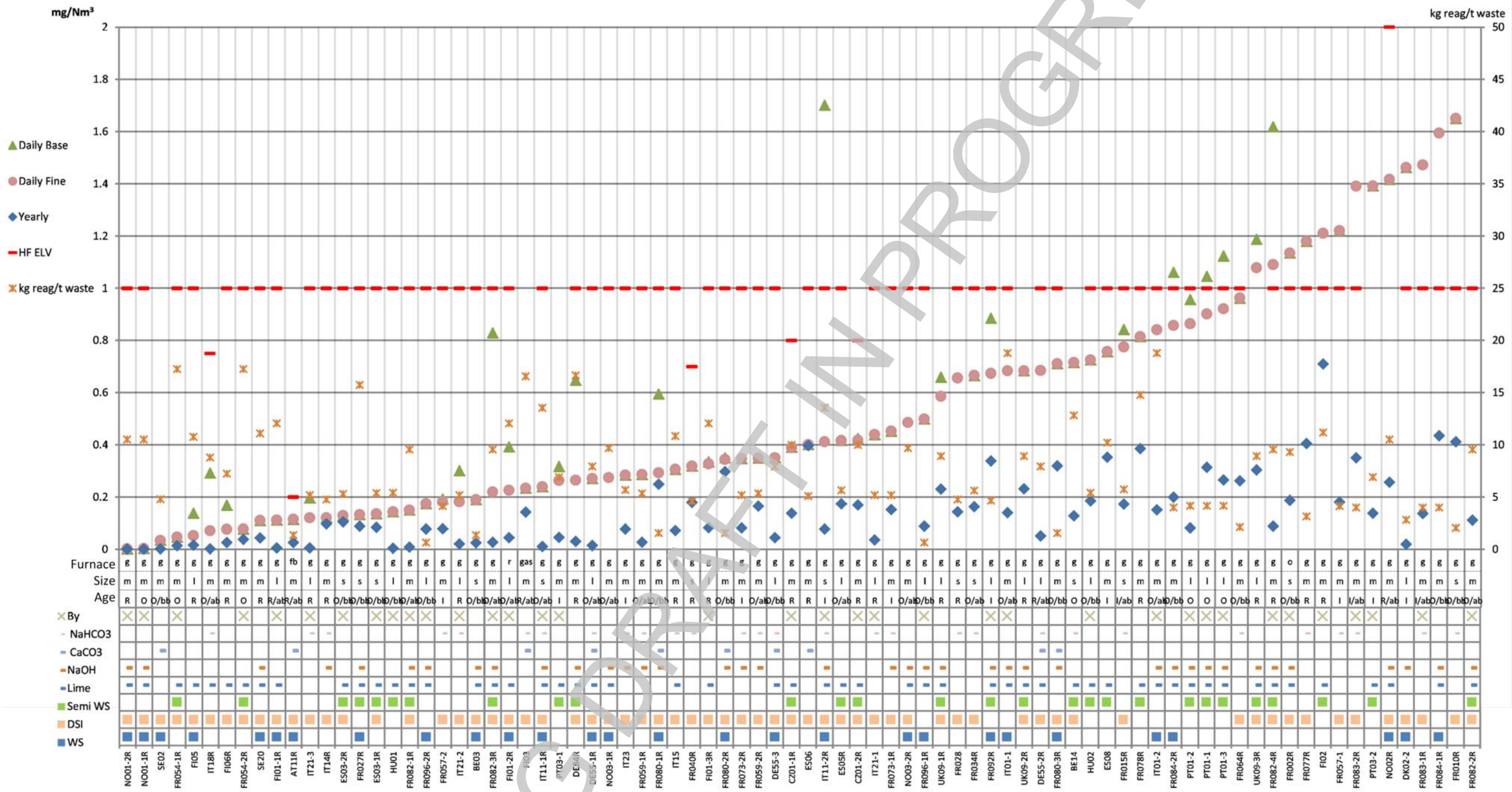
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.7: Discontinuously monitored HF emissions to air from medium-size plants incinerating predominantly municipal solid waste



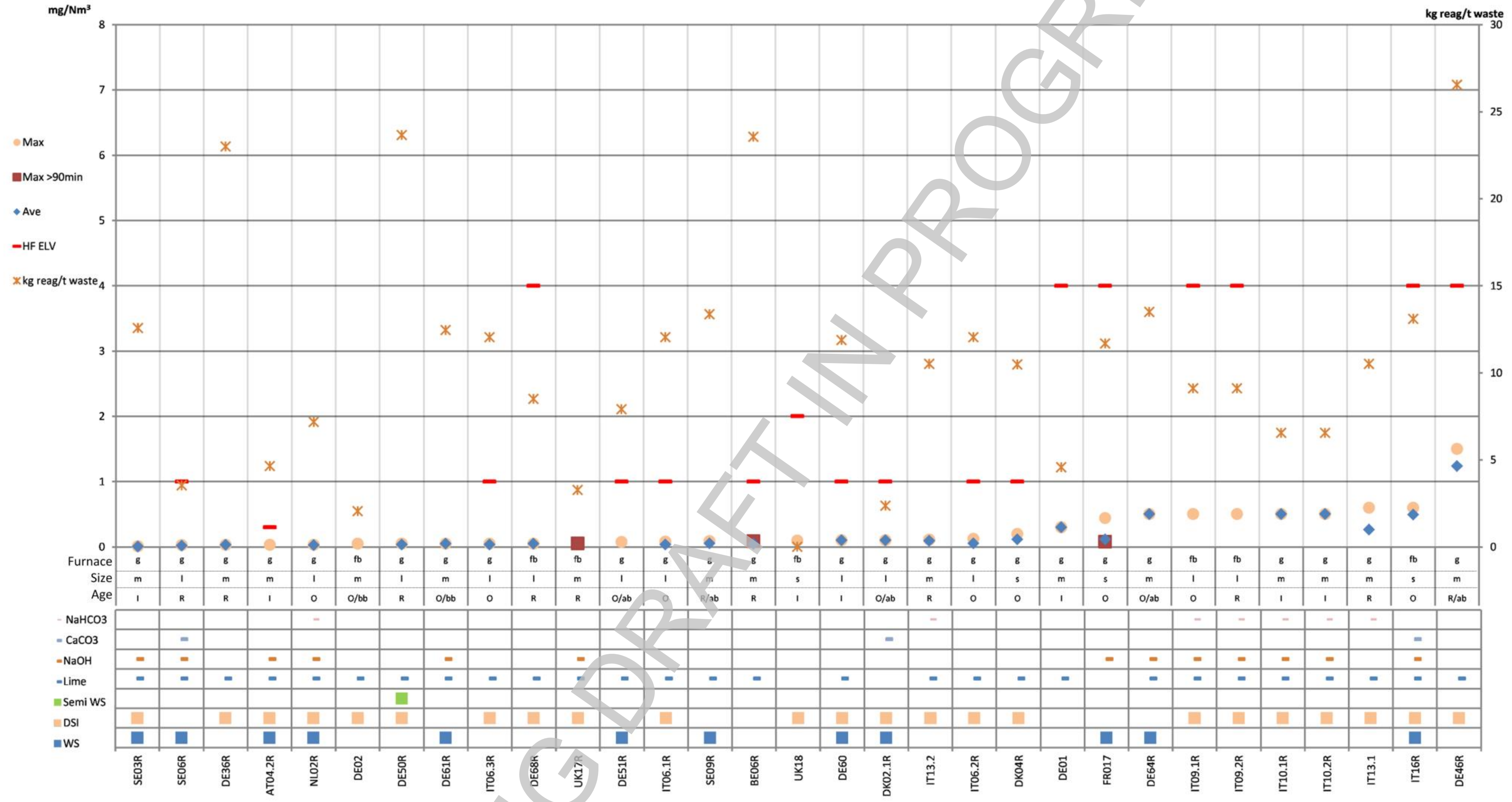
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.8: Discontinuously monitored HF emissions to air from large plants incinerating predominantly municipal solid waste



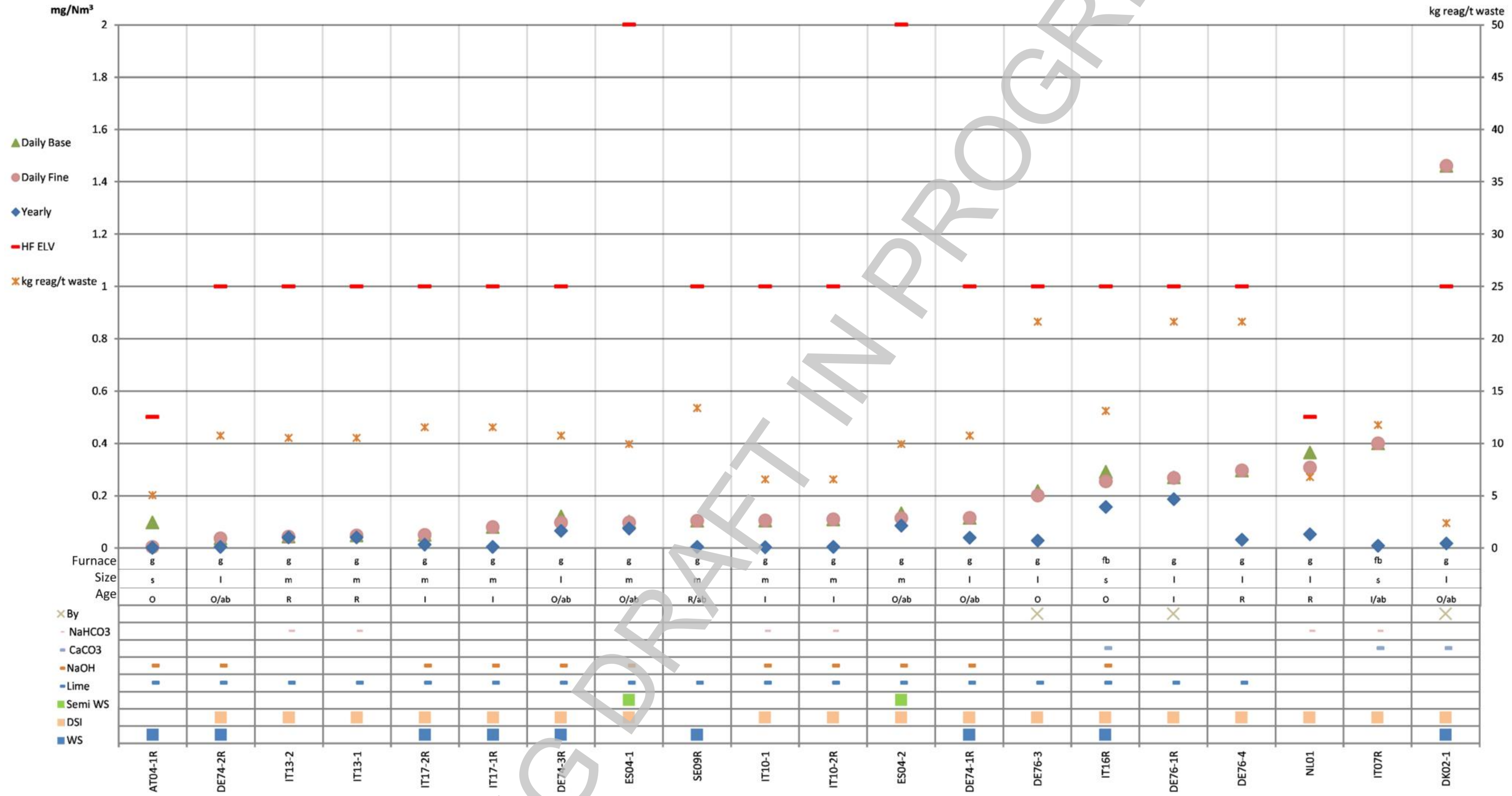
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.9: Continuously monitored HF emissions to air from plants incinerating predominantly municipal solid waste



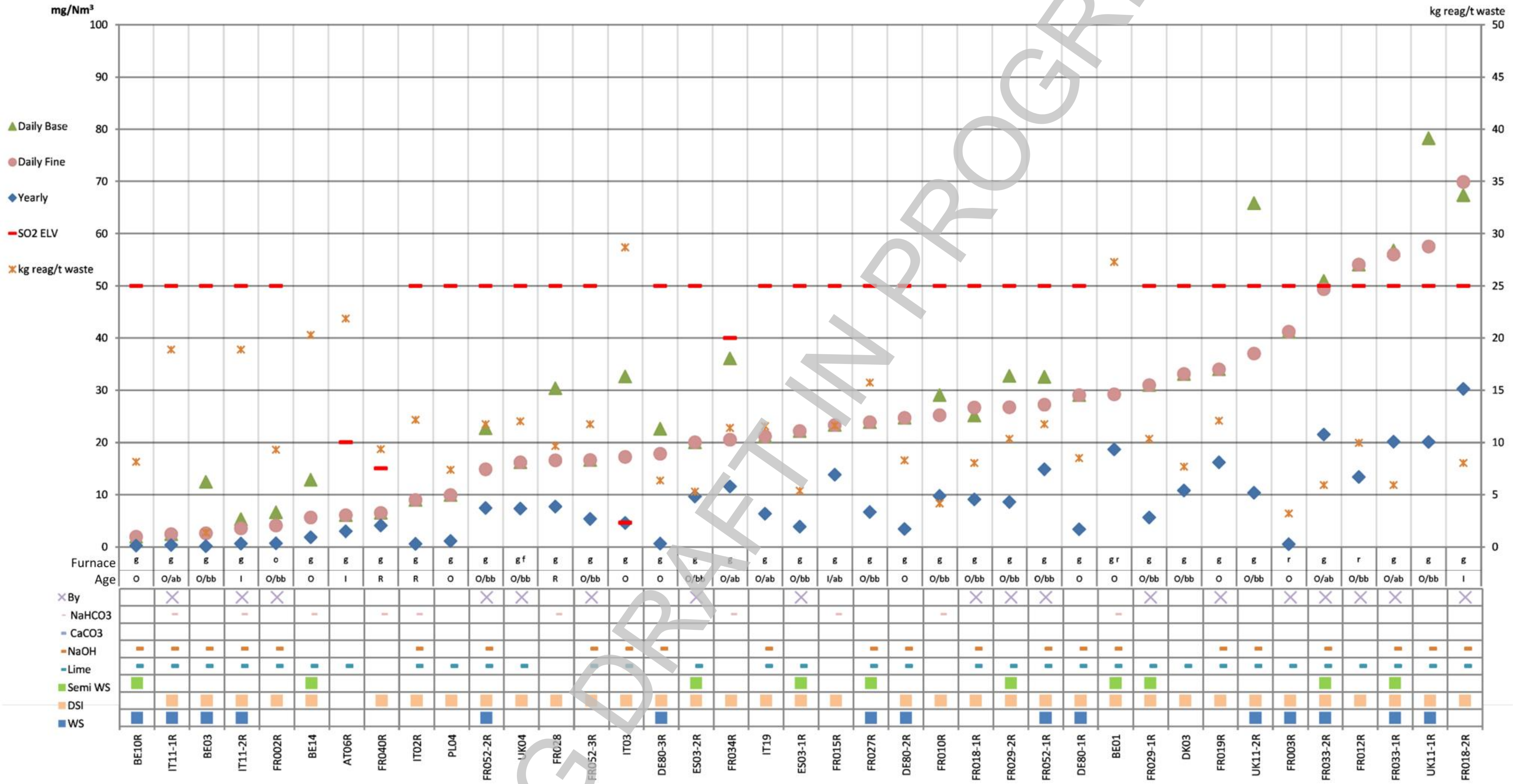
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: $NaHCO_3$ = Sodium Bicarbonate; $CaCO_3$ = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.10: Discontinuously monitored HF emissions to air from plants incinerating predominantly other non-hazardous waste



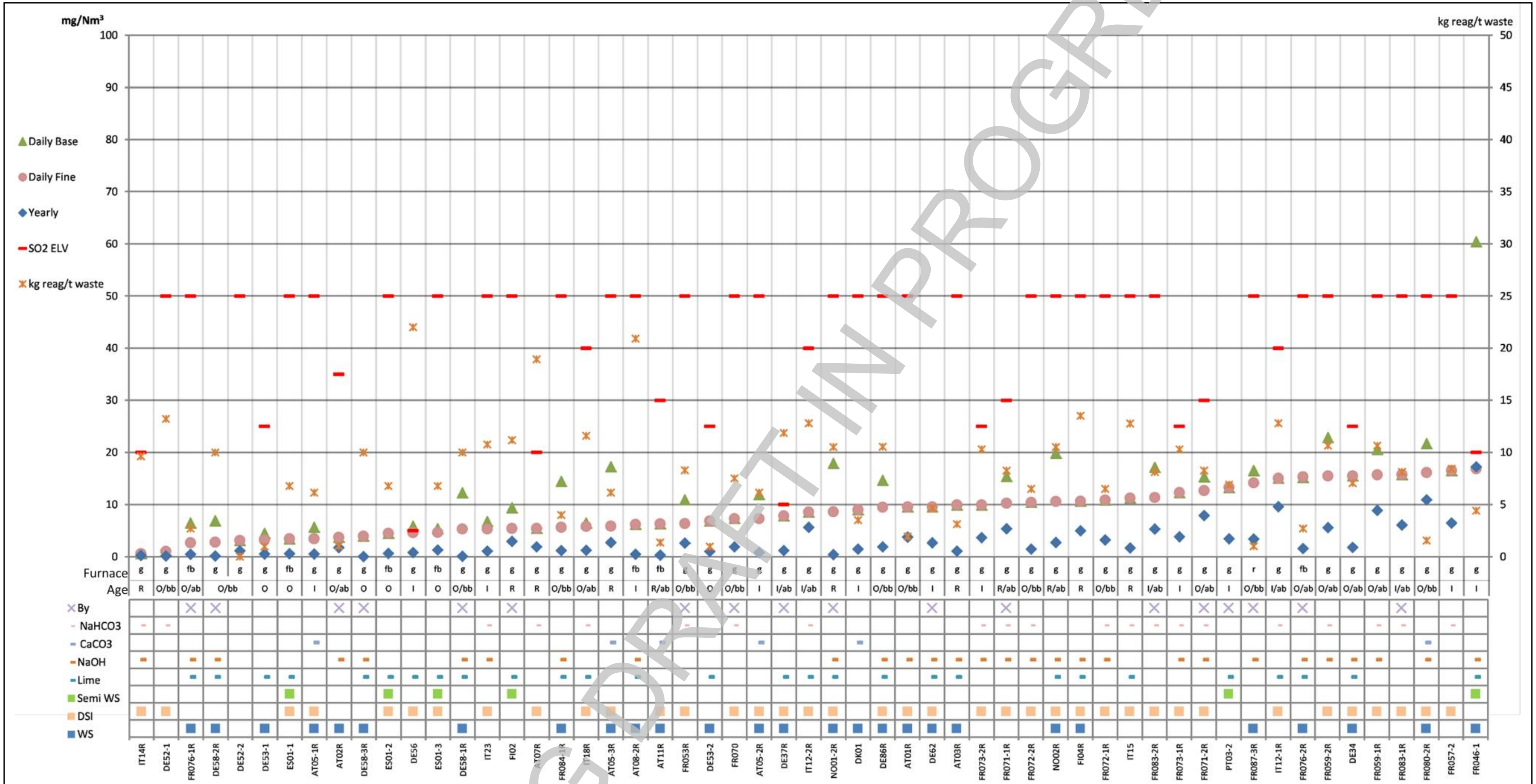
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.11: Continuously monitored HF emissions to air from plants incinerating predominantly other non-hazardous waste



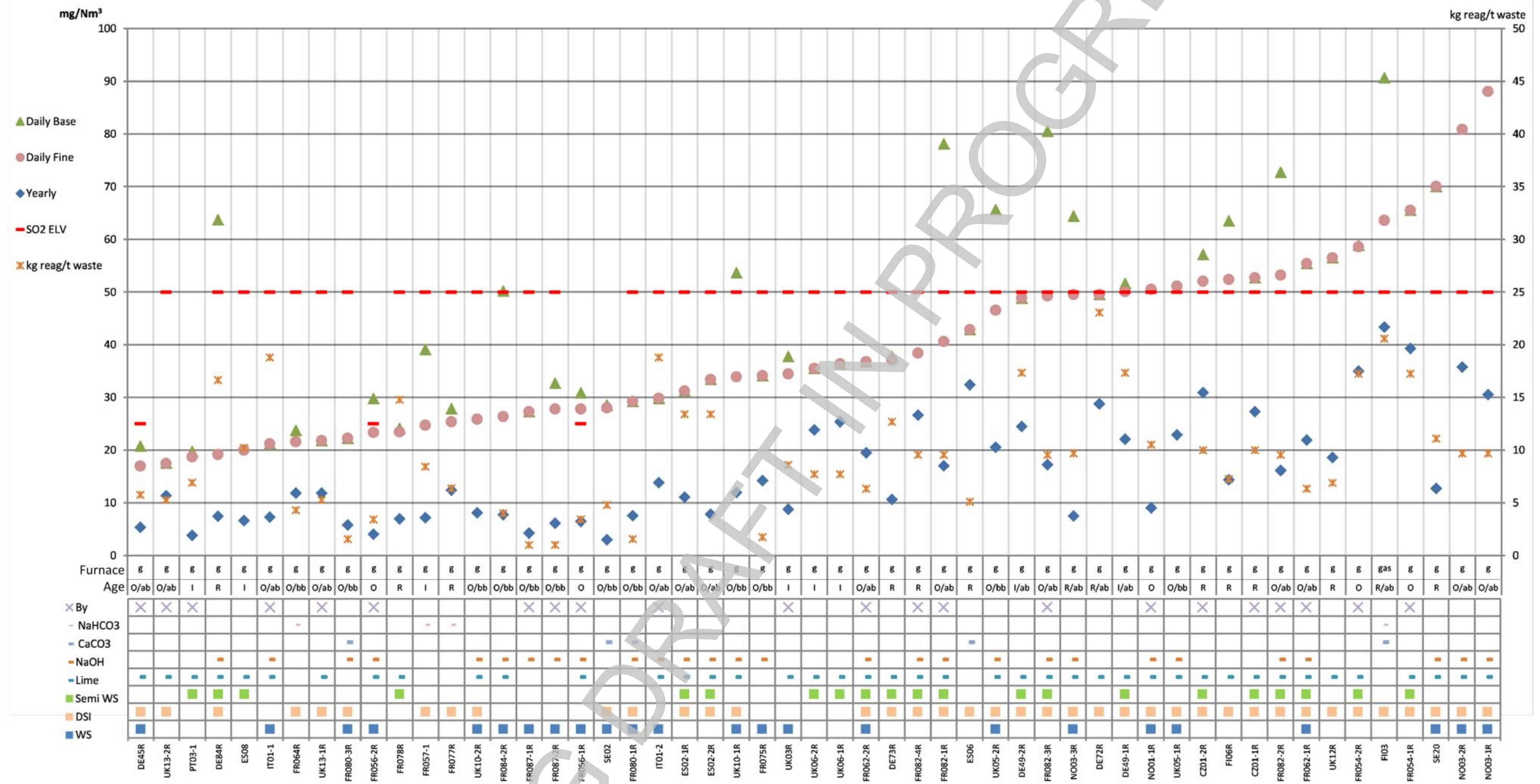
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.12: Continuously monitored SO_2 emissions to air from small plants incinerating predominantly municipal solid waste



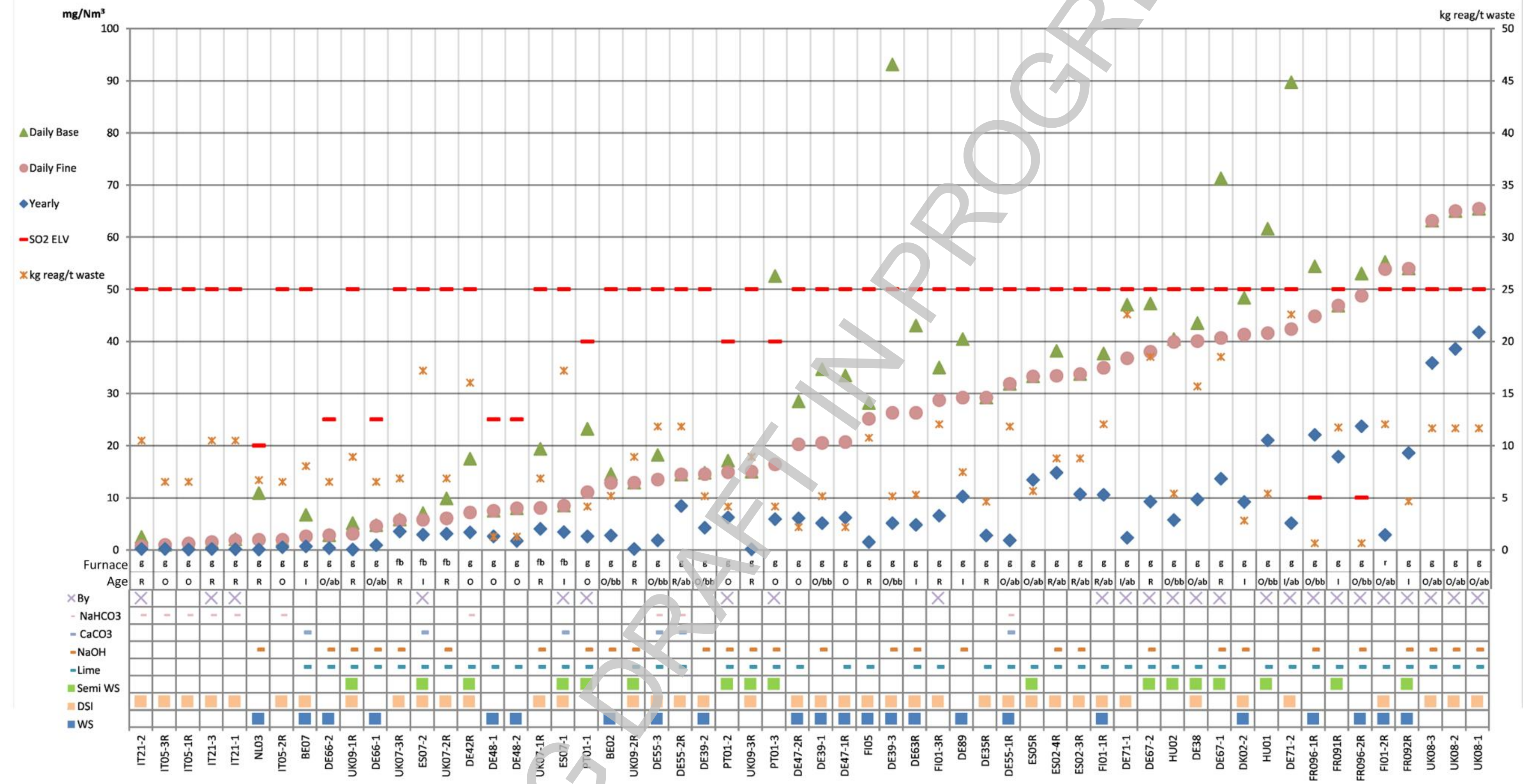
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.13: Continuously monitored SO_2 emissions to air from medium-size plants incinerating predominantly municipal solid waste (1/2)



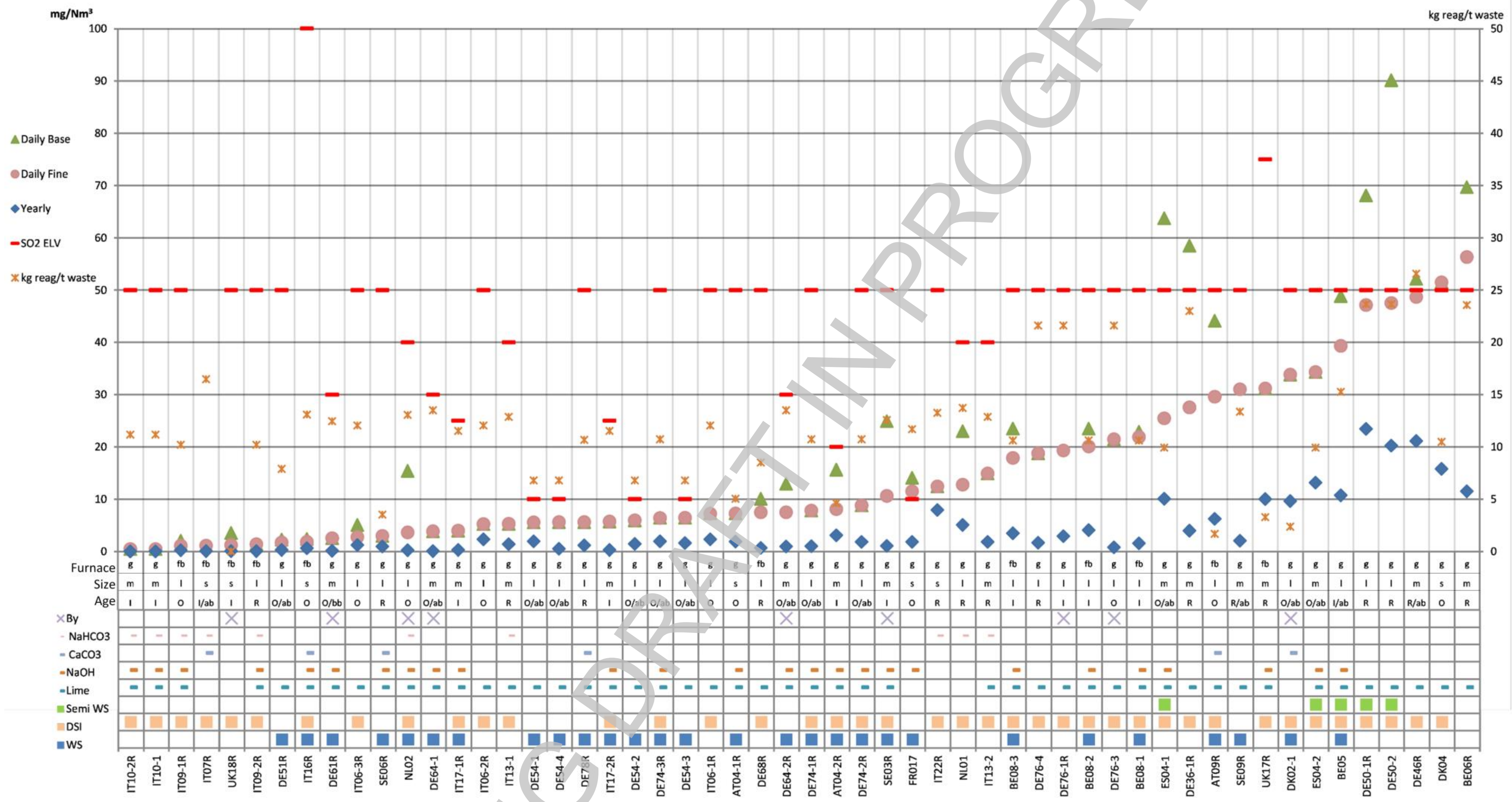
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.14: Continuously monitored SO_2 emissions to air from medium-size plants incinerating predominantly municipal solid waste (2/2)



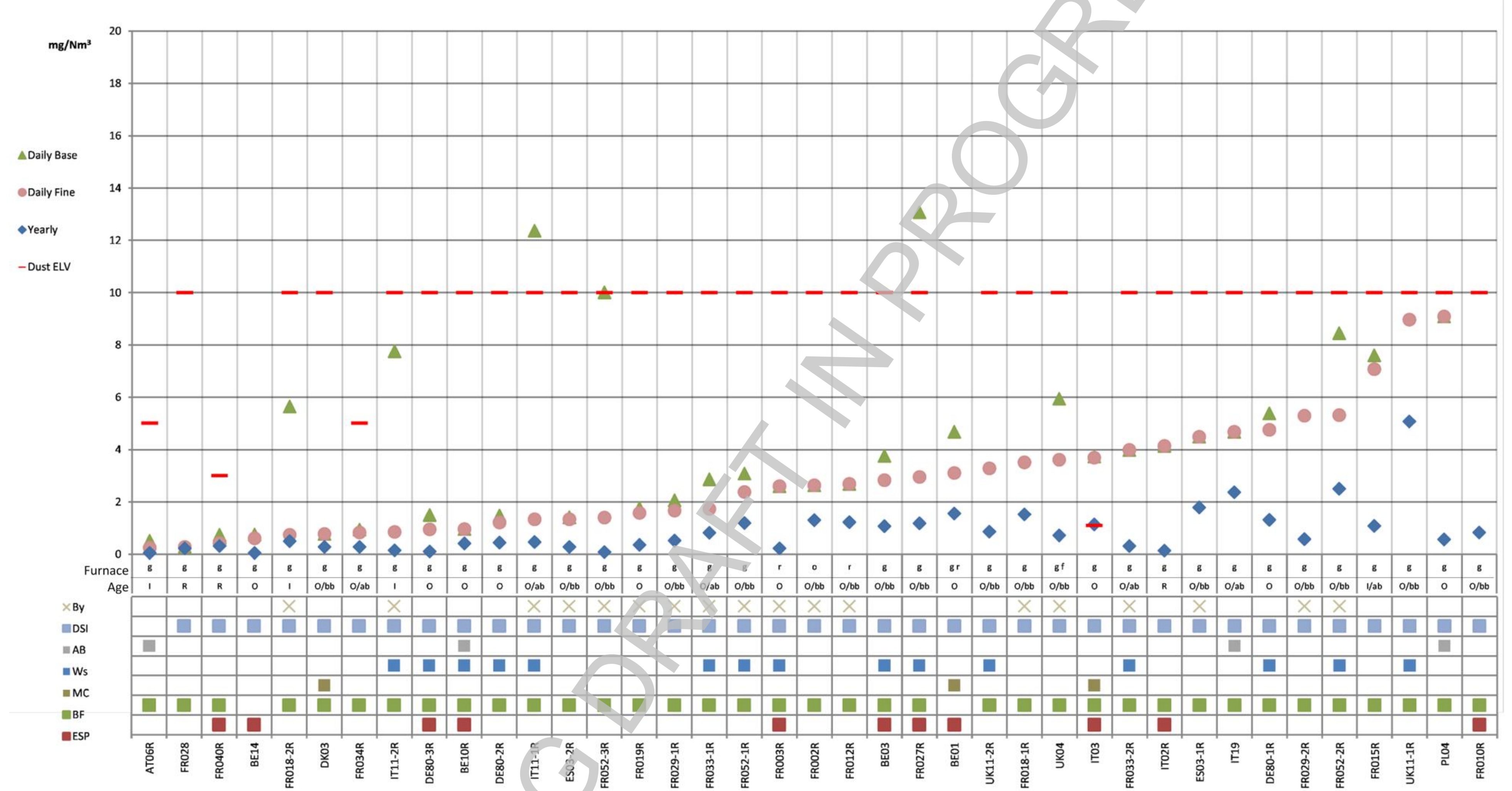
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: $NaHCO_3$ = Sodium Bicarbonate; $CaCO_3$ = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.15: Continuously monitored SO_2 emissions to air from large plants incinerating predominantly municipal solid waste



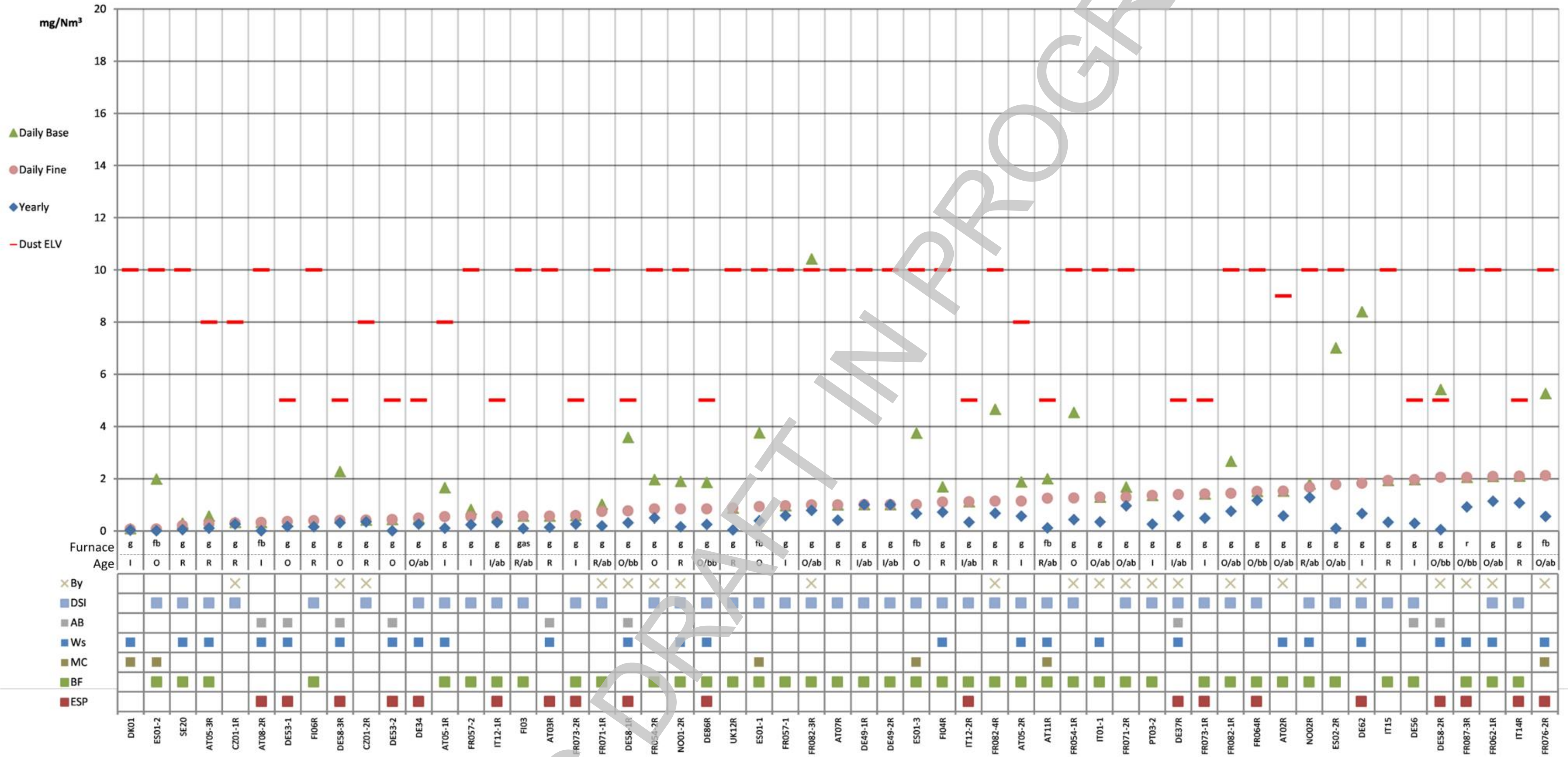
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.16: Continuously monitored SO_2 emissions to air from plants incinerating predominantly other non-hazardous waste



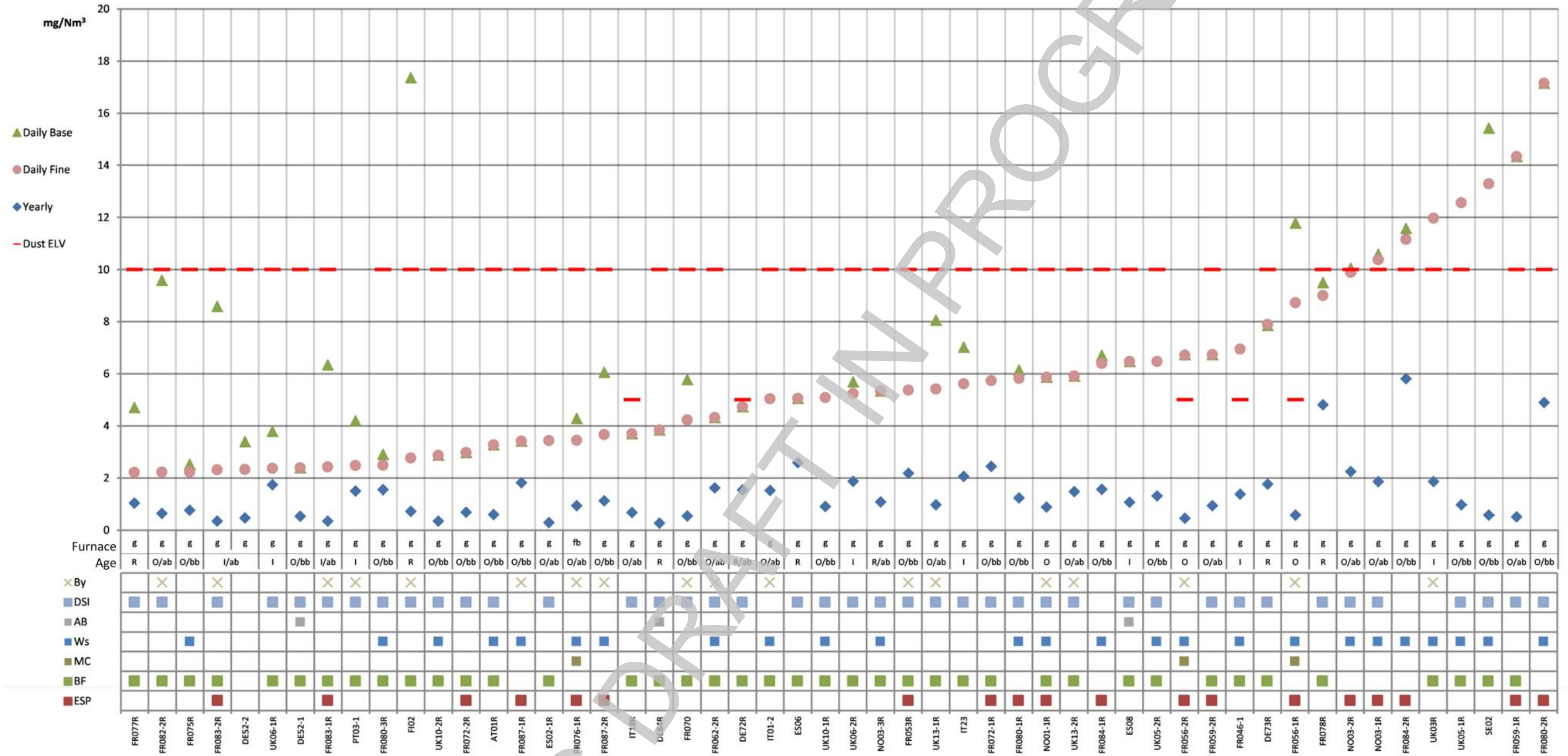
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed; WS = Wet Scrubber; MC = Multi-cyclone; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.17: Continuously monitored Dust emissions to air from small plants incinerating predominantly municipal solid waste



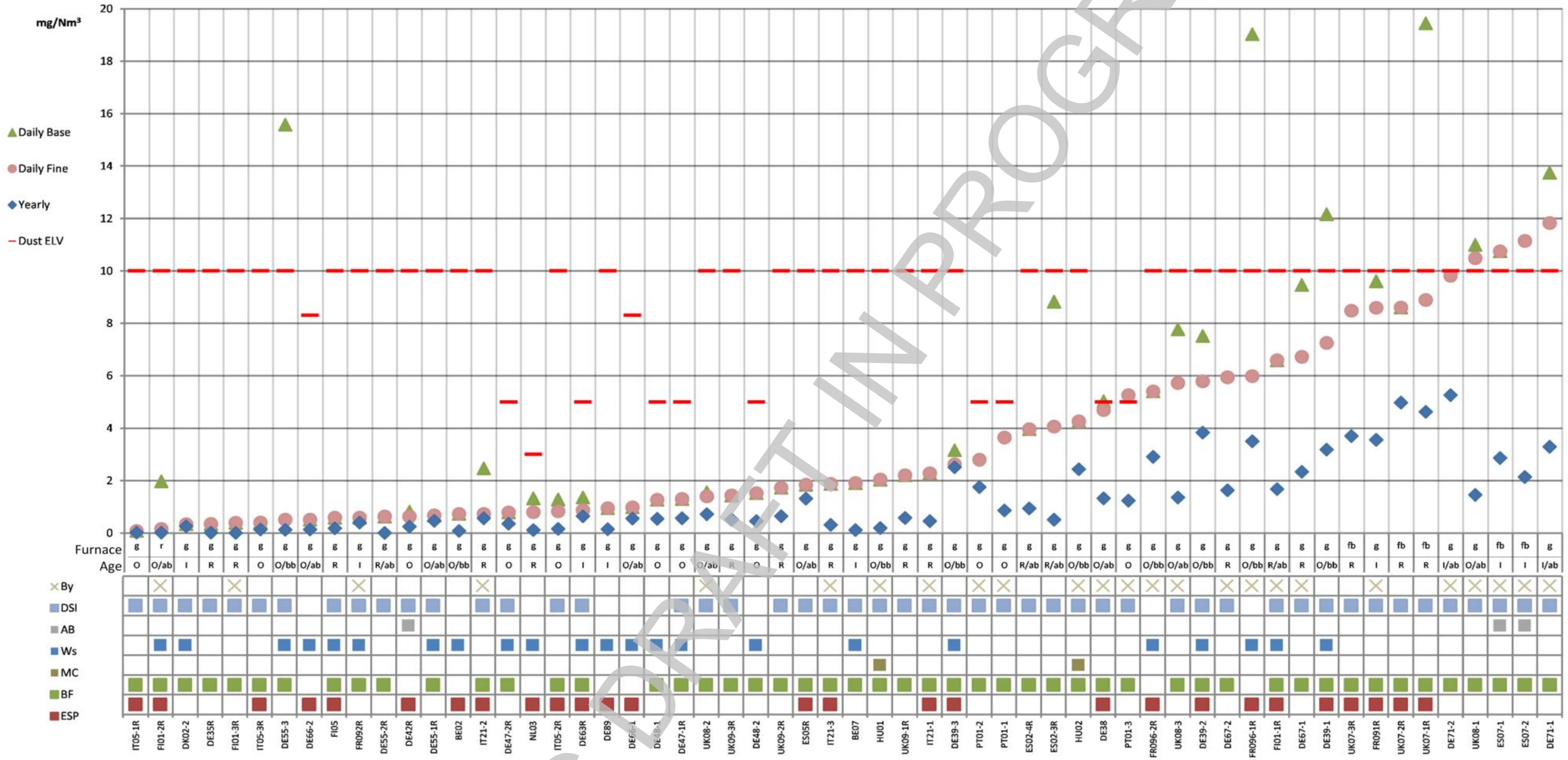
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed; WS = Wet Scrubber; MC = Multi-cyclone; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.18: Continuously monitored Dust emissions to air from medium-size plants incinerating predominantly municipal solid waste (1/2)



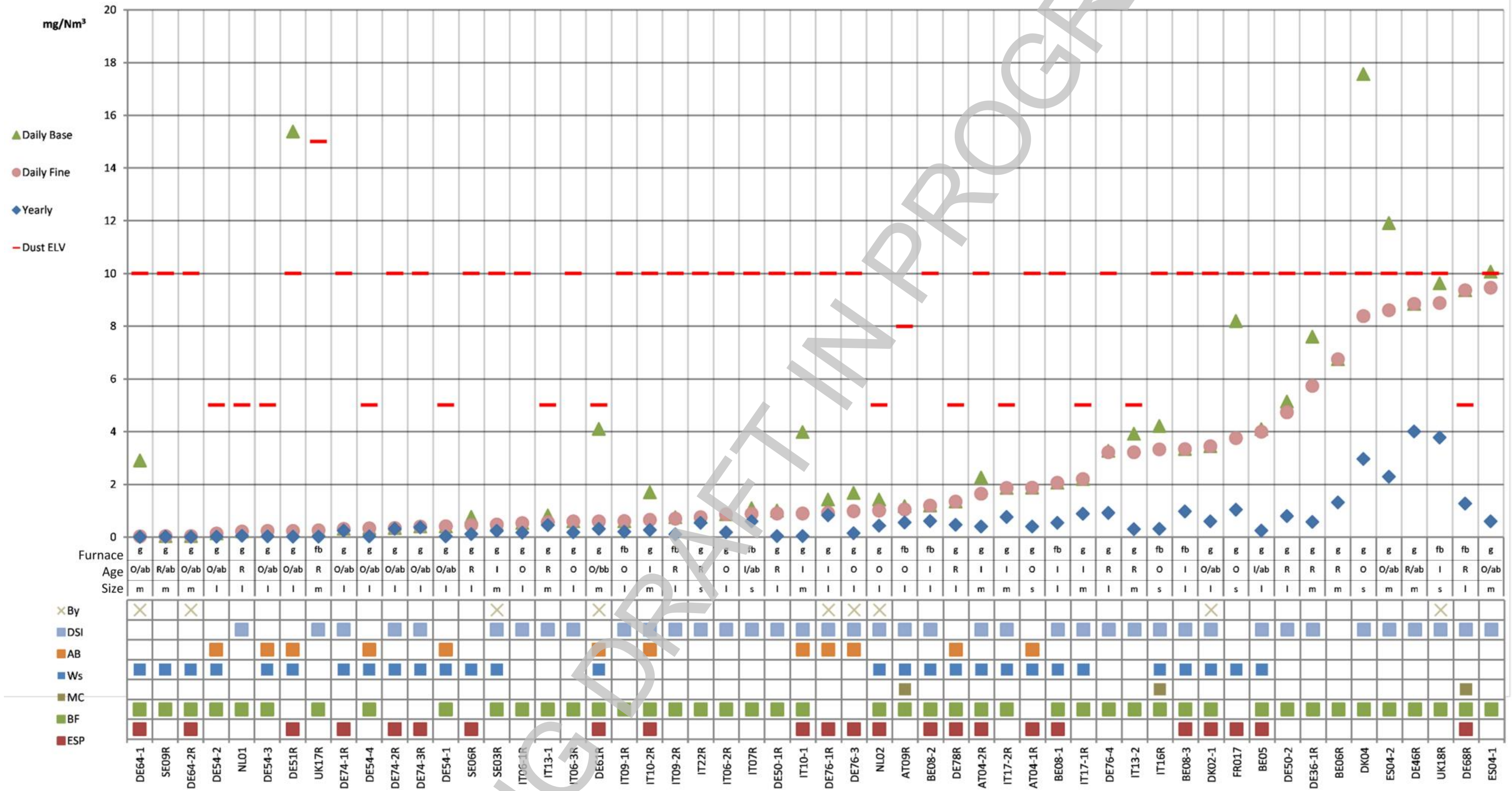
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed; WS = Wet Scrubber; MC = Multi-cyclone; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.19: Continuously monitored Dust emissions to air from medium-size plants incinerating predominantly municipal solid waste (2/2)



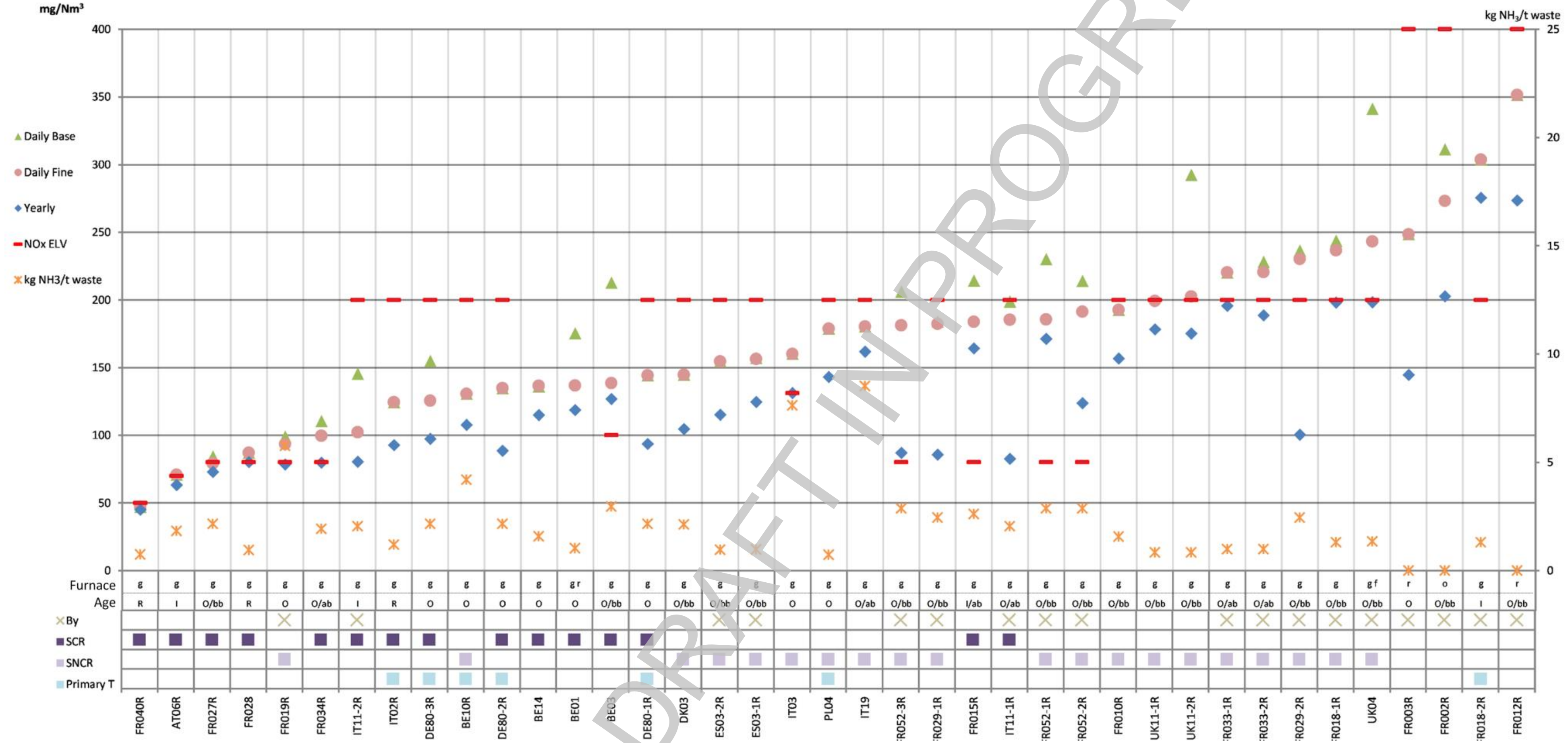
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed; WS = Wet Scrubber; MC = Multi-cyclone; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.20: Continuously monitored Dust emissions to air from large plants incinerating predominantly municipal solid waste



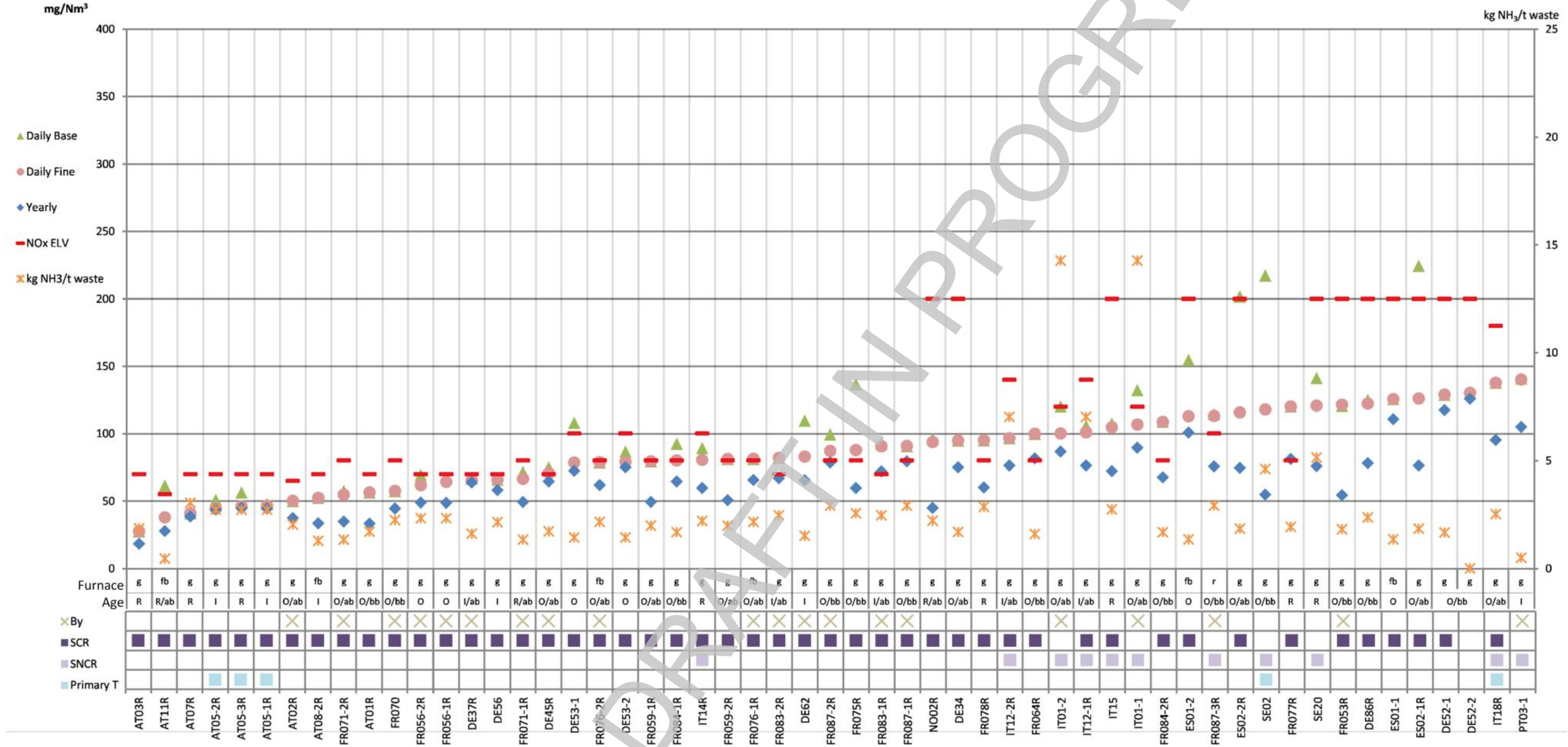
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Plant size: s = small; m = medium; l = large.
BY = ByPass.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed; WS = Wet Scrubber; MC = Multi-cyclone; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.21: Continuously monitored Dust emissions to air from plants incinerating predominantly other non-hazardous waste



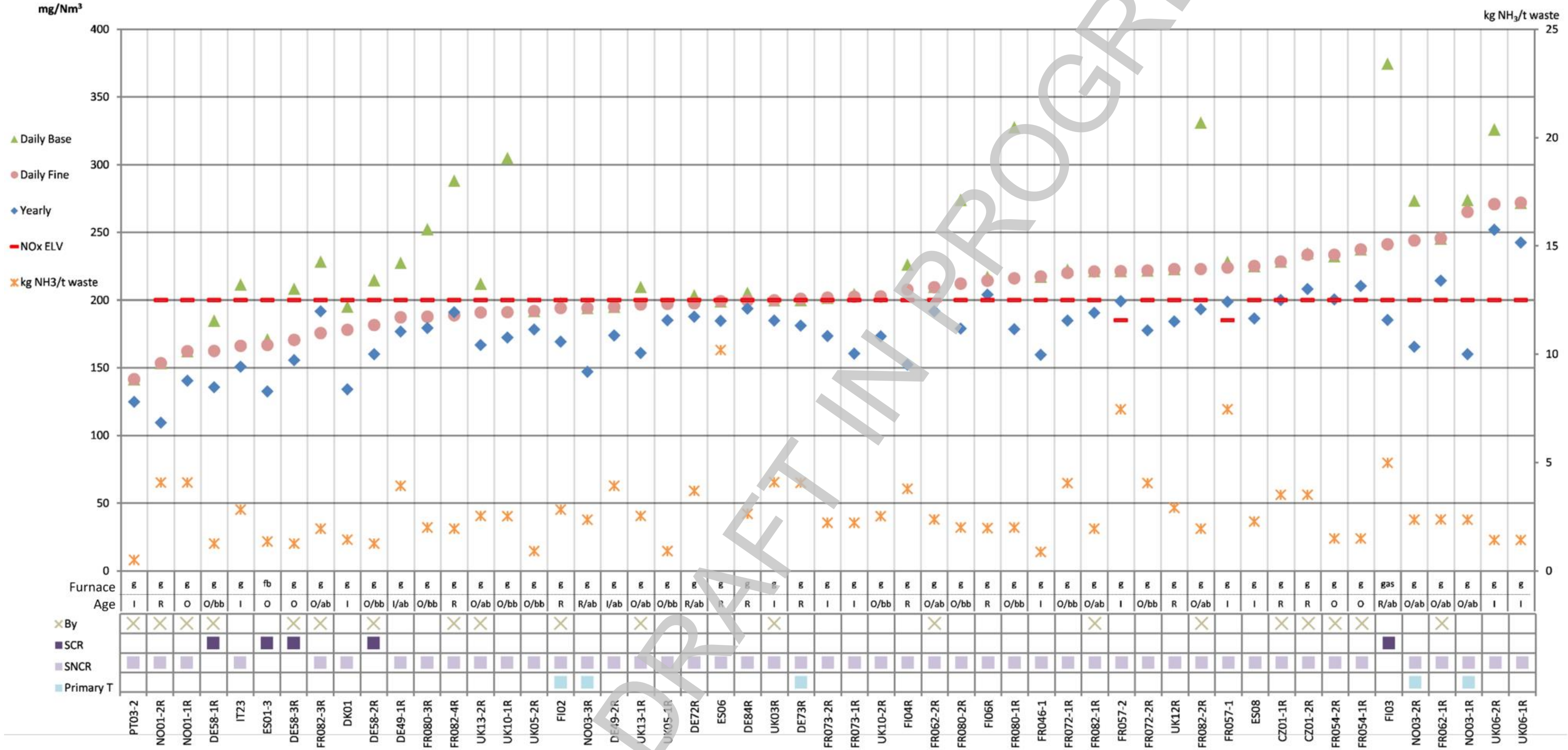
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction; Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.22: Continuously monitored NO_x emissions to air from small plants incinerating predominantly municipal solid waste



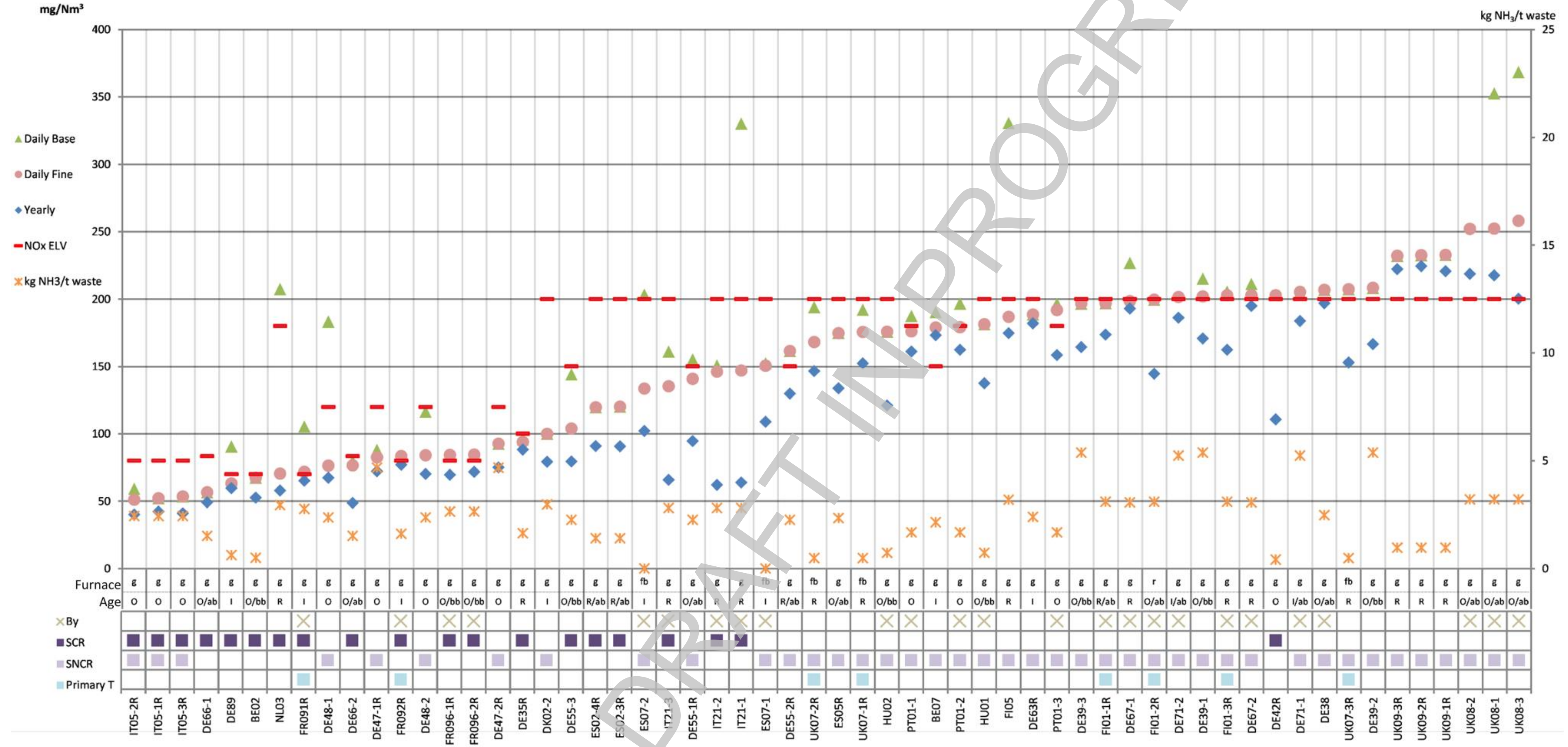
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction; Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.23: Continuously monitored NO_x emissions to air from medium-size plants incinerating predominantly municipal solid waste (1/2)



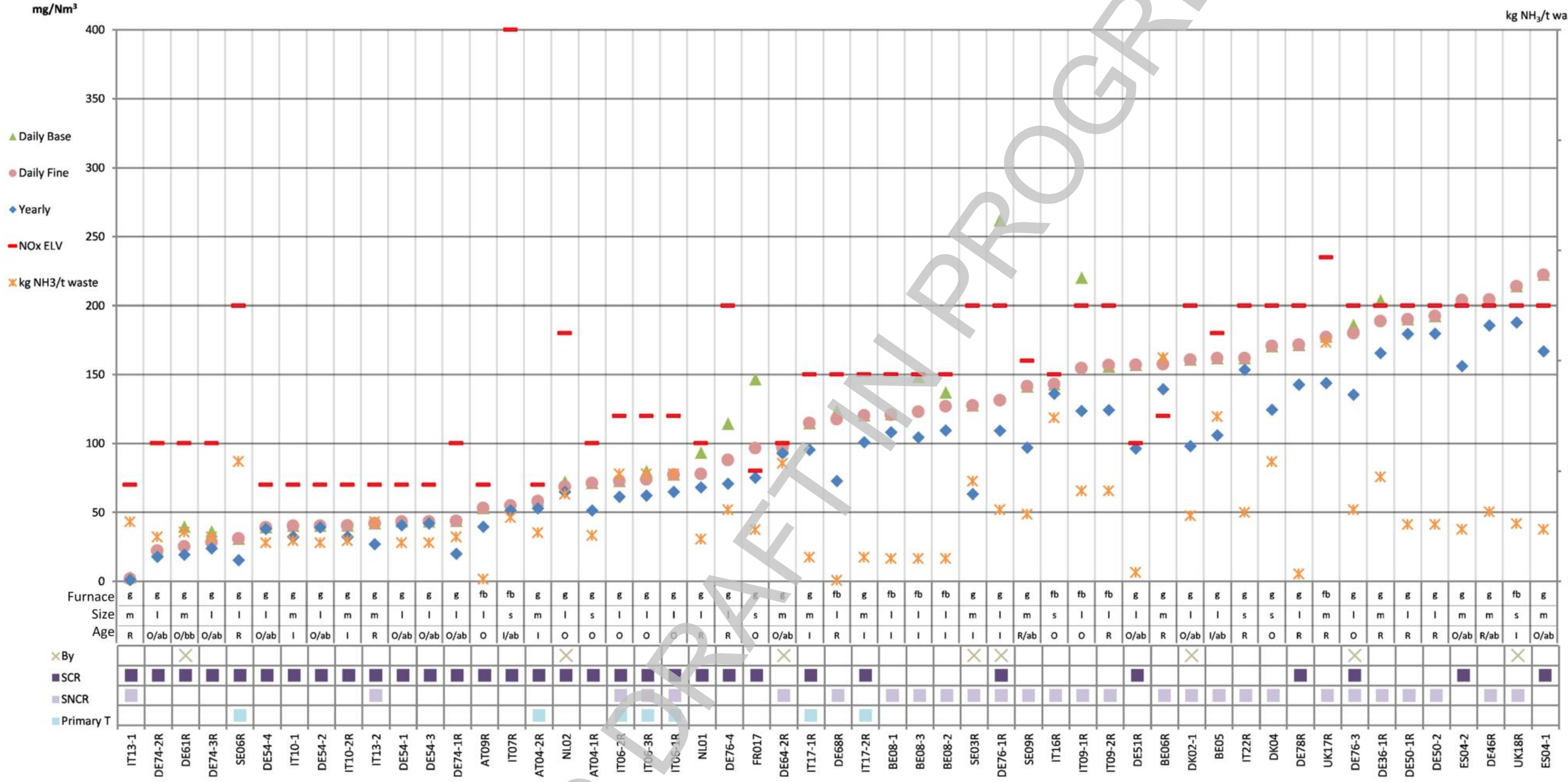
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction; Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.24: Continuously monitored NO_x emissions to air from medium-size plants incinerating predominantly municipal solid waste (2/2)



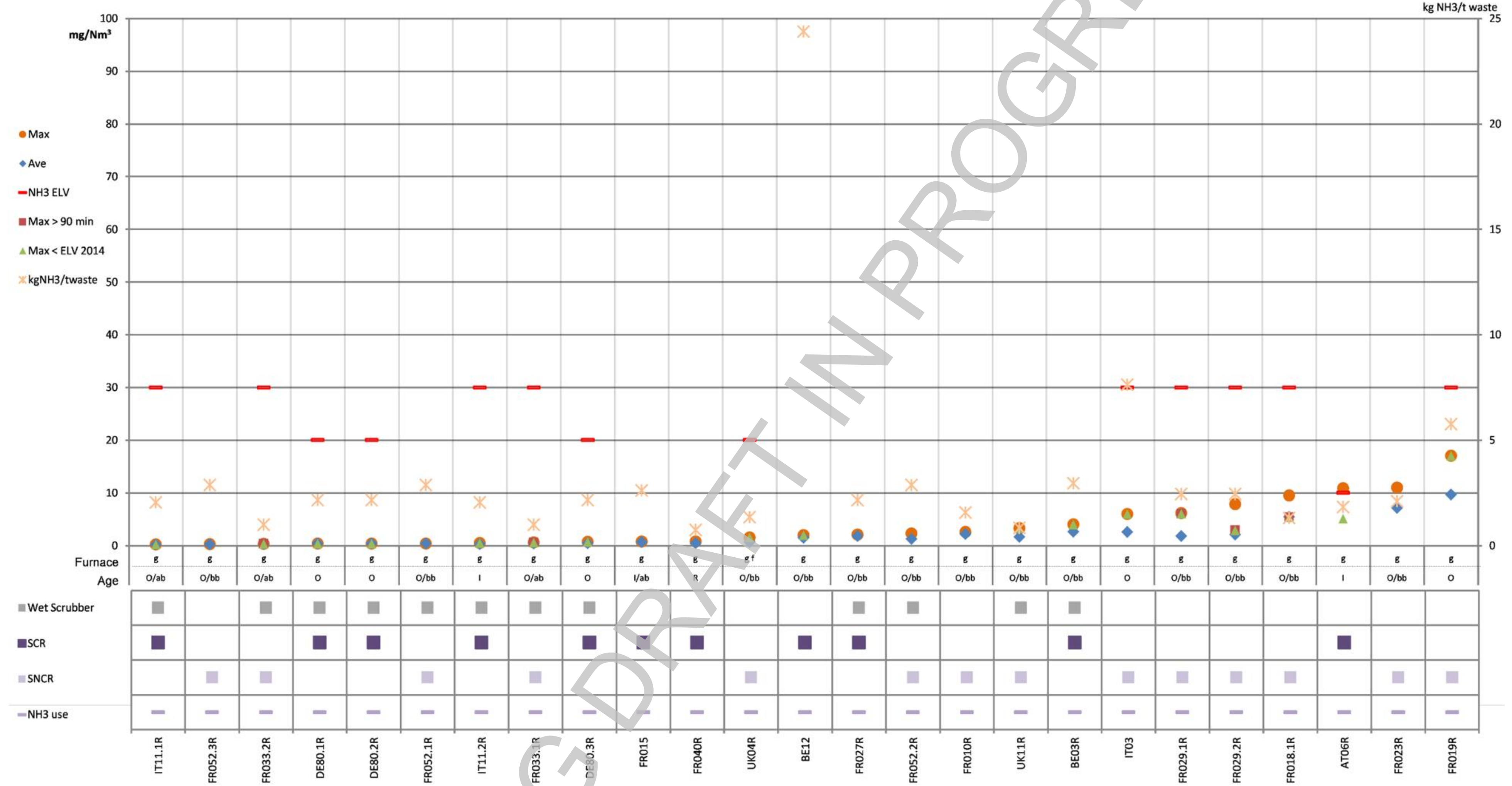
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction; Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.25: Continuously monitored NO$_x$ emissions to air from large plants incinerating predominantly municipal solid waste



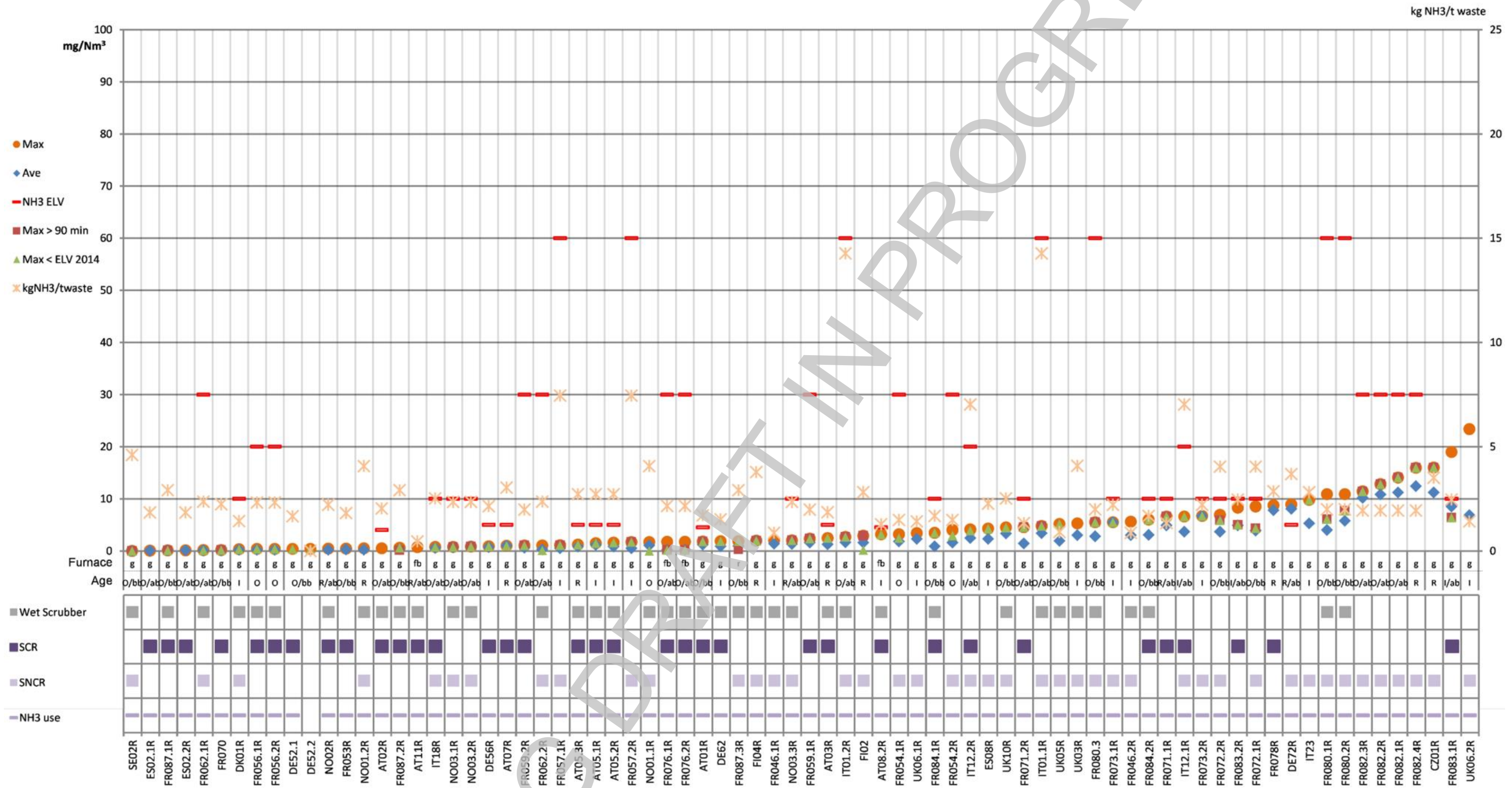
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction; Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.26: Continuously monitored NO_x emissions to air from plants incinerating predominantly other non-hazardous waste



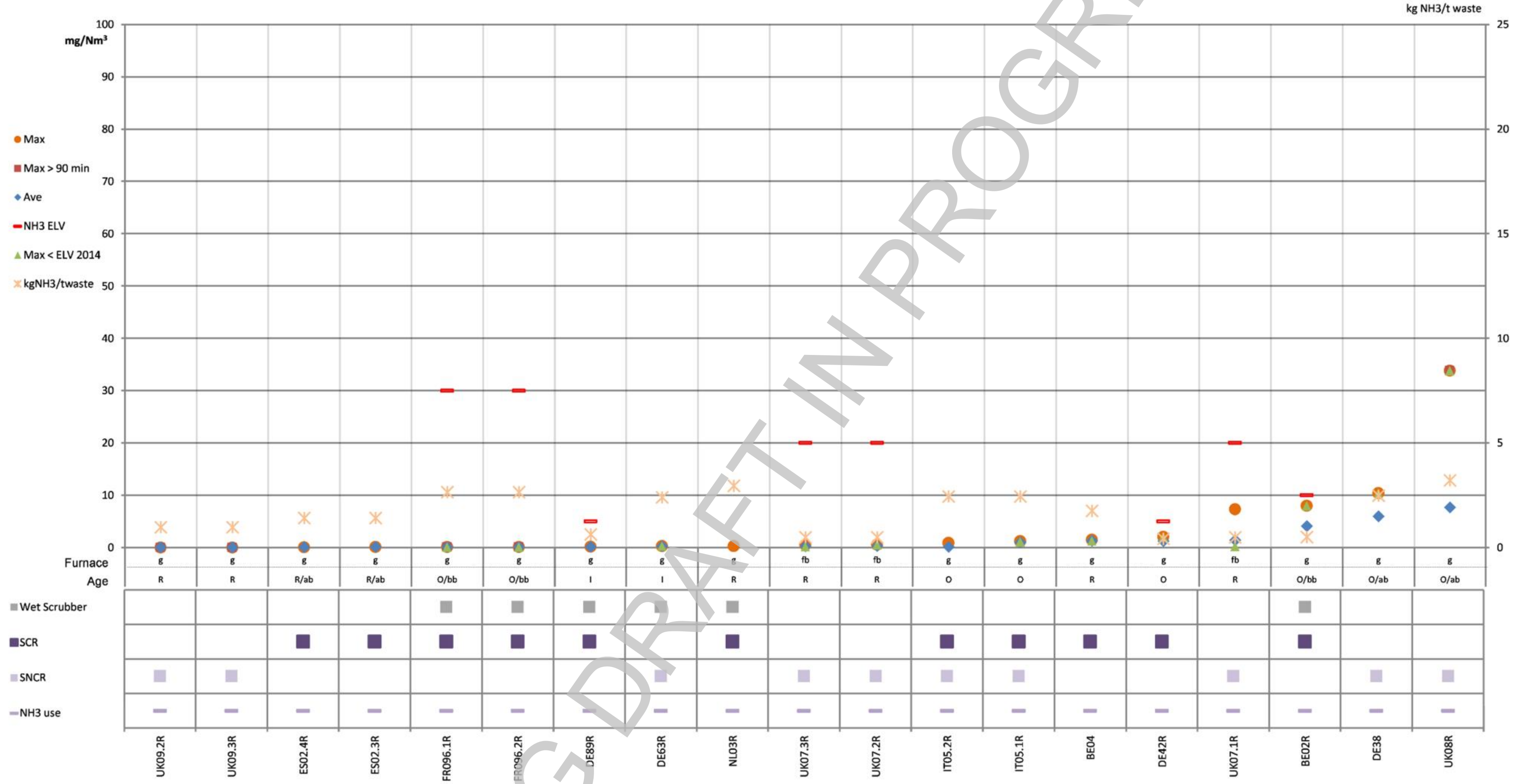
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction.
Reagents Used: NH3 = Ammonia.
Source: [81, TWG 2016].

Figure 3.27: Discontinuously monitored NH_3 emissions to air from small plants incinerating predominantly municipal solid waste



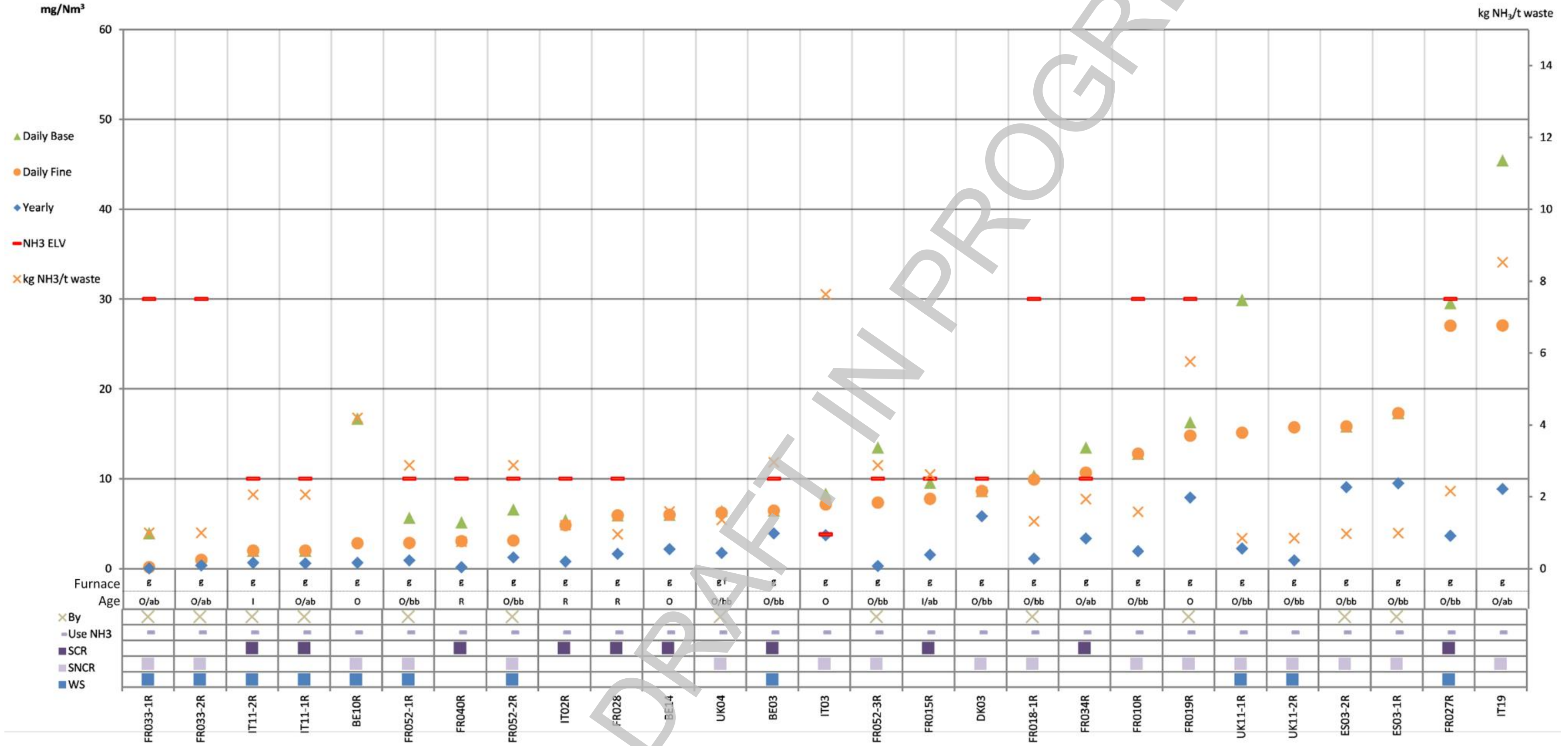
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction.
Reagents Used: NH3 = Ammonia.
Source: [81, TWG 2016].

Figure 3.28: Discontinuously monitored NH_3 emissions to air from medium-size plants incinerating predominantly municipal solid waste



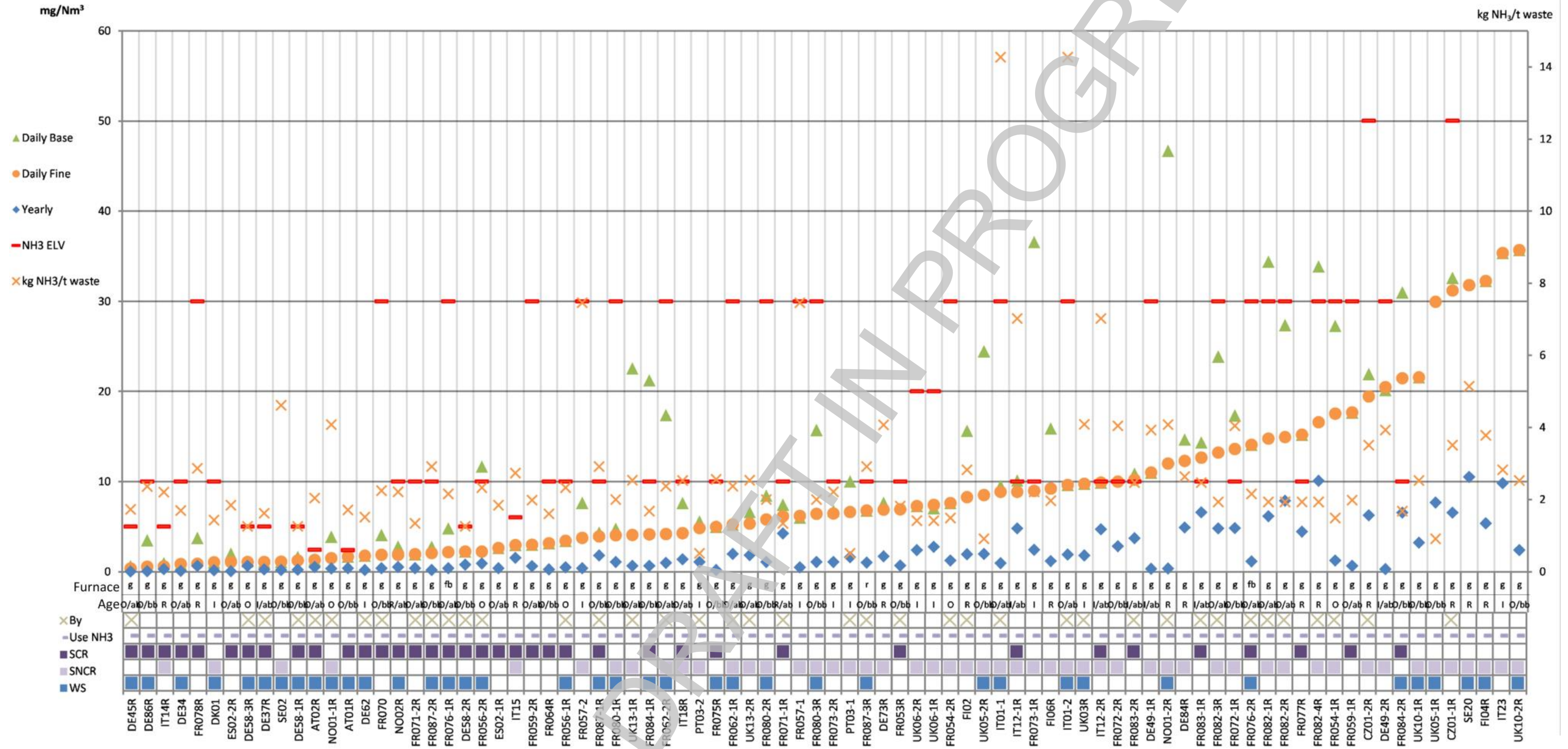
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction.
Reagents Used: NH3 = Ammonia.
Source: [81, TWG 2016].

Figure 3.29: Discontinuously monitored NH_3 emissions to air from large plants incinerating predominantly municipal solid waste



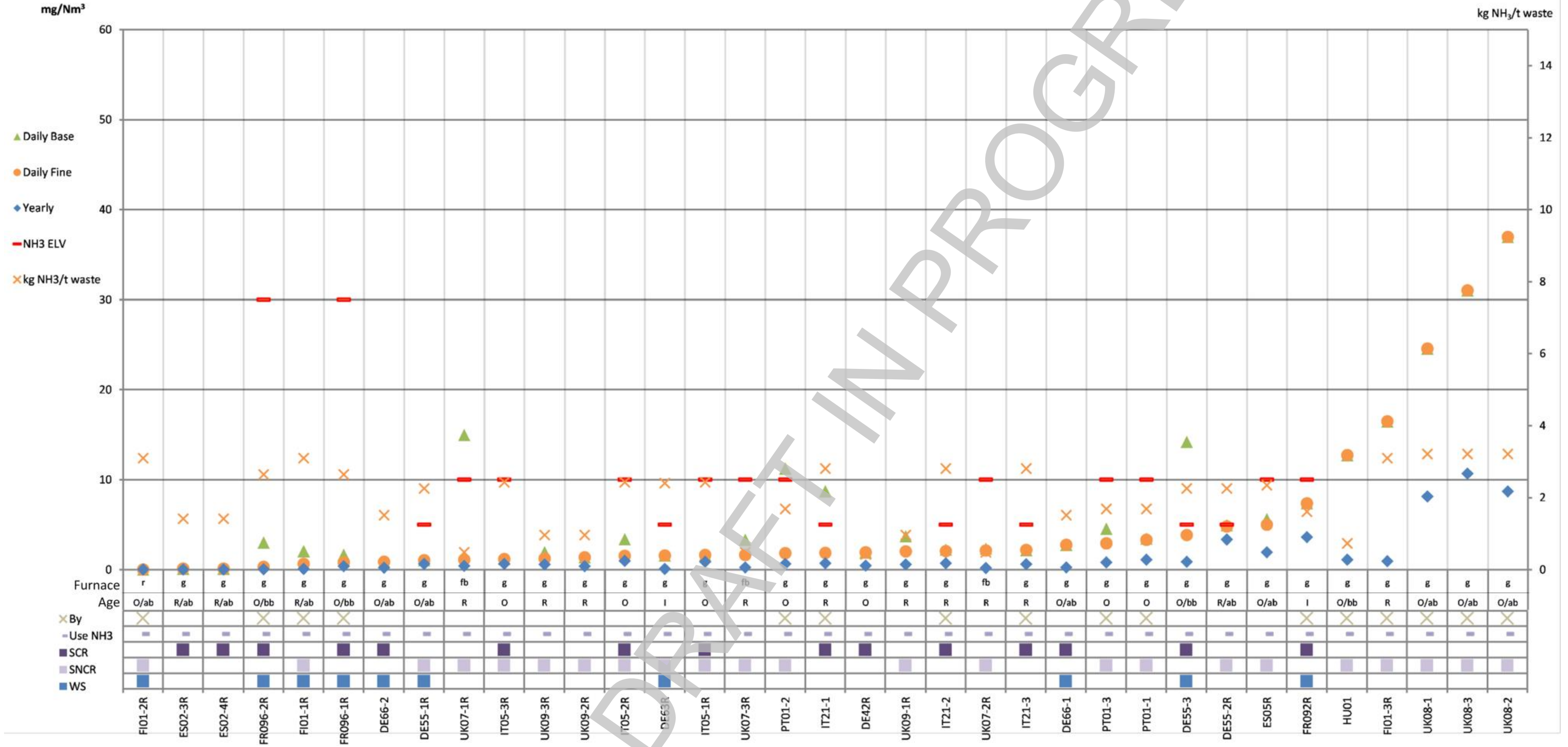
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NH3 = Ammonia.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.30: Continuously monitored NH_3 emissions to air from small plants incinerating predominantly municipal solid waste



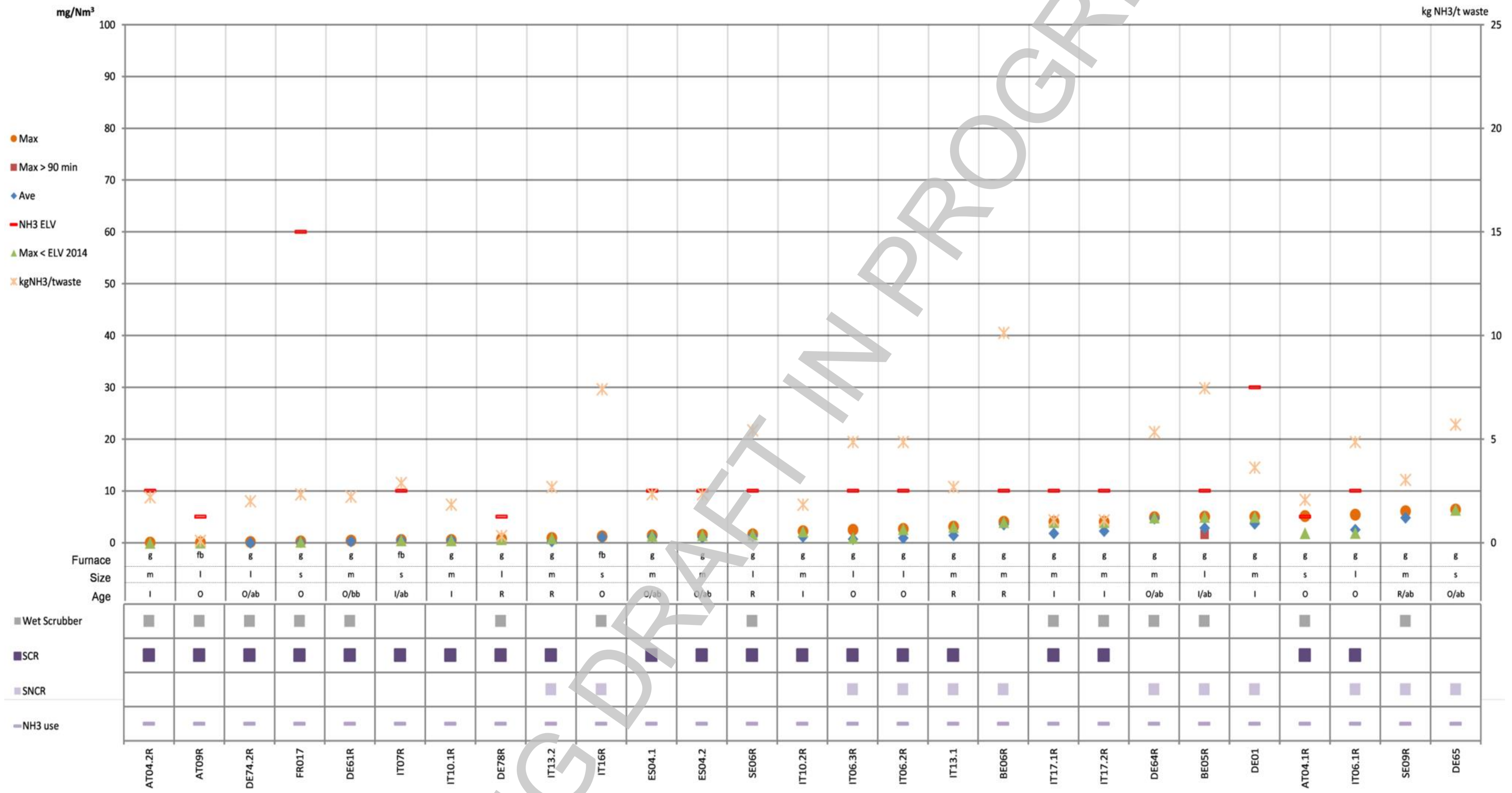
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NH3 = Ammonia.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction. WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.31: Continuously monitored NH_3 emissions to air from medium-size plants incinerating predominantly municipal solid waste



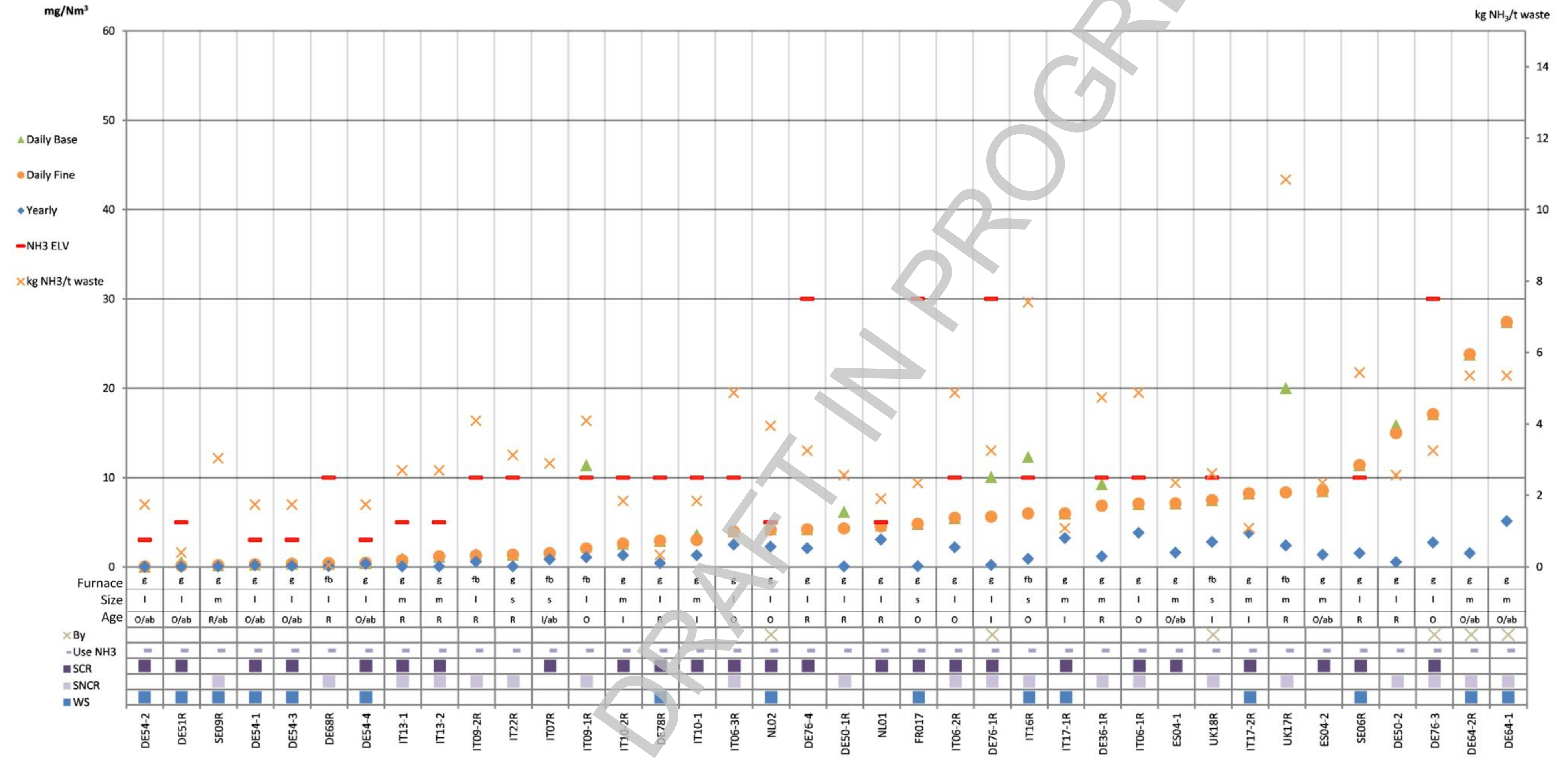
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NH3 = Ammonia.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.32: Continuously monitored NH_3 emissions to air from large plants incinerating predominantly municipal solid waste



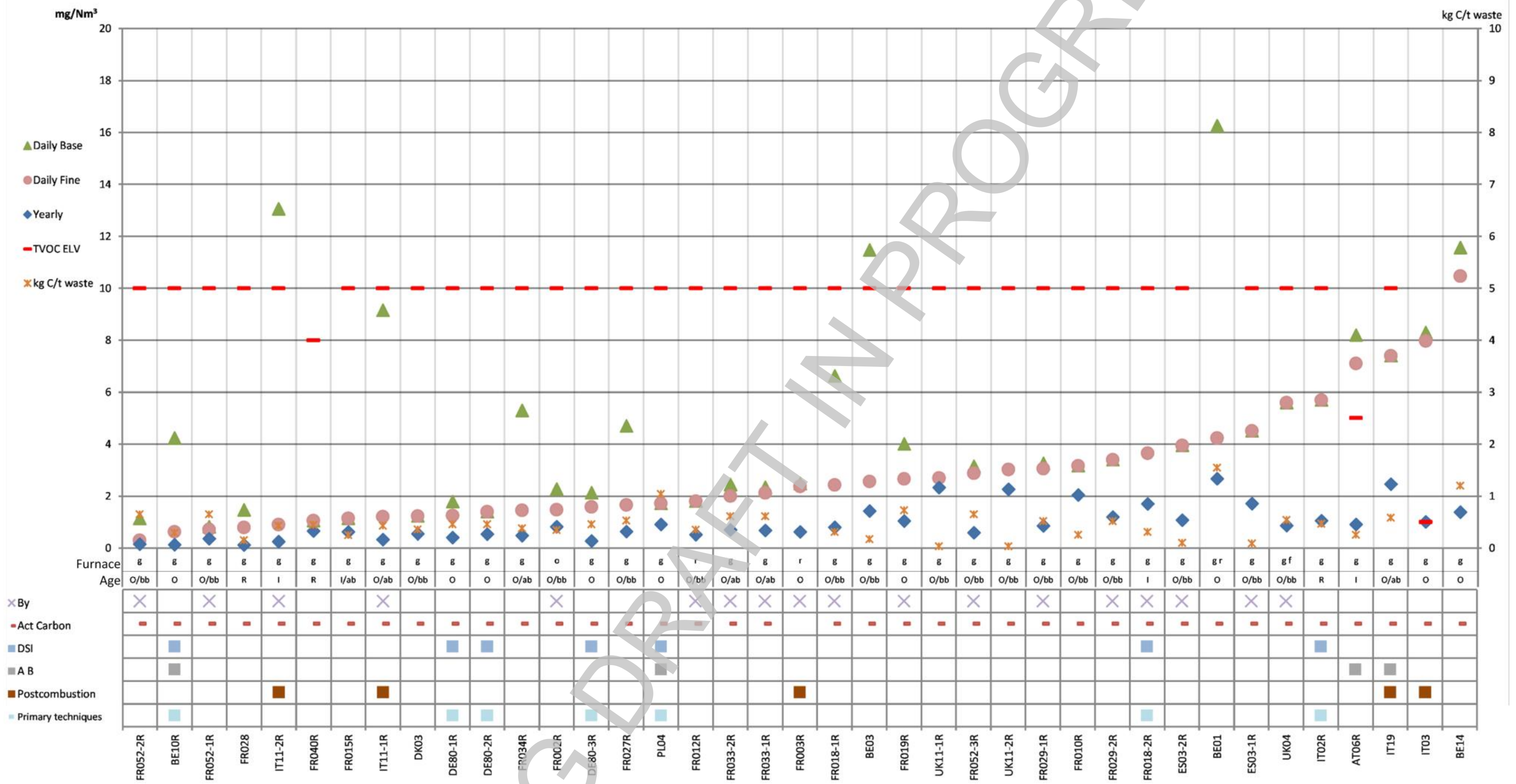
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction.
Reagents Used: NH3 = Ammonia.
Source: [81, TWG 2016].

Figure 3.33: Discontinuously monitored NH_3 emissions to air from plants incinerating predominantly other non-hazardous waste



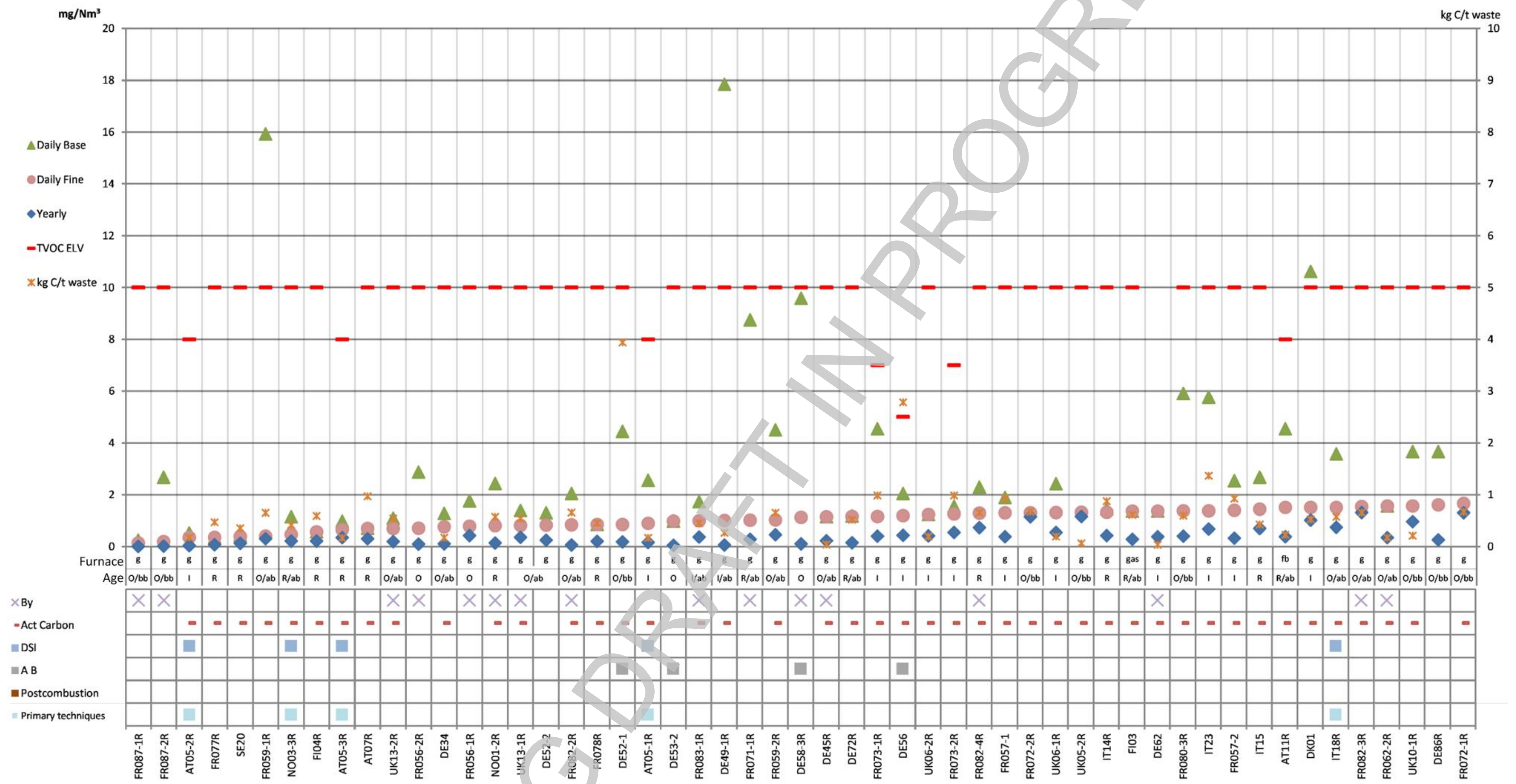
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NH3 = Ammonia.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.34: Continuously monitored NH_3 emissions to air from plants incinerating predominantly other non-hazardous waste



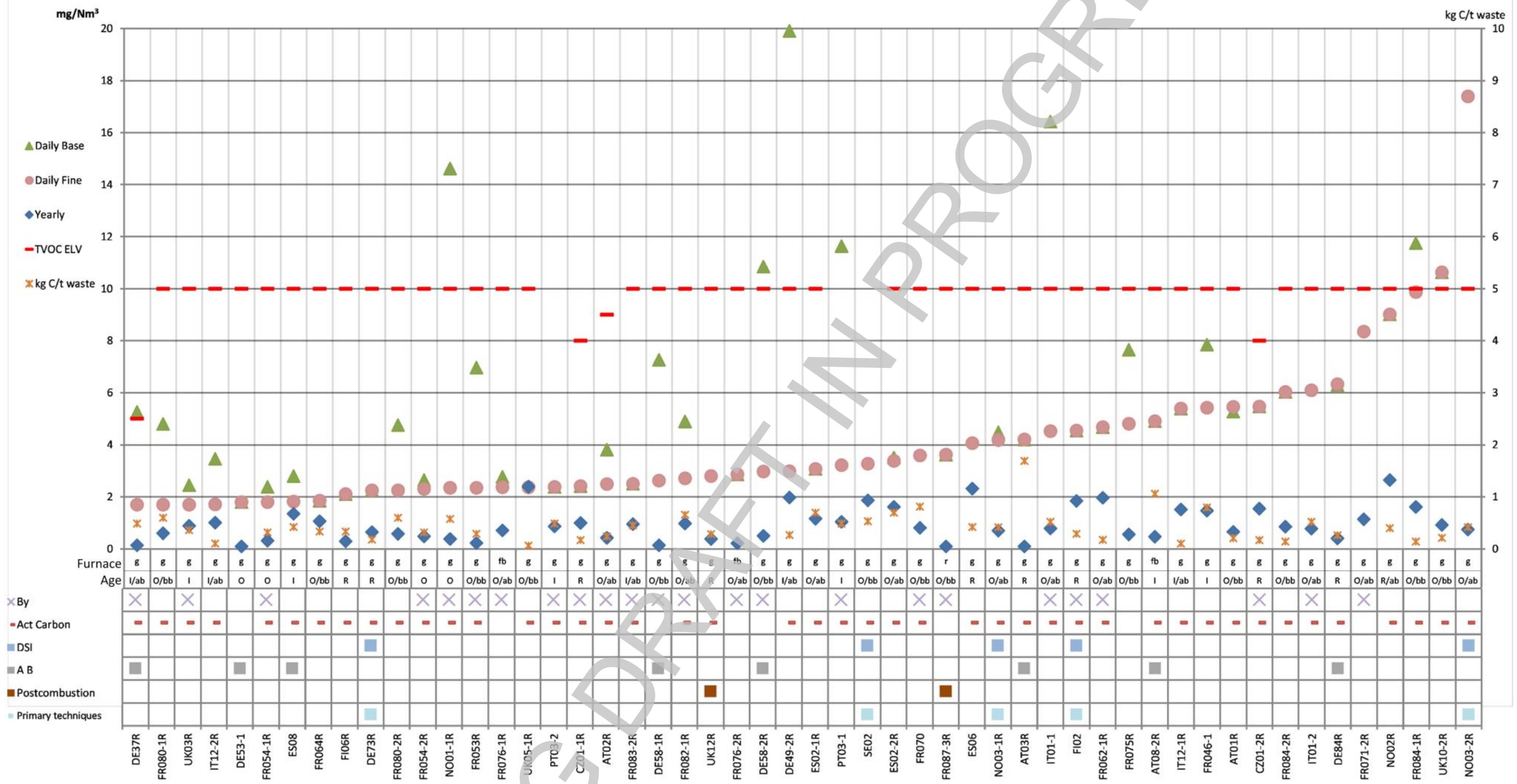
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed.
Source: [81, TWG 2016].

Figure 3.35: Continuously monitored TVOC emissions to air from small plants incinerating predominantly municipal solid waste



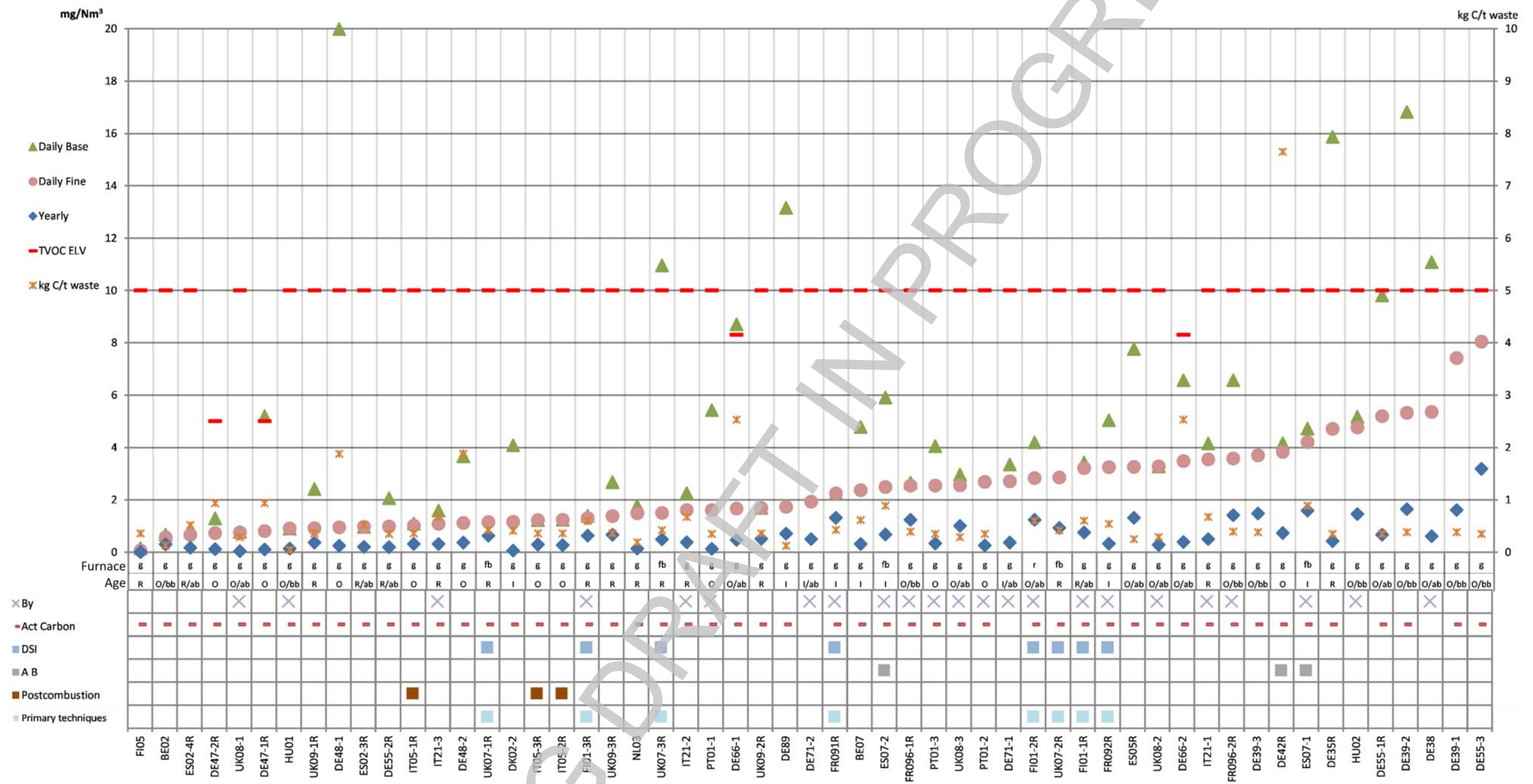
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed.
Source: [81, TWG 2016].

Figure 3.36: Continuously monitored TVOC emissions to air from medium-size plants incinerating predominantly municipal solid waste (1/2)



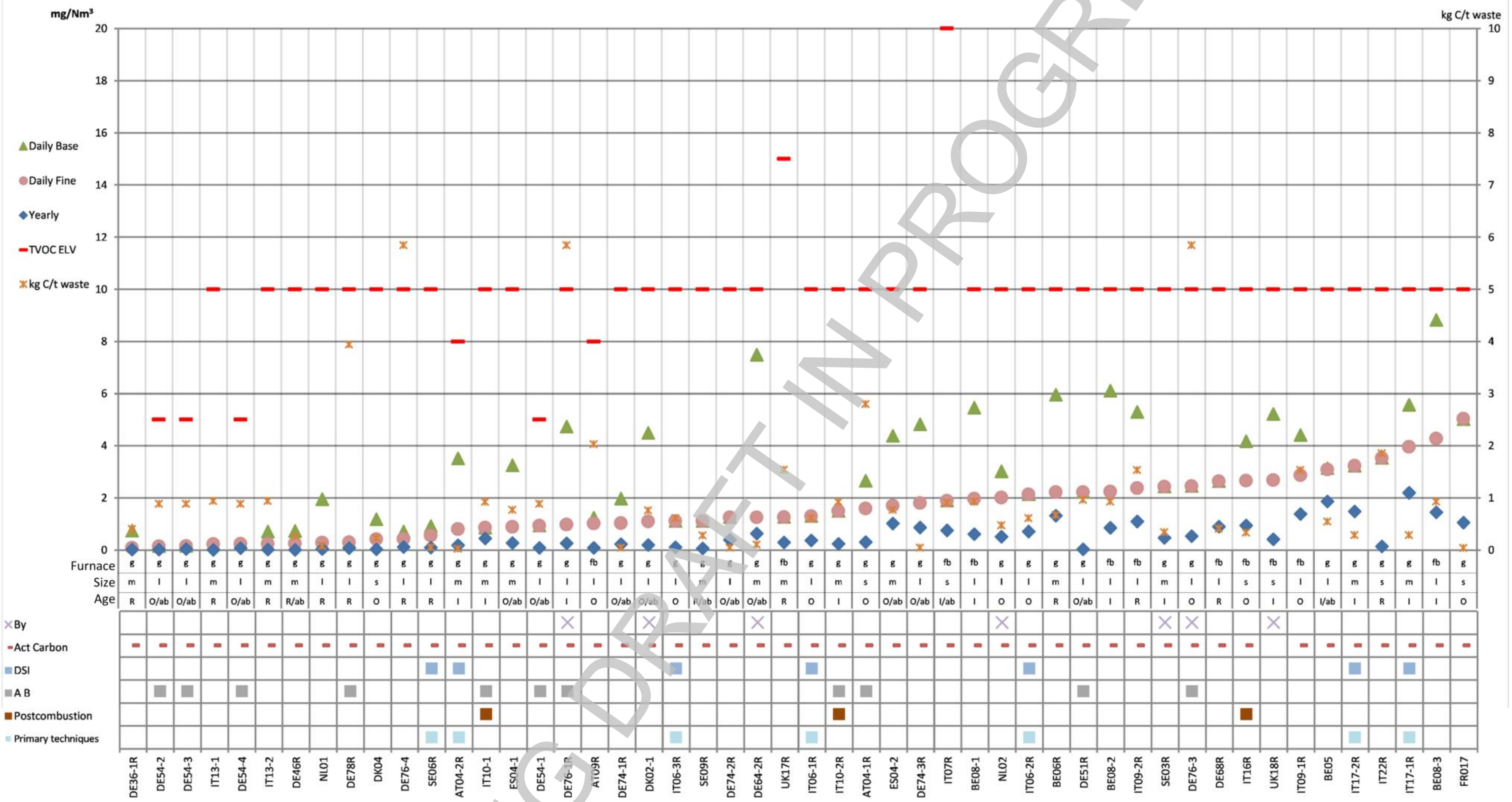
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed.
Source: [81, TWG 2016].

Figure 3.37: Continuously monitored TVOC emissions to air from medium-size plants incinerating predominantly municipal solid waste (2/2)



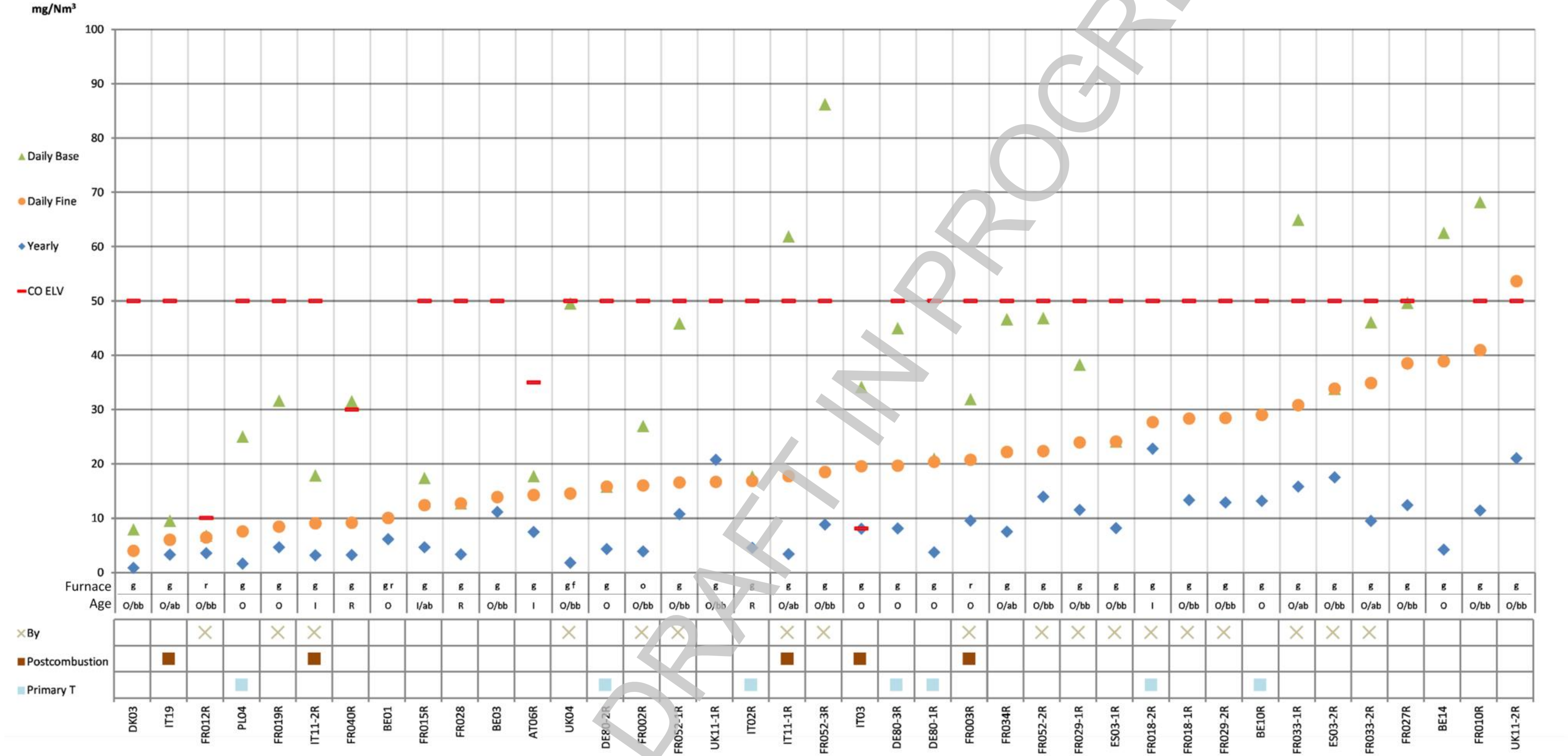
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed; Primary.
Source: [81, TWG 2016].

Figure 3.38: Continuously monitored TVOC emissions to air from large plants incinerating predominantly municipal solid waste



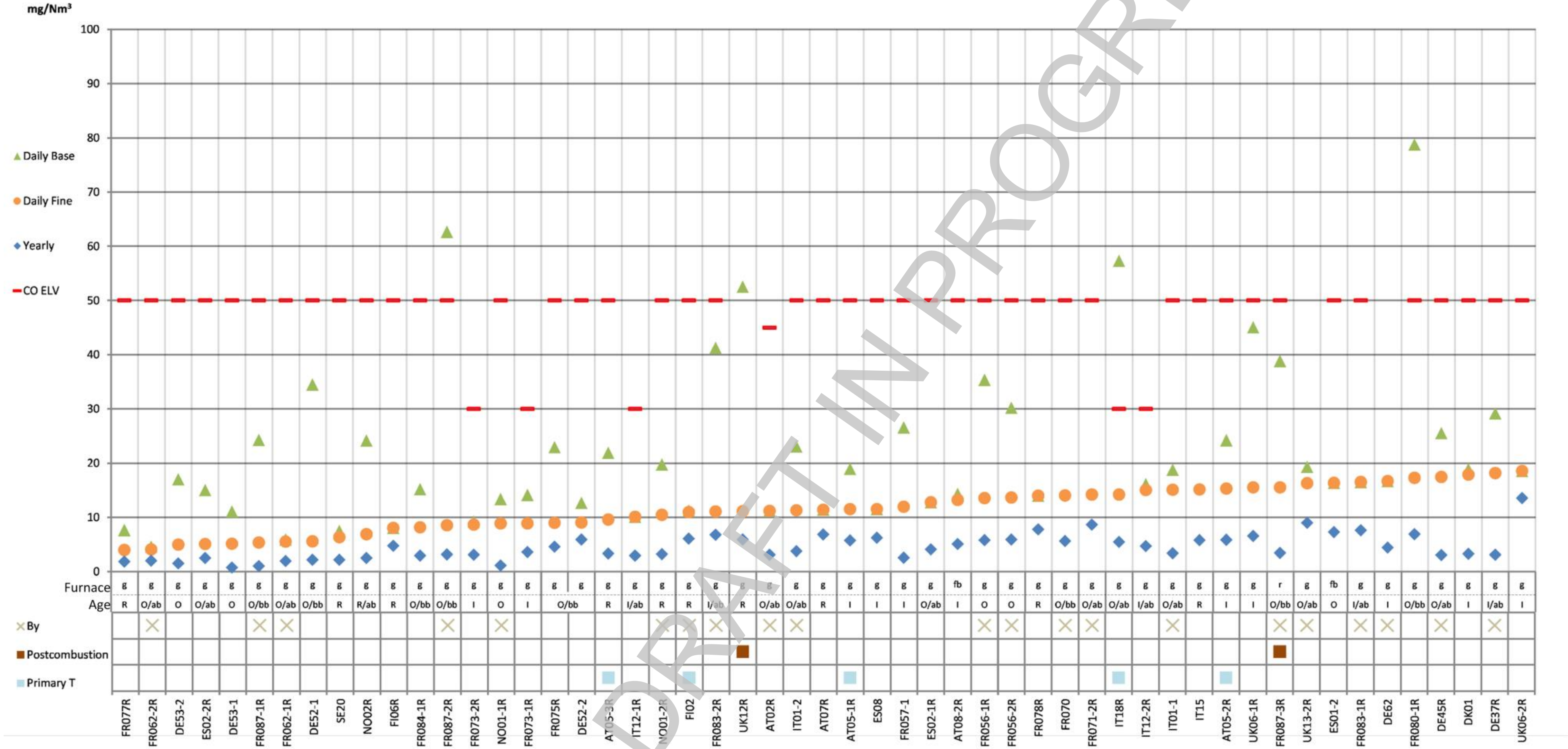
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed.
Source: [81, TWG 2016].

Figure 3.39: Continuously monitored TVOC emissions to air from plants incinerating predominantly other non-hazardous waste



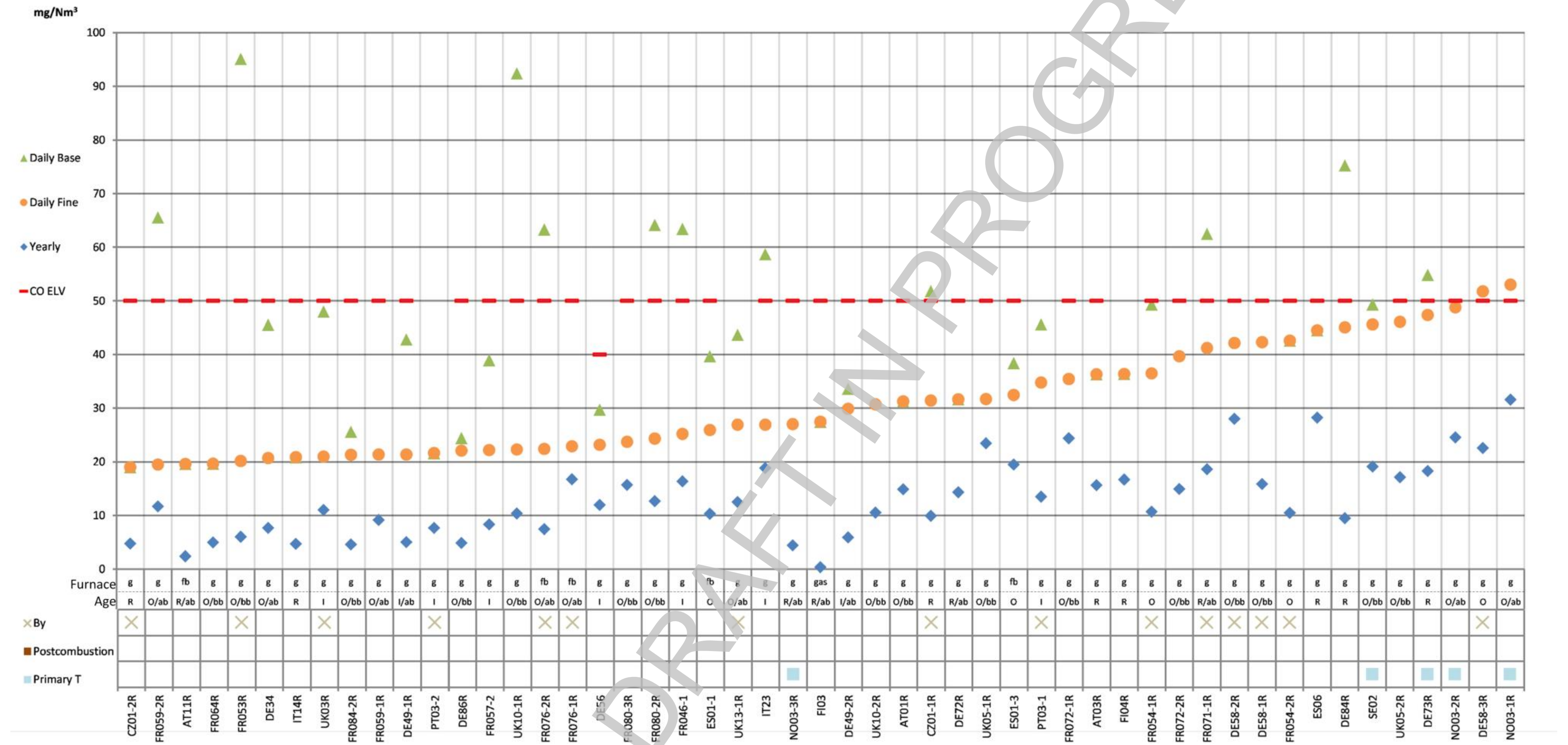
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.40: Continuously monitored CO emissions to air from small plants incinerating predominantly municipal solid waste



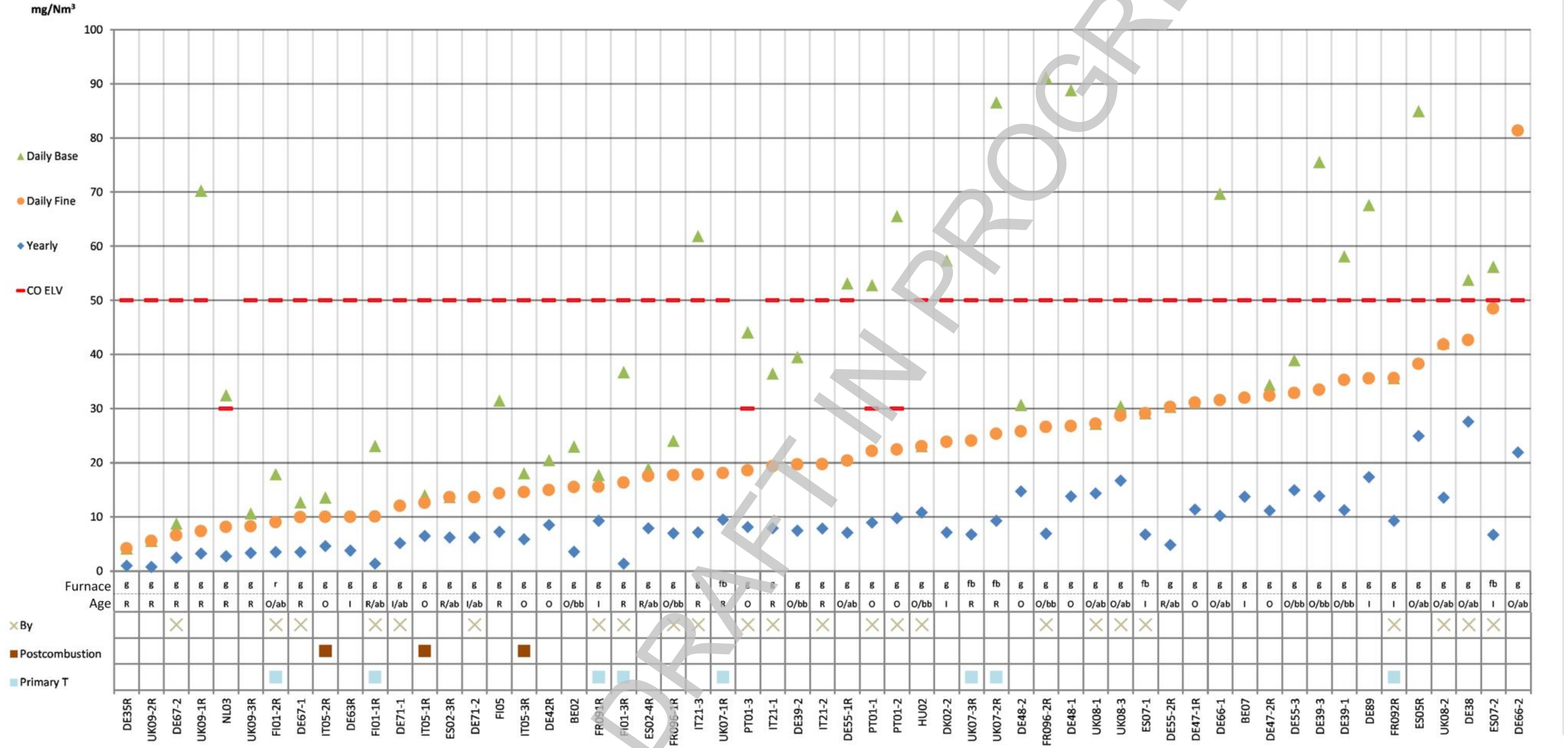
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.41: Continuously monitored CO emissions to air from medium-size plants incinerating predominantly municipal solid waste (1/2)



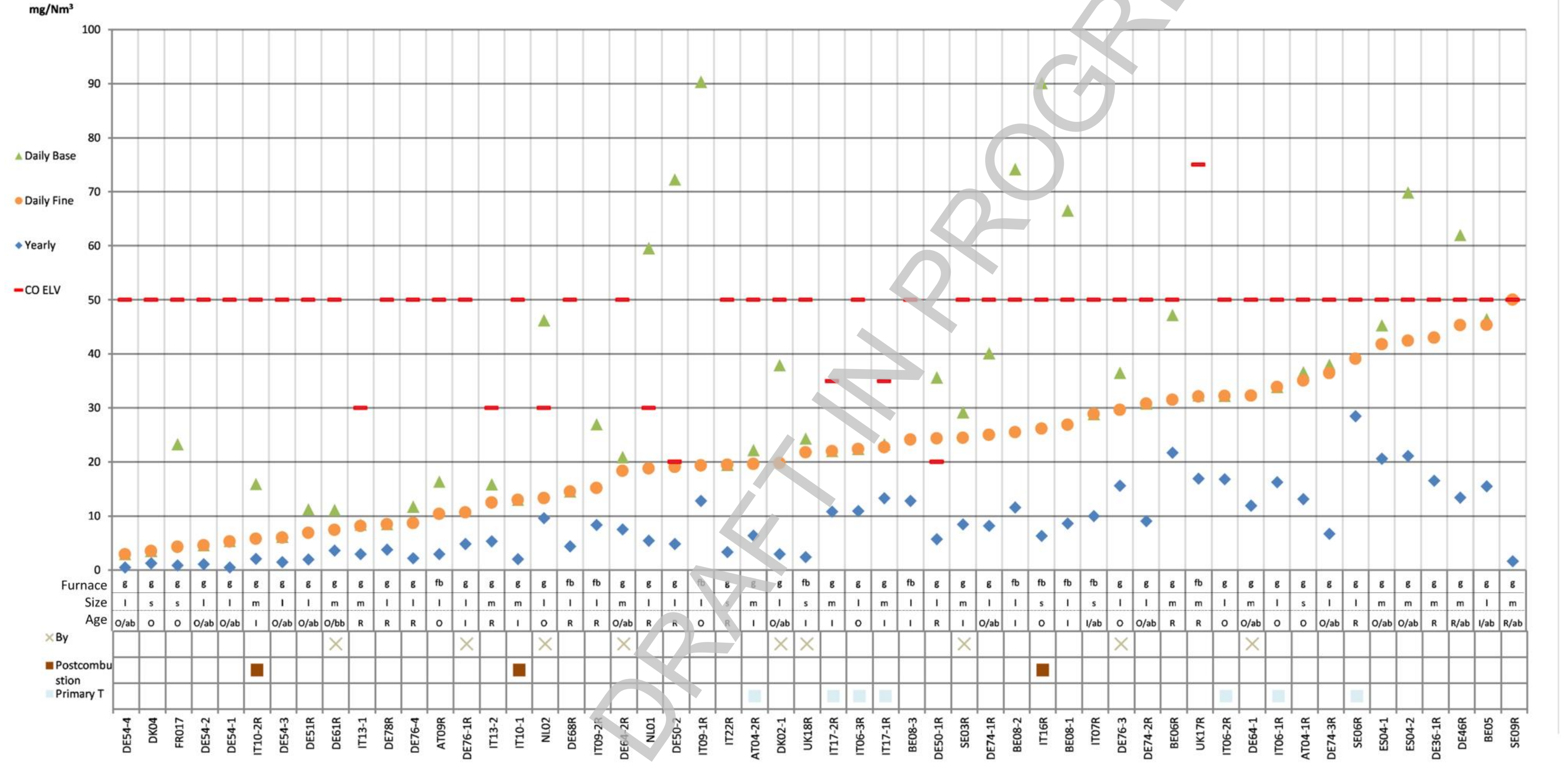
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.42: Continuously monitored CO emissions to air from medium-size plants incinerating predominantly municipal solid waste (2/2)



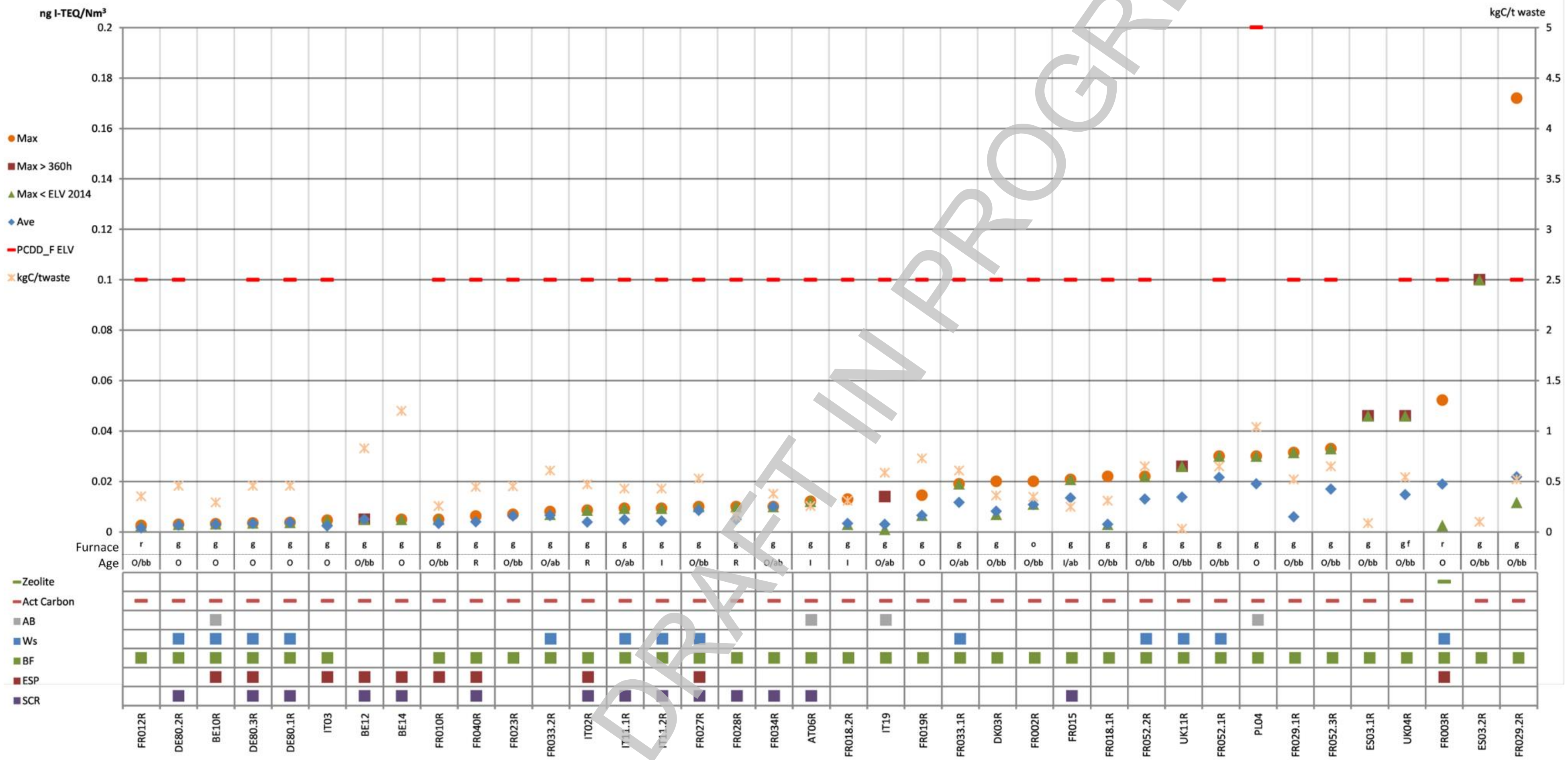
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.43: Continuously monitored CO emissions to air from large plants incinerating predominantly municipal solid waste



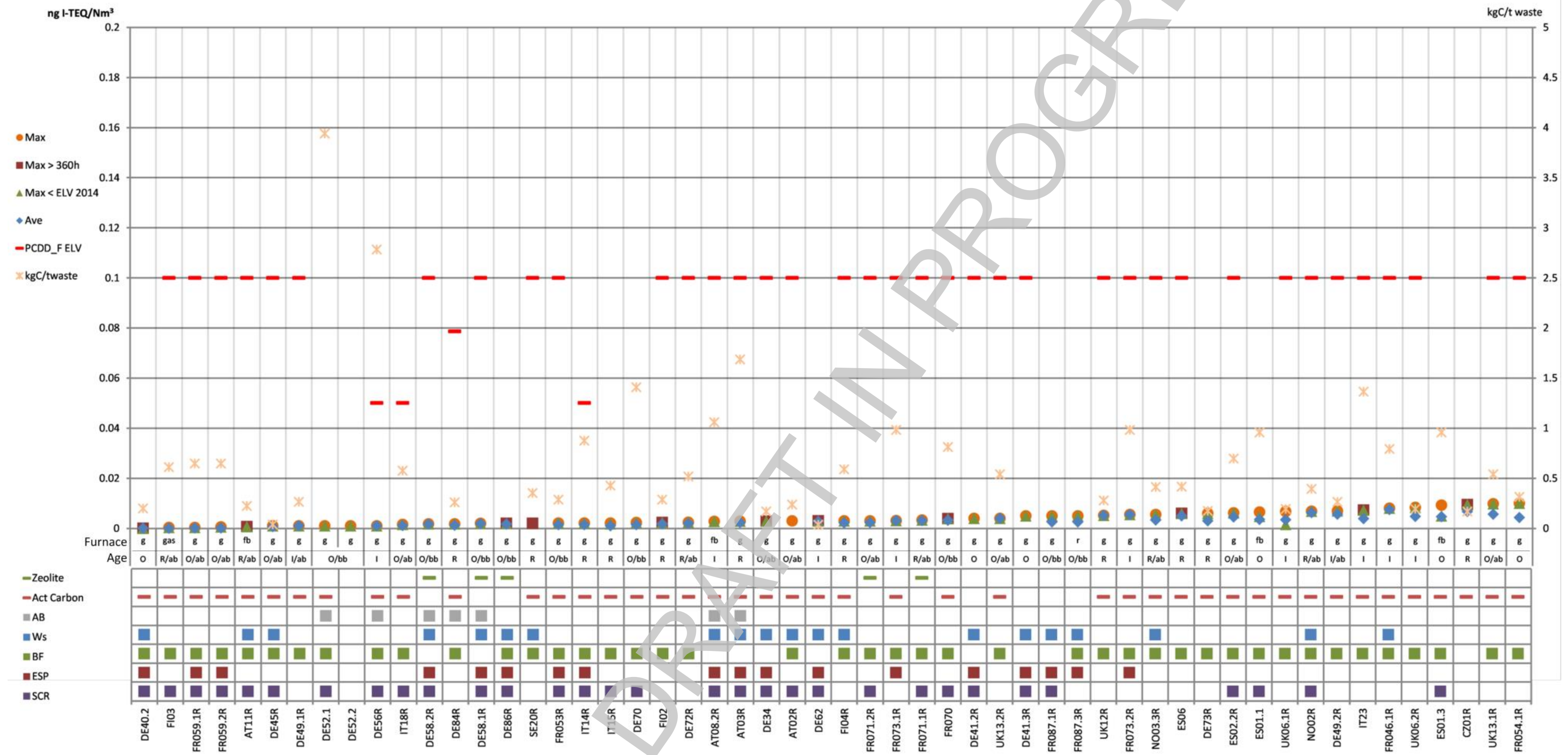
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.44: Continuously monitored CO emissions to air from plants incinerating predominantly other non-hazardous waste



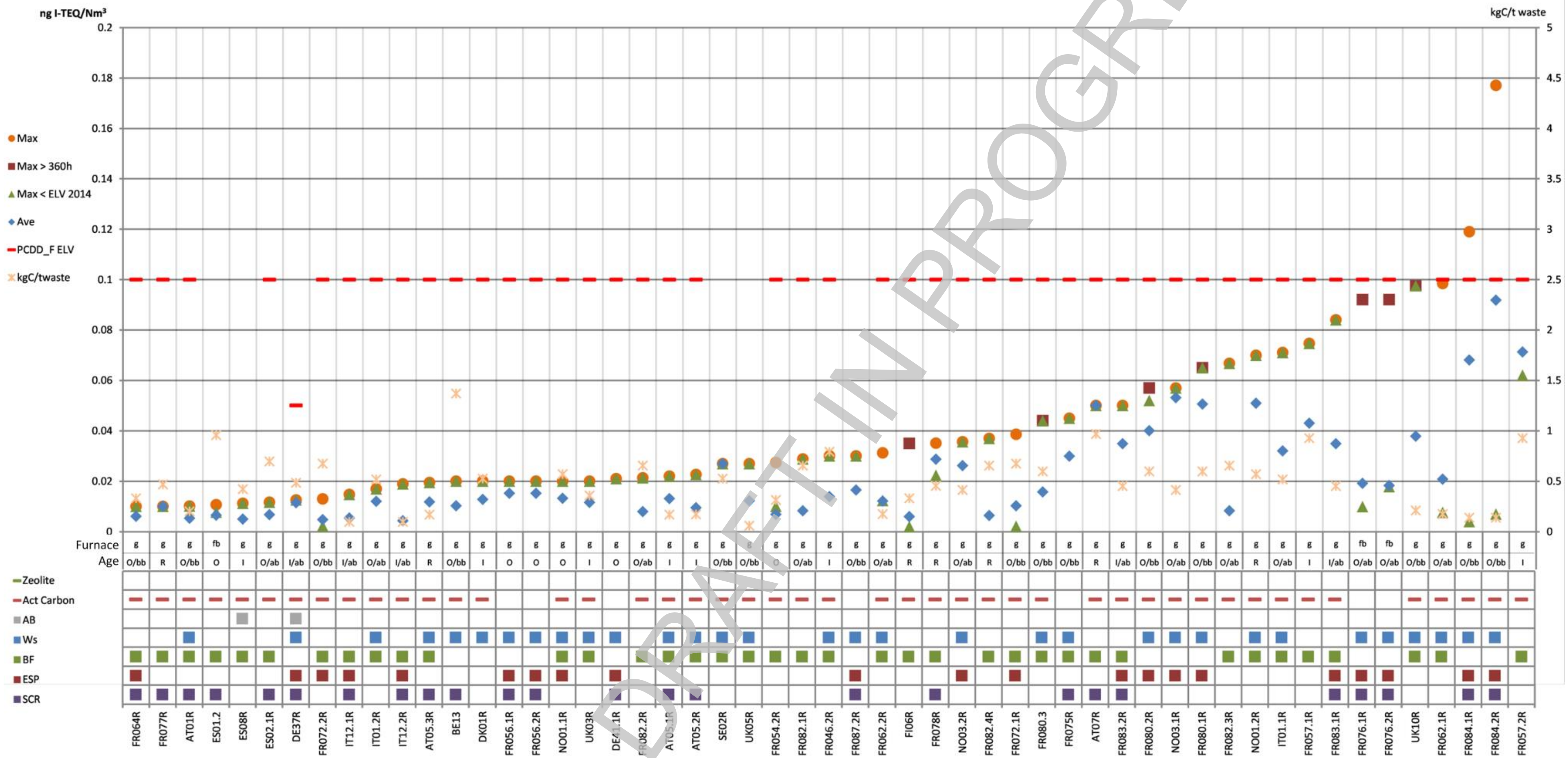
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction.
Source: [81, TWG 2016].

Figure 3.45: Discontinuously monitored PCDD/F emissions to air from small plants incinerating predominantly municipal solid waste



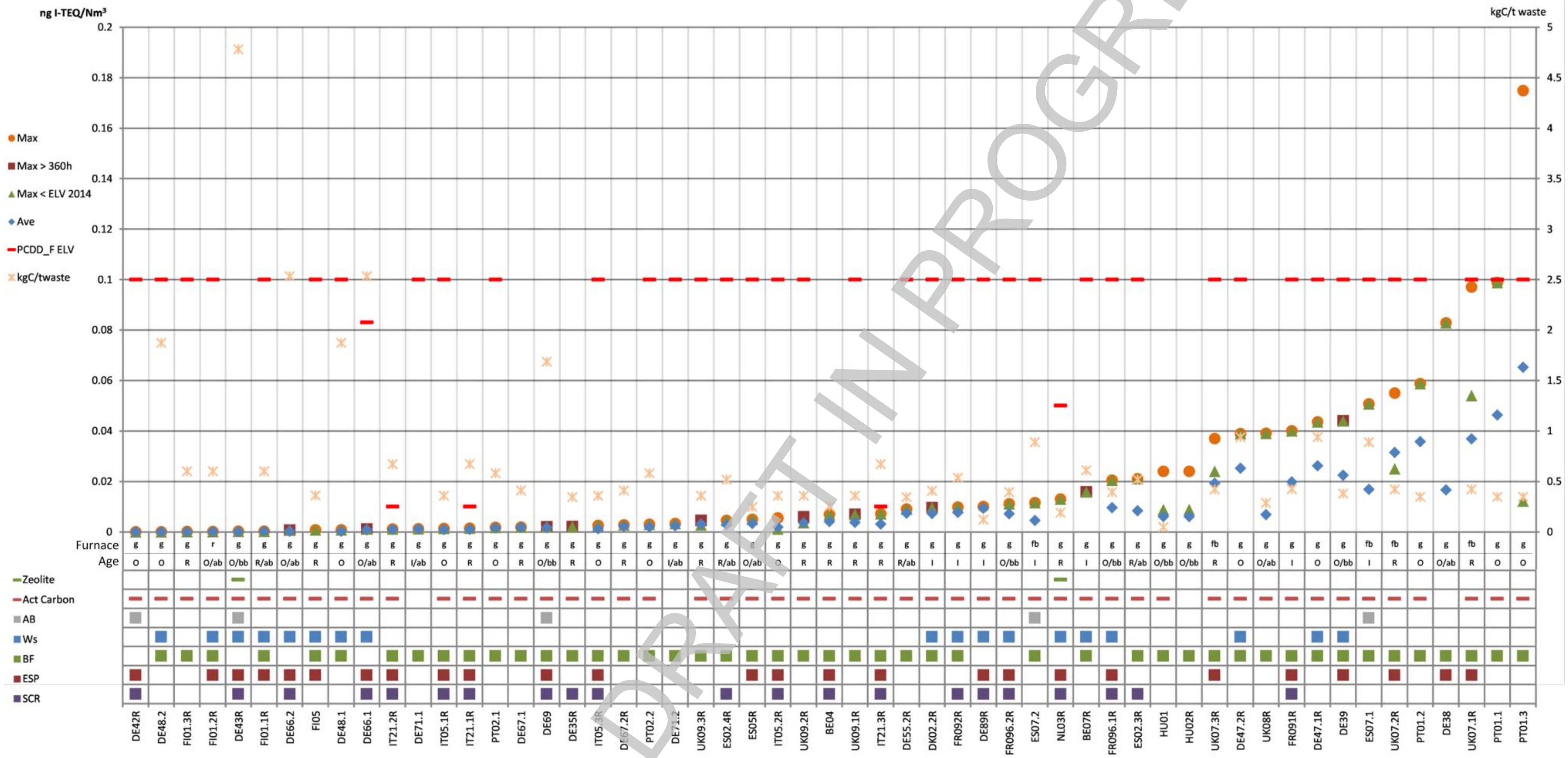
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction.
Source: [81, TWG 2016].

Figure 3.46: Discontinuously monitored PCDD/F emissions to air from medium-size plants incinerating predominantly municipal solid waste (1/2)



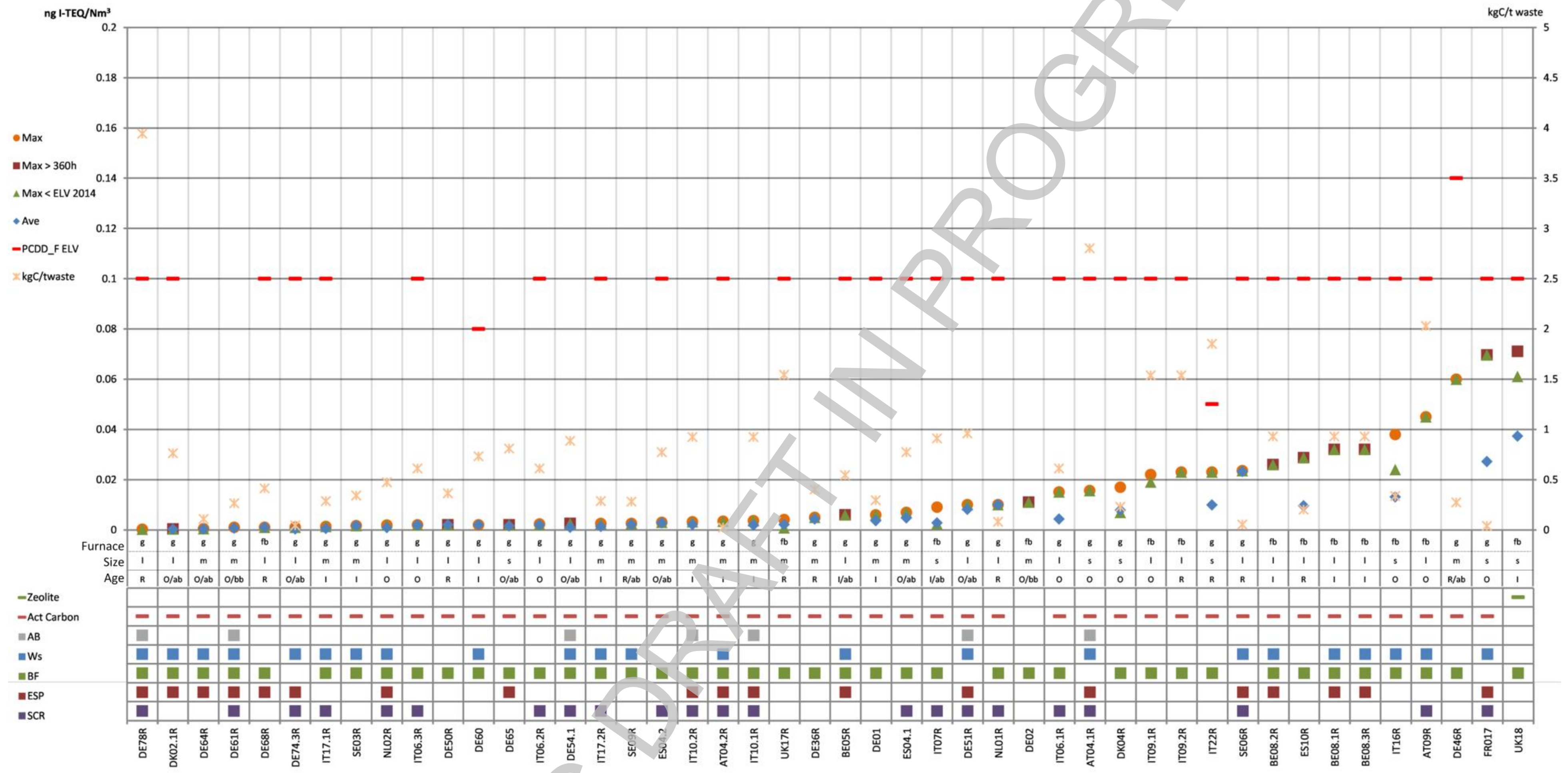
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction.
Source: [81, TWG 2016].

Figure 3.47: Discontinuously monitored PCDD/F emissions to air from medium-size plants incinerating predominantly municipal solid waste (2/2)



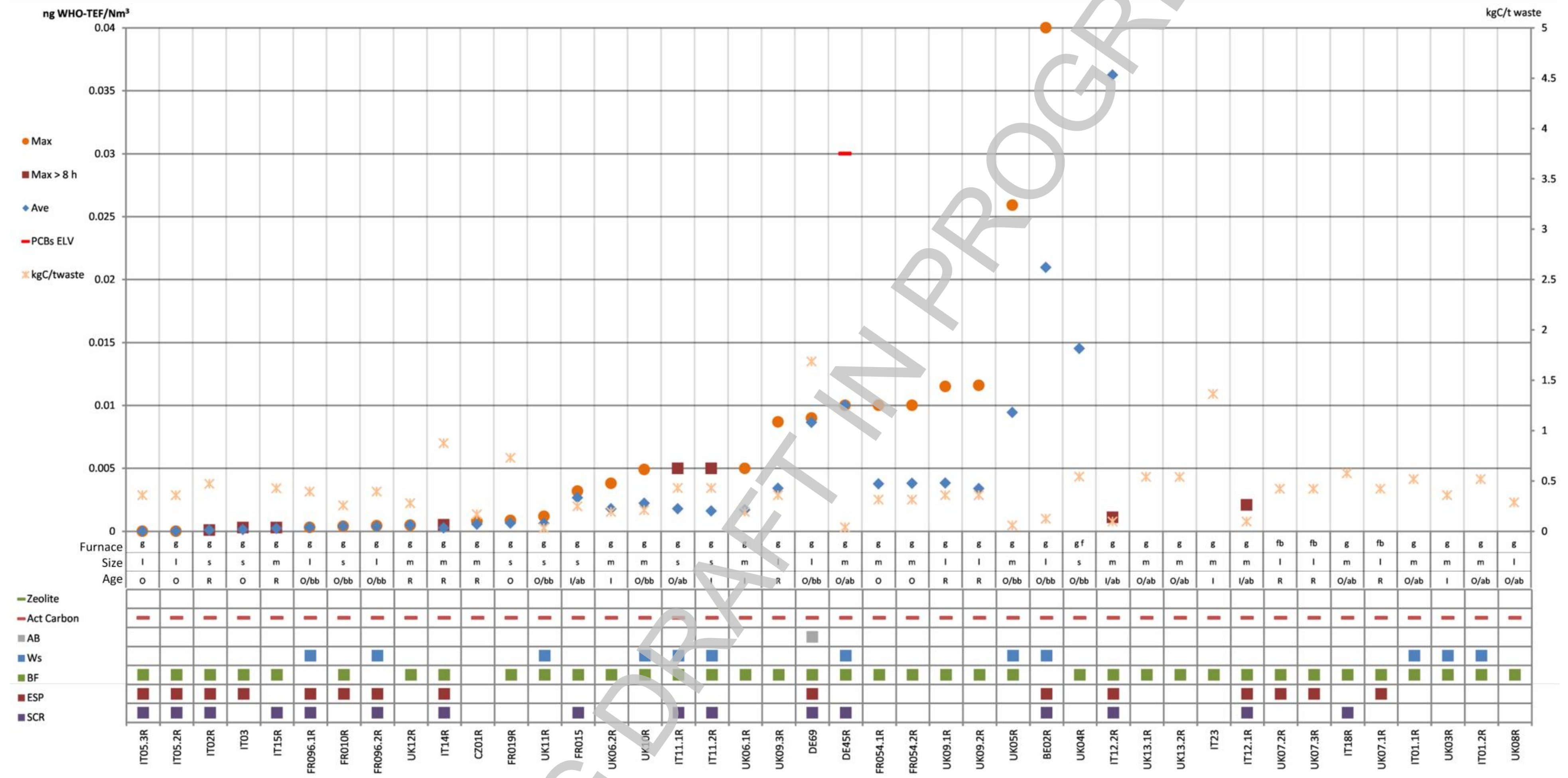
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction.
Source: [81, TWG 2016].

Figure 3.48: Discontinuously monitored PCDD/F emissions to air from large plants incinerating predominantly municipal solid waste



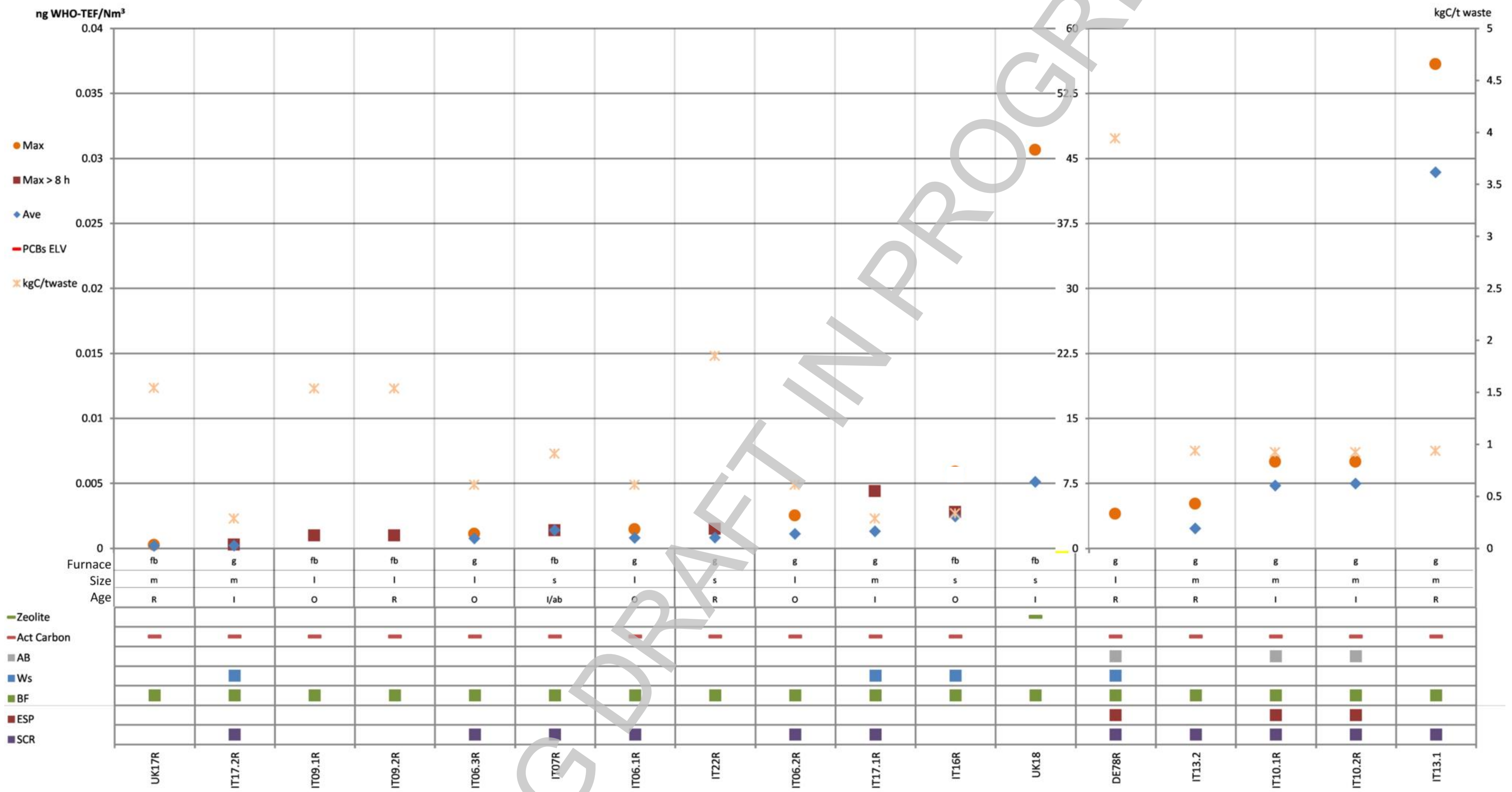
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction.
Source: [81, TWG 2016].

Figure 3.49: Discontinuously monitored PCDD/F emissions to air from plants incinerating predominantly other non-hazardous waste



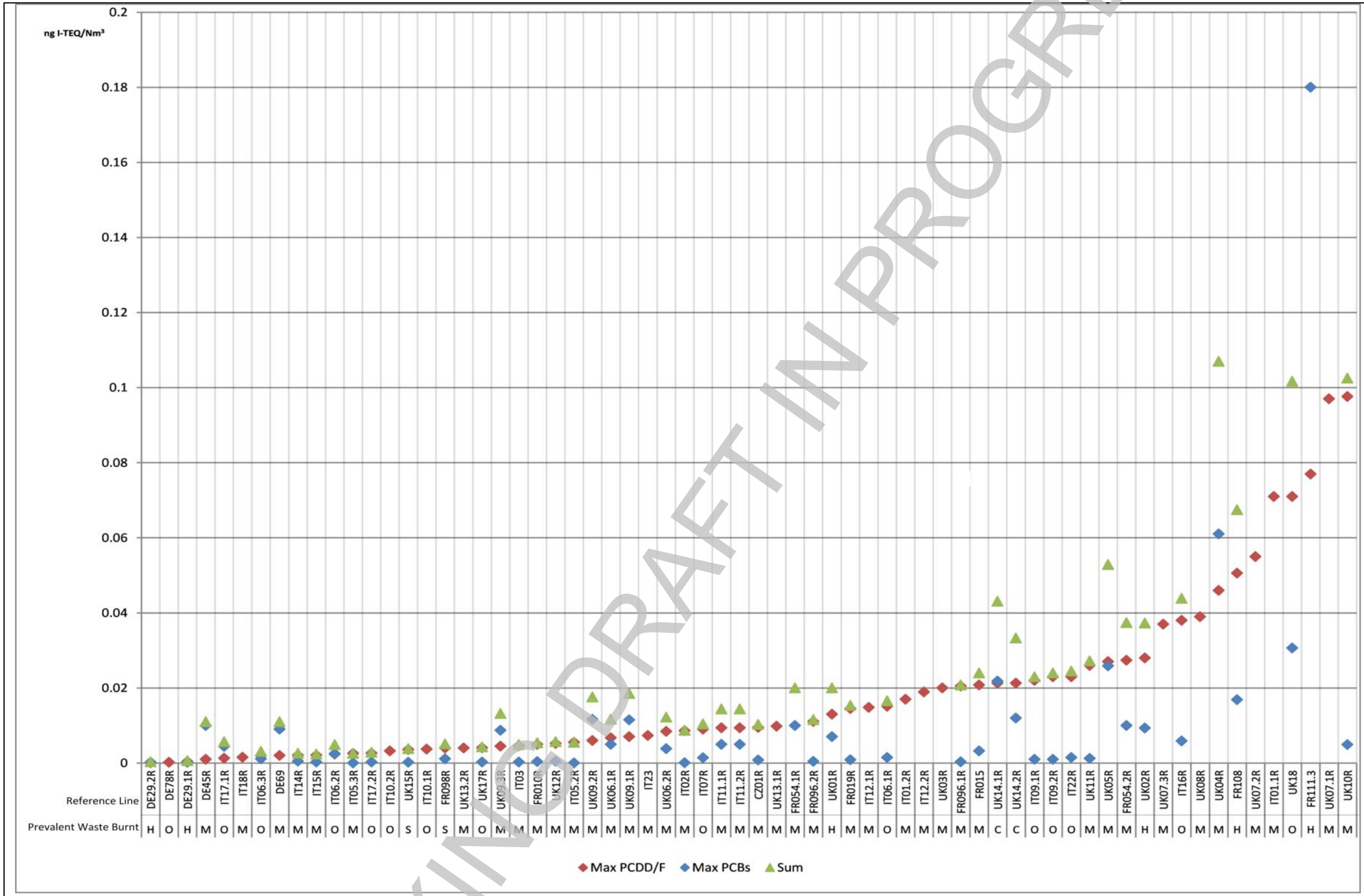
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction.
Source: [81, TWG 2016].

Figure 3.50: Discontinuously monitored PCBs emissions to air from plants incinerating predominantly municipal solid waste



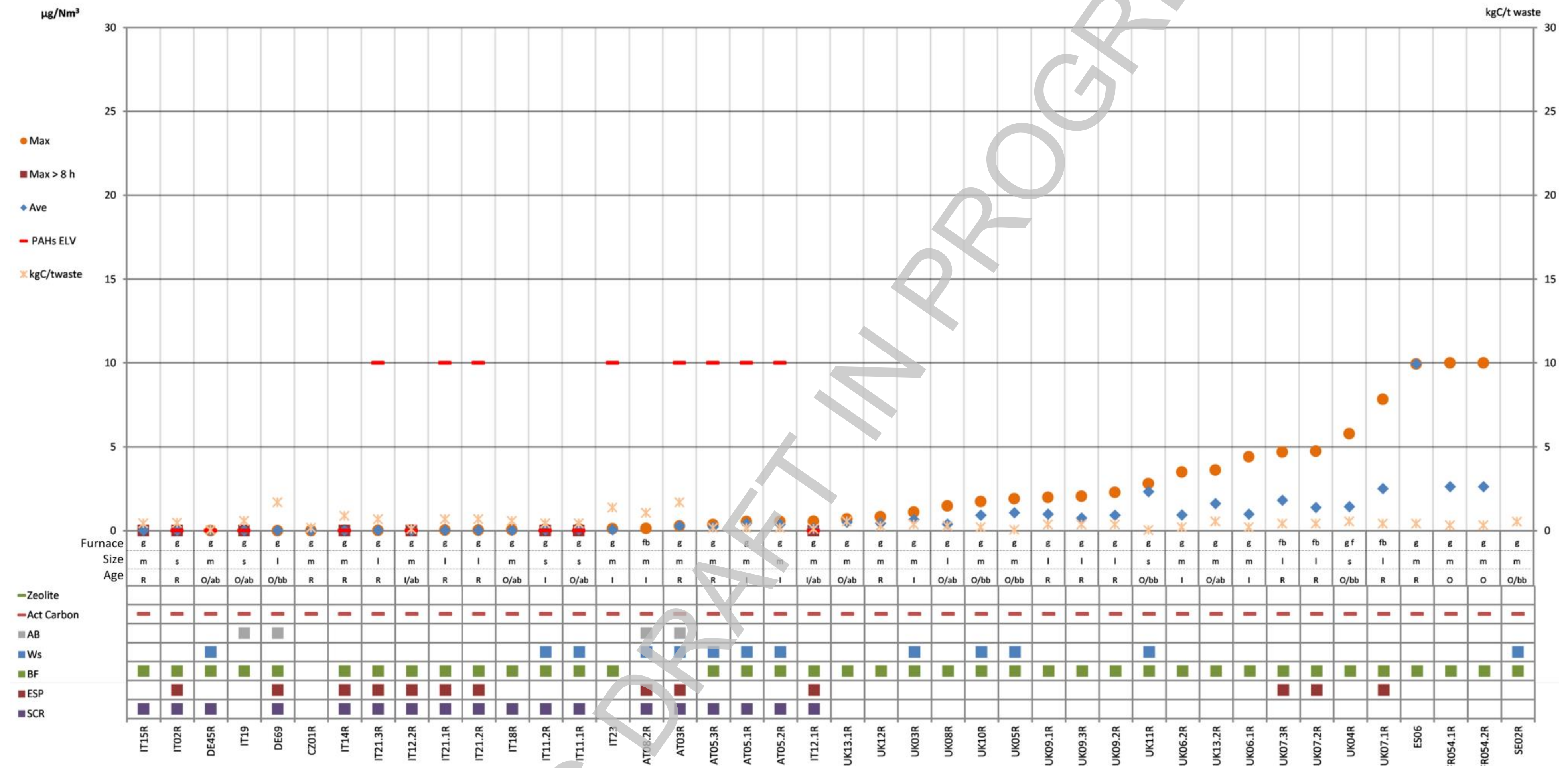
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction
Source: [81, TWG 2016].

Figure 3.51: Discontinuously monitored PCBs emissions to air from plants incinerating predominantly other non-hazardous waste



Note:
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Source: [81, TWG 2016].

Figure 3.52: Discontinuously monitored PCDD/F vs PCBs emissions to air

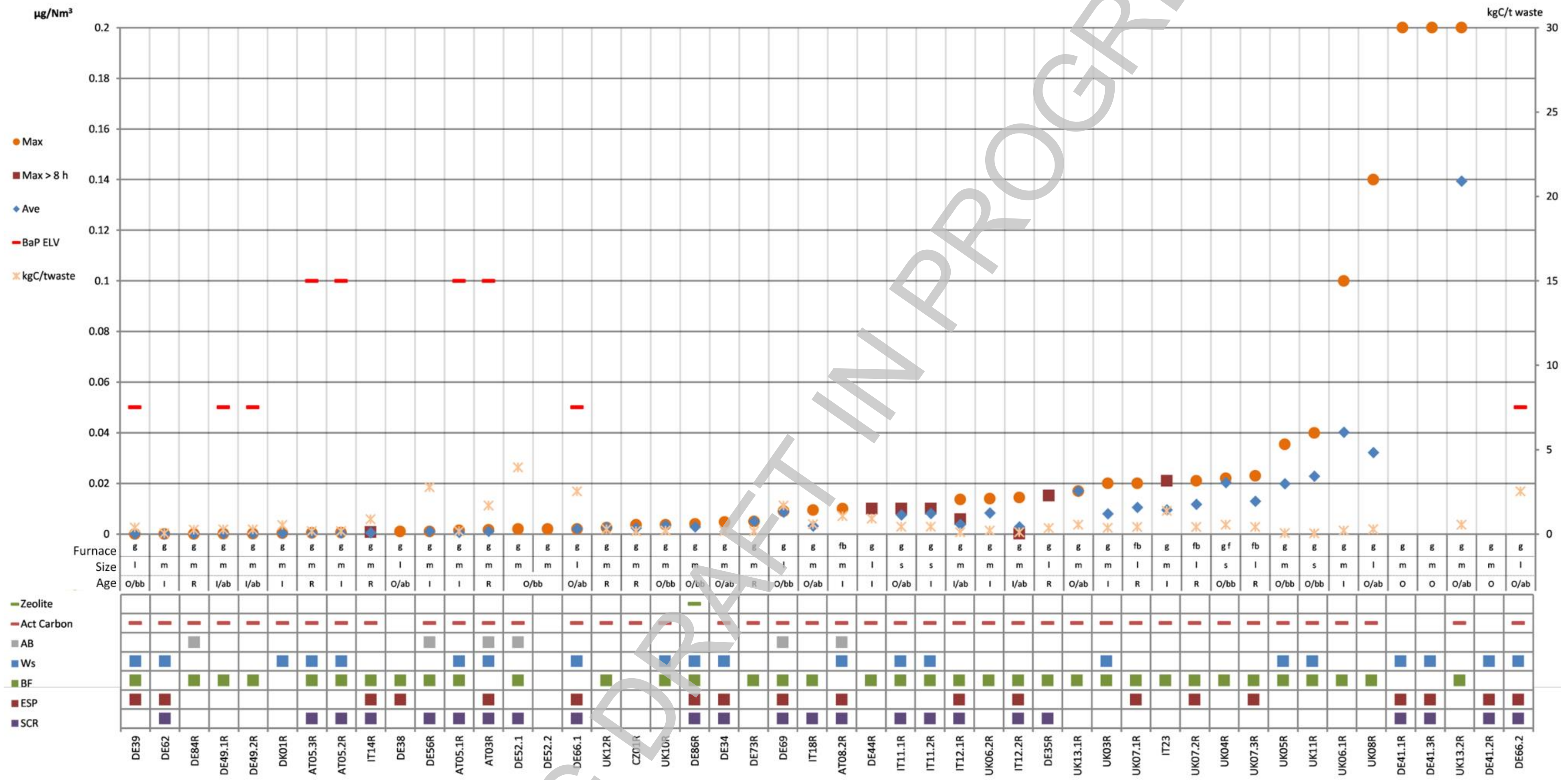


Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction
Source: [81, TWG 2016].

Figure 3.53: Discontinuously monitored PAHs emissions to air from plants incinerating predominantly municipal solid waste

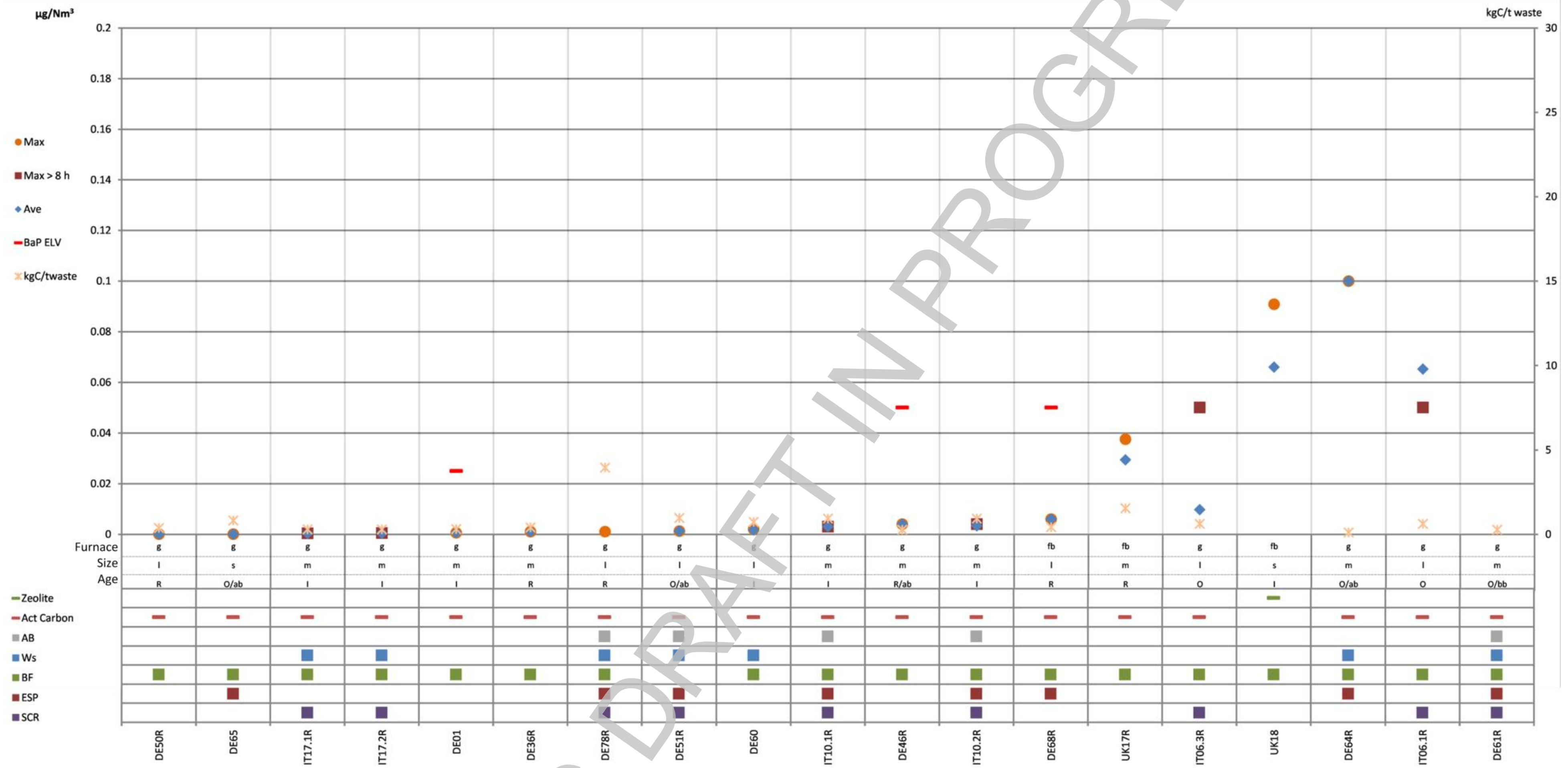
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction
Source: [81, TWG 2016].

Figure 3.54: Discontinuously monitored PAHs emissions to air from plants incinerating predominantly other non-hazardous waste



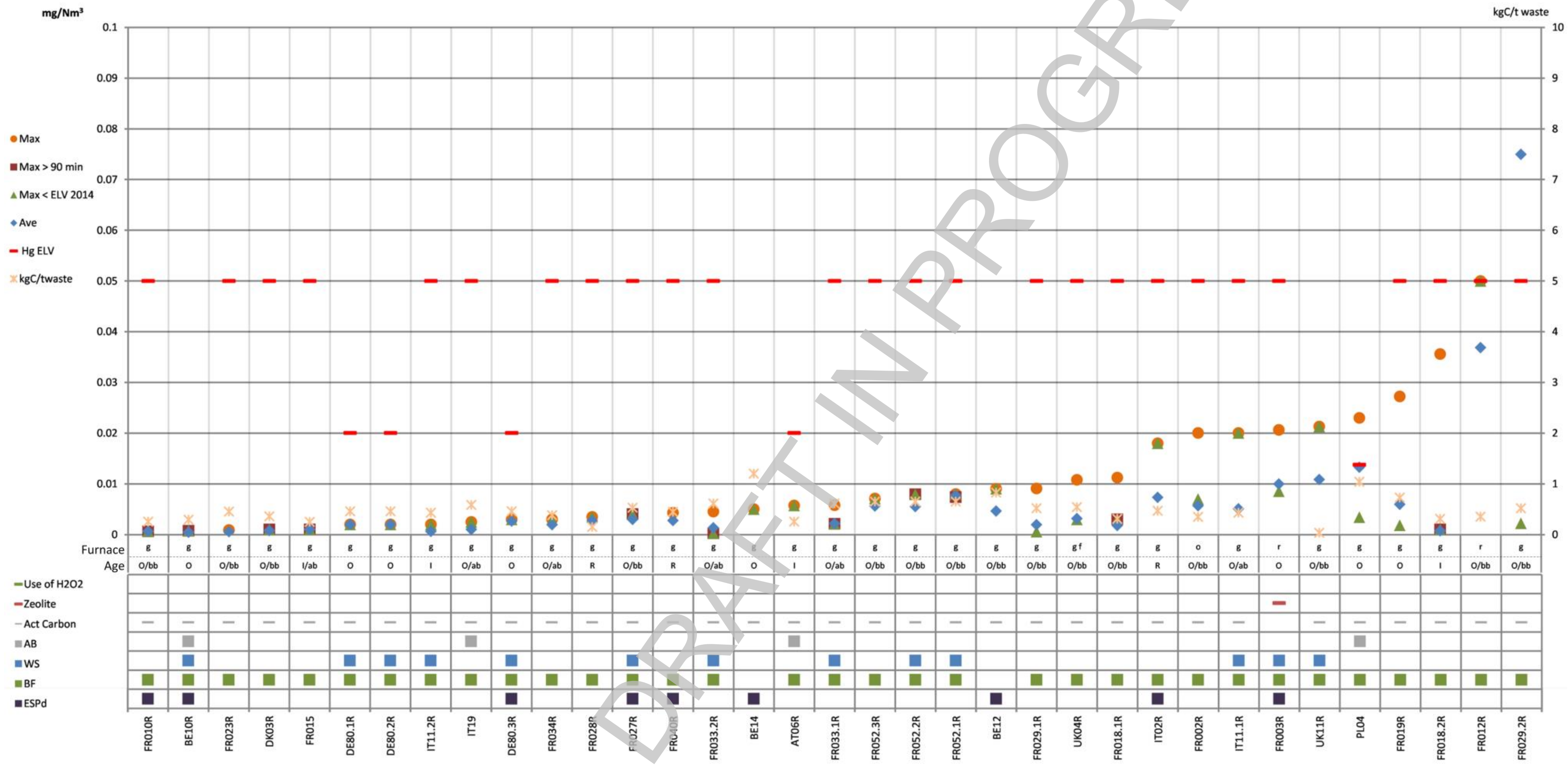
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction
Source: [81, TWG 2016].

Figure 3.55: Discontinuously monitored BaP emissions to air from plants incinerating predominantly municipal solid waste



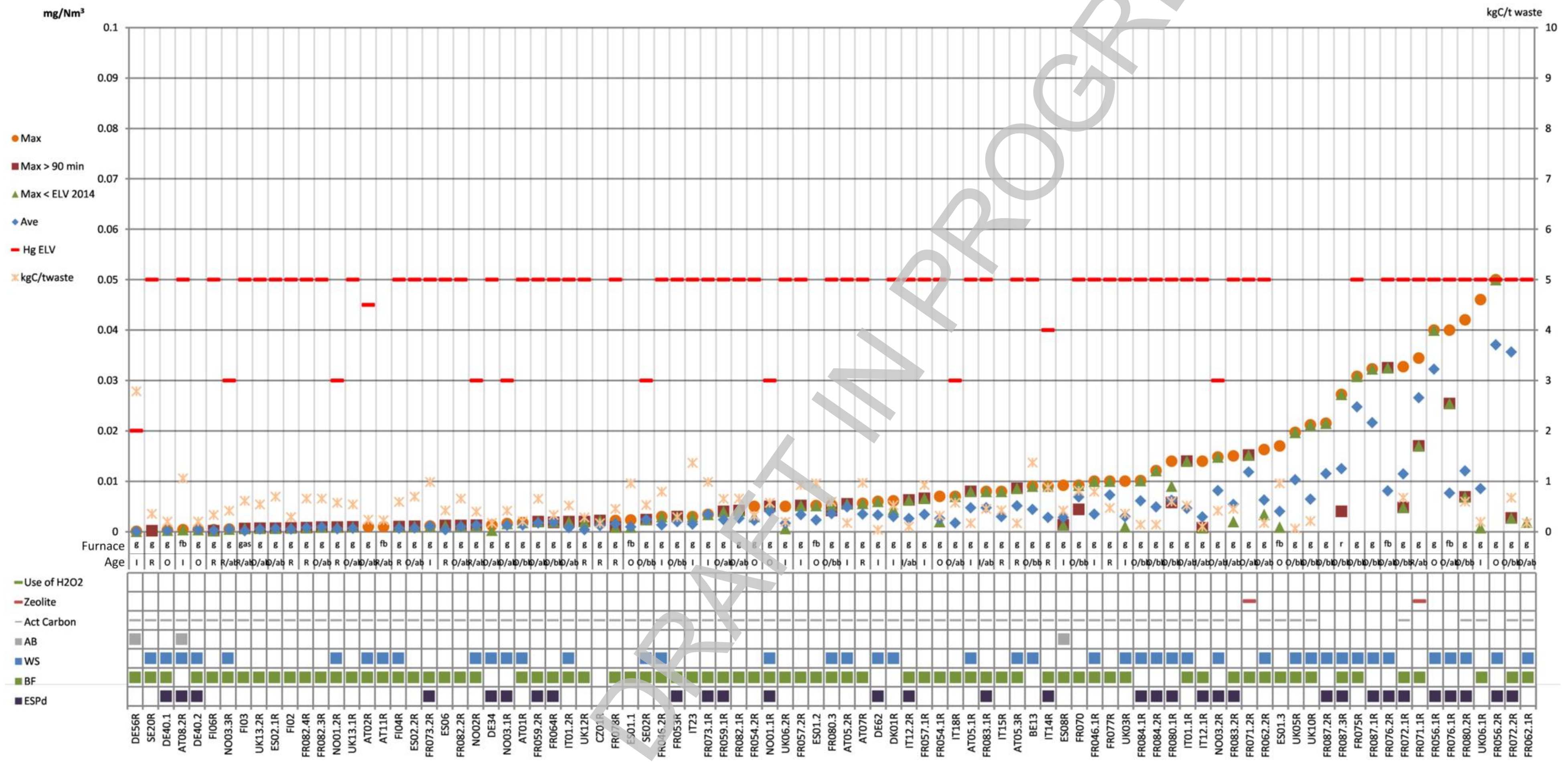
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction
Source: [81, TWG 2016].

Figure 3.56: Discontinuously monitored BaP emissions to air from plants incinerating predominantly other non-hazardous waste



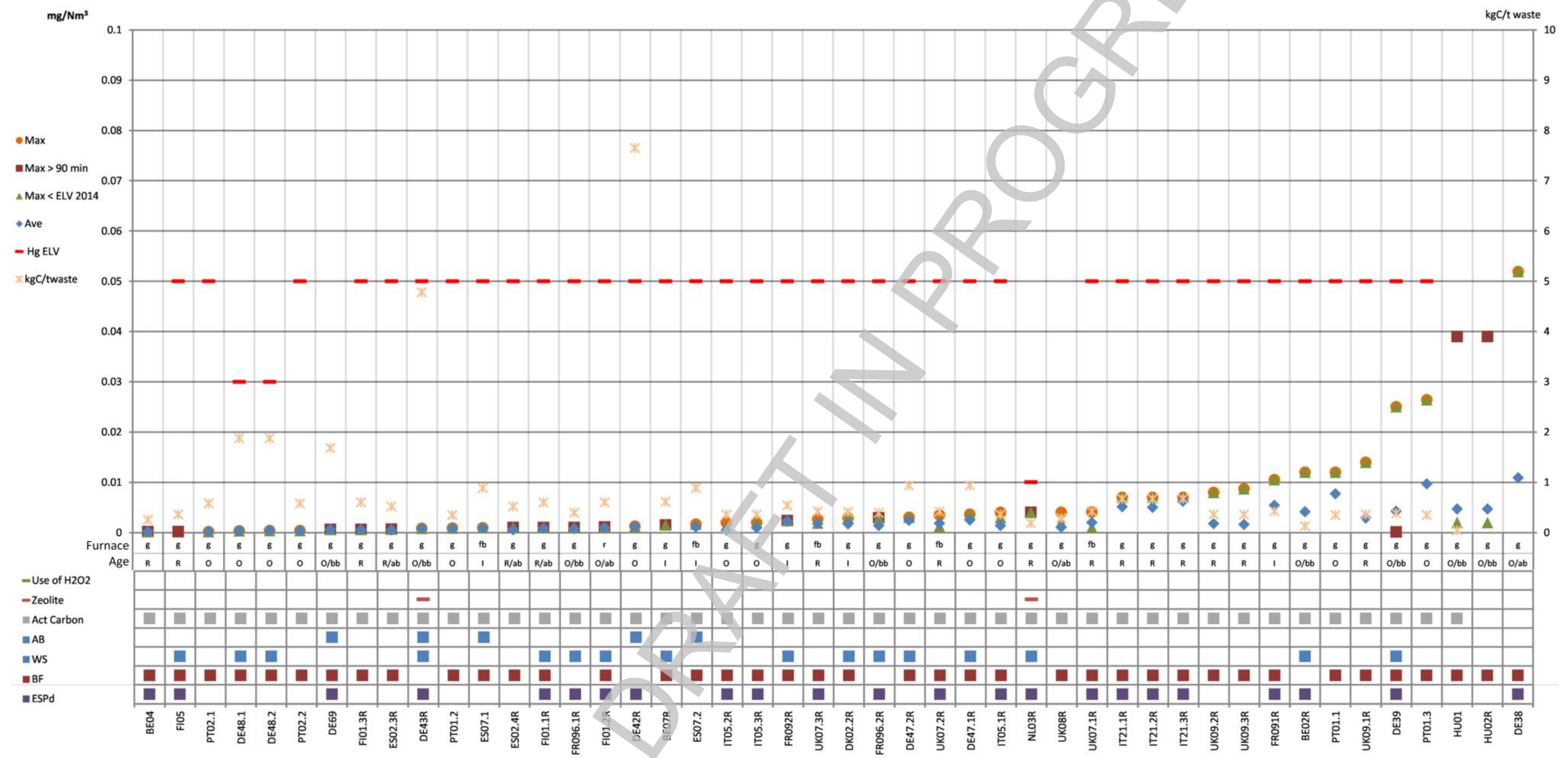
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: H2O2 = peroxide; Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.57: Discontinuously monitored Hg emissions to air from small plants incinerating predominantly municipal solid waste



Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: H2O2 = peroxide; Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.58: Discontinuously monitored Hg emissions to air from medium-size plants incinerating predominantly municipal solid waste



Note:

Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.

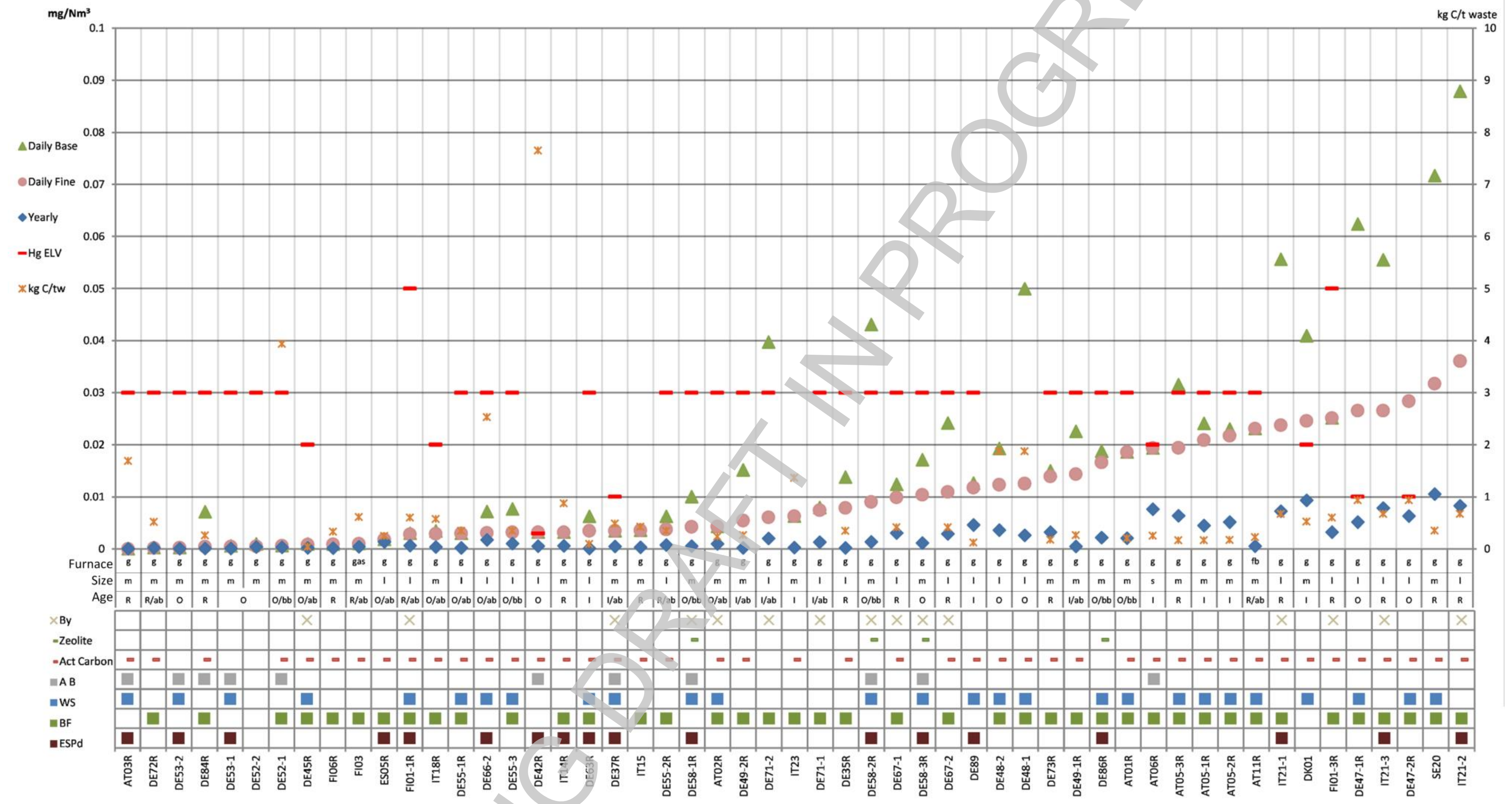
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).

Reagents Used: H2O2 = peroxide; Act Carbon = Activated Carbon.

Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.

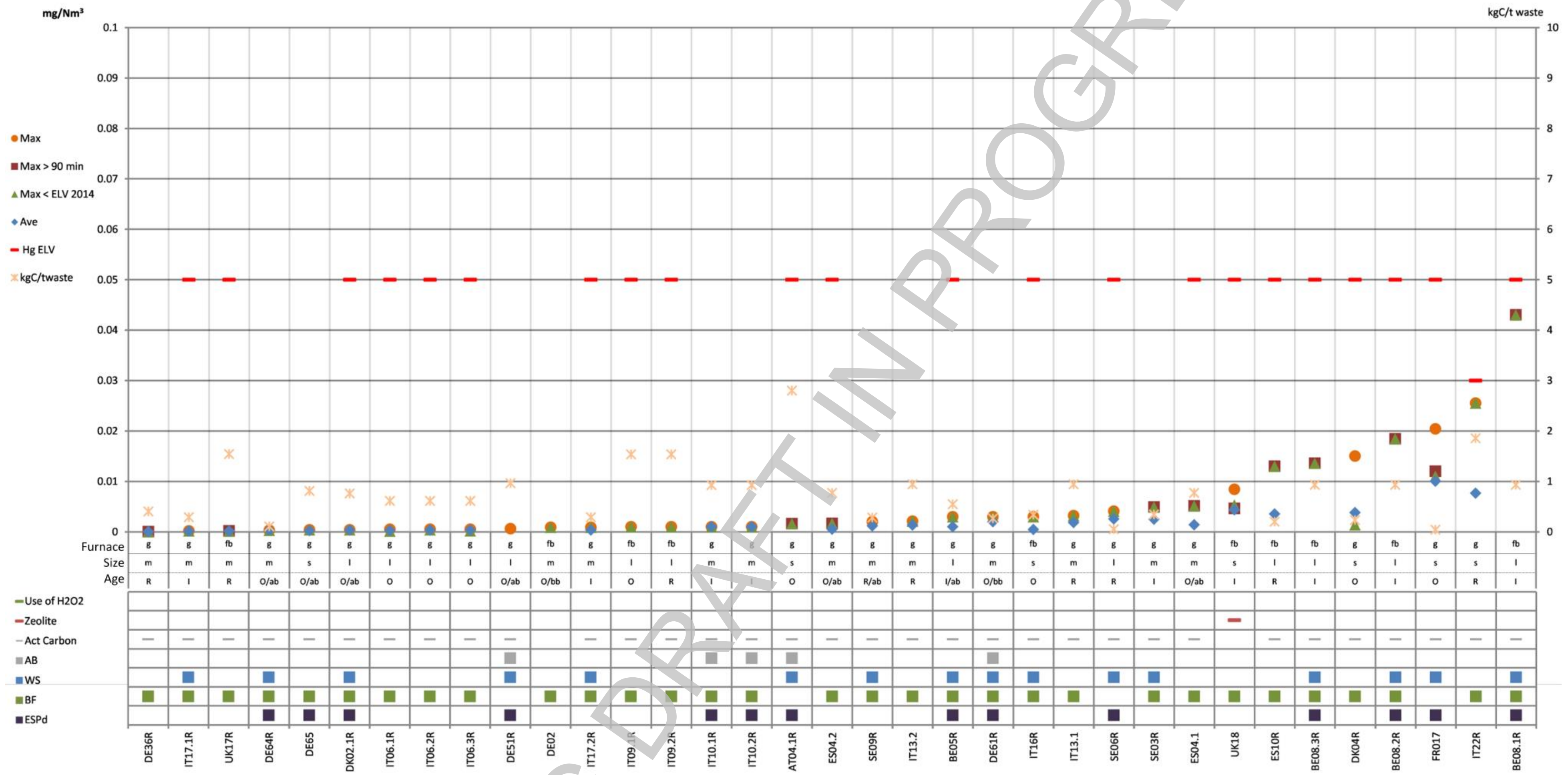
Source: [81, TWG 2016].

Figure 3.59: Discontinuously monitored Hg emissions to air from large plants incinerating predominantly municipal solid waste



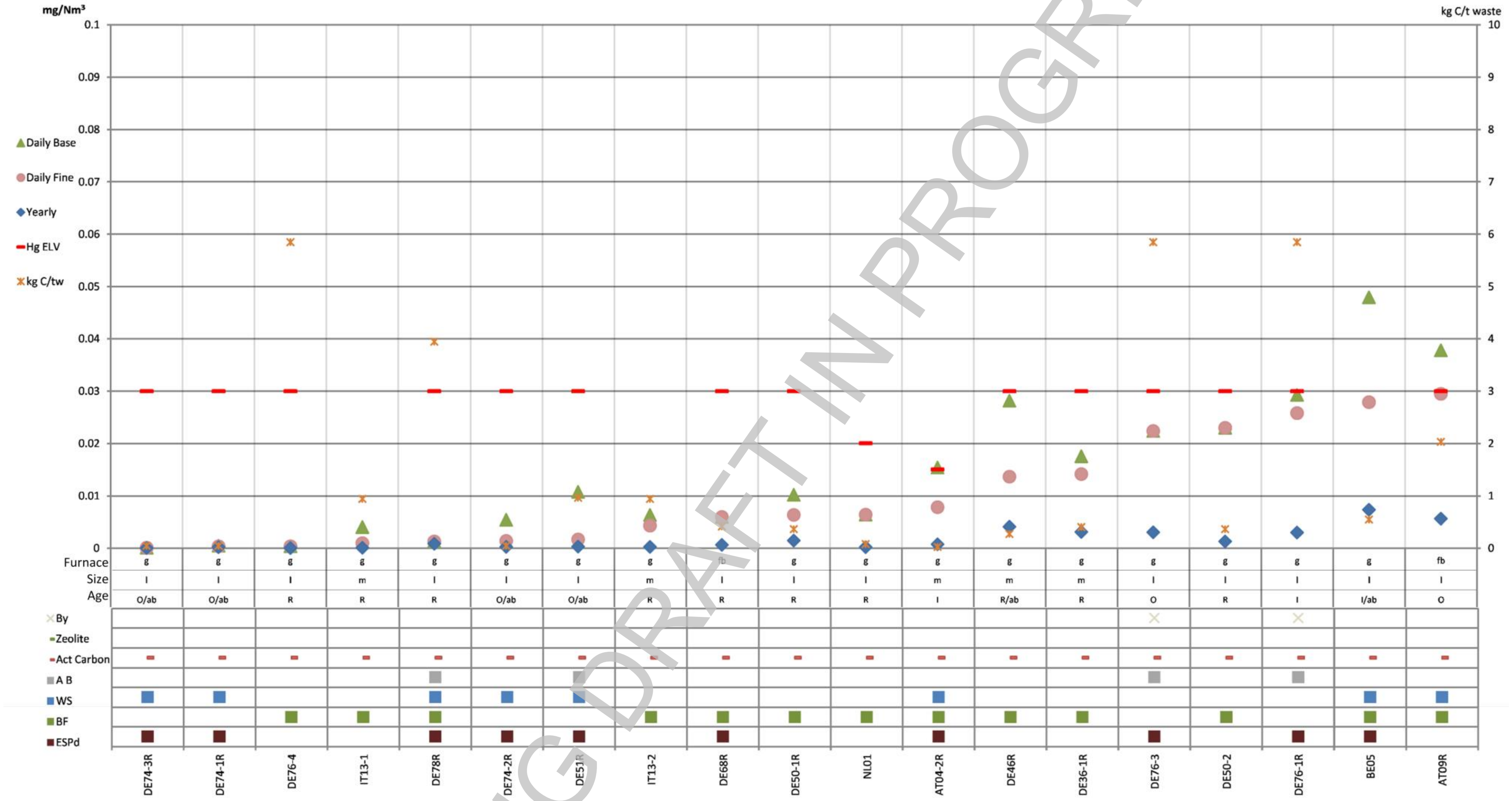
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.60: Continuously monitored Hg emissions to air from plants incinerating predominantly municipal solid waste



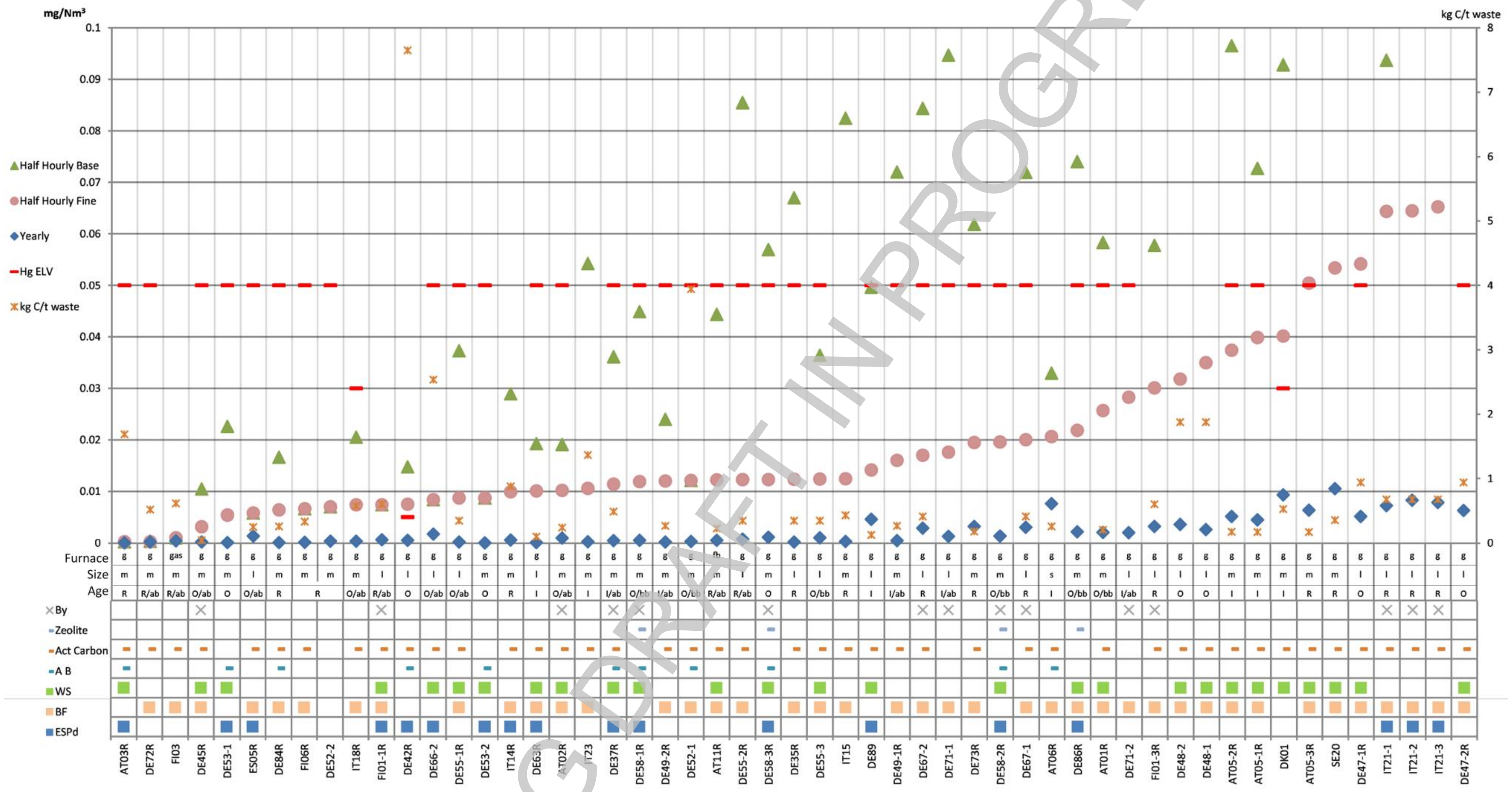
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: H2O2 = peroxide; Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.61: Discontinuously monitored Hg emissions to air from plants incinerating predominantly other non-hazardous waste



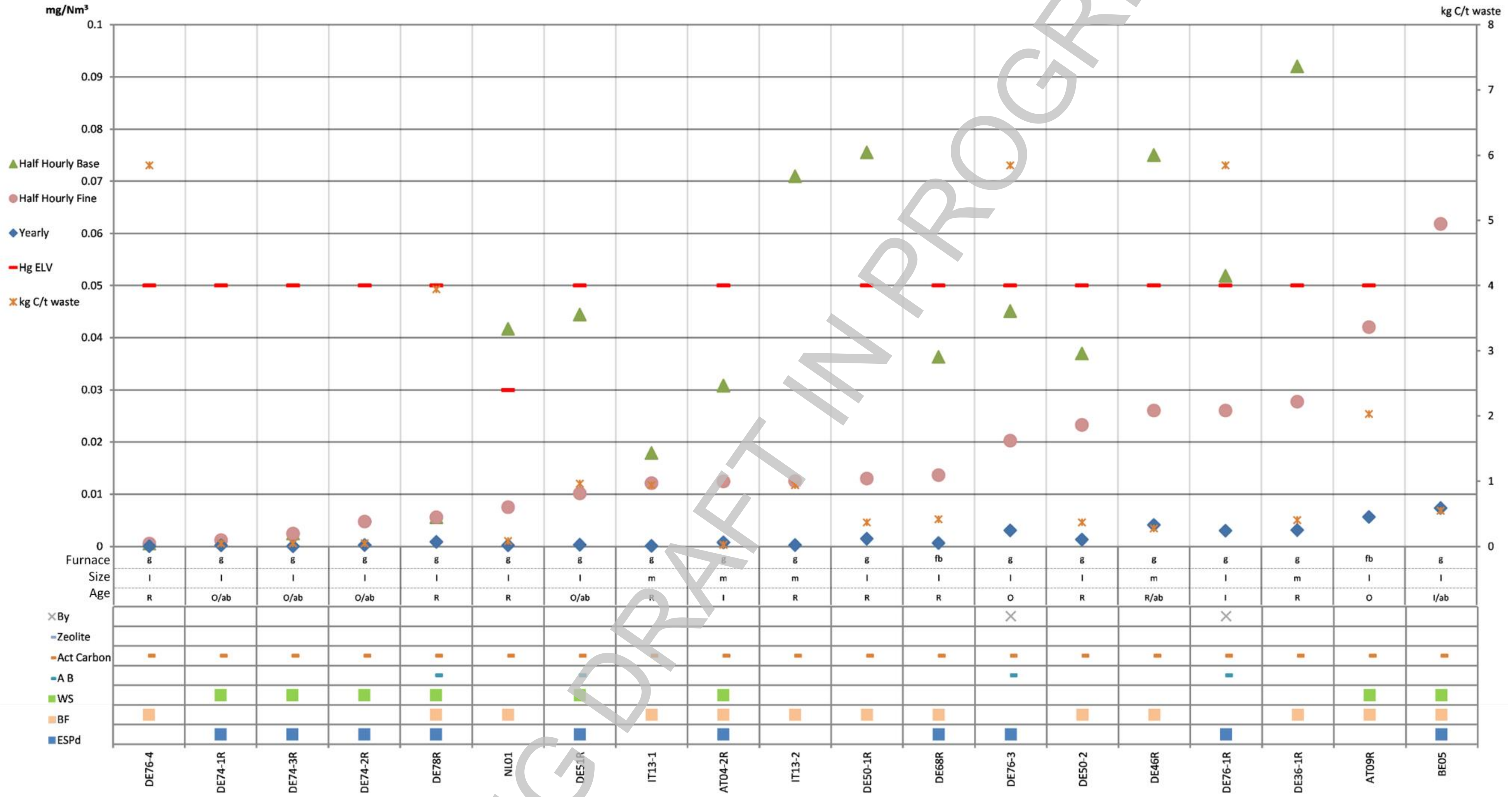
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.62: Continuously monitored Hg emissions to air from plants incinerating predominantly other non-hazardous waste



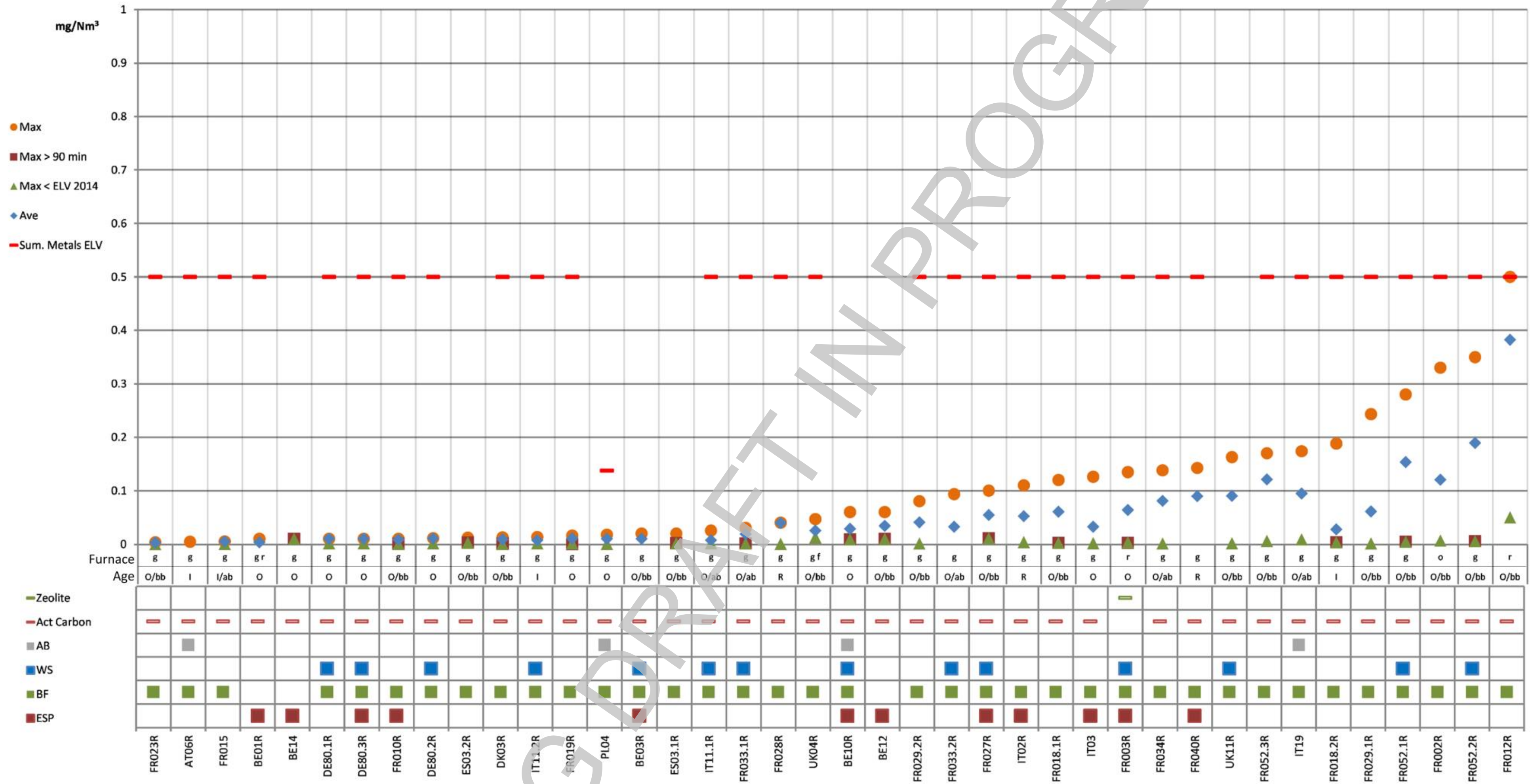
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.63: Half-hourly monitored Hg emissions to air from plants incinerating predominantly municipal solid waste



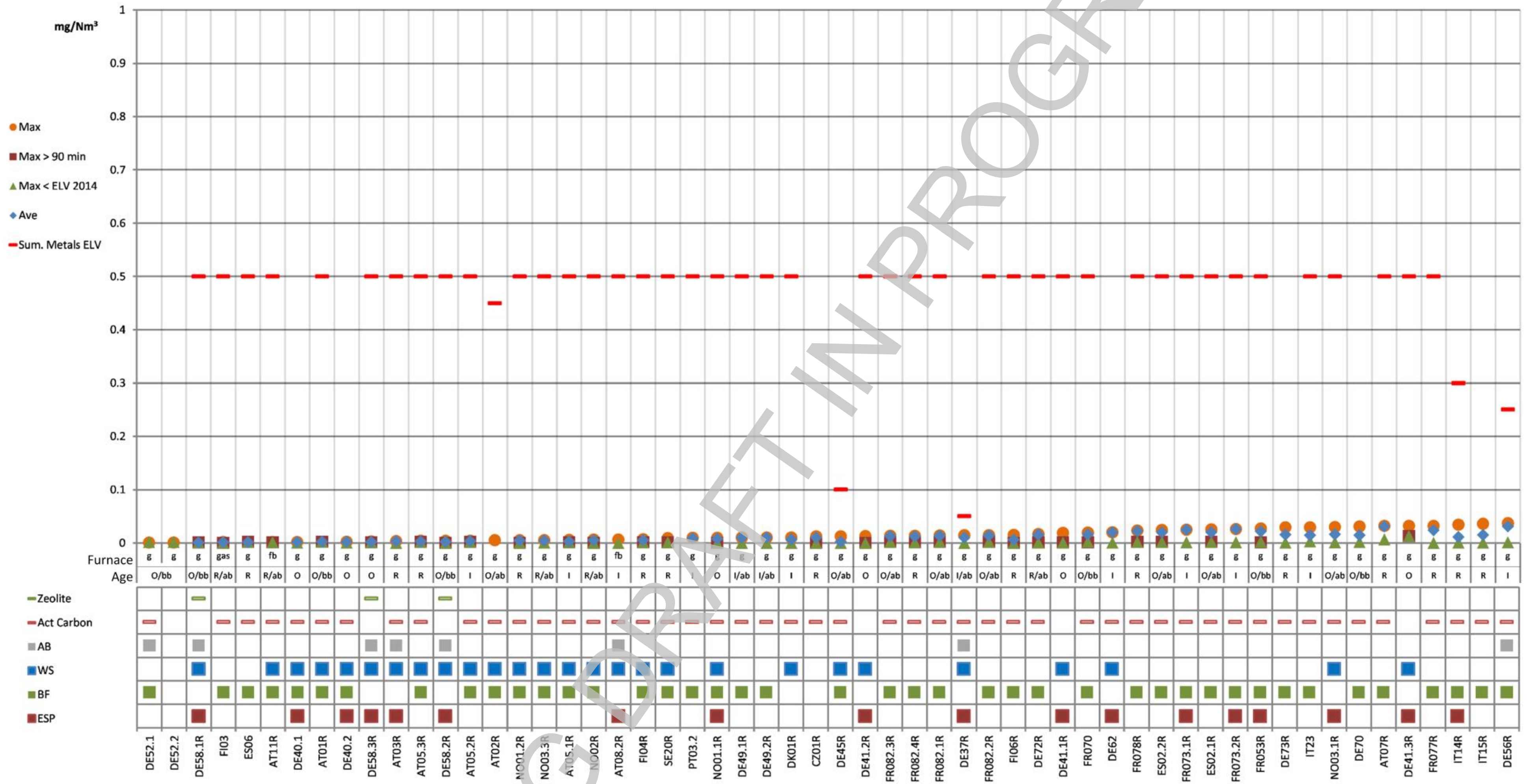
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.64: Half-hourly monitored Hg emissions to air from plants incinerating predominantly other non-hazardous waste



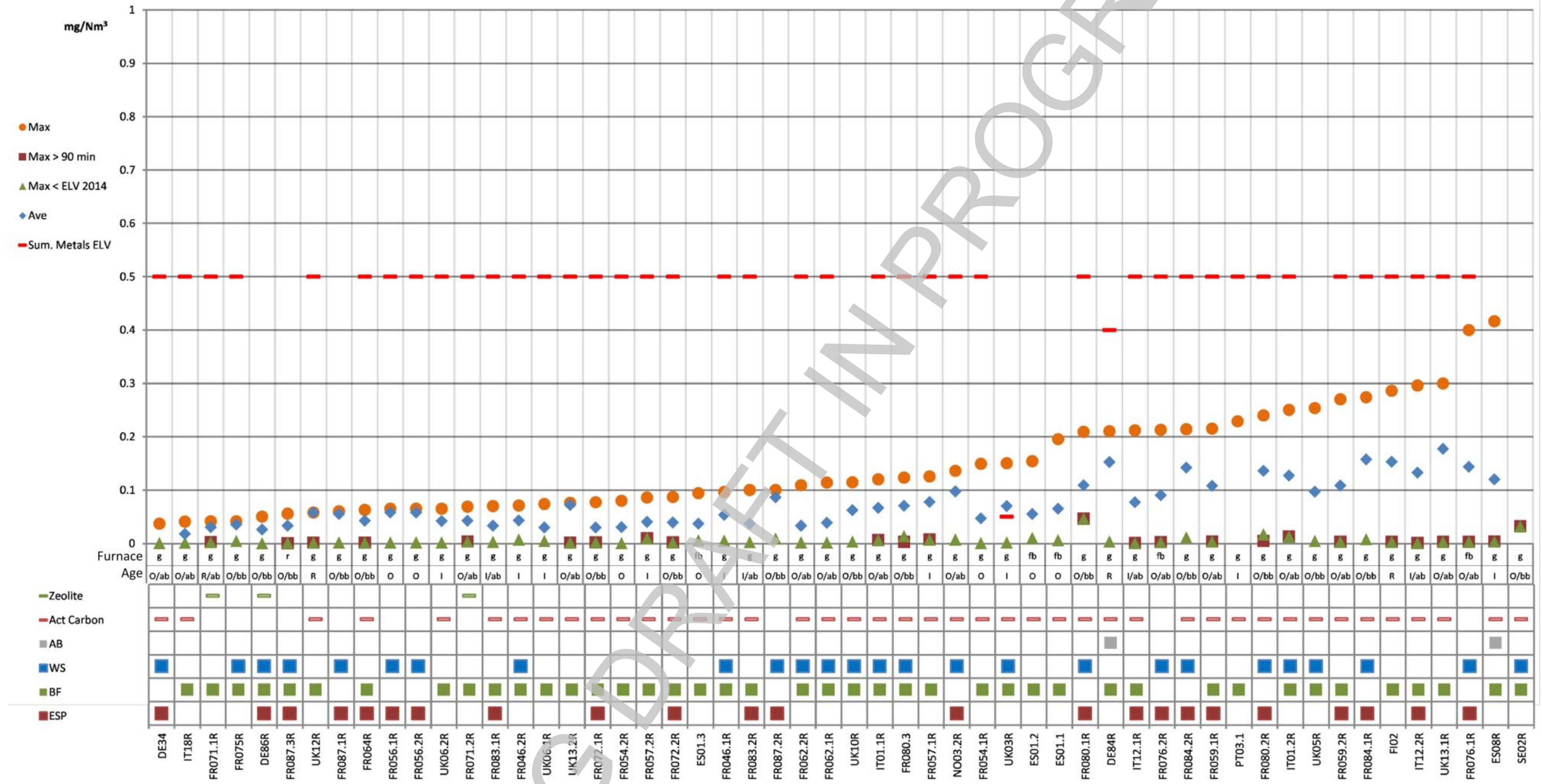
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.65: Discontinuously monitored Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V emissions to air from small plants incinerating predominantly municipal solid waste



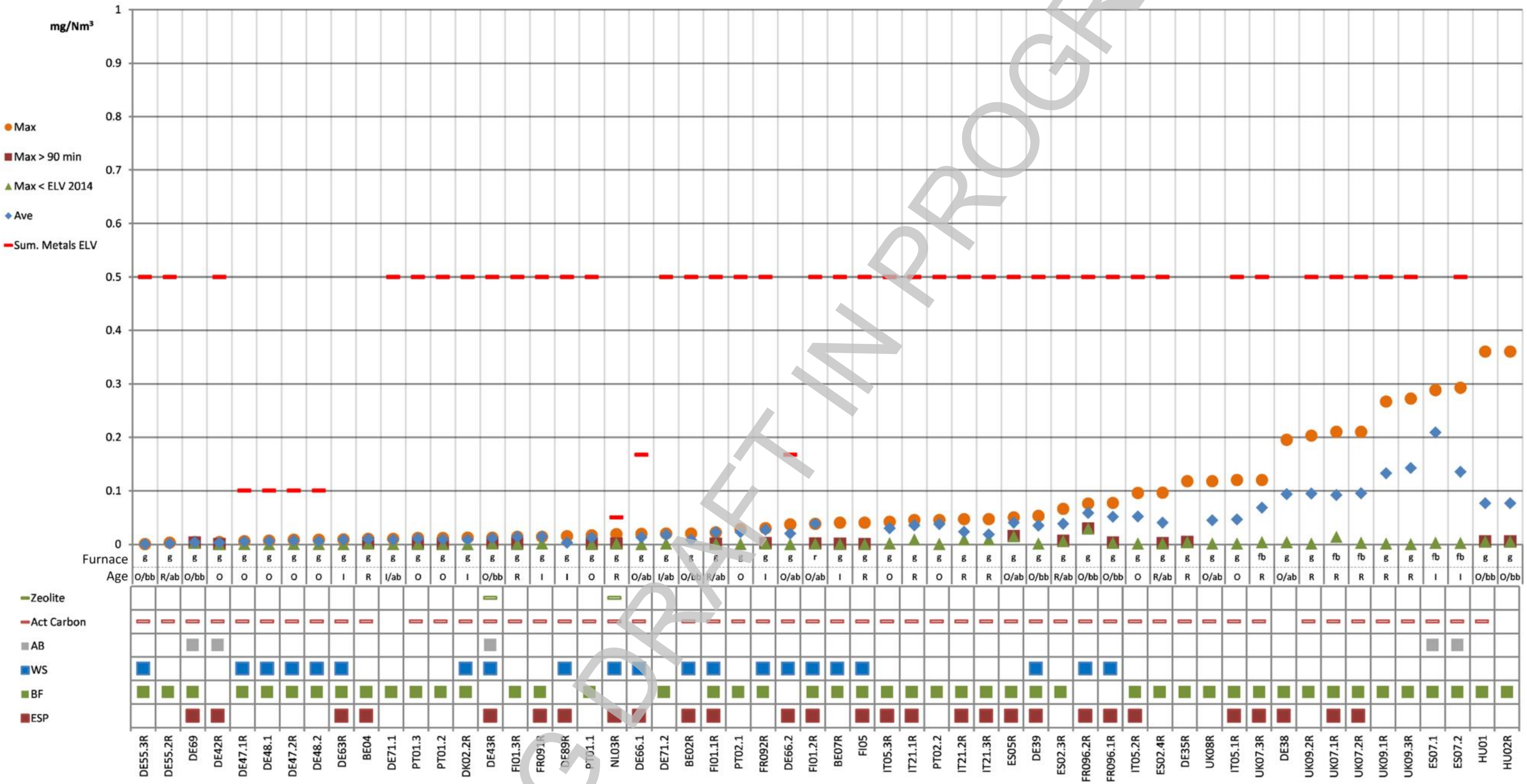
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.66: Discontinuously monitored Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V emissions to air from medium-size plants incinerating predominantly municipal solid waste (1/2)



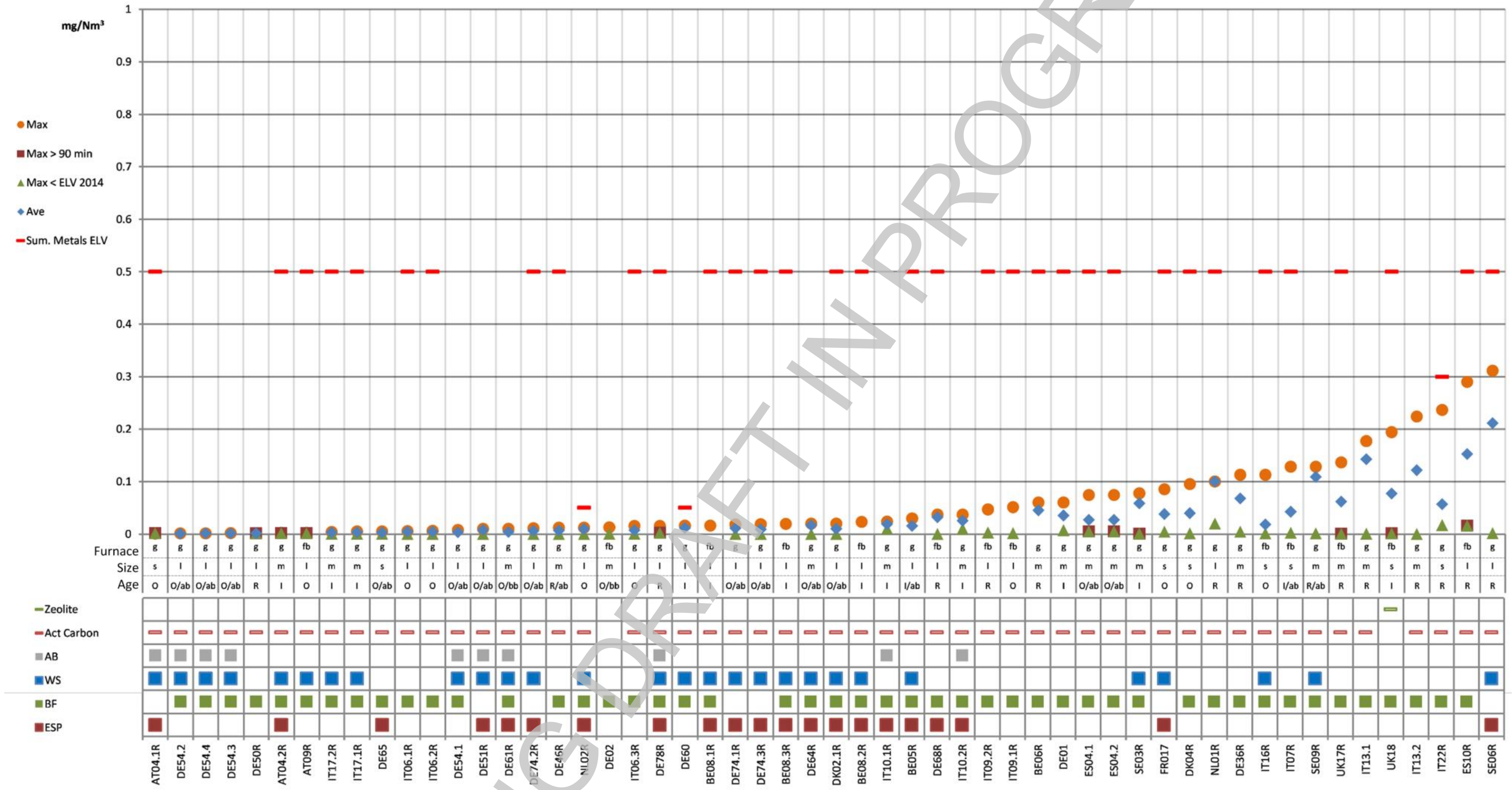
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.67: Discontinuously monitored Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V emissions to air from medium-size plants incinerating predominantly municipal solid waste (2/2)



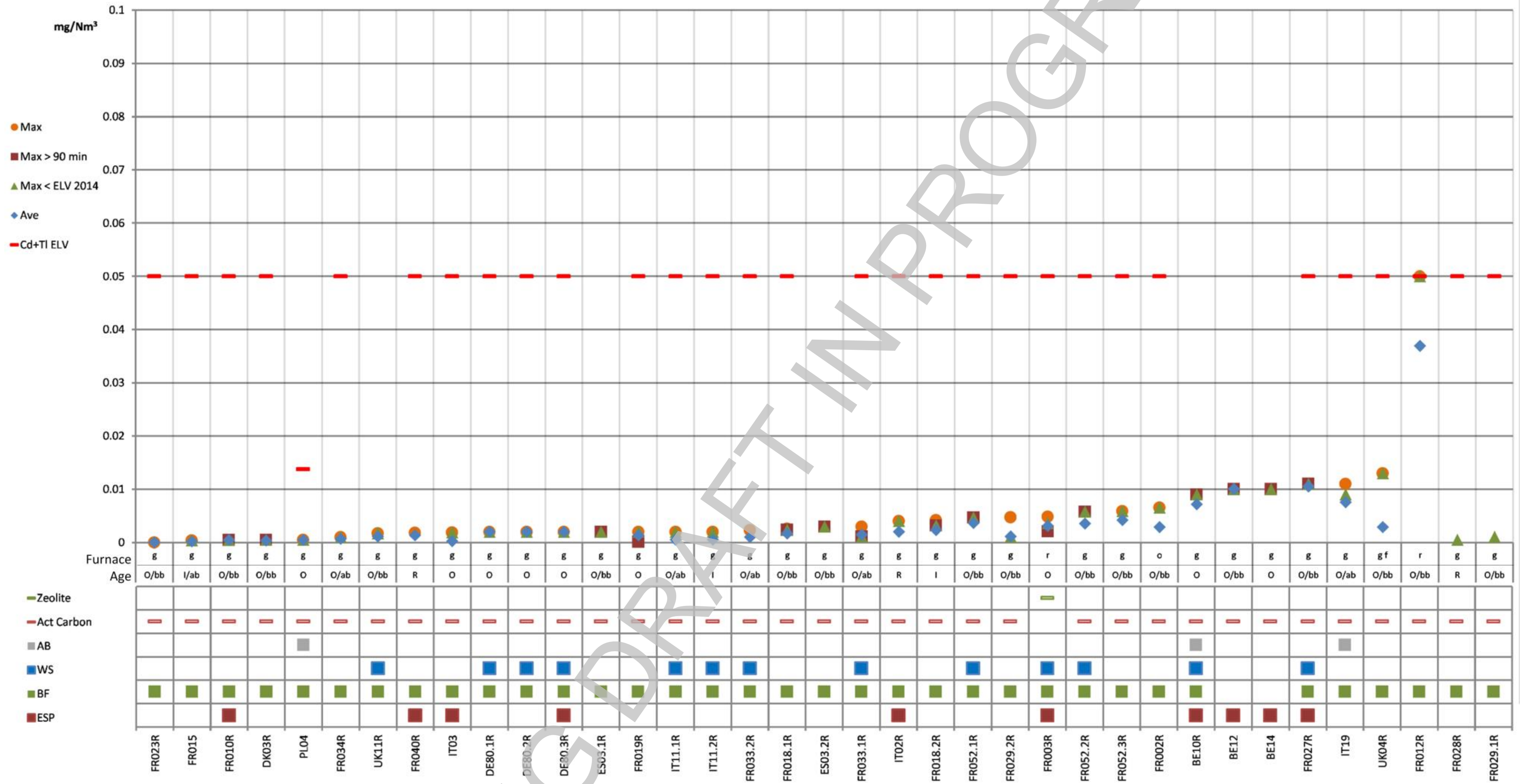
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.68: Discontinuously monitored Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V emissions to air from large plants incinerating predominantly municipal solid waste



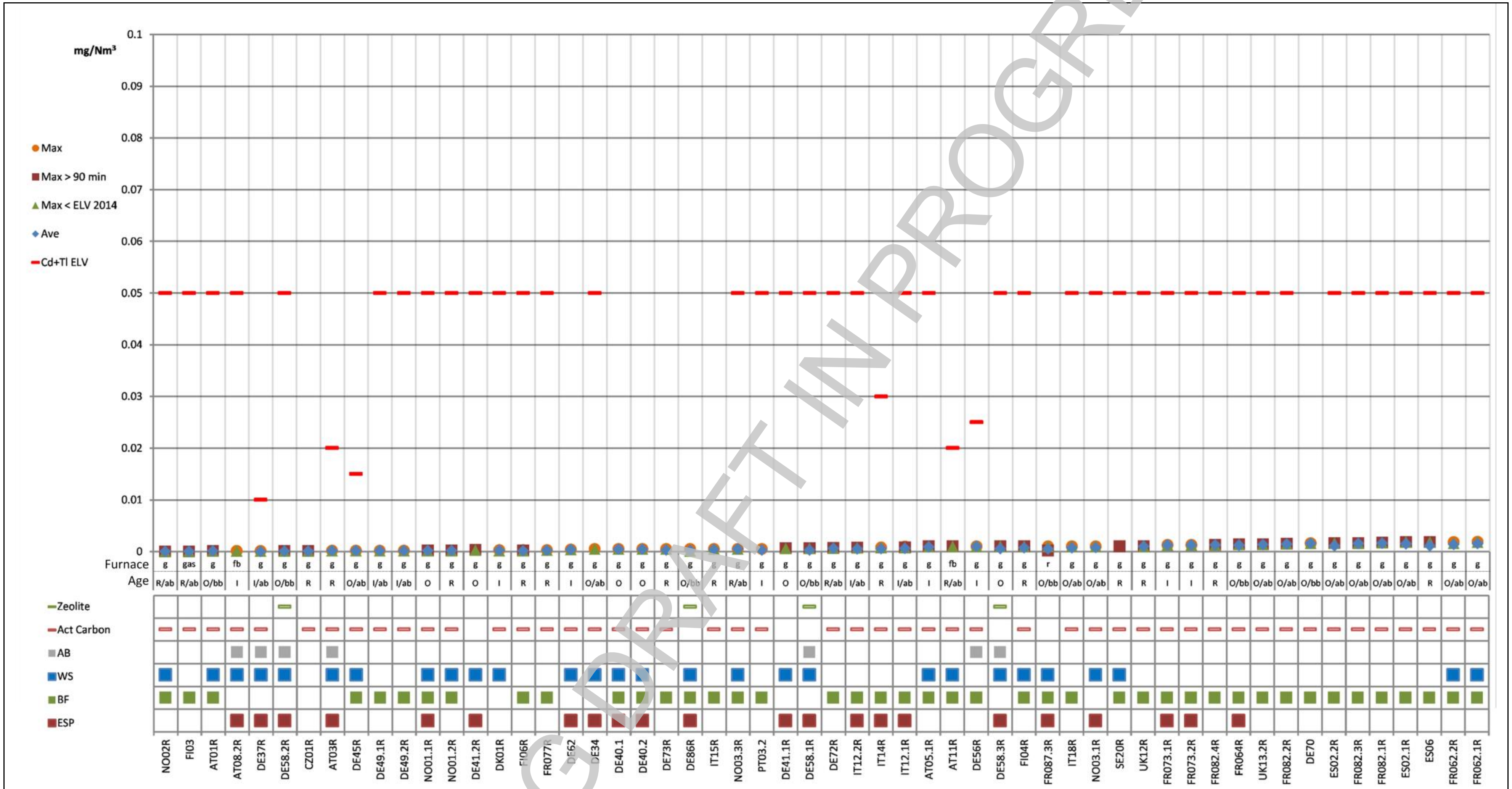
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.69: Discontinuously monitored Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V emissions to air from plants incinerating predominantly other non-hazardous waste



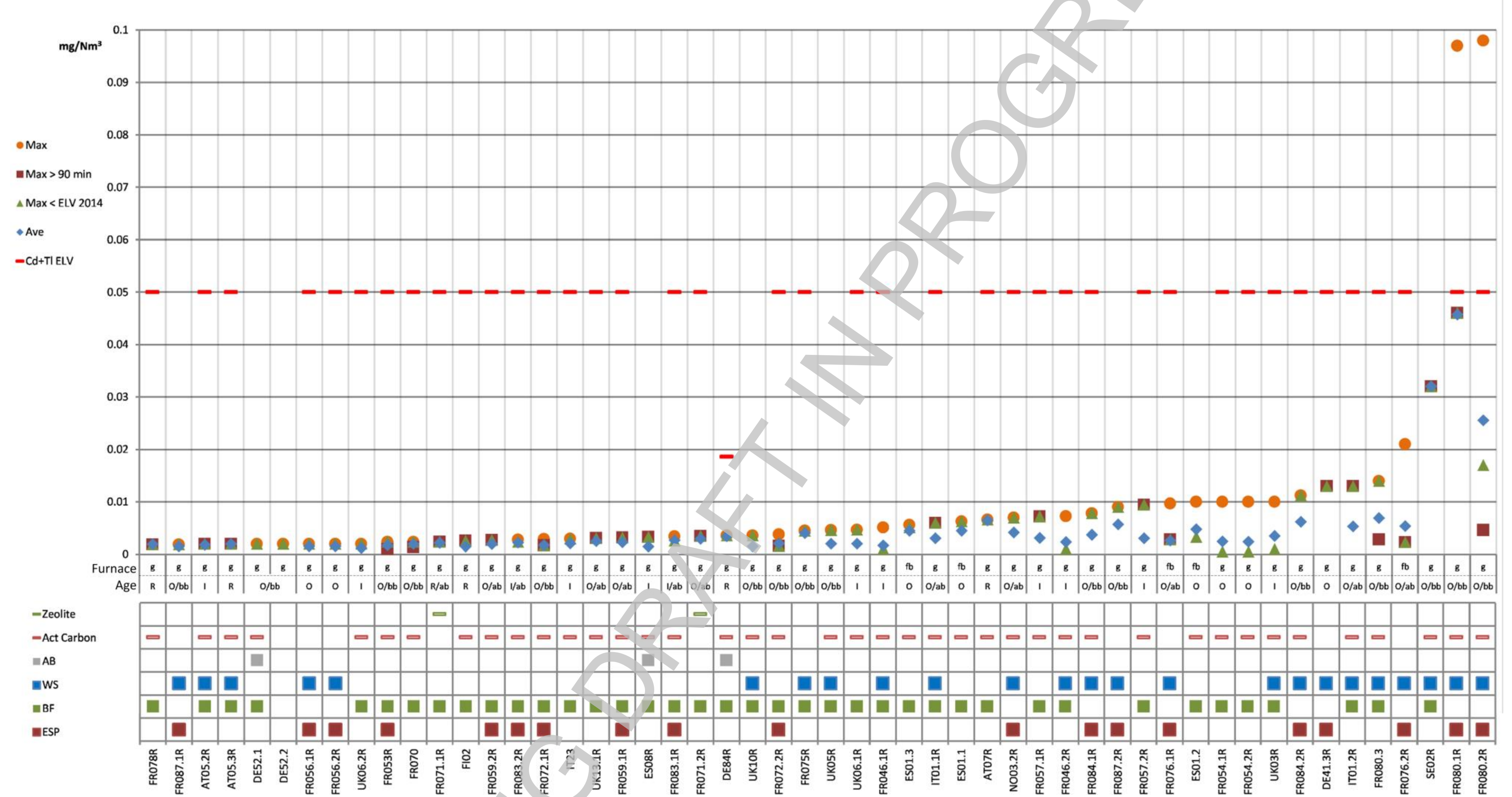
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.70: Discontinuously monitored Cd+Tl emissions to air from small plants incinerating predominantly municipal solid waste



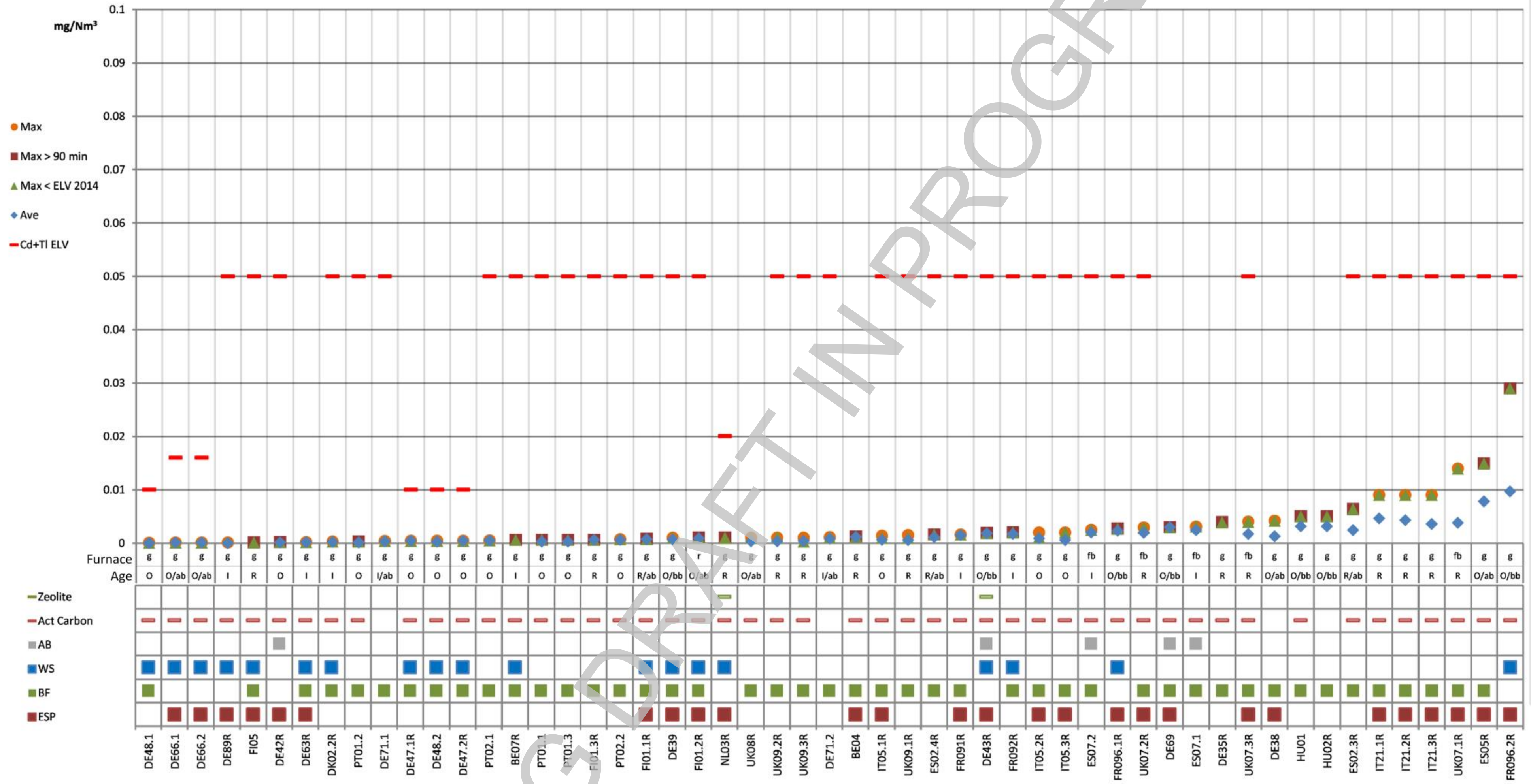
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.71: Discontinuously monitored Cd+Tl emissions to air from medium-size plants incinerating predominantly municipal solid waste (1/2)



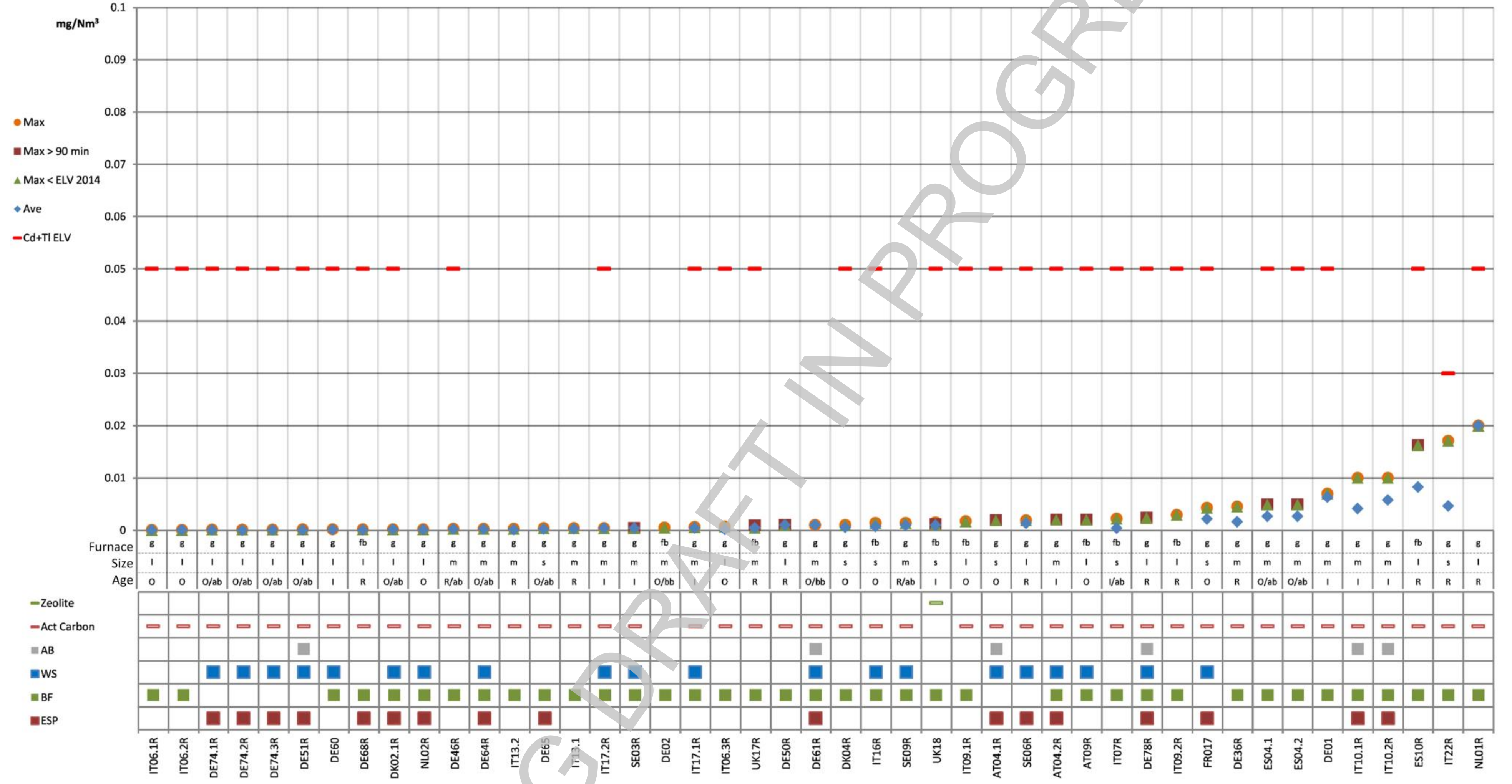
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.72: Discontinuously monitored Cd+Tl emissions to air from medium-size plants incinerating predominantly municipal solid waste (2/2)



Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.73: Discontinuously monitored Cd+Tl emissions to air from large plants incinerating predominantly municipal solid waste



Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.74: Discontinuously monitored Cd+Tl emissions to air from plants incinerating predominantly other non-hazardous waste

~~3.2.2.3 Emissions to air from fluidised bed incinerators~~

~~Efficient heat and mass transfer allows operation at lower temperatures than other combustor designs, but there is still a lower limit. The lower temperatures often used together with the more uniform distribution of temperatures, which eliminates hot spots and high oxygen zones, thermal NO_X production may then be reduced and the conversion of fuel nitrogen into NO_X can also be very low. The lower combustion temperatures together with the lack of air can sometimes lead to the formation of nitrous oxide (N_2O). Normal N_2O emission levels for fluidised bed sludge incineration are approx 10 mg/Nm³, with some values reported up to 100 mg/Nm³ and above. These values are higher than with other combustion systems.~~

~~The generally lower NO_X production that results from combining prepared or selected wastes with fluidised bed combustion can lead to similar or lower emission levels using simpler FGC than inherently high NO_X combustion systems.~~

~~Due to relatively lower temperature of the fluidised bed combustion, the contents of heavy metals in the raw flue-gas (and hence FGC residues) may be lower than from mixed waste grate combustion. The actual emissions to air depend on the waste, and on the chosen flue-gas cleaning system.~~

~~A combination of fluidised bed incineration at 850 - 950 °C and SNCR (ammonia) is reported to reduce NO_X emissions at Dutch sewage sludge incinerators to less than 70 mg/Nm^3.~~
~~[2, infomil, 2002]~~

~~3.2.3 Hazardous waste incineration plants~~

~~3.2.2.2 Summary data of the emissions to air from HWI~~

~~Table~~ 3.20 ~~represents the results of a survey of European (mainly German and Dutch) operators of plants with regard to typical emissions from plants. Thirty minute, daily and annual averages are shown. It is important to note that data that are the result of non-continuous measurements are also included in the table, and is indicated (N) in the type of measurement column. Furthermore, where non-continuous measurements appear in an averaging column, the values presented for non-continuous measurements are not collected over the stated averaging period for that column, and should only be interpreted as non-continuous measurements:~~

~~Table 3.20: Typical range of clean gas emissions to air from hazardous waste incineration plants~~

~~Parameter~~	~~Type of measurement~~	~~Daily averages (mg/Nm³)~~		~~Thirty-minute Averages (mg/Nm³)~~		~~Annual averages (mg/Nm³)~~
	~~C: cont.~~ ~~N: non-cont.~~	~~Limits in 2000/76/EU~~	~~Typical range of values~~	~~Limits in 2000/76/EU~~	~~Typical range of values~~	~~Typical range of values~~
~~Dust~~	~~C~~	~~10~~	~~0.1 – 10~~	~~20~~	~~0.1 – 15~~	~~0.1 – 2~~
~~HCl~~	~~C~~	~~10~~	~~0.1 – 10~~	~~60~~	~~0.1 – 60~~	~~0.3 – 5~~
~~HF~~	~~C/N~~	~~1~~	~~0.04 – 1~~	4	~~0.1 – 2~~	~~0.05 – 1~~
~~SO_2~~	~~C~~	~~50~~	~~0.1 – 50~~	~~200~~	~~0.1 – 150~~	~~0.1 – 30~~
~~NO_X~~	~~C~~	~~200~~	~~40 – 200~~	~~400~~	~~50 – 400~~	~~70 – 180~~
~~TOC~~	~~C~~	~~10~~	~~0.1 – 10~~	~~20~~	~~0.1 – 20~~	~~0.01 – 5~~
~~CO~~	~~C~~	~~50~~	~~5 - 50~~	~~100~~	~~5 – 100~~	~~5 – 50~~
~~Hg~~	~~C/N~~	~~0.05~~	~~0.0003 – 0.03~~	~~n/a~~	~~0.0003- 1~~	~~0.0004 – 0.05~~
~~Cd +Tl~~	~~N~~	~~0.05~~	~~0.0005 – 0.05~~	~~n/a~~		~~0.0005 – 0.05~~
~~Σ other heavy metals~~	~~N~~	~~0.5~~	~~0.0013 – 0.5~~	~~n/a~~		~~0.004 – 0.4~~
~~PCDD/PCDF (ng TEQ/m³)~~	~~N~~	~~0.1~~	~~0.002 – 0.1~~	~~n/a~~		~~0.0003 – 0.08~~

~~1. Data is standardised at 11 % Oxygen, dry gas, 273K and 101.3kPa.~~
~~2. Other metals = Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V~~
~~*Source:* [1, UBA, 2001], [2, infomil, 2002], [64, TWGComments, 2003], [74, TWGComments, 2004]~~

3.2.2.3 Emissions to air from the incineration of sewage sludge

Hydrogen chloride and hydrogen fluoride

Sewage sludge (SS) incineration plants that participated in the 2016 data collection are fitted either with wet or dry systems; none of the plants reported the use of semi-wet or semi-dry systems.

HCl emission data from plants incinerating predominantly SS, based on continuous measurements, are shown in Figure 3.75.

The emission levels range between close to the limit of quantification and 8 mg/Nm^3 as a yearly average and 10 mg/Nm^3 as a maximum of the daily average ('fine' data filtering). In most cases the maximum daily average obtained with 'base' data filtering does not substantially change from the value obtained with 'fine' data filtering; the most notable exception is plant DE87.2R where the maximum daily average rises from 5.8 mg/Nm^3 to 14.8 mg/Nm^3 on a day where emissions recorded at start-up are substantially higher than usual levels and the daily average includes only a limited number of half-hourly periods.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used or the age and size of the plant. All plants are fluidised bed incinerators.

Hydrogen fluoride (HF) emission data from for plants incinerating predominantly SS, based either on continuous or discontinuous measurements, are shown in the following figures:

- Figure 3.76, for plants monitoring HF discontinuously;
- Figure 3.77, for plants monitoring HF continuously.

The emission levels range between close to the limit of quantification and 0.3 mg/Nm^3 as a yearly average and 1.2 mg/Nm^3 as a maximum daily average or average over the sampling period. The maximum daily average obtained with 'base' data filtering does not substantially change from the value obtained with 'fine' data filtering. One plant shows an emission level above 1 mg/Nm^3 (1.2 mg/Nm^3 as a maximum daily average), whereas the remaining plants are below 0.9 mg/Nm^3 as a maximum daily average.

Mostly, plants monitoring HF continuously are fitted with DSI and use $NaHCO_3$ as a reagent, while plants monitoring HF discontinuously are commonly fitted with DSI or WS, and mostly use NaOH as a reagent.

The reported data do not show a clear correlation between the achieved emission levels and the age and size of the plant. All plants are fluidised bed incinerators.

Sulphur dioxide

The types of flue-gas cleaning systems in use are the same as those for HCl, with the main difference that wet scrubbers are operated at a slightly basic pH (usually 7–8).

SO_2 emission data from plants incinerating predominantly SS, based on continuous measurements, are shown in Figure 3.78.

The emission levels range between close to the limit of quantification and 40 mg/Nm^3 as a yearly average and 72 mg/Nm^3 as a maximum daily average. The graph shows that the plants fitted with a combination of DSI and WS techniques generally achieve emission levels below 30 mg/Nm^3 as a maximum daily average.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used or the age and size of the plant. All plants are fluidised bed incinerators.

Dust

Sewage sludge incineration plants that participated in the 2016 data collection are fitted either with an electrostatic precipitator (ESP) or with a bag filter (BF) for the reduction of dust emissions.

In several cases, both techniques are combined, for example an electrostatic precipitator for pre-dedusting after the boiler with a bag filter before the stack. This allows the separation of fly ash from FGC residues and separate recycling/disposal. Some plants also use cyclones or multi-cyclones for pre-dedusting.

Wet scrubbers and fixed adsorption beds can also contribute to dust removal.

Interdependencies between different parts of the system are frequently seen in the overall flue-gas cleaning system design. For instance, in the case of dry and semi-wet systems, bag filters also act as a reactor for acid gas removal. In addition, they can enable the removal of PCDD/F and metals (including mercury and cadmium) if a suitable reagent is used (e.g. activated carbon). Two reference lines, PL01.1 and PL01.2, report a dry system in combination with a cyclone without a bag filter. *Could the TWG (POLAND) please check that this is indeed the correct description of the PL01 FGC system?*

Dust emission data for plants incinerating predominantly SS, based on continuous measurements, are shown in Figure 3.79.

The emission levels range between close to the limit of quantification and 3.4 mg/Nm^3 as a yearly average and 6.2 mg/Nm^3 as a maximum daily average ('fine' data filtering). In some cases the maximum daily average obtained with 'base' data filtering may be substantially higher, generally related to OTNOC situations. The graph shows that all plants with maximum daily average levels above 3.7 mg/Nm^3 ('fine' data filtering) are small plants of recent construction, while all plants of a medium and large size achieve lower levels. All plants are fluidised bed incinerators.

Nitrogen oxides

The fluidised bed incineration process used in sewage sludge incinerators provides for lower NO_X levels than other furnace types. Around 60 % of the sewage sludge incinerators that participated in the 2016 data collection use SCR and/or SNCR as secondary techniques for the further reduction of NO_X emissions.

NO_X emission data for plants incinerating predominantly SS, based on continuous measurements, are shown in Figure 3.80.

The emission levels range between 12 mg/Nm^3 and 223 mg/Nm^3 as a yearly average and between 20 mg/Nm^3 and 233 mg/Nm^3 as a maximum daily average ('fine' data filtering). Values above 140 mg/Nm^3 are observed in plants fitted with SNCR or without any secondary techniques for the reduction of NO_X.

For plants fitted with SCR, no significant difference is observed between the maximum daily average obtained with 'base' and 'fine' data filtering, while for plants fitted with SNCR or with no secondary techniques this difference is generally higher, reflecting the lower intrinsic stability of the process.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used, or with the age and size of the plant. All plants are fluidised bed incinerators.

Ammonia

Ammonia emissions are related to reactant slip from SCR or SNCR. The main technique in use to control such emissions is process optimisation as well as good maintenance of the catalyst in the case of SCR. SCR can also be implemented as slip catalyst to further react the unreacted ammonia after the main reduction has taken place in a SNCR system.

Ammonia emission data for plants incinerating predominantly SS are based either on continuous or discontinuous measurement and are shown in Figure 3.81 for plants monitoring NH_3 discontinuously and in Figure 3.82 for plants monitoring NH_3 continuously.

With the exception of PL02, which is fitted with SNCR and reports NH_3 emission levels close to 90 mg/Nm^3 as a yearly average and 235 mg/Nm^3 as a maximum daily average, the emission levels achieved by the plants montoring ammonia continuously range between close to the limit of quantification and 19 mg/Nm^3 as a yearly average and 47 mg/Nm^3 as a maximum daily average. Plants fitted with SNCR and a wet scrubber generally achieve emission levels below 13.4 mg/Nm^3. None of the plants fitted with SCR monitor ammonia continuously. In addition to PL02, reference lines PL07.1 and PL07.2 are also fitted with SNCR and report elevated NH_3 emission levels (32 mg/Nm^3 and 46 mg/Nm^3 as a maximum daily average); at the same time, these two reference lines report extremely low NO_X levels (11 mg/Nm^3 and 19 mg/Nm^3 as a yearly average), indicating that the ammonia injection rate applied gives rise to substantial cross-media effects.

No significant difference is apparent between the maximum daily averages obtained with 'base' and 'fine' data filtering.

Only three plants reported data for discontinuous monitoring, in all cases below 5.7 mg/Nm^3.

The data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used or the age and size of the plant. All plants are fluidised bed incinerators.

TVOC

TVOC emission data for plants incinerating predominantly SS are based on continuous measurements and are shown in Figure 3.83.

The emission levels range between close to the limit of quantification and 3 mg/Nm^3 as a yearly average and 5.1 mg/Nm^3 as a maximum daily average ('fine' data filtering). For three reference lines, the maximum daily average shows higher emission peaks when using the 'base' data filtering, generally related to OTNOC.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed, the type and amount of reagent used or the age and size of the plant. All plants are fluidised bed incinerators.

Carbon monoxide

CO emission data for plants incinerating predominantly SS are based on continuous measurements and are shown in Figure 3.84.

The emission levels range between close to the limit of quantification and 29 mg/Nm^3 as a yearly average and 42 mg/Nm^3 as a maximum daily average ('fine' data filtering). Similar to TVOC emissions, in some cases higher emission peaks are observed in the values obtained under the 'base' data filtering, generally related to OTNOC.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed, the type and amount of reagent used or the age and size of the plant. All plants are fluidised bed incinerators.

PCDD/F, PCBs and PAHs

For reaching low levels of PCDD/F emissions, primary as well as secondary measures are important. In the firing system, effective mixing of the gases (high turbulence) improves the destruction of PCDD/F and similar compounds already present in the waste. Avoiding the temperature window for the recombination of PCDD/F and similar compounds in the boiler and flue-gas treatment system avoids the *de novo* synthesis of new PCDD/F.

For further reduction, three main types of techiques are in use:

1. static activated carbon filter;
2. bag filter with injection of activated carbon (usually mixed with other reagents);
3. destruction of gaseous PCDD/F on a catalyst.

The use of activated carbon has the advantage of also reducing mercury emissions. Catalysts are mainly used to reduce NO_X emissions.

PCDD/F emission data for plants incinerating predominantly SS are based on discontinuous measurements, with 43 % of the reference lines using long-term sampling, and are shown in Figure 3.85.

The emission levels range between close to the limit of quantification and 0.011 ng I-TEQ/Nm^3, except for one reference line showing a level of 0.06 ng I-TEQ/Nm^3, for both the average over the sampling period and the long-term sampling average.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used or the age and size of the plant. All plants are fluidised bed incinerators.

Polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs) are removed by the same techniques as PCDD/F, meaning that an effective flue-gas cleaning system for PCDD/F will also deal with PCBs and PAHs.

PCB emission data for plants incinerating predominantly SS are based on discontinuous measurements and are shown in Figure 3.86.

Two reference lines reported emission levels for PCBs. The maximum value reported is 0.001 ng WHO-TEF.

PAH emission data from plants incinerating predominantly SS are based on discontinuous measurements and are shown in Figure 3.87.

Emission levels range from 0.002 µg/Nm^3 to 13 µg/Nm^3 for PAH. Only one reference line reported BaP emissions, with a level of 0.1 µg/Nm^3.

Mercury

The great majority of plants use activated carbon, either as a fixed-bed system or in an entrained flow activated carbon injection system with a bag filter. The consumption rate as well as the quality of activated carbon (e.g. sulphur impregnation) directly affect the emission levels. Other less frequently used techniques are the use of zeolites or the capture of mercury in the acidic wet scrubber, which can serve as a sink for mercury if it is present in the Hg(II) chloride form. The mercury that has been transferred from the gas stream to the scrubber liquor can then be removed by a waste water treatment plant.

If mercury is present in metallic form, the use of other techniques is needed (see mercury removal techniques). [74, TWGComments, 2004]

Under certain conditions (e.g. high input rate of mercury), the removal capacity limits of the FGC systems may be exceeded, leading to temporarily elevated mercury emissions. This may be reflected by cases where the performance levels of a reference line for different averaging periods show large differences.

Mercury emission data for plants incinerating predominantly SS are based either on continuous or discontinuous measurement and are shown in the following figures:

- Figure 3.88, for plants monitoring mercury discontinuously;
- Figure 3.89, for plants monitoring mercury continuously.

Additionally, maximum half-hourly levels are shown in Figure 3.90

For half-hourly levels, the 'fine' data filtering is the same as the 'base' filtering but excludes the levels recorded in the 30 hours of highest emissions in the year. For monthly levels, which are hardly affected by short-term peaks, only the 'base' filtering mode is presented.

The emission levels range between close to the limit of quantification and 0.01 mg/Nm^3 as a yearly and monthly average, and 0.024 mg/Nm^3 as a maximum daily average ('fine' data filtering). In certain cases the maximum daily average obtained with 'base' data filtering may be substantially higher (up to 0.036 mg/Nm^3), which may reflect not only high mercury input episodes, but also OTNOC situations where the daily average typically includes only a few half-hourly periods and where the mercury levels are measured elevated.

Plants that measure mercury discontinuously report averages over the sampling period generally below 0.01 mg/Nm^3, with four exceptions (PL02, PL05, PL07-2 and PL07-1) that reported values between 0.04 mg/Nm^3 and 0.13 mg/Nm^3.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used or the age and size of the plant. All plants are fluidised bed incinerators.

Antimony, arsenic, chromium, cobalt, copper, lead, manganese, nickel and vanadium

The techniques used to remove dust reduce the emissions of dust-bound metals.

[Sb+As+Cr+Co+Cu+Pb+Mn+Ni+V] emission data for plants incinerating predominantly SS are based on discontinuous measurements and are shown in Figure 3.91.

The emission levels range between close to the limit of quantification and 0.3 mg/Nm^3 with the exception of one reference line showing a level of 0.5 mg/Nm^3 as a maximum of the averages over the sampling period.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed or the age and size of the plant. All plants are fluidised bed incinerators.

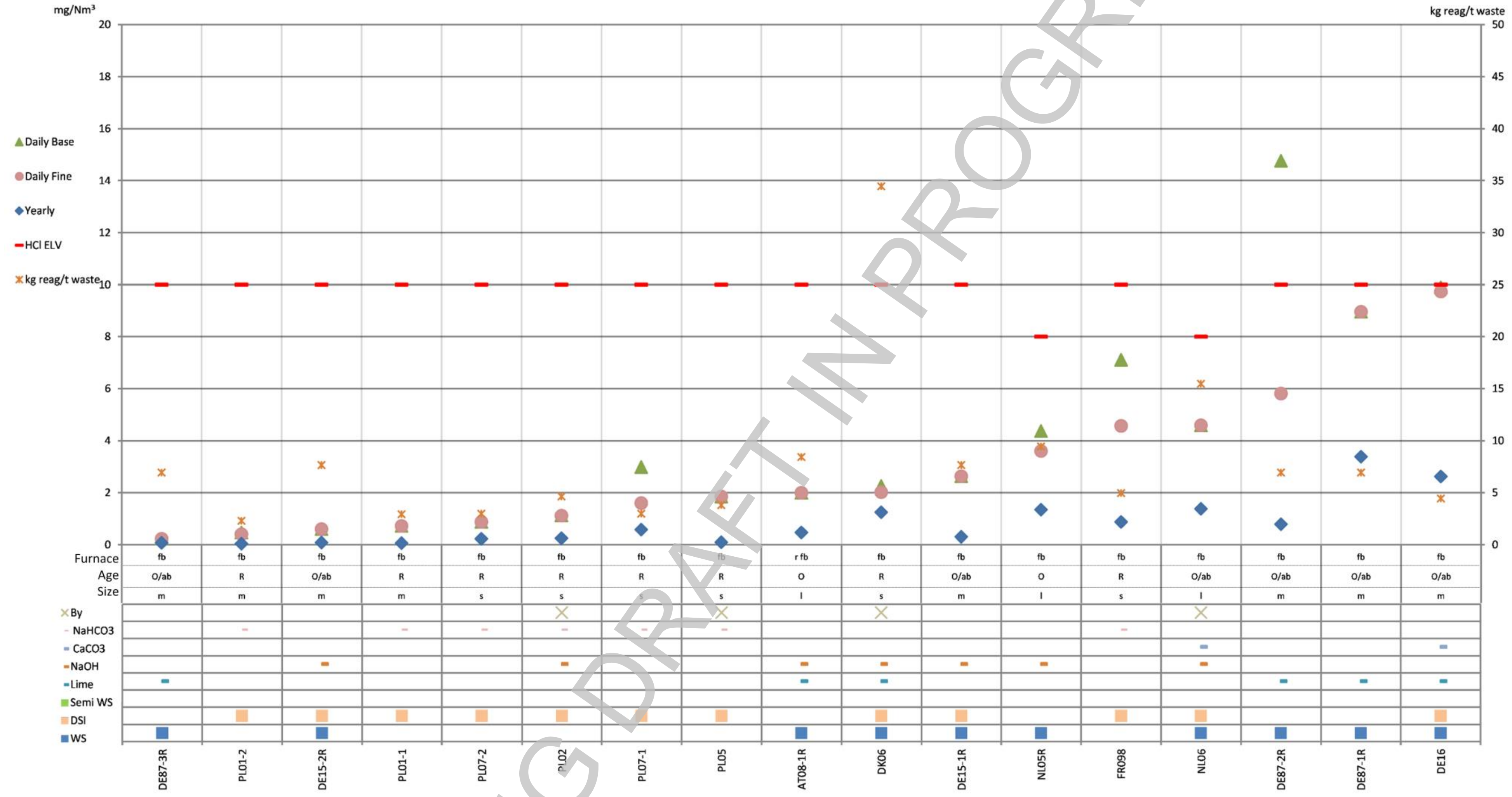
Cadmium and thallium

The techniques used to remove dust also reduce the emissions of dust-bound metals.

[Cd+Tl] emission data for plants incinerating predominantly SS are based on discontinuous measurements and are shown in Figure 3.92.

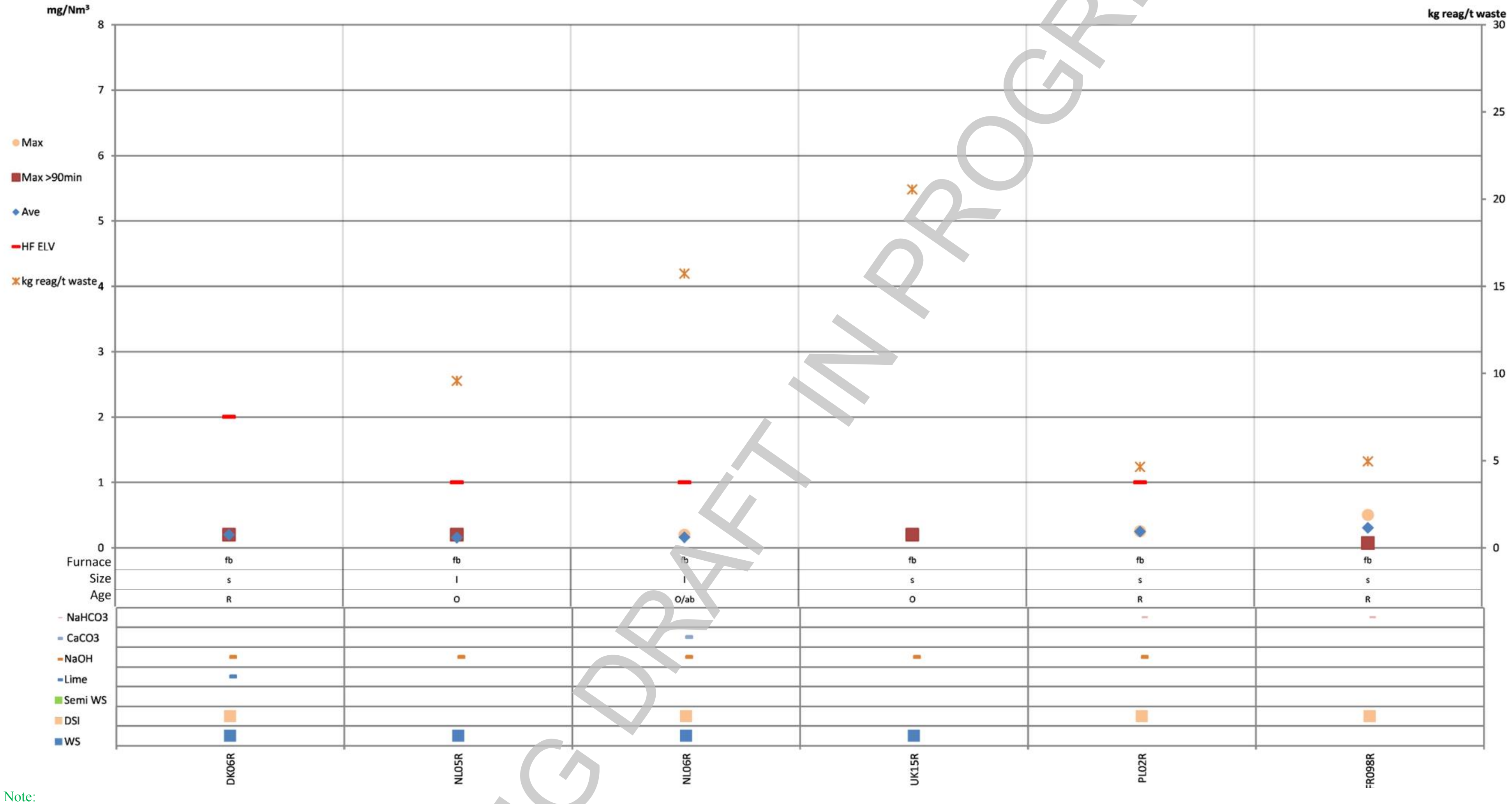
The emission levels are almost always very low and range between close to the limit of quantification and 0.005 mg/Nm^3,with the exception of two reference lines (NL06 and PL05) showing levels of 0.02 mg/Nm^3 and 0.036 mg/Nm^3 respectively, as a maximum of the averages over the sampling period.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed or the age and size of the plant. All plants are fluidised bed incinerators.



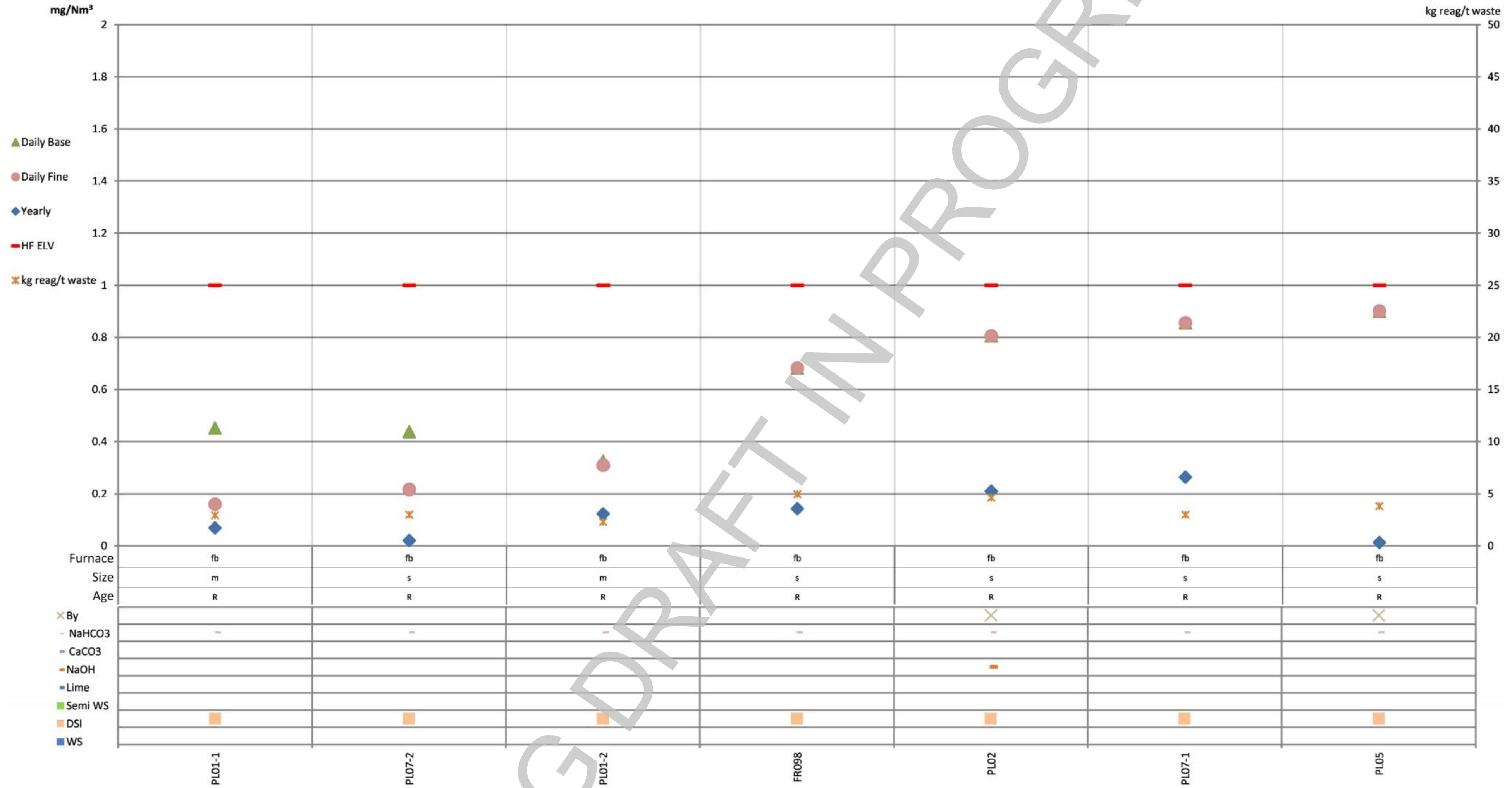
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Plant size: s = small; m = medium; l = large.
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.75: Continuously measured HCl emissions to air from plants incinerating predominantly sewage sludge



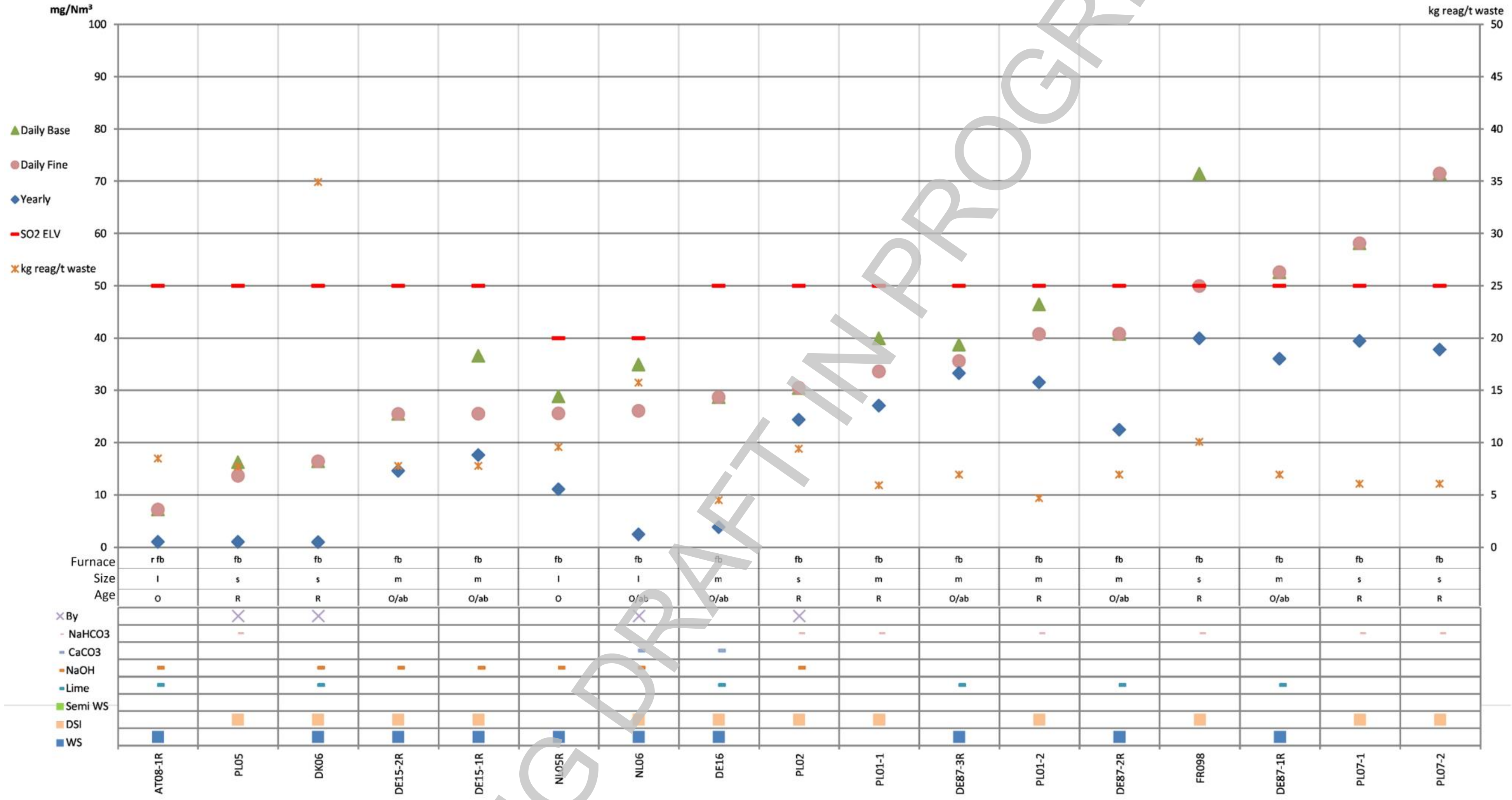
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.76: Discontinuously monitored HF emissions to air from plants incinerating predominantly sewage sludge



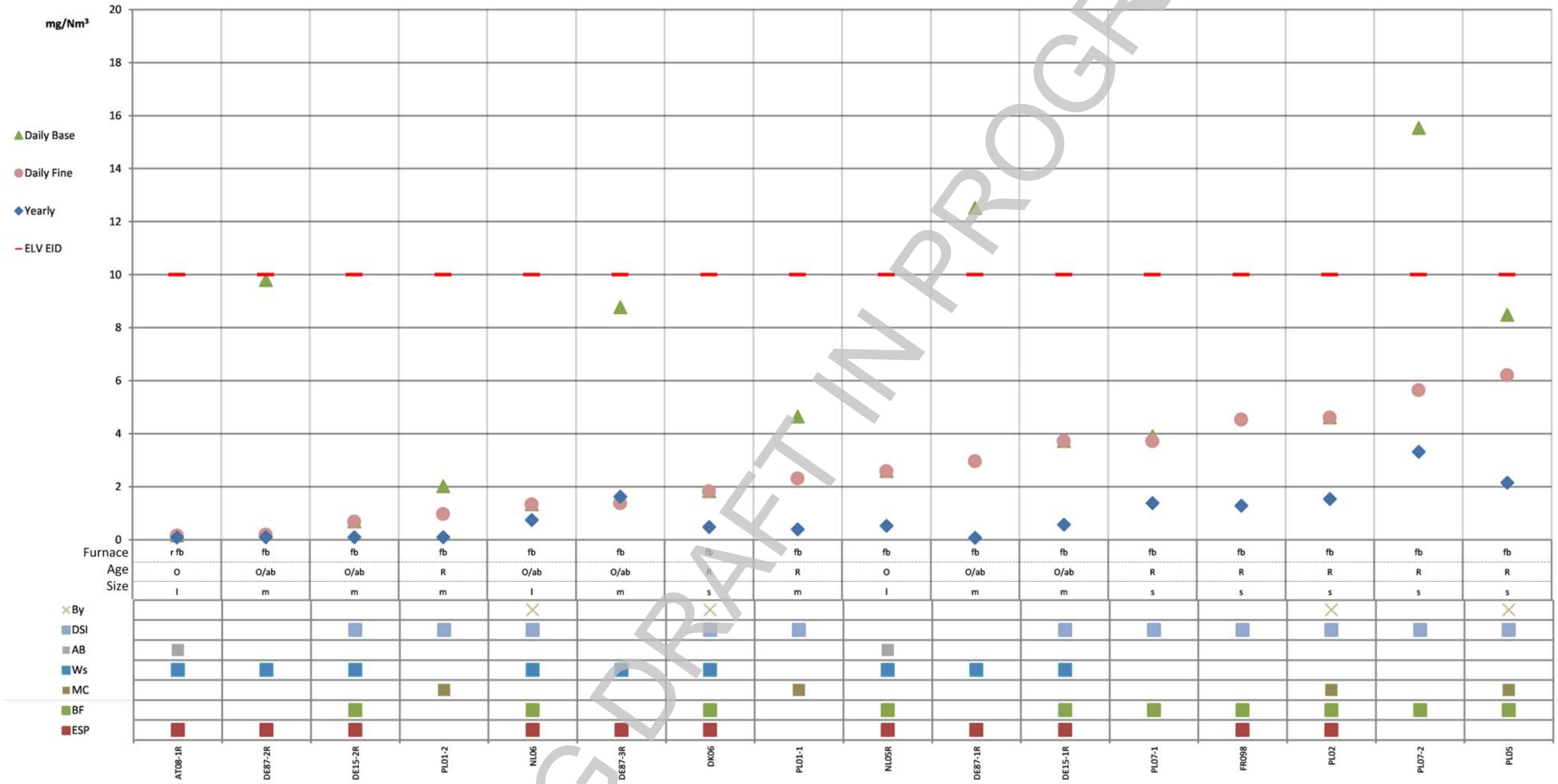
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: $NaHCO_3$ = Sodium Bicarbonate; $CaCO_3$ = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.77: Continuously monitored HF emissions to air from plants incinerating predominantly sewage sludge



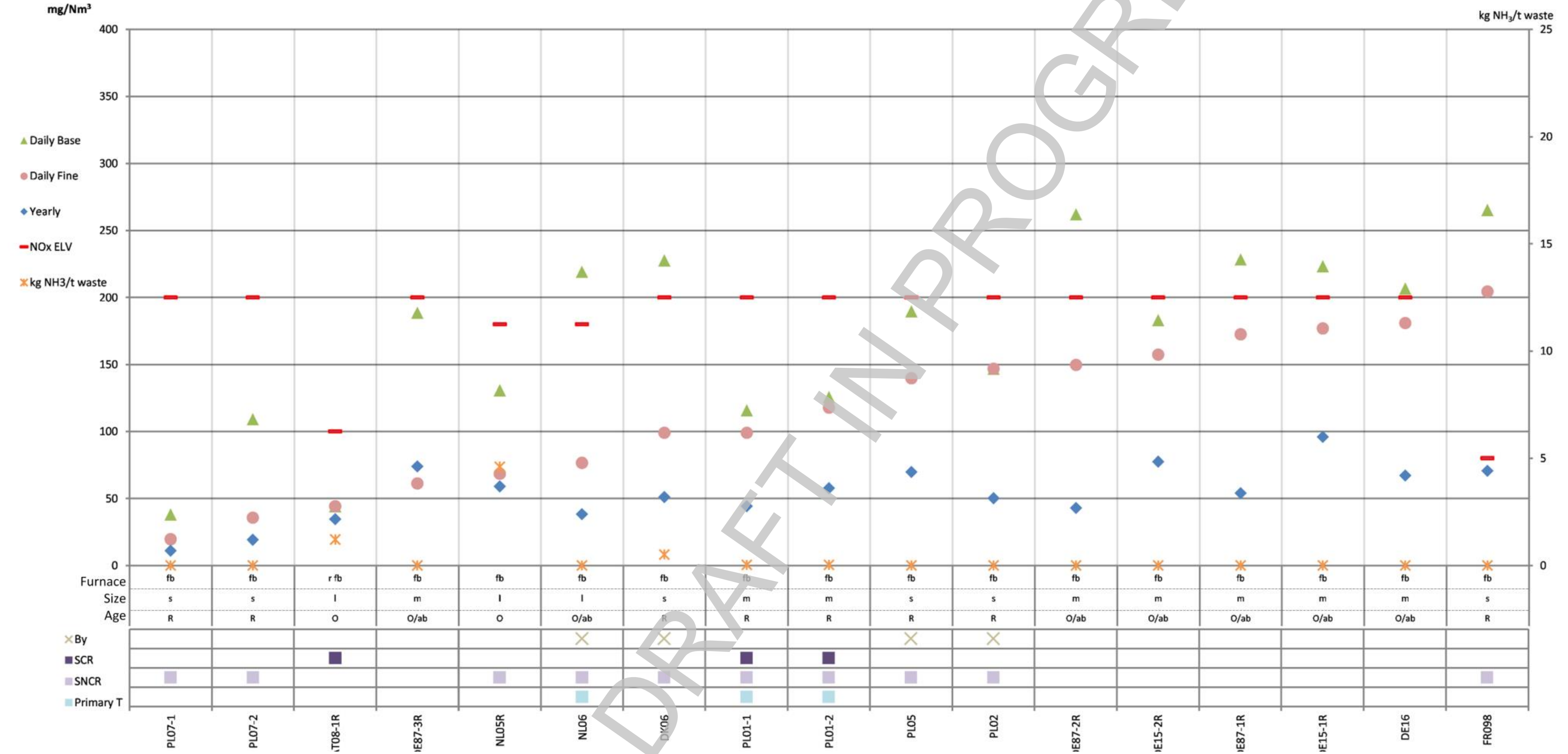
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.78: Continuously monitored SO_2 emissions to air from plants incinerating predominantly sewage sludge



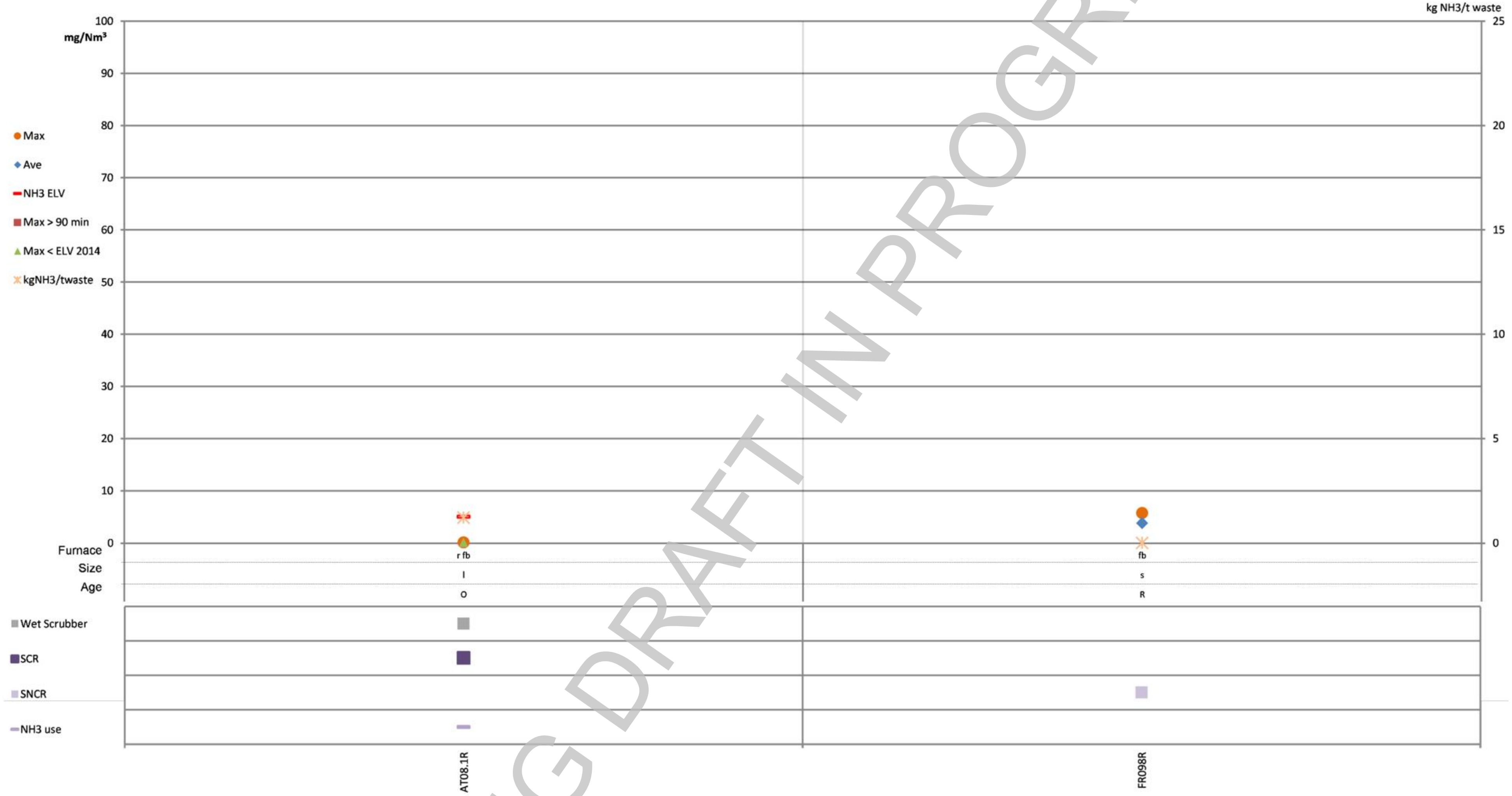
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Plant size: s = small; m = medium; l = large.
BY = ByPass.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed; WS = Wet Scrubber; MC = Multi-cyclone; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.79: Continuously monitored Dust emissions to air from plants incinerating predominantly sewage sludge



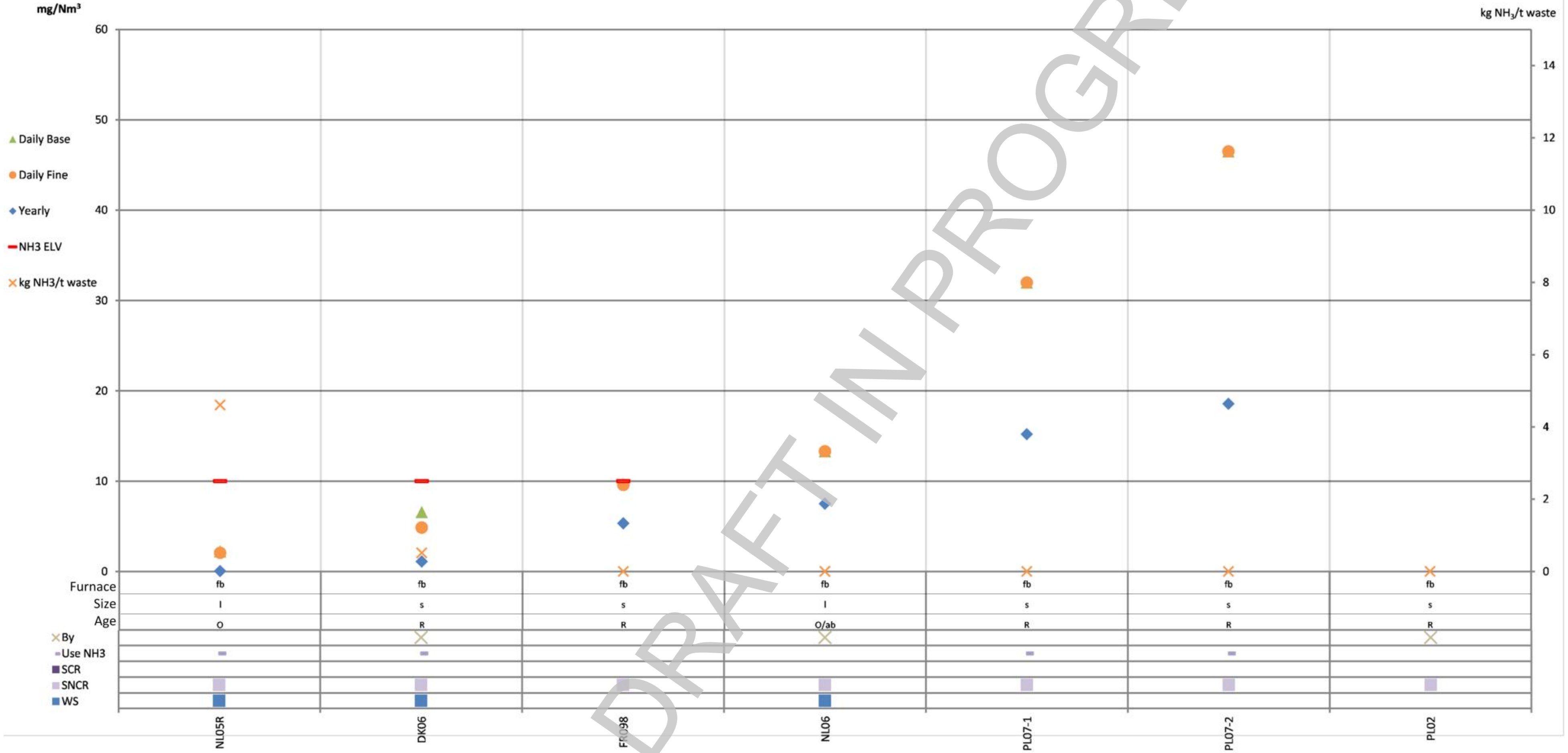
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction; Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.80: Continuously monitored NO_x emissions to air from plants incinerating predominantly sewage sludge



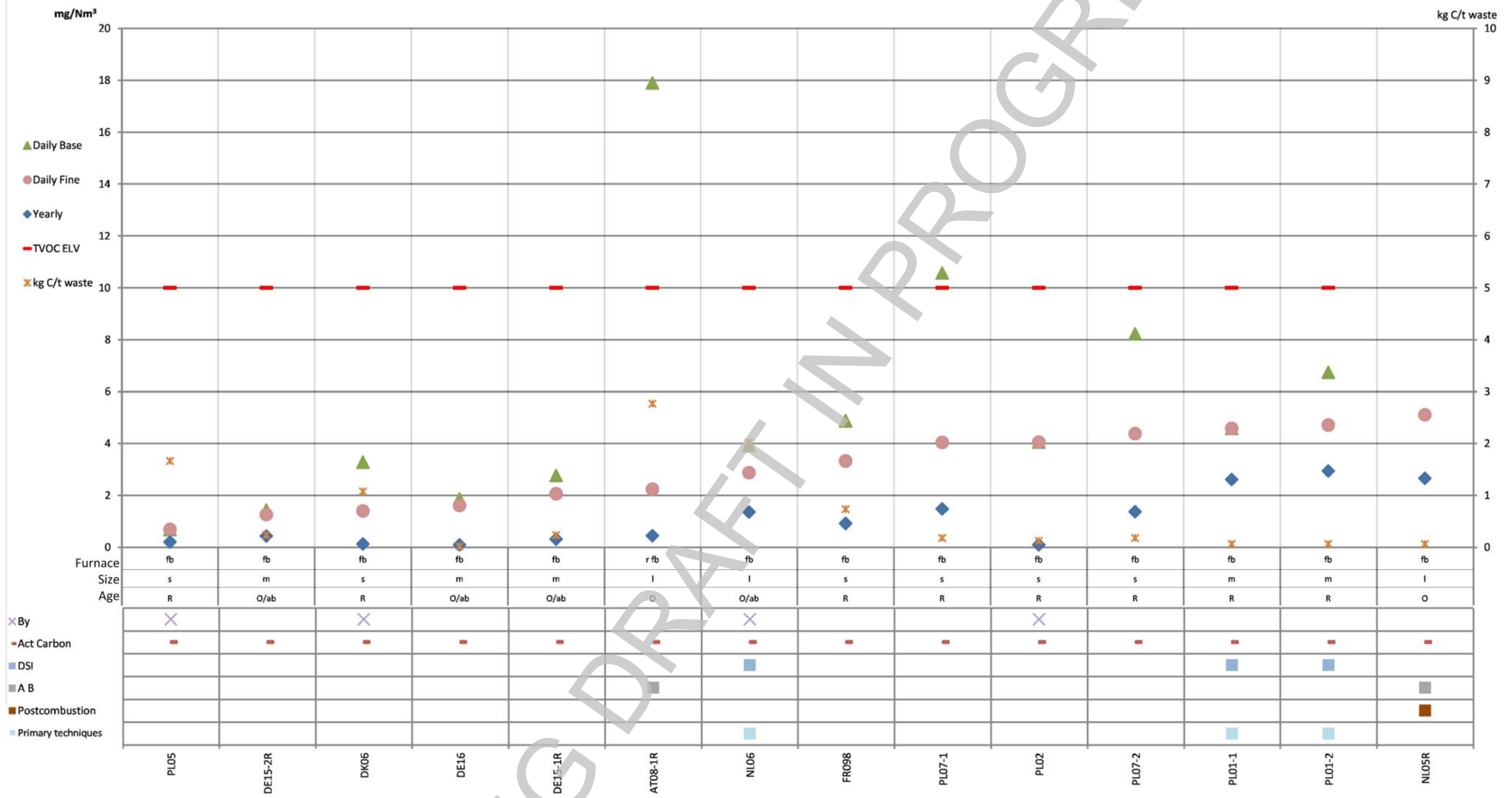
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction.
Reagents Used: NH3 = Ammonia.
Source: [81, TWG 2016].

Figure 3.81: Discontinuously monitored NH_3 emissions to air from plants incinerating predominantly sewage sludge



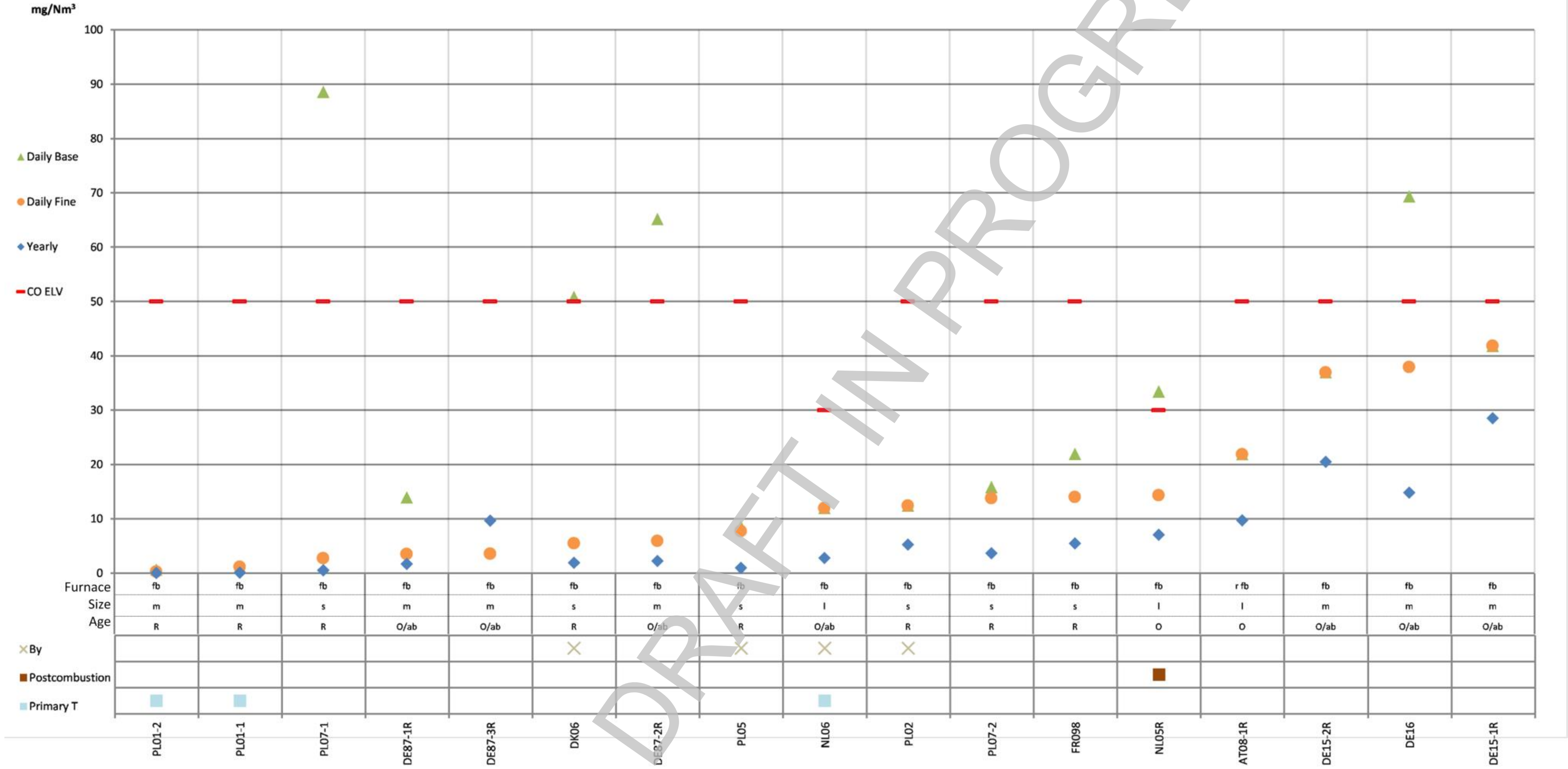
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NH3 = Ammonia.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.82: Continuously monitored NH_3 emissions to air from plants incinerating predominantly sewage sludge



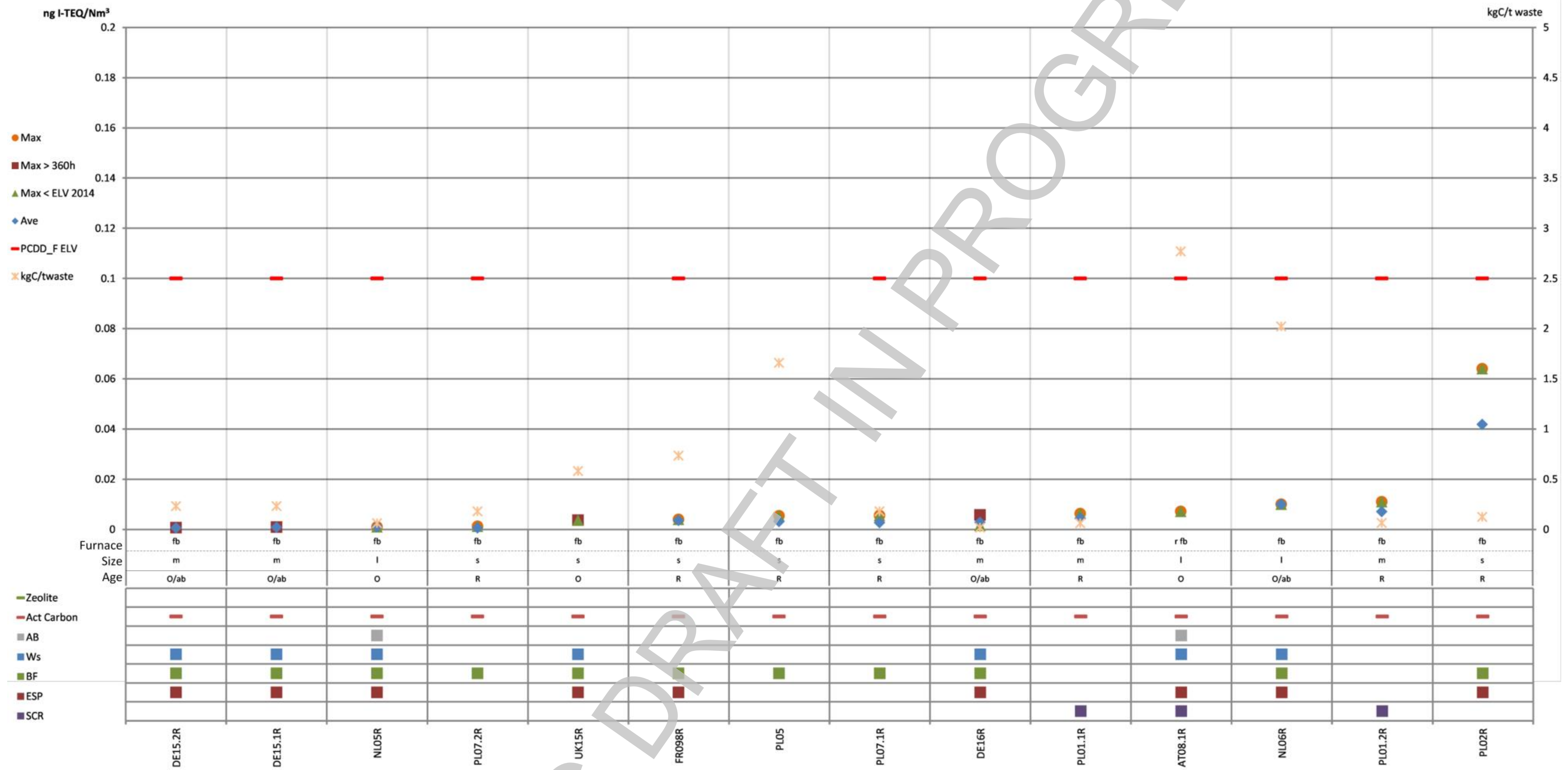
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed.
Source: [81, TWG 2016].

Figure 3.83: Continuously monitored TVOC emissions to air from plants incinerating predominantly sewage sludge



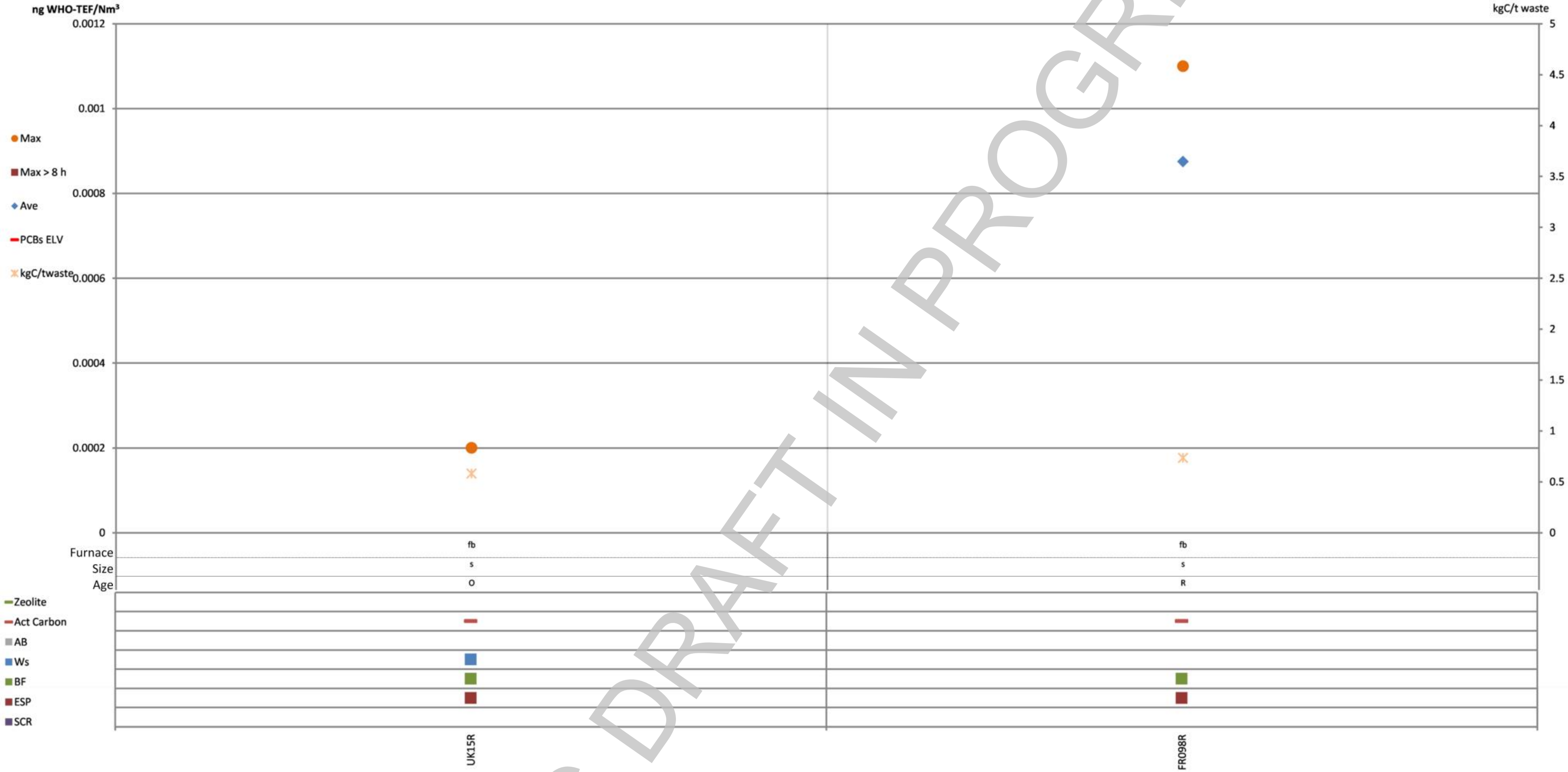
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.84: Continuously monitored CO emissions to air from plants incinerating predominantly sewage sludge



Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction.
Source: [81, TWG 2016].

Figure 3.85: Discontinuously monitored PCDD/F emissions to air from plants incinerating predominantly sewage sludge

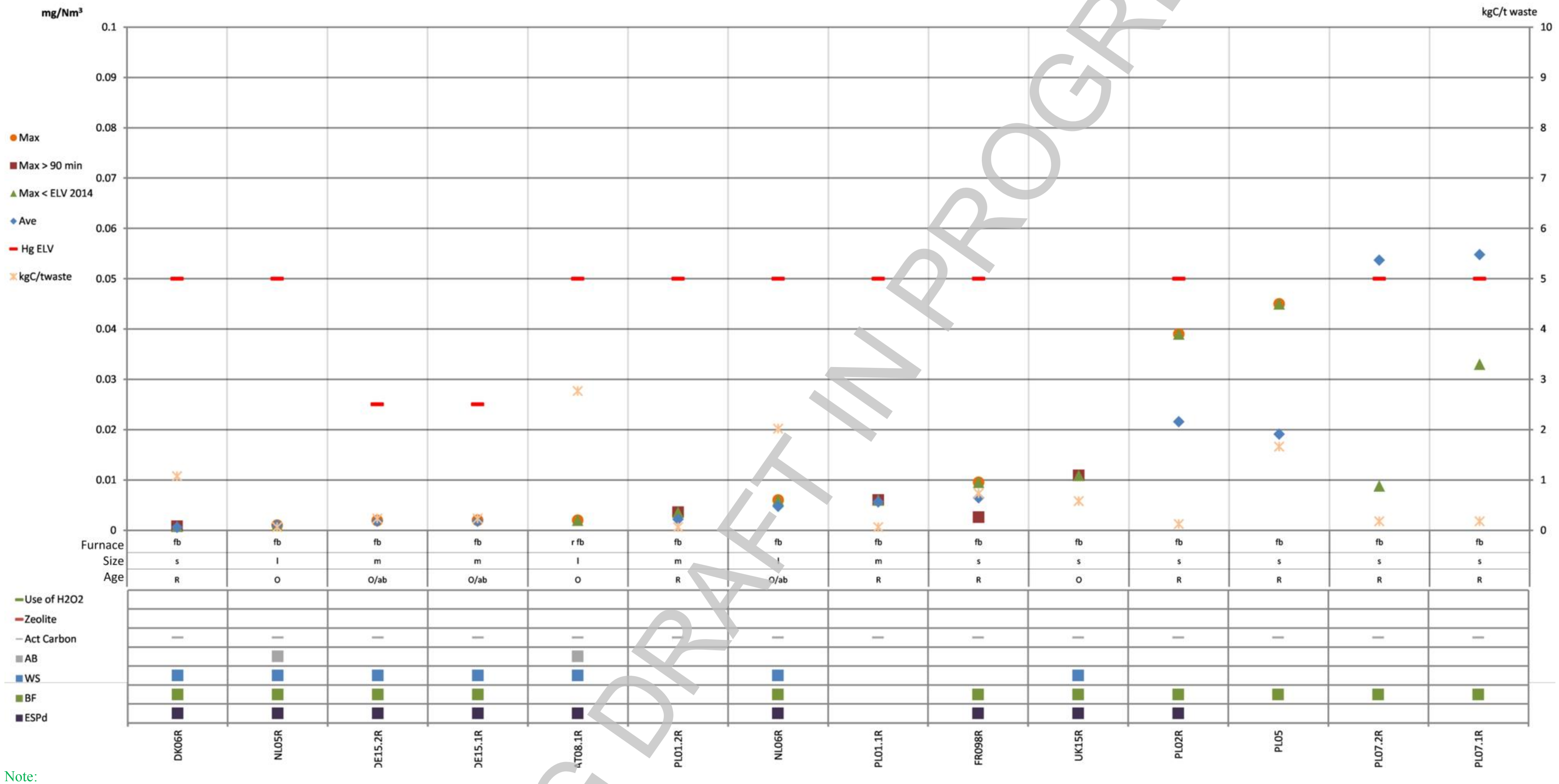


Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction
Source: [81, TWG 2016].

Figure 3.86: Discontinuously monitored PCBs emissions to air from plants incinerating predominantly sewage sludge

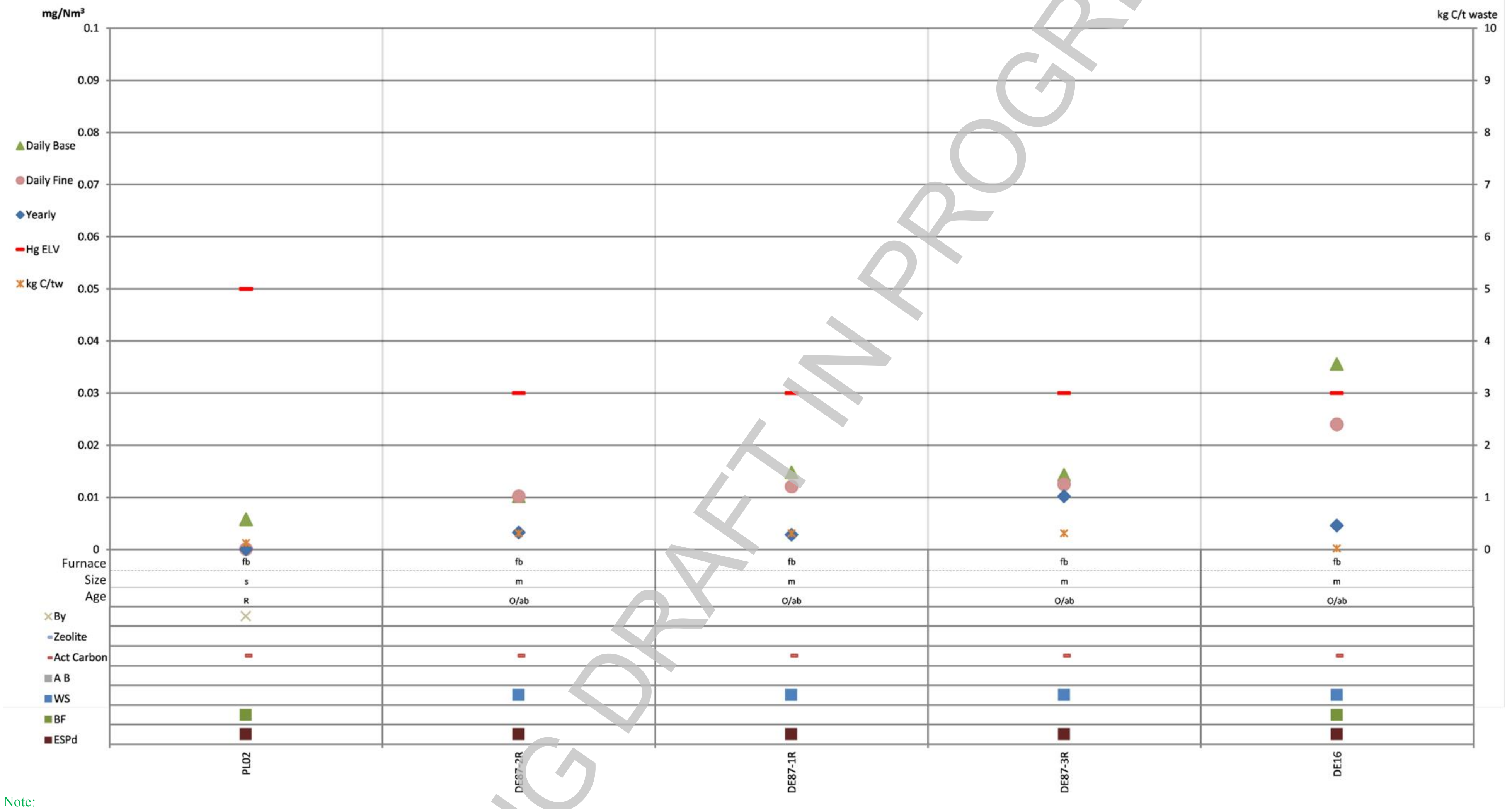
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction.
Source: [81, TWG 2016].

Figure 3.87: Discontinuously monitored PAHs emissions to air from plants incinerating predominantly sewage sludge



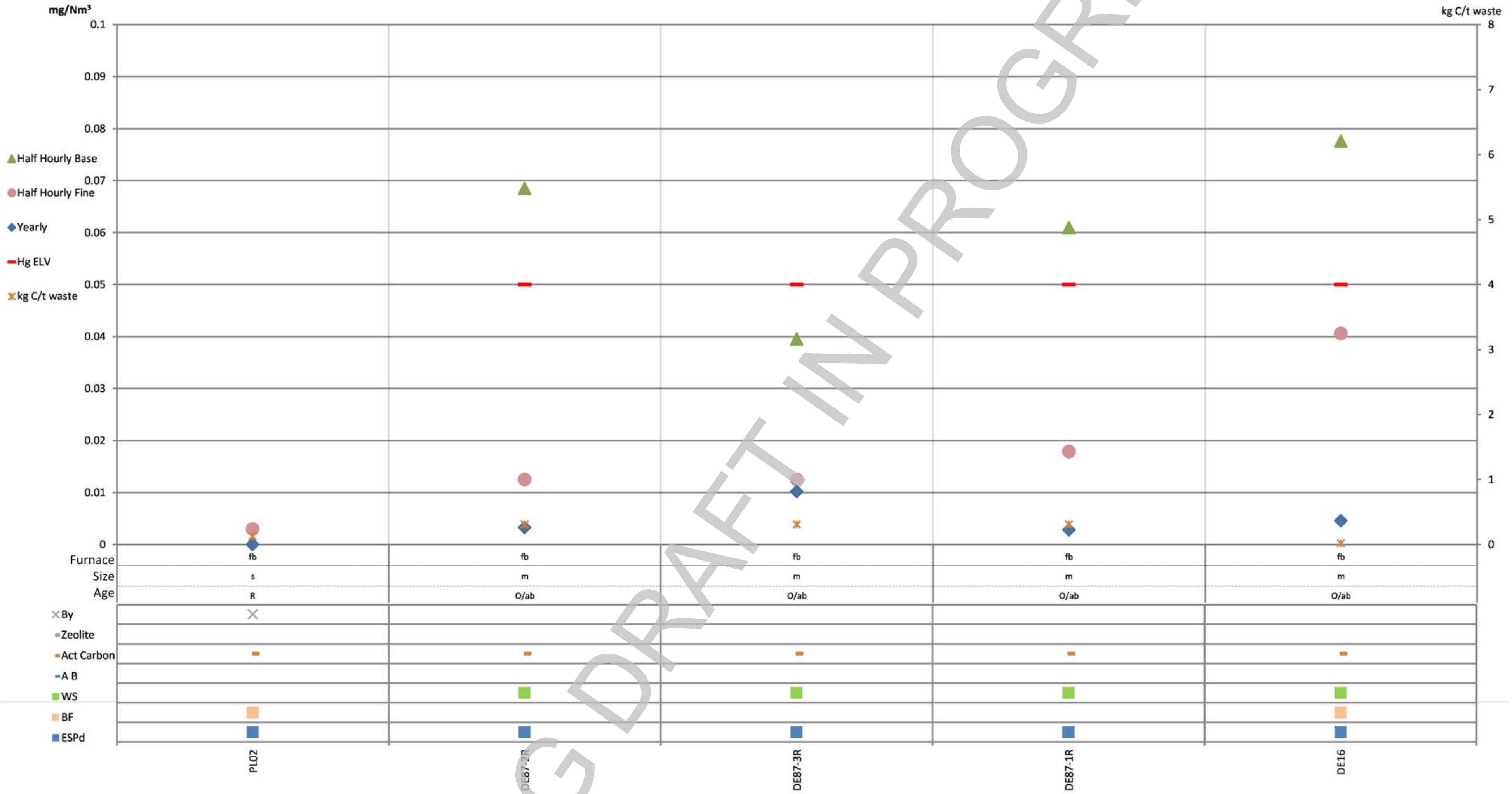
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: H2O2 = peroxide; Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.88: Discontinuously monitored Hg emissions to air from plants incinerating predominantly sewage sludge



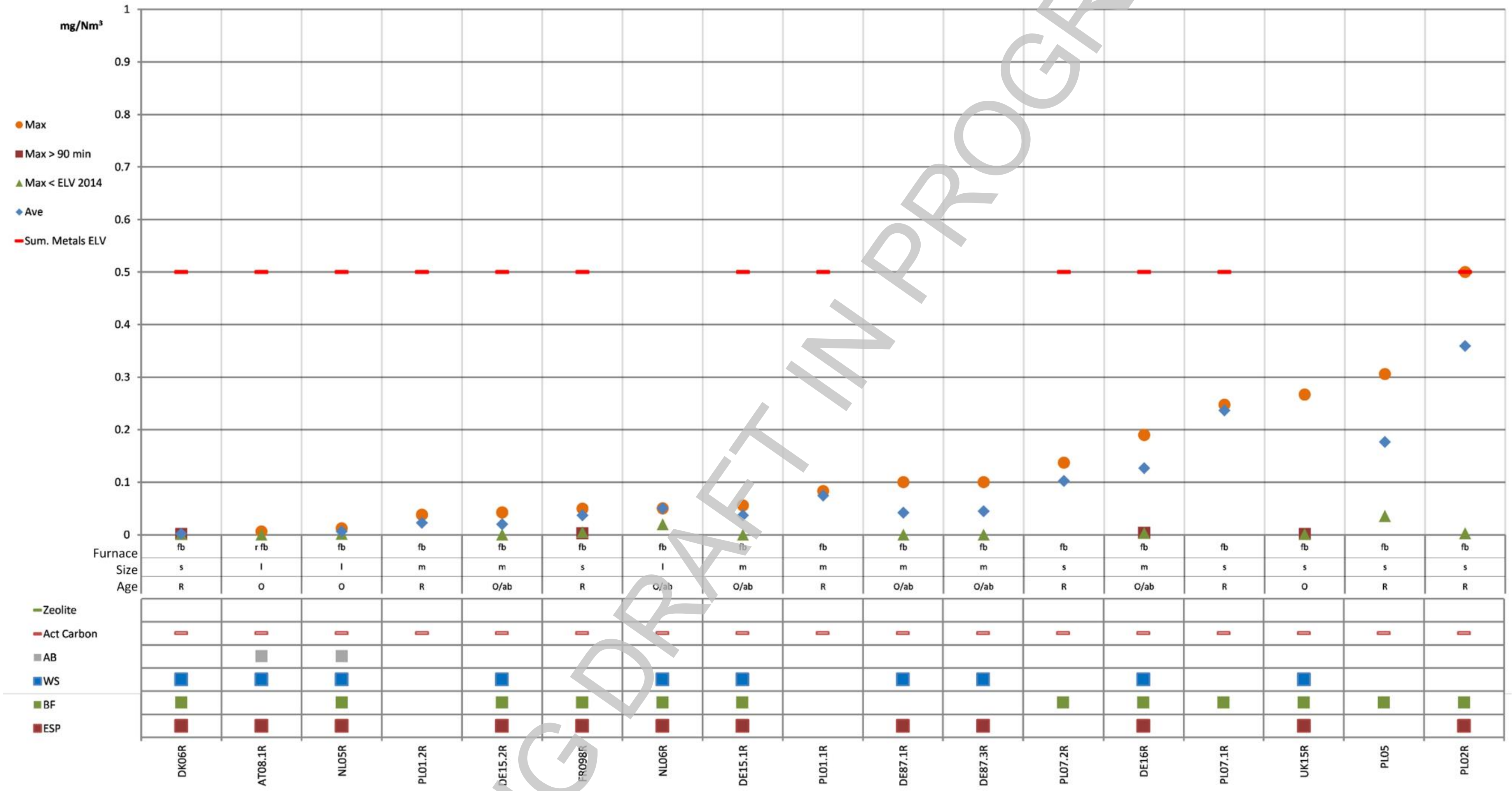
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.89: Continuously monitored Hg emissions to air from plants incinerating predominantly sewage sludge



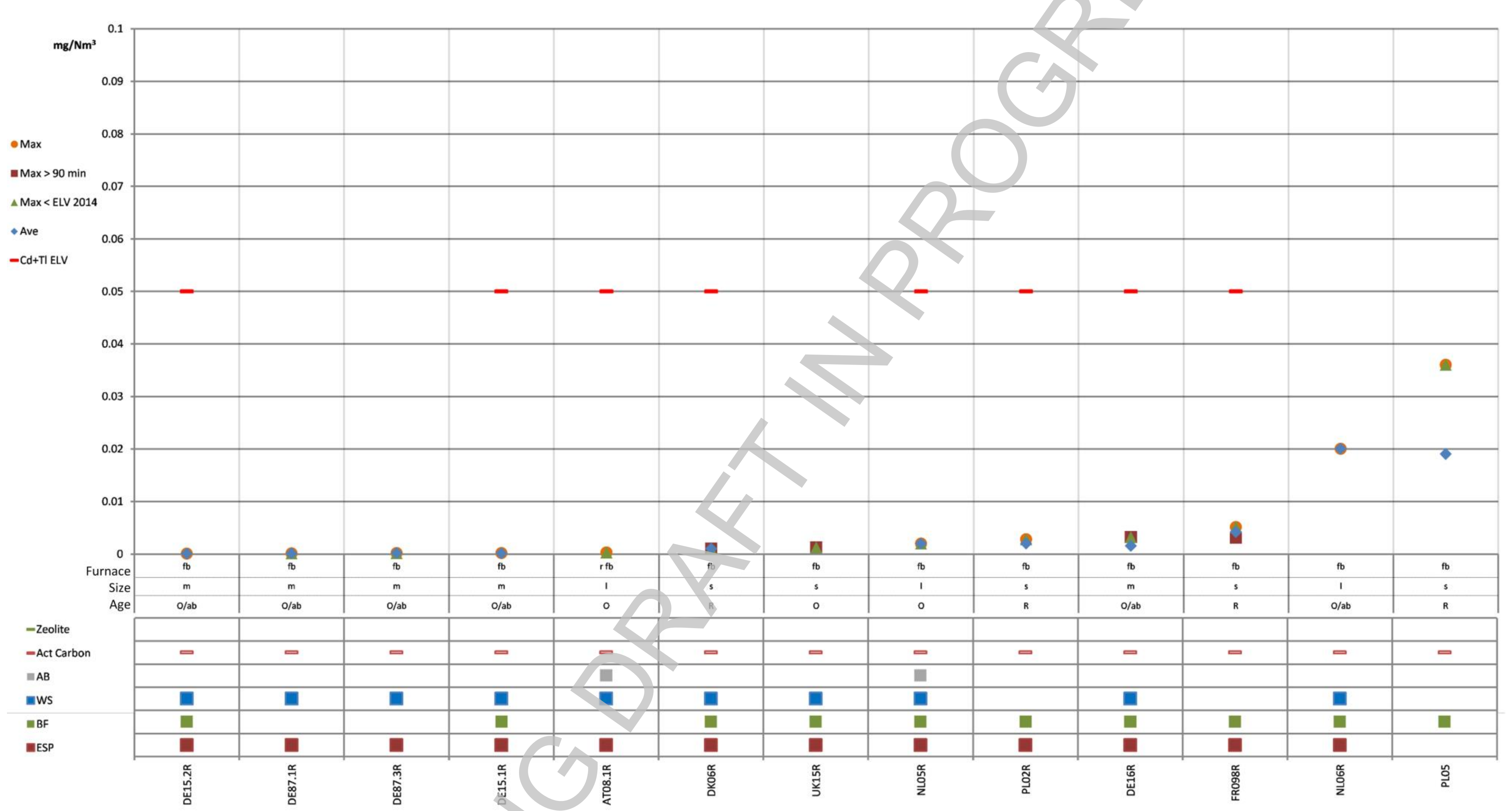
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.90: Half-hourly monitored Hg emissions to air from plants incinerating predominantly sewage sludge



Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.91: Discontinuously monitored Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V emissions to air from plants incinerating predominantly sewage sludge



Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.92: Discontinuously monitored Cd+Tl emissions to air from plants incinerating predominantly sewage sludge

3.2.2.4 Emissions to air from the incineration of hazardous waste ~~European air emissions survey data for HWI~~

Hydrogen chloride and hydrogen fluoride

With few exceptions, the plants that participated in the 2016 data collection that predominantly incinerate hazardous waste are rotary kilns fitted with wet abatement systems. The exceptions are mostly liquid waste furnaces incinerating residues from the chemical sector and grate incinerators fitted with dry or semi-wet systems, such as DE31, DE32 and DE33, which incinerate contaminated waste wood.

HCl emission data from plants incinerating predominantly HW, based on continuous measurements, are shown in Figure 3.102.

The emission levels range between close to the limit of quantification and 7.5 mg/Nm^3 as a yearly average and 12 mg/Nm^3 as a maximum of the daily average ('fine' data filtering). In most cases the maximum daily average obtained with 'base' data filtering does not substantially change from the value obtained with 'fine' data filtering; some exceptions where these values diverge are related to unreported maintenance periods (e.g. BE09.1 and BE09.3).

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used or the age and size of the plant. Most plants are rotary kilns.

Hydrogen fluoride (HF) emission data are based either on continuous or discontinuous measurement and are shown in the following figures:

HF emission data for plants incinerating predominantly HW are shown in the following figures:

- Figure 3.103, for plants monitoring HF discontinuously;
- Figure 3.104, for plants monitoring HF continuously.

The emission levels range between close to the limit of quantification and 0.35 mg/Nm^3 as a yearly average and 1.6 mg/Nm^3 as a maximum daily average; all but one plants measuring HF discontinuously report maximum levels as an average over the sampling period below 0.66 mg/Nm^3. The maximum daily average obtained with 'base' data filtering does not substantially change from the value obtained with 'fine' data filtering.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used or the age and size of the plant.

Sulphur dioxide

The types of flue-gas cleaning systems in use are the same as those for HCl, with the main difference that wet scrubbers are operated at a slightly basic pH (usually 7–8).

SO_2 emission data from plants incinerating predominantly HW, based on continuous measurements, are shown in Figure 3.105.

The emission levels range between close to the limit of quantification and 43 mg/Nm^3 as a yearly average and between 5 mg/Nm^3 and 78 mg/Nm^3 as a maximum daily average. The graph shows that the great majority of plants fitted with wet abatement techniques generally achieve emission levels below 40 mg/Nm^3 as a maximum daily average ('fine' data filtering).

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used or the age and size of the plant. Most plants are rotary kilns.

Dust

Compared to other types of incinerators, hazardous waste incineration plants that participated in the 2016 data collection are seldom fitted with a bag filter (BF) and mostly use an ESP for the reduction of dust emissions, with the wet scrubber further acting as a polishing dedusting stage and in some cases a (multi)cyclone for pre-dedusting. The use of a fixed adsorption bed, which on the one hand may provide further dust reduction and on the other is associated with substantial pressure drop, is also relatively frequent in hazardous waste incinerators.

Dust emission data for plants incinerating predominantly HW, based on continuous monitoring, are shown in Figure 3.106.

The emission levels range between close to the limit of quantification and 8.6 mg/Nm^3 as a yearly average and 14.6 mg/Nm^3 as a maximum daily average ('fine' data filtering). In some cases the maximum daily average obtained with 'base' data filtering may be substantially higher, generally related to OTNOC situations.

Of the four plants reporting yearly average emission concentrations above 3.2 mg/Nm^3, only Plant DE32R is fitted with a bag filter. The dust emission pattern reported by this plant indicates probable deterioration of the filter bags.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagents used or the age and size of the plant. Most plants are rotary kilns.

Nitrogen oxides

Around a third of the hazardous waste incinerators that participated in the 2016 data collection report no or only primary techniques for the reduction of NO_X emissions, another third use SNCR and the remaining thrid SCR.

NO_X emission data for plants incinerating predominantly HW are based on continuous measurements and are shown in Figure 3.107.

The emission levels range between 26 mg/Nm^3 and 197 mg/Nm^3 as a yearly average and between 68 mg/Nm^3 and 329 mg/Nm^3 as a maximum daily average ('fine' data filtering). Values significantly above 200 mg/Nm^3 are only observed in plants fitted with SNCR or without secondary techniques for the reduction of NO_X, Plant FR109 being fitted with SNCR but without reporting the use of reagent (neither ammonia not urea).

For plants fitted with SCR, no significant difference is observed between the maximum daily average obtained with 'base' and 'fine' data filtering, while for plants fitted with SNCR or with no secondary techniques this difference is generally higher, reflecting the lower intrinsic stability of the process.

The reported data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used, or with the age and size of the plant. Most plants are rotary kilns.

Ammonia

Ammonia emissions are related to reactant slip from SCR or SNCR. The main technique in use to control such emissions is process optimisation as well as good maintenance of the catalyst in the case of SCR. SCR can also be implemented as slip catalyst to further react the unreacted ammonia after the main reduction has taken place in a SNCR system.

Ammonia emission data for plants incinerating predominantly HW are based either on continuous or discontinuous measurement and are shown in Figure 3.108 for plants monitoring NH_3 discontinuously and in Figure 3.109 for plants monitoring NH_3 continuously.

With the exception of DE32R, which is fitted with SNCR without a downstream wet abatement system and which reports NH_3 emission leves close to 12 mg/Nm^3 as a yearly average and 78 mg/Nm^3 as a maximum daily average, the emission levels achieved by the plants montoring ammonia continuously range between 0.3 mg/Nm^3 and 1.8 mg/Nm^3 as a yearly average and between 1 mg/Nm^3 and 13 mg/Nm^3 as a maximum daily average.

All but one of the plants reporting data for discontinuous monitoring are fitted with a downstream wet abatement system, and report emissions in all cases below 2.3 mg/Nm^3.

The data do not show a clear correlation between the achieved emission levels and the type and amount of reagent used or the age and size of the plant. Most plants are rotary kilns.

TVOC

TVOC emission data for plants incinerating predominantly HW are based on continuous measurements and are shown in Figure 3.110.

In all but two cases, the emission levels range between close to the limit of quantification and 2 mg/Nm^3 as a yearly average and 8 mg/Nm^3 as a maximum daily average ('fine' data filtering). In the case of some reference lines, the maximum daily average shows higher emission peaks when using the 'base' data filtering, generally related to OTNOC.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed, the type and amount of reagent used or the age and size of the plant. Most plants are rotary kilns.

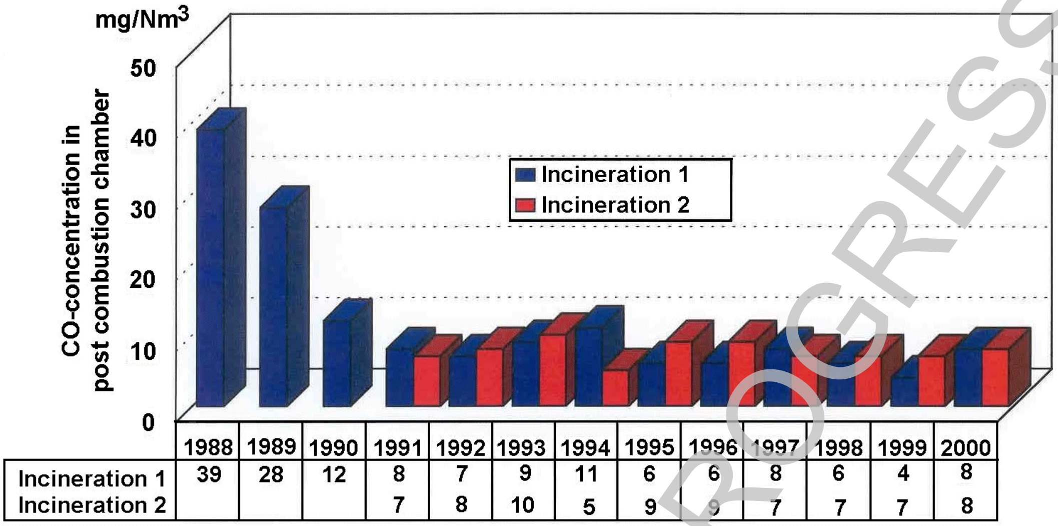
Carbon monoxide

Combustion efficiency is partly described by CO levels, which also indicates formation of other products of incomplete combustion ~~(PICs)~~.

The yearly average values for all installations surveyed, obtained as a result of continuous measurements, vary from 3 mg/Nm^3 to 26 mg/Nm^3.

CO is a typical parameter with a low baseline emission but which periodically shows sharp peak emissions, due to sudden variations in local combustion conditions (e.g. variations in temperature ~~of~~ in parts of the kiln). The monitoring and control of these peak emissions is an important aspect of the daily operation of an incinerator. With the pretreatment of drummed waste and feed equalisation, it is possible to decrease CO peaks.

Figure 3.93 below shows the reductions in CO emissions achieved at a HWI following the introduction of drum shredding and other waste input blending techniques (technique described in Section 2.2.2.3).



	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Incineration 1	39	28	12	8	7	9	11	6	6	8	6	4	8
Incineration 2				7	8	10	5	9	9	7	7	7	8

1988 - 1989 without pre-treatment and feed equalization
1990 - 2000 with pre-treatment and feed equalization

Source: [20, EKOKEM, 2002]

Figure 3.93: CO emission reductions achieved following introduction of pretreatment techniques at a hazardous waste incinerator

CO emission data for plants incinerating predominantly HW are based on continuous measurements and are shown in Figure 3.111.

The emission levels range between close to the limit of quantification and 42 mg/Nm^3 as a yearly average and between 2 mg/Nm^3 and 72 mg/Nm^3 as a maximum daily average ('fine' data filtering). Similar to TVOC emissions, in some cases higher emission peaks are observed in the values obtained under the 'base' data filtering, generally related to OTNOC.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed, the type and amount of reagent used or the age and size of the plant. All plants are fluidised bed incinerators.

PCDD/F, PCBs and PAHs

For reaching low levels of PCDD/F emissions, primary as well as secondary measures are important. In the firing system, effective mixing of the gases (high turbulence) improves the destruction of PCDD/F and similar compounds already present in the waste. Avoiding the temperature window for the recombination of PCDD/F and similar compounds in the boiler and flue-gas treatment system avoids the *de novo* synthesis of new PCDD/F.

For further reduction, three main types of techniques are in use:

4. static activated carbon filter;
5. bag filter with injection of activated carbon (usually mixed with other reagents);
6. destruction of gaseous PCDD/F on a catalyst.

The use of activated carbon has the advantage of also reducing mercury emissions. Catalysts are mainly used to reduce NO_X emissions.

PCDD/F emission data for plants incinerating predominantly HW are based on discontinuous measurements, with 43 % of the reference lines using long-term sampling, are shown in Figure 3.112.

The emission levels range in all but five cases between close to the limit of quantification and 0.06 ng I-TEQ/Nm^3, except for one reference line showing a level of 0.06 ng I-TEQ/Nm^3, for both the average over the sampling period and the long-term sampling average. In three cases the maximum emission levels are above 0.1 ng I-TEQ/Nm^3. All plants fitted with a fixed adsorption bed show emission levels below 0.1 ng I-TEQ/Nm^3, and only one exceeds 0.06 ng I-TEQ/Nm^3.

The reported data do not show a clear correlation between the achieved emission levels and the amount of reagent used or the age and size of the plant. Most plants are rotary kilns.

Polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) are removed by the same techniques as PCDD/F, meaning that an effective flue-gas cleaning system for PCDD/F will also deal with PCBs and PAHs.

PCB emission data for plants incinerating predominantly HW are based on discontinuous measurements and are shown in Figure 3.113.
Six reference lines reported emission levels for PCBs. The maximum value recorded is 0.18 ng WHO-TEF. It is the only case where the emission level of PCBs is above the emission level of PCCD/F (see Figure 3.52).

PAH and BaP emission data from plants incinerating predominantly HW are based on discontinuous measurements and are shown in Figure 3.114 for PAH emissions and in Figure 3.115 for BaP emissions.

Emission levels range from 0.003 µg/Nm^3 to 21 µg/Nm^3 for PAHs. Reported BaP emissions are mostly within 0.025 µg/Nm^3, with three reference lines reporting levels between 0.2 µg/Nm^3 and 0.3 µg/Nm^3.

Mercury

The great majority of plants use activated carbon, either as a fixed-bed system or in an entrained flow activated carbon injection system with a bag filter. The consumption rate as well as the quality of activated carbon (e.g. sulphur impregnation) directly affect the emission levels. Other less frequently used techniques are the use of zeolites or the capture of mercury in the acidic wet scrubber, which can serve as a sink for mercury if it is present in the Hg(II) chloride form. The mercury that has been transferred from the gas stream to the scrubber liquor can then be removed by a waste water treatment plant.

If mercury is present in metallic form, the use of other techniques is needed; some HW incineration plants use reagents such as hydrogen peroxide to promote the oxidation of mercury and thus significantly enhance its capture in the wet scrubber (see also mercury removal techniques). [74, TWGComments, 2004]

Under certain conditions (e.g. high input rate of mercury), the removal capacity limits of the FGC systems may be exceeded, leading to temporarily elevated mercury emissions. This may be reflected by cases where the performance levels of a reference line for different averaging periods show large differences.

The mercury in the flue-gases originates from mercury-containing waste. There is a direct linear relationship between the amount of mercury in the raw flue-gases and the amount of mercury in the waste. For one installation equipped with wet gas scrubbing and an activated carbon filter, it is calculated that the total mercury input via the waste amounts to 1 000 kg/yr for an installation with an incineration capacity of 50 000 t/yr. Taking into account a maximum yearly emitted mercury flow via the flue-gases of less than 1.25 kg~~/yr~~, this means a total removal efficiency of 99.99 %.

Installations with a continuously or temporarily high mercury input are able to take operational measures such as adding sulphur-containing reagents in the wet scrubber system or injecting highly active sulphur-impregnated activated carbon to increase the mercury removal efficiency. The screening of the waste inputs for mercury and/or the continuous monitoring of mercury are ~~is~~ therefore important.

Mercury emission data for plants incinerating predominantly HW are based either on continuous or discontinuous measurement and are shown in the following figures:

- Figure 3.116, for plants monitoring mercury discontinuously;
- Figure 3.117, for plants monitoring mercury continuously.

Additionally, maximum half-hourly levels are shown in Figure 3.118.

For half-hourly levels, the 'fine' data filtering is the same as the 'base' filtering but excludes the levels recorded in the 30 hours of highest emissions in the year. For monthly levels, which are hardly affected by short-term peaks, only the 'base' filtering mode is presented.

With the exception of one plant (FR110), the emission levels range between close to the limit of quantification and 0.004 mg/Nm^3 as a yearly average, 0.01 mg/Nm^3 as a monthly average, and 0.024 mg/Nm^3 as a maximum daily average ('fine' data filtering). In certain cases the maximum daily average obtained with 'base' data filtering may be substantially higher (up to 0.036 mg/Nm^3), which may reflect not only high mercury input episodes, but also OTNOC situations where the daily average typically includes only a few half-hourly periods and where the mercury levels measured are elevated.
Plant FR110 reports 0.021 mg/Nm^3 as a yearly average, 0.04 mg/Nm^3 as a maximum monthly average, and maximum daily averages spanning the range from 0.032 mg/Nm^3 to 0.38 mg/Nm^3 with 'fine' and 'base' data filtering.

More than half of the plants that measure mercury discontinuously report averages over the sampling period below 0.003 mg/Nm^3, eight plants report levels between 0.009 mg/Nm^3 and 0.038 mg/Nm^3, and four plants report values between 0.054 mg/Nm^3 and 0.095 mg/Nm^3. Most of the best performing plants use a fixed adsorption bed and/or inject hydrogen peroxide in the wet scrubber. One plant reporting the use of wet scrubber with hydrogen peroxide (SE21R) reported a maximum level exceeding 0.06 mg/Nm^3, but this was ascertained to relate to a malfunction of the waste water treatment plant, resulting in the re-injection of mercury-contaminated water in the quench system.

The reported data do not show a clear correlation between the achieved emission levels and the amount of activated carbon used or the age and size of the plant. Most plants are rotary kilns.

Antimony, arsenic, chromium, cobalt, copper, lead, manganese, nickel and vanadium

The techniques used to remove dust also reduce the emissions of dust-bound metals.

[Sb+As+Cr+Co+Cu+Pb+Mn+Ni+V] emission data for plants incinerating predominantly HW are based on discontinuous measurements and are shown in Figure 3.119.

The emission levels range between close to the limit of quantification and 0.33 mg/Nm^3 with the exception of two reference lines showing levels of 0.48 mg/Nm^3 as a maximum of the averages over the sampling period.

All four plants reporting levels above 0.3 mg/Nm^3 are small plants, and two of them are furnaces incinerating liquid residues from the chemical industry.

Cadmium and thallium

The techniques used to remove dust also reduce the emissions of dust-bound metals.

[Cd+Tl] emission data for plants incinerating predominantly SS are based on discontinuous measurements and are shown in Figure 3.120.

The emission levels are between close to the limit of quantification and 0.021 mg/Nm^3, with the exception of reference line FR107R, a furnace incinerating liquid residues from the chemical industry, reporting a level of 2.83 mg/Nm^3 as a maximum of the averages over the sampling period.

The reported data do not show a clear correlation between the achieved emission levels and the technique installed, or the age and size of the plant.

~~[41, EURITS, 2002]~~
~~This section gives an overview of the merchant hazardous waste incineration sector in the EU. Information is given for 24 European merchant rotary kiln installations which collectively have a total annual capacity of 1 500 000 tonnes of waste (70 % of the total capacity of specialised waste incinerators in the EU that is commercially available to third parties). On-site installations, such as those in the chemical industry, are not considered in this overview. The reference year for data collection is 1999 - 2000. Some specific data are more recent and refer to the year 2001 - 2002.~~

~~There is a very high diversity of waste streams treated in these installations. Composition and physical constitution can vary a lot from kiln to kiln and for each kiln over a period of time. For this reason the kilns are equipped with sophisticated flue-gas cleaning systems.~~

~~**General overview**~~

~~Due to efficient flue-gas cleaning, the air emissions of the different installations covered in this survey already meet the emission standards of Directive 2000/76/EC on incineration of waste.~~

~~In~~
~~Table~~ 3.21 ~~below, an overview is given of the emissions of the waste incinerators as average yearly concentrations. The minimum and maximum values of the individual installations, and the average of all installations, are also given.~~

~~**Table 3.21: Survey data of the annual average emissions to air from hazardous waste incinerators in Europe**~~

~~**Parameter mg/Nm^3 unless stated**~~	~~**Yearly average**~~		
	~~**Minimum**~~	~~**Maximum**~~	~~**Average**~~
~~HF~~	~~0.01~~	~~<1~~	~~0.3~~
~~TOC~~	~~0.01~~	~~6~~	~~1.5~~
~~O_2 (%)~~	~~8~~	~~13.66~~	~~11.0~~
~~NO_X~~	~~44.4~~	~~<300~~	~~139~~
~~Dust~~	~~0.075~~	~~9.7~~	~~1.69~~
~~HCl~~	~~0.25~~	~~8.07~~	~~1.56~~
~~SO_2~~	~~0.1~~	~~22.7~~	~~7.8~~
~~Hg~~	~~0.0004~~	~~0.06~~	~~0.01~~
~~Cd +Tl~~	~~0.00014~~	~~0.046~~	~~0.01~~

~~Sum metals~~	~~<0.004~~	~~0.84~~	~~0.2~~
~~PCDD/PCDF (ngTEQ/Nm^3)~~	~~0.0003~~	~~<0.1~~	~~0.038~~
~~CO~~	~~3~~	~~26~~	~~12.9~~
~~*Source:* [41, EURITS, 2002]~~			

~~In~~

~~Table 3.22 below, the average of the mass flows (in kg/t of incinerated waste) for some substances, together with the total amount of all the installations (if recorded) are given. The latter demonstrates the outputs of the sector as a result of the treatment of about 1.3 to 1.5 million tonnes of waste per year.~~

~~Table 3.22: Survey data of mass flow and annual sector emissions to air from merchant hazardous waste incinerators in Europe~~

~~Parameter~~	**~~Average mass flow (kg/t of waste incinerated)~~**	**~~Total amount recorded (t/yr)~~**
~~Dust~~	~~0.0098~~	~~16.2~~
~~SO_2~~	~~0.047~~	~~60.6~~
~~NO_X~~	~~0.87~~	~~1 191~~
~~Hg~~	~~0.000056~~	~~0.083~~
~~Sum of metals~~	~~0.0013~~	~~1.3~~
~~CO~~	~~0.07~~	~~76.2~~
~~HCl~~	~~0.0097~~	~~16.8~~
~~*Source:* [41, EURITS, 2002]~~		

~~Overview by each parameter~~

~~In the following paragraphs, the emissions for each parameter are discussed in more detail. Where possible, the relationship between these emissions and the installed technology is described.~~

~~The numbering given in the X-axes of the graphs below is not related to the specific installations. Also, concentrations (bars, relating to the left Y-axis) and mass flows (diamonds, relating to the right Y-axis) are given in the graphs. Mass flows based on non-absolute values (e.g. values smaller than the determination level) are expressed as hollow diamonds.~~

~~**HF** is not described in detail because all the data collected for the 24 installations, which is mostly obtained as a result of continuous monitoring, are below 1 mg/Nm^3, which is the analytical lower determination level (LDL) of this monitoring technique. Additional data obtained by discontinuous measurements, a technique with a lower detection limit, confirm this conclusion.~~

~~**TOC** is not described in detail because 95 % of the data collected, which again is mostly obtained as a result of continuous monitoring, are below 1 - 2 mg/Nm^3. Two installations have higher yearly average emission of 4 and 6 mg/Nm^3.~~

~~**O_2** data are given to indicate that the average concentration level is close to the standard reference value of 11 %, to which all raw data have to be calculated.~~

~~Nitrogen oxides~~

~~In the graph below the yearly average NO_X values for all installations are given and given as:~~

- ~~average concentration of NO_X expressed as NO_2, in mg/Nm^3, 11 % O_2, dry and standard conditions~~
- ~~average mass flow of NO_X expressed as NO_2 in g/t of incinerated waste.~~

~~The data are the result of continuous measurements of this parameter in the flue-gas. The individual measurement points are in general integrated over half an hour, and then respectively the daily, monthly and yearly averages are calculated. The analytical lower determination level for continuous monitoring of this parameter is usually 5 - 10 mg/Nm^3.~~

~~For each installation the installed NO_X abatement technique is shown, which may be:~~

- ~~the use of selective non-catalytic reduction (indicated as SNCR)~~
- ~~the use of selective catalytic reduction (indicated as SCR)~~
- ~~no specific abatement technique.~~

~~Figure 3.94: Graph of NO_X annual average emissions to air and applied abatement technique at European HWIs FIGURE DELETED~~

~~General conclusions from the graph:~~

- ~~90 % of the installations perform below 200 mg/Nm^3~~
- ~~50 % of the installations perform between 50 - 150 mg/Nm^3. For these there is no clear direct relationship with the abatement technique which is installed (note: some installations operate at a set point which is not the lowest level that is technically achievable, e.g. No. 5 an SCR operating at 180 mg/Nm^3)~~
- ~~for the four installations equipped with an SCR, the emissions are 180, 120, 72 and 59 mg/Nm^3, respectively. The set point for the operation of each of these installations is different and does not necessarily reflect the lowest level that is technically achievable. In addition, the influence of conditions which determine the formation of NO_X during incineration cannot be deduced from the available data~~
- ~~for the three installations equipped with an SNCR, the emissions are 157, 118 and 93 mg/Nm^3 respectively; for these results the same remark applies as that given in previous bullet points~~
- ~~for the other installations not equipped with an SCR/SNCR there is a wide variation in the emissions, mainly as a result of the different conditions for NO_X formation in the individual installations~~
- ~~several of the installations without SCR or SNCR but with low NO_X emissions (<120 mg/Nm^3) operate at lower temperatures in the post combustion chamber (PCC): 950 - 1 000 °C, in comparison with other installations operating at 1 100 - 1 200 °C in the PCC.~~

~~Dust~~

~~In the graph below, the yearly average dust values for all installations are given and given as:~~

- ~~the average concentration of dust in mg/Nm^3, 11 % O_2, dry and standard conditions~~
- ~~the average mass flow of dust in g/tonne incinerated waste.~~

~~The data are the result of continuous measurements of this parameter in the flue-gas. The individual measurement points are, in general, integrated over half an hour, and then respectively the daily, monthly and yearly average is calculated. The analytical lower determination level for continuous monitoring of this parameter is around 1 - 2 mg/Nm^3.~~
~~For each installation the dust emission technique is indicated. In this case, there is:~~

- ~~the use of electrostatic precipitators (ESPs), a dry ESP or a wet ESP~~
- ~~the use of a bagfilter~~

- ~~the use of a combination of these two techniques.~~

~~Figure 3.95: Graph of annual average dust emissions to air and applied abatement technique at European HWIs FIGURE DELETED~~

~~General conclusions from the graph:~~

- ~~96 % of the installations perform below 5 mg/Nm~~^{3}
- ~~one installation has a dust emission between 5 - 10 mg/Nm~~^{3}~~.~~

~~Hydrogen chloride and hydrogen fluoride HCl~~

~~In the graph below, the yearly average HCl values for all installations are given and given as:~~

- ~~the average concentration of HCl and volatile chloride compounds in mg/Nm~~^{3}~~, 11 %~~ O_2~~, dry and standard conditions~~
- ~~the average mass flow of HCl in g/t incinerated waste.~~

~~The data are the result of continuous measurement of this parameter in the flue-gas. The individual measurement points are, in general, integrated over half an hour, and then respectively the daily, monthly and yearly average is calculated. The analytical lower determination level for continuous monitoring of this parameter is about 1 - 2 mg/Nm~~^{3}~~.~~

~~For each installation the installed HCl abatement technique is shown. The techniques used are:~~

- ~~initial quenching of the flue-gases~~
- ~~the use of a wet scrubber (injection of lime-based compounds in water) with subsequent evaporation of scrubbing water~~
- ~~the use of a wet scrubber with subsequent discharge of the treated scrubbing water~~
- ~~the use of a dry or semi-wet scrubber with the injection of lime based compounds in water~~
- ~~the injection of~~ $NaHCO_3$~~.~~

~~Most of the HCl in raw flue-gases from hazardous waste incineration originates from organics containing chlorine but some of it also comes from inorganic salts such as NaCl.~~

~~At the temperatures achieved during incineration the Deacon equilibrium is important to consider:~~

$$4\ HCl + O_2 \Leftrightarrow 2\ H_2O + 2\ Cl_2\ (+\ 114.5\ kJ)$$

~~During the combustion of hydrocarbon-containing waste the equilibrium is shifted to the left side of the equation, due to the fact that during combustion an excess of~~ H_2O ~~is formed, and as a result, chlorine is present in the HCl form in the combustion gas. When, for example, low hydrogen-containing waste, e.g. PCB, is incinerated this is not the case and the equilibrium is shifted to the right side of the equation, meaning that a mixture of HCl and~~ Cl_2 ~~will be formed. In this case, the flue-gas cleaning has to be adapted for the de-chlorination of the combustion gases.~~

~~Figure 3.96: Graph of HCl annual average emissions to air and applied abatement technique at European HWIs FIGURE DELETED~~

~~General conclusions from the graph:~~

- ~~90 % of the installations perform below 2 mg/Nm~~^{3}

- ~~this data does not reveal any clear relationship between technique and annual average emission levels~~
- ~~for the three other installations the emissions are 8, 4 and 3 mg/Nm^3 respectively.~~

~~SO_2~~

~~In the graph below, the yearly average SO_2 values for all installations are given. These are given as:~~

- ~~average concentrations of SO_2 in mg/Nm^3, 11 % O_2, dry and standard conditions~~
- ~~average mass flow of SO_2 in g/t incinerated waste.~~

~~The data are the result of continuous measurements of this parameter in the flue-gas. The individual measurement points are in general integrated over half an hour, and then the daily, monthly and yearly average respectively is calculated. The analytical lower determination level for continuous monitoring of this parameter is around 1 – 5 mg/Nm^3.~~

~~For each installation the installed SO_2 emission abatement technique is shown. In this case there is:~~

- ~~initial quenching of the flue-gases~~
- ~~the use of a wet scrubber (injection of lime-based compounds in water) and subsequently the evaporation of the scrubbing water~~
- ~~the use of a wet scrubber and subsequently the discharge of the treated scrubbing water~~
- ~~the use of a dry or semi-wet scrubber (injection of lime based compounds in water)~~
- ~~the injection of $NaHCO_3$ in the flue-gas transport channel.~~

~~The formation of SO_2 in incineration processes originates from S-compounds in the waste e.g.~~

$$\cancel{C_xH_yS + z\,O_2 \Leftrightarrow CO_2 + SO_2 + H_2O}$$

~~There is a direct linear relationship between the amount of SO_2 in the raw flue-gases and the amount of sulphur in the waste. Most sulphur containing compounds, also inorganic, degrade during combustion and end up in the raw gas as SO_2.~~

~~Figure 3.97: Graph of annual average sulphur dioxide emissions to air and applied abatement technique at European HWIs FIGURE DELETED~~

~~General conclusions from the graph:~~

- ~~90 % of the installations perform below 20 mg/Nm^3~~
- ~~dry systems give results in the range of 5 – 23 mg/Nm^3, with a median value of approximately 12 mg/Nm^3. SO_X abatement is reported to be improved with dry sodium bicarbonate than dry lime systems [74, TWGComments, 2004]~~
- ~~wet systems give results in the range of 2 – 22 mg/Nm^3, with a median value of approximately 4 mg/Nm^3~~
- ~~about 50 % of the installations perform below 5 mg/Nm^3 which is near the analytical lower determination level for continuous monitoring of this parameter~~
- ~~for the two other installations the emissions are respectively 23 and 21 mg/Nm^3.~~

~~Mercury~~

~~In the graph below, the yearly average mercury values for all installations are given. These are given as:~~

- ~~the average concentration of mercury in mg/Nm^3, 11 % O_2, dry and standard conditions~~
- ~~the average mass flow of mercury in g/t incinerated waste.~~

~~The data of eight installations are the result of continuous measurements of this parameter in the flue-gas. The individual measurement points are in general integrated over half an hour, and then the daily, monthly and yearly average respectively is calculated. The analytical lower determination level for continuous monitoring of this parameter is 1 - 2 µg/Nm^3.~~

~~All of these continuously monitored installations have yearly average emission levels below 5µg/Nm^3.~~

~~The data of the other installations are obtained by periodic discontinuous Hg measurements, ranging from twice a month to twice a year. The analytical lower determination level for this method is 1 µg/Nm^3.~~

~~For each installation the installed mercury abatement technique is shown. In this case, there is:~~

- ~~the use of a wet scrubber system (the lower the pH of the scrubbing water, the higher the removal efficiency of Hg)~~
- ~~the injection of activated carbon (or an alternative reagent, e.g. brown-coal cokes)~~
- ~~the use of a static activated carbon filter (or an alternative reagent, e.g. brown-coal cokes).~~

~~In the graph, the availability of activated carbon injection or the presence of an activated carbon filter is not mentioned because all the installations are equipped with it, except installations numbered 5, 6 and 11.~~

~~The mercury in the flue-gases originates from mercury-containing waste. There is a direct linear relationship between the amount of mercury in the raw flue-gases and the amount of mercury in the waste. For one installation equipped with wet gas scrubbing and an activated carbon filter, it is calculated that the total mercury input via the waste amounts to 1 000 kg/yr for an installation with an incineration capacity of 50 000 t/yr. Taking into account a maximum yearly emitted Hg flow via the flue-gases of less than 1.25 kg/yr, this means a total removal efficiency of 99.99 %.~~

~~Installations with a continuously or temporarily high Hg input are able to add sulphur-containing reagents in the wet scrubber system to increase the removal efficiency of Hg. The screening of the waste inputs for Hg is, therefore, important.~~

~~Figure 3.98: Graph of Hg annual average emissions to air and applied abatement technique at European HWIs FIGURE DELETED~~

~~General conclusions from the graph:~~

- ~~90 % of the installations perform below 0.01 mg/Nm^3~~
- ~~for the 3 other installations the emissions are 0.06, 0.04 and 0.013 mg/Nm^3 respectively.~~

~~Although not shown in these results, practical experience is that the type of activated carbon (physical characteristics and the impregnation of the carbon) has an influence on Hg removal efficiency.~~

~~Other metals: Sum of As, Sb, Pb, Cr, Co, Cu, Mn, Ni, V, Sn~~

~~In the graph below, the yearly average metal emissions for all installations are given. These values are given as:~~

- ~~the average concentration of the sum of the metals in mg/Nm^3, 11 % O_2, dry and standard conditions~~
- ~~the average mass flow of the sum of the metals in g/t incinerated waste.~~

~~For most installations this shows an average concentration of two to eight discontinuous measurements a year. These measurements are performed based on the US Environmental Protection Agency (EPA) Method 29.~~

~~Over 60 % of the installations perform under 0.2 mg/Nm^3.~~

~~Detection limit reporting differences:~~
~~The key potential difference in reported values is partly a result of the manner of reporting of undetected metals. In some countries these metals are calculated as zero, in other countries the detection limit values of the metals are reported.~~

~~The detection limit of the analysed metals depends on the total amount of sample taken and on the type of metal analysed (detection limits up to 0.018 mg/Nm^3 for some metals are reported). In other countries one detection limit value (0.001 or 0.005 mg/Nm^3) for all metals is reported, independent of the type of metal or the amount of sample taken.~~

~~Taking account of the detection limit value of the undetected metals, results in the reporting of a much higher sum value of the ten reported metals.~~

~~As a result only the data equal to or higher than 0.05 mg/Nm^3 are shown in the graph and the results below 0.05 mg/Nm^3 are indicated as less than 0.05 mg/Nm^3.~~

~~Figure 3.99: Annual average emissions to air of other metals and applied abatement technique at European HWIs~~ ~~FIGURE DELETED~~

~~General conclusions from the graph:~~

- ~~63 % of the installations perform below 0.2 mg/Nm^3 and for these installations there is no direct relationship with the abatement technique that is installed~~
- ~~the other five installations, all equipped with a bagfilter, have a higher metal emission.~~

~~Cadmium and thallium~~

~~In the graph below, the yearly average metal emissions for all installations are given. These values are given as:~~

- ~~the average concentration of the sum of Cd and Tl in mg/Nm^3, 11 % O_2, dry and standard conditions.~~

~~For most installations this shows an average concentration of two to eight discontinuous measurements a year. These measurements are performed based on the US Environmental Protection Agency (EPA) Method 29.~~

~~75 % of the installations perform under 0.02 mg/Nm^3. The key potential difference in reported values is partly a result of the different way of treatment of undetected metals as discussed in the paragraph on *other metals* (above). Using the detection limit value of the undetected metals results in a higher sum value of the reported metals. As a result, only the data equal to or higher than 0.01 mg/Nm^3 are shown in the graph and the results below 0.01 mg/Nm^3 are indicated as less than 0.01 mg/Nm^3.~~

~~Figure 3.100:Graph of Cd and Tl annual average emissions to air and applied abatement technique at European HWIs~~ ~~FIGURE DELETED~~

~~Dioxins and furans~~

~~In the graph below, the data for polychlorinated dibenzo-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) for all surveyed installations are given. These are given as average concentrations expressed as TEQ ng/Nm^3, 11 % O$_2$, dry and standard conditions. For most installations, it shows an average of two to four discontinuous measurements a year (based on CEN: EN1948).~~

~~Detection limit differences:~~
~~Between the official laboratories which are certified for the determination of dioxins, there is a large difference in the reporting of the attainable detection limit of the analytical method. It ranges from 0.01 to less than 0.001 ng TEQ/Nm^3, notwithstanding the fact that comparable sampling procedures are followed (e.g. 6 - 8 hour sampling period). The lowest detection limits are reported by German laboratories.~~

~~Here, only the data equal or higher than 0.01 ng TEQ/Nm^3 are shown in the graph and the results below 0.01 ng TEQ/Nm^3 are indicated as less than 0.01 ng TEQ/Nm^3.~~

~~The key potential difference in reported values is possibly a result of the inconsistent treatment of undetected PCDD/PCDF isomers some being calculated at the LOD (EN 1948 pt 3 refers), others being calculated as zero. The relative influence of the variation therein, is the function merely of the respectively assigned toxic equivalence factor (TEF) for that isomer.~~

~~From the graph, no specific conclusion can be drawn regarding the performance of the different techniques, as the ranking of the results is not directly related to the type of abatement technique installed. The low emission values and the variable accuracy of the analytical measurements at this level are additional confounding factors. Monitoring results from plants using continuous sampling show similar levels as short period monitoring.~~

~~Figure 3.101:Graph of PCDD/F annual average emissions to air and applied abatement technique at European HWIs~~ **~~FIGURE DELETED~~**

~~PCBs and PAHs~~

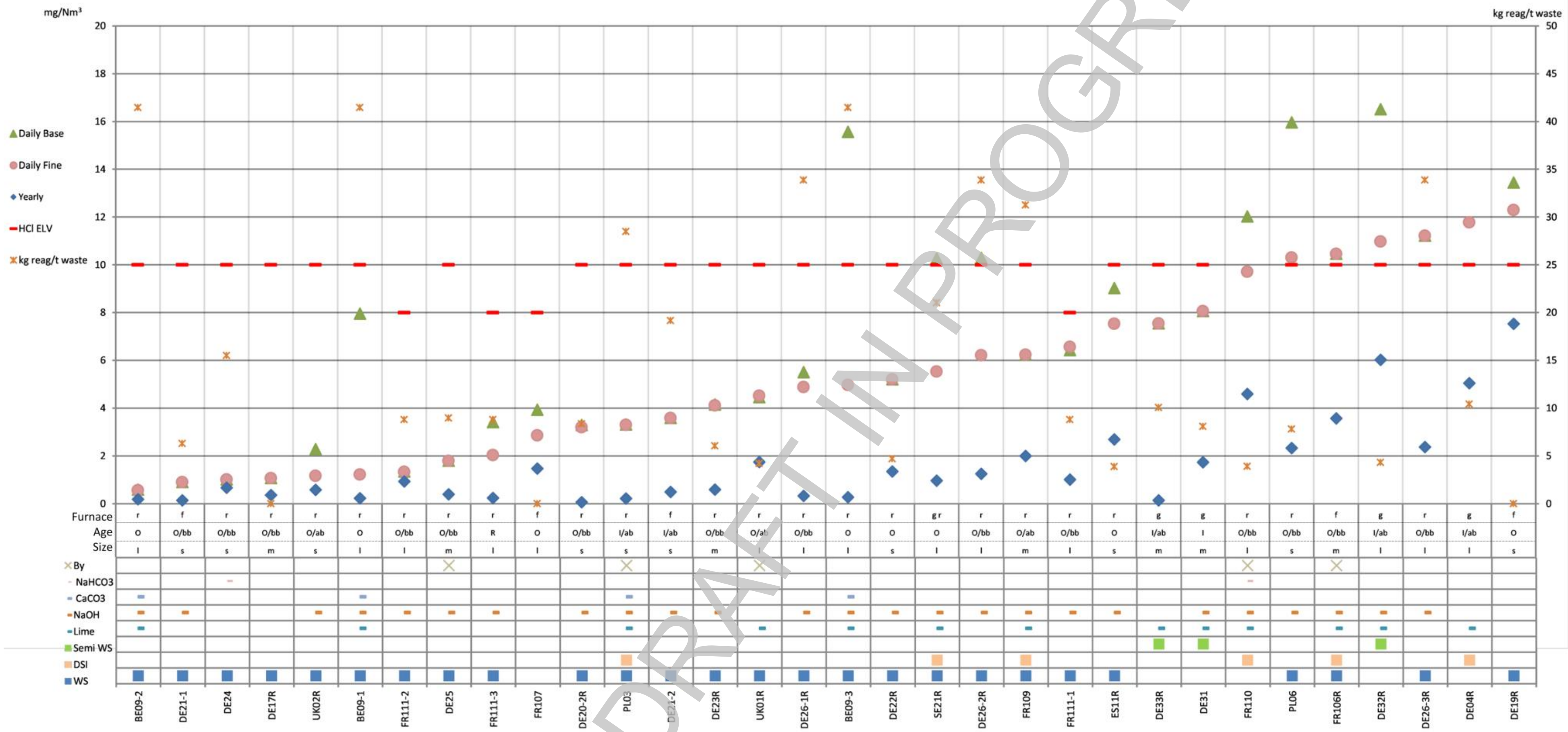
~~The emission of Poly Chlorinated Biphenyls (PCBs) is not always monitored. The available data show values mostly less than detection limit and ranging from <1 µg/Nm^3 to <2 ng/Nm^3. Here again, a critical analytical remark has to be made about the variability of the reported detection limits of the measurement methods.~~

~~The emission of Poly-Aromatic-Hydrocarbons (PAHs) is also not always monitored. The available data show values range from <1 µg/Nm^3 to <0.1 µg/Nm^3. Here also, a critical analytical remark has to be made about the variability of the reported detection limits of the measurement methods.~~

~~Carbon monoxide~~

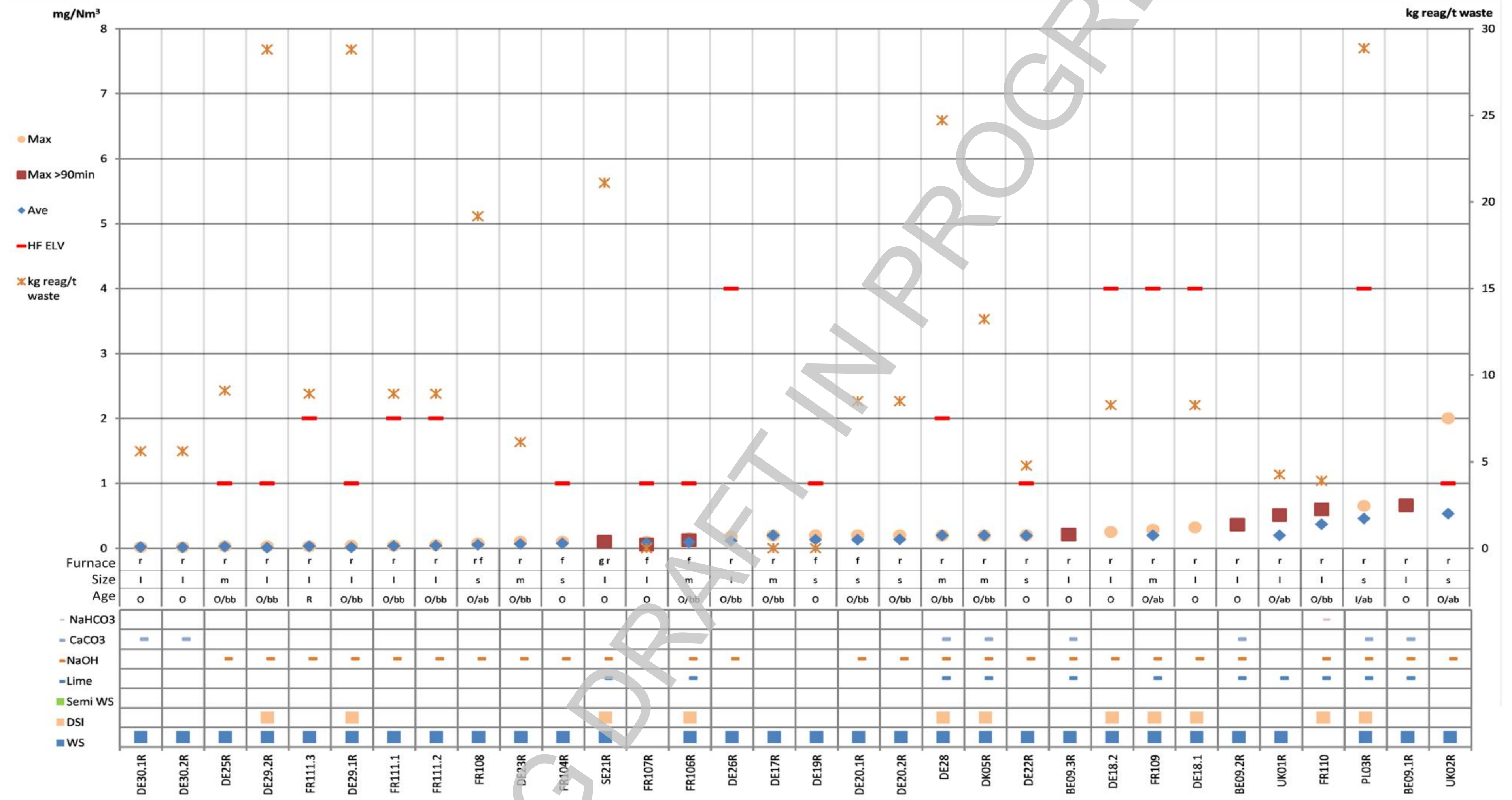
~~Text moved to section 3.2.2.4~~

~~Figure 2.2: Examples of some hazardous waste pretreatment systems used at some merchant HWIs~~ ~~FIGURE DELETED~~



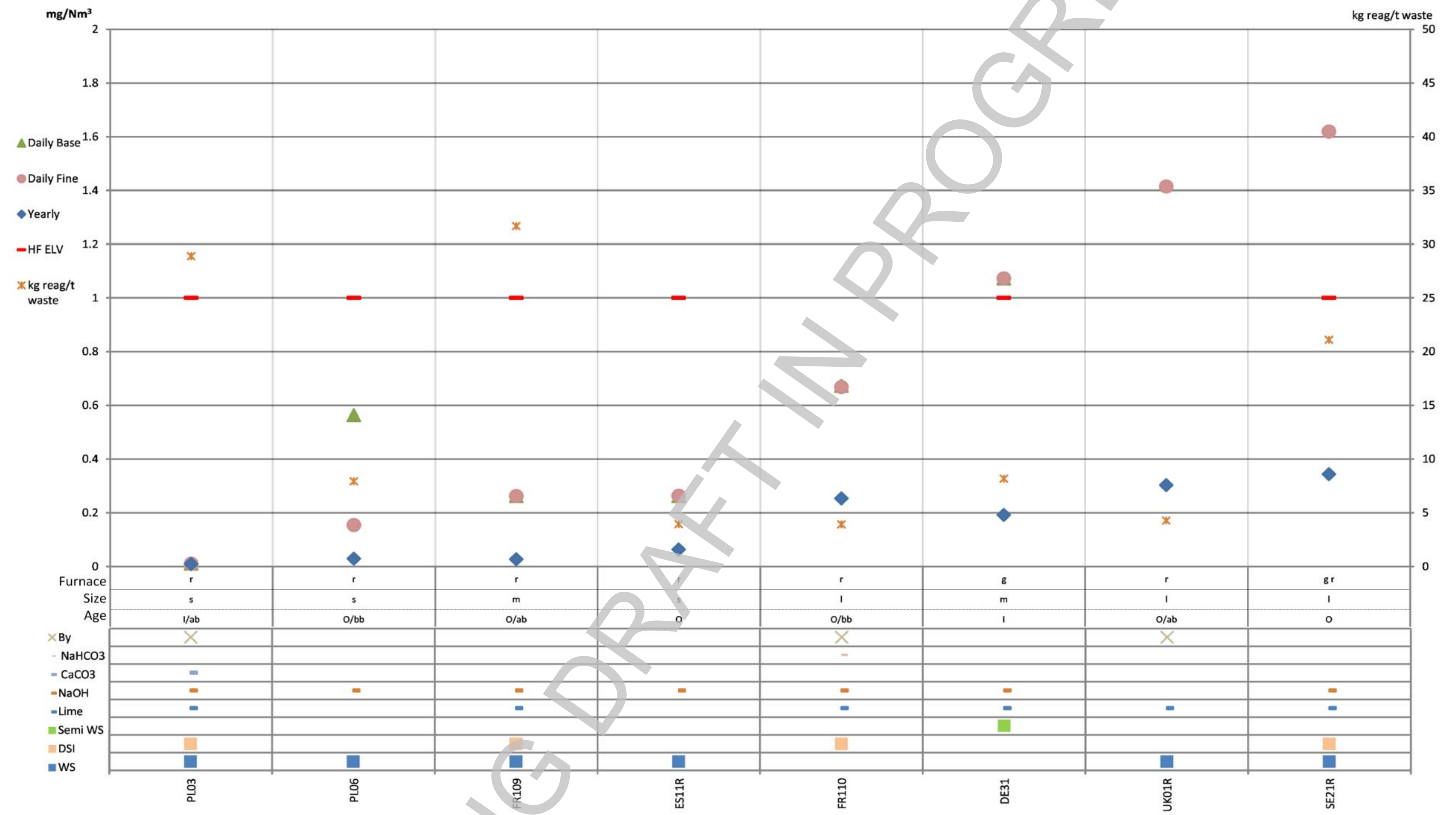
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Plant size: s = small; m = medium; l = large.
BY = ByPass.
Reagents Used: $NaHCO_3$ = Sodium Bicarbonate; $CaCO_3$ = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.102:Continuously monitored HCl emissions to air from plants incinerating predominantly hazardous waste



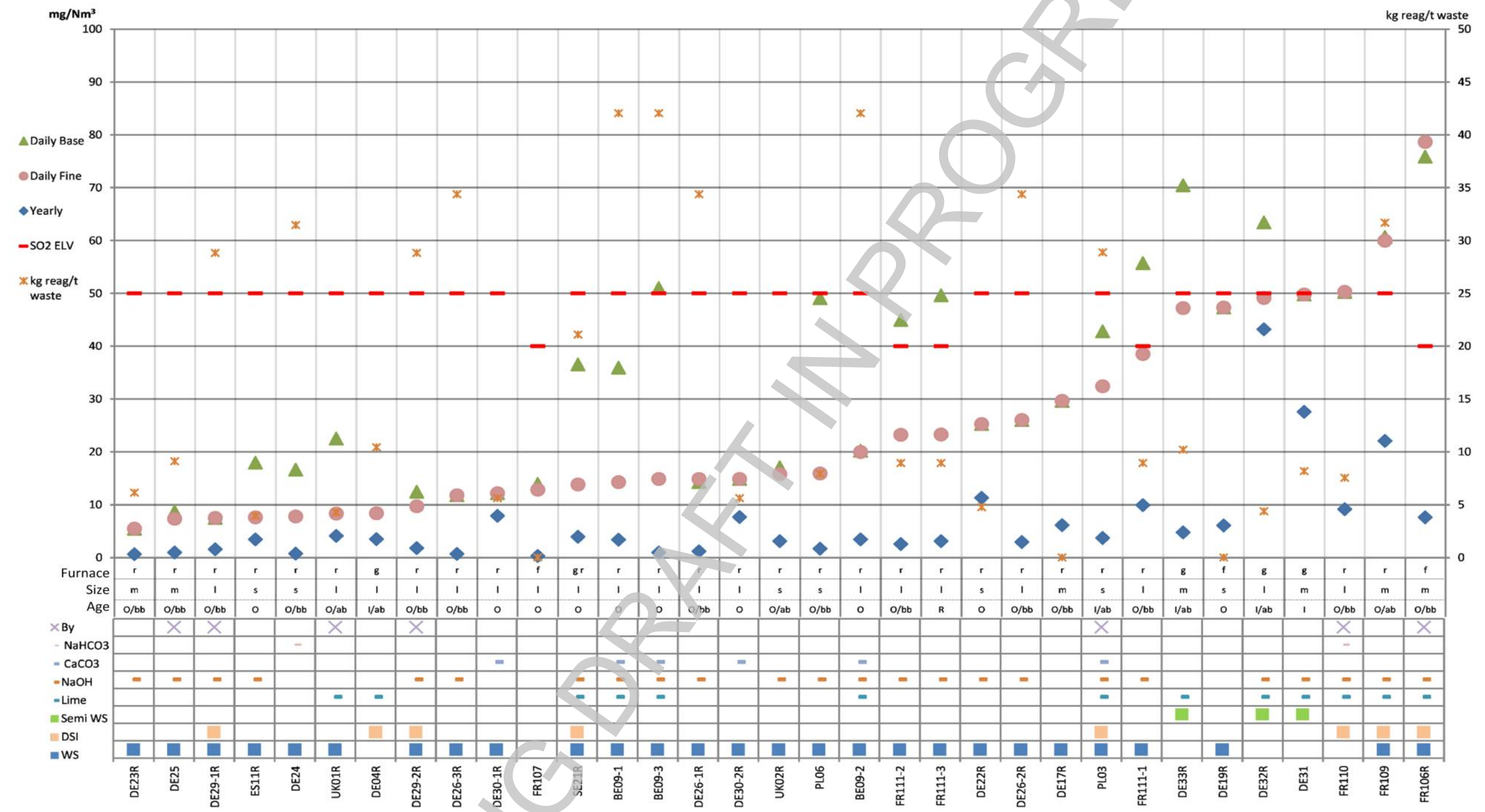
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: $NaHCO_3$ = Sodium Bicarbonate; $CaCO_3$ = Limestone; NaOH = Sodium Hydroxide
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.103: Discontinuously monitored HF emissions to air from plants incinerating predominantly hazardous waste



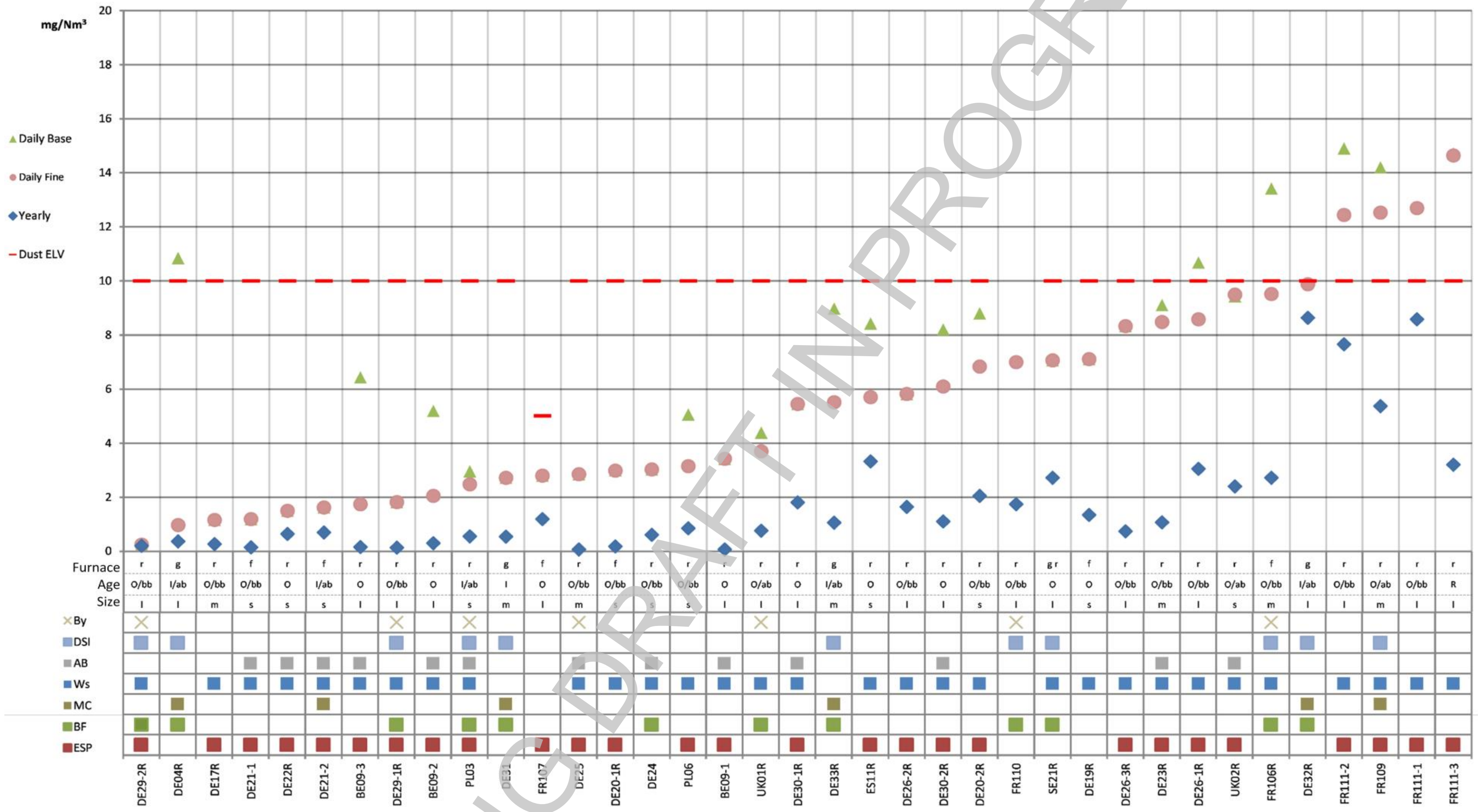
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NaHCO3 = Sodium Bicarbonate; CaCO3 = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber
Source: [81, TWG 2016].

Figure 3.104:Continuously monitored HF emissions to air from plants incinerating predominantly hazardous waste



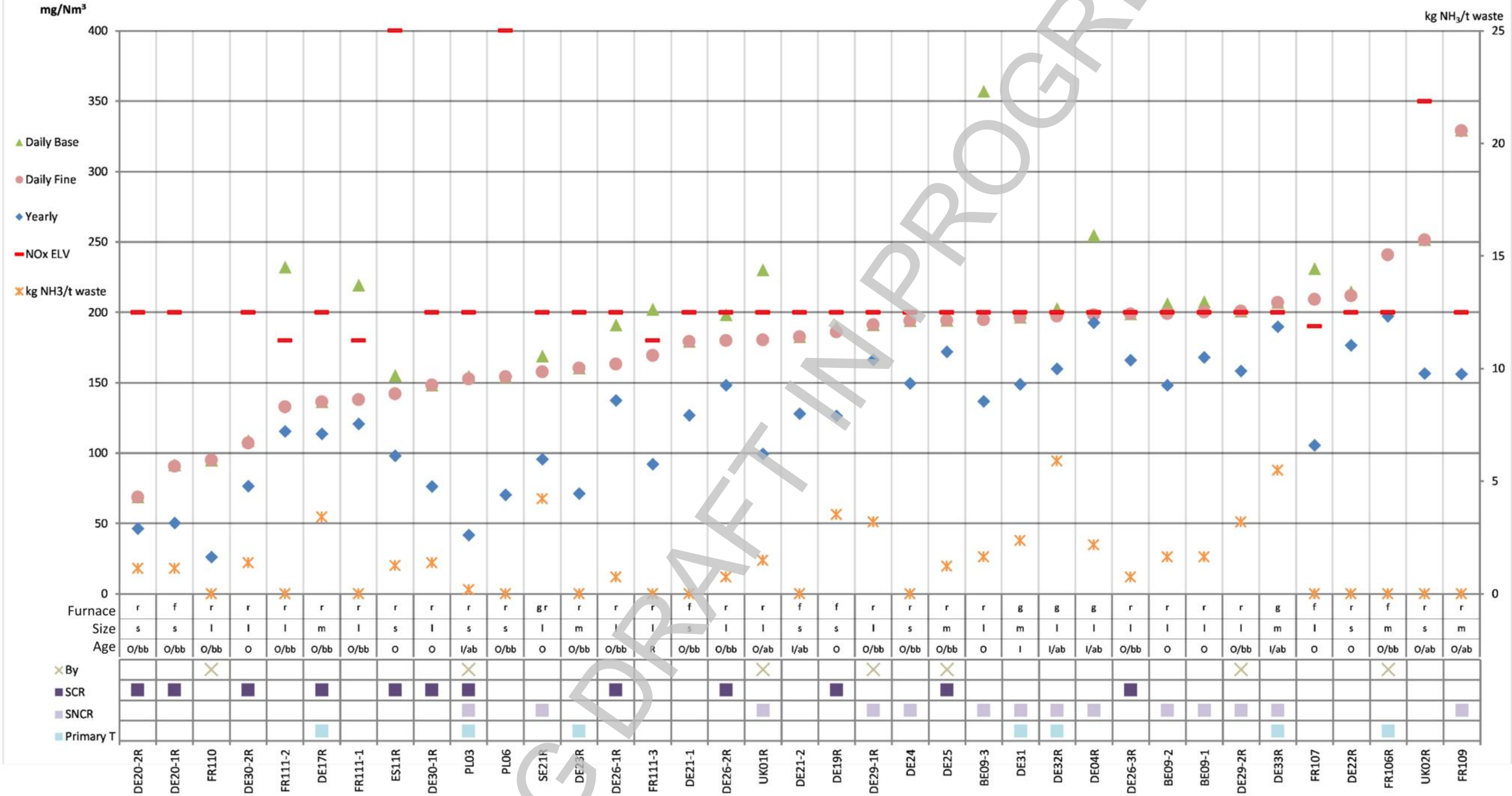
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: $NaHCO_3$ = Sodium Bicarbonate; $CaCO_3$ = Limestone; NaOH = Sodium Hydroxide.
Techniques installed: Semi WS = Semi Wet Scrubber; DSI = Dry Sorbent Injection; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.105: Continuously monitored SO_2 emissions to air from plants incinerating predominantly hazardous waste



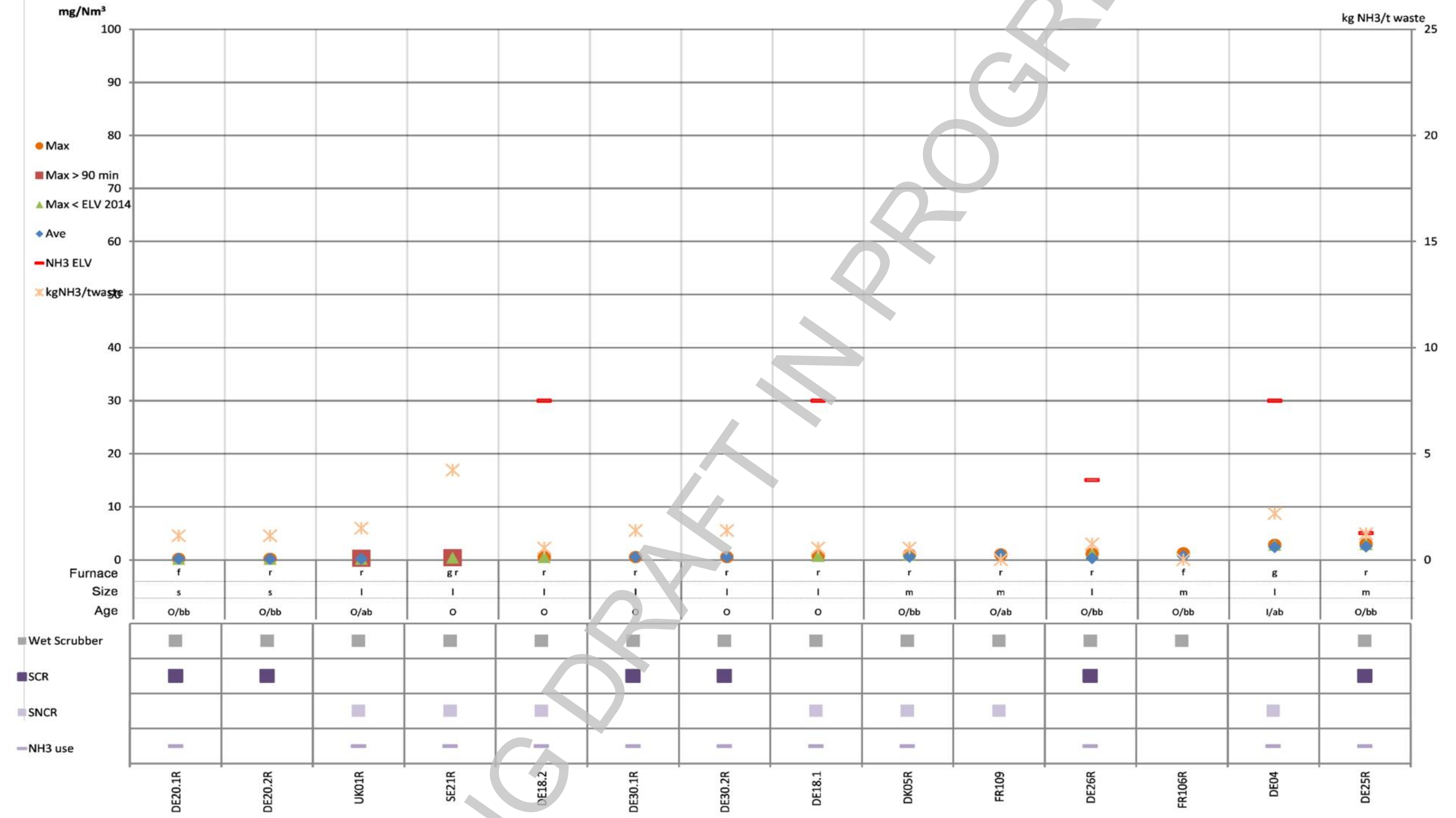
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Plant size: s = small; m = medium; l = large.
BY = ByPass.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed; WS = Wet Scrubber; MC = Multi-cyclone; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.106:Continuously monitored Dust emissions to air from plants incinerating predominantly hazardous waste



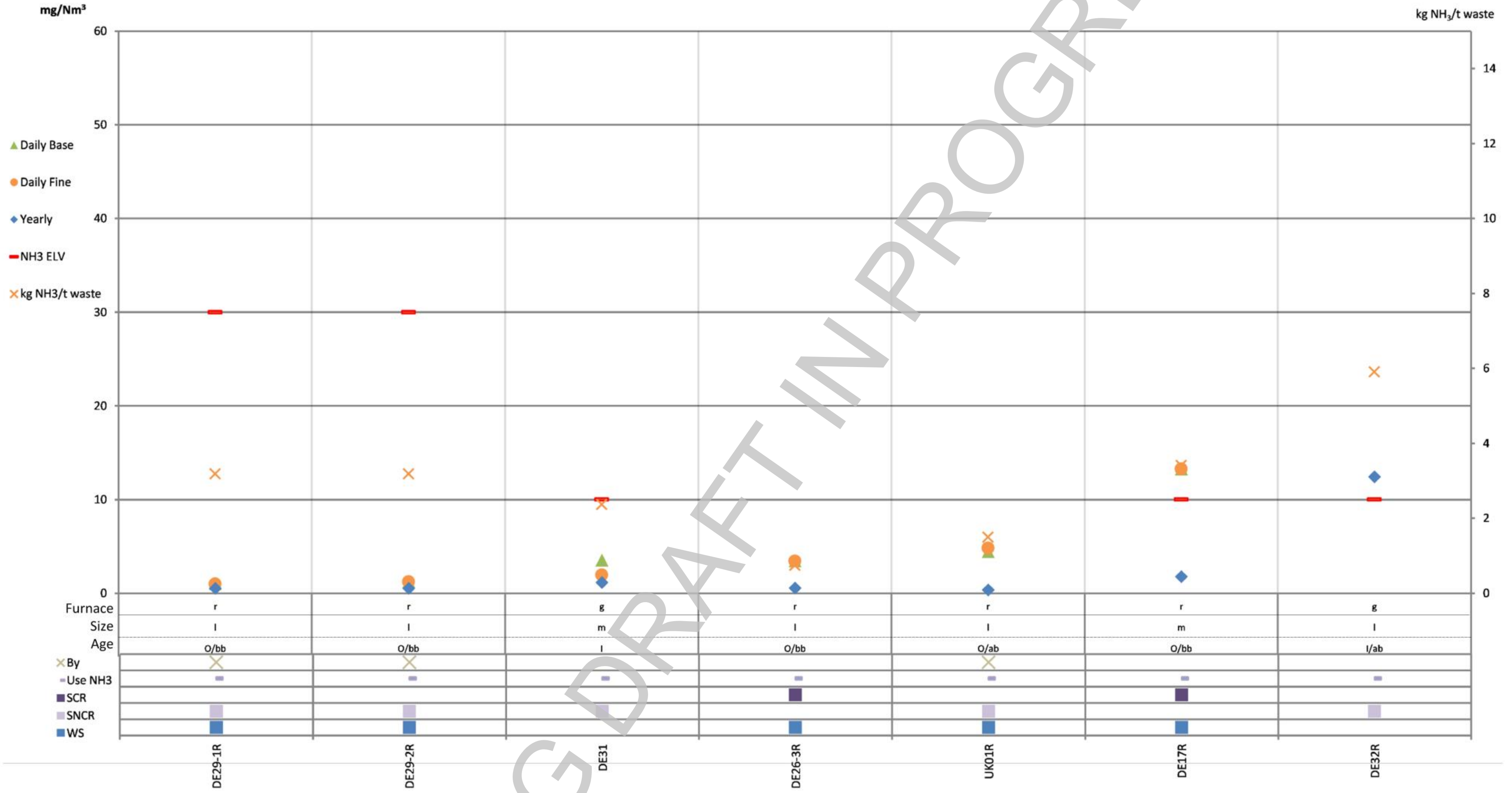
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction; Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.107:Continuously monitored NO$_x$ emissions to air from plants incinerating predominantly hazardous waste



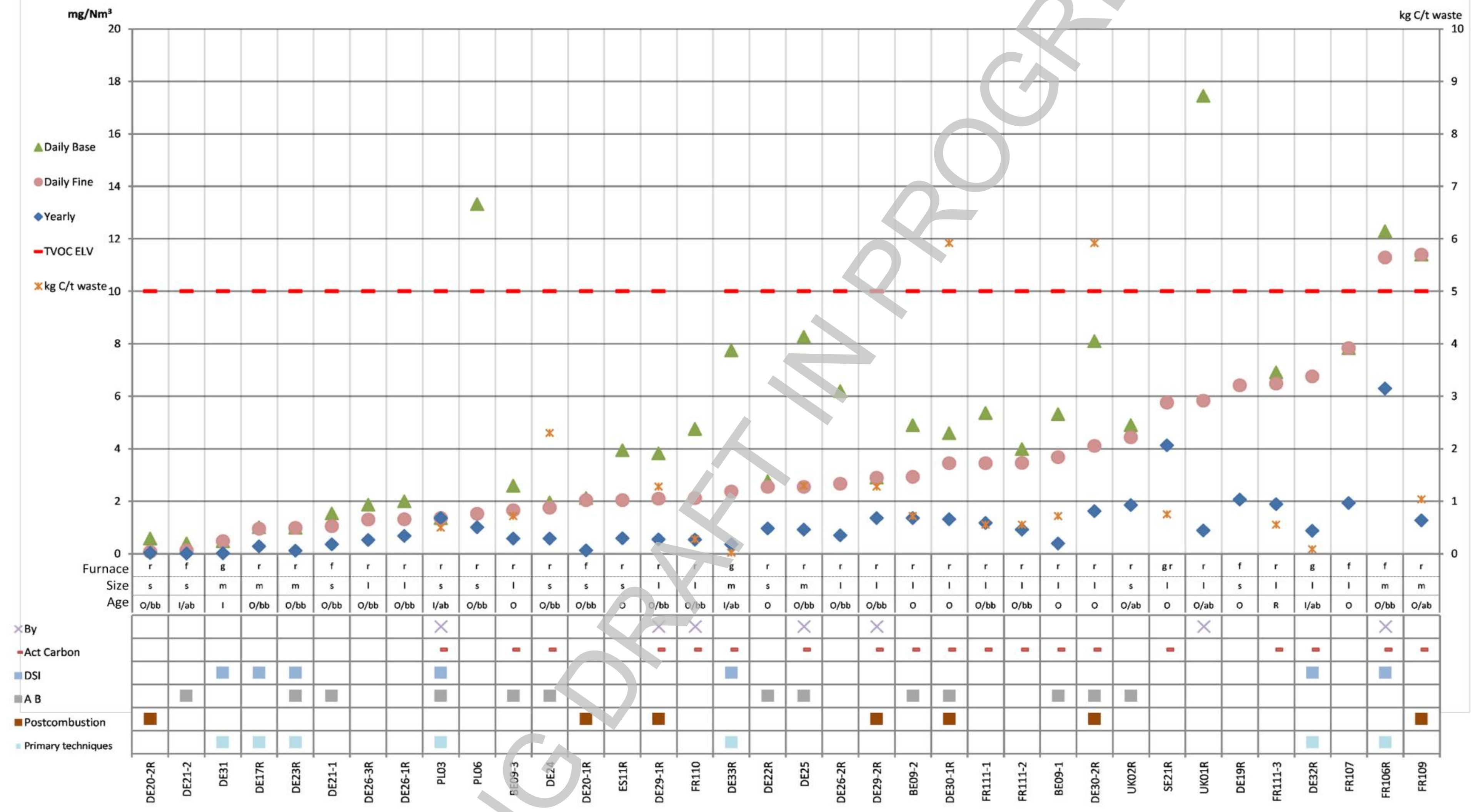
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction.
Reagents Used: NH3 = Ammonia.
Source: [81, TWG 2016].

Figure 3.108:Discontinuously monitored NH_3 emissions to air from plants incinerating predominantly hazardous waste



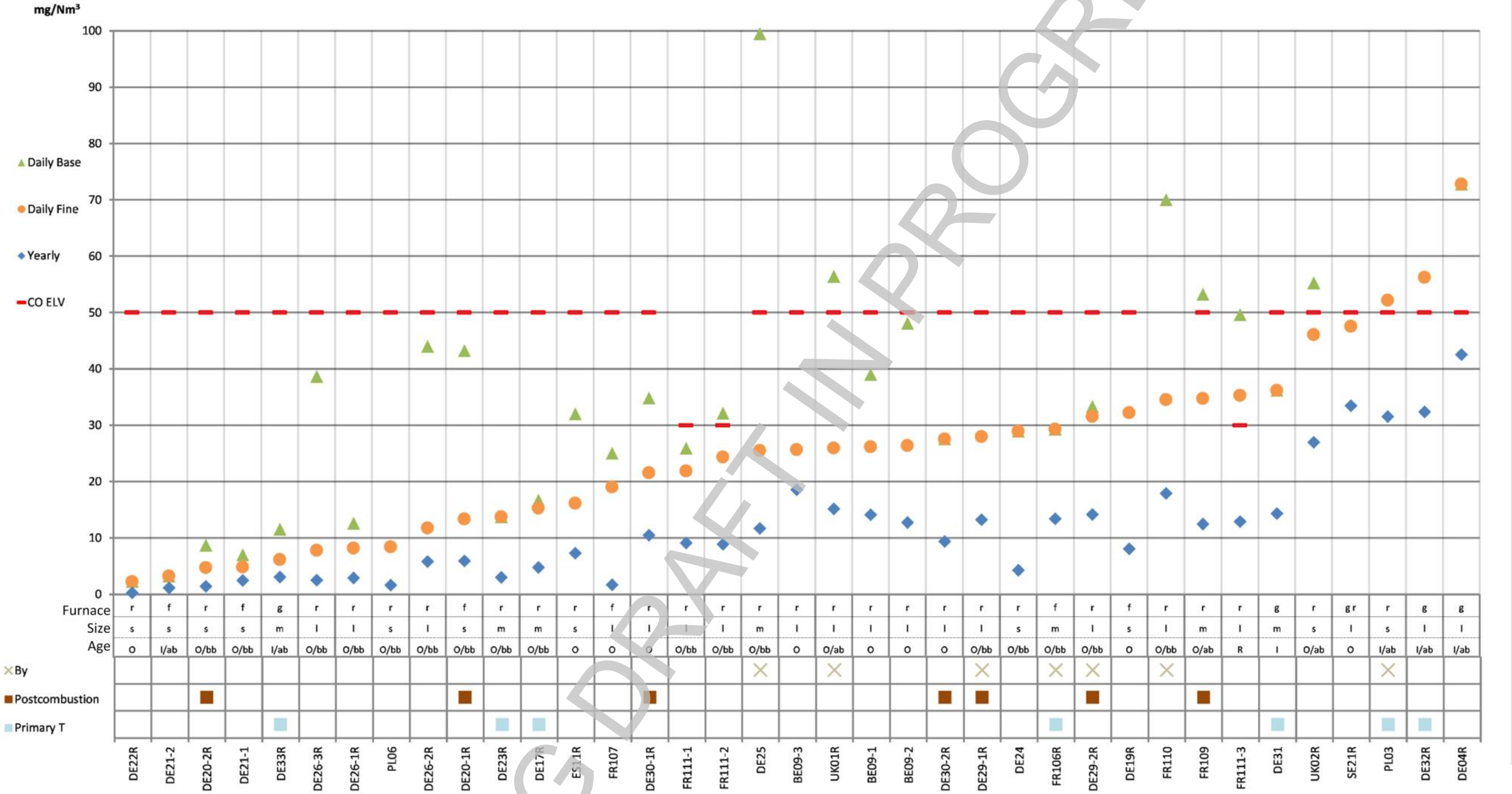
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: NH3 = Ammonia.
Techniques installed: SCR = Selective Catalytic Reduction; SNCR = Selective Non-Catalytic Reduction; WS = Wet Scrubber.
Source: [81, TWG 2016].

Figure 3.109:Continuously monitored NH_3 emissions to air from plants incinerating predominantly hazardous waste



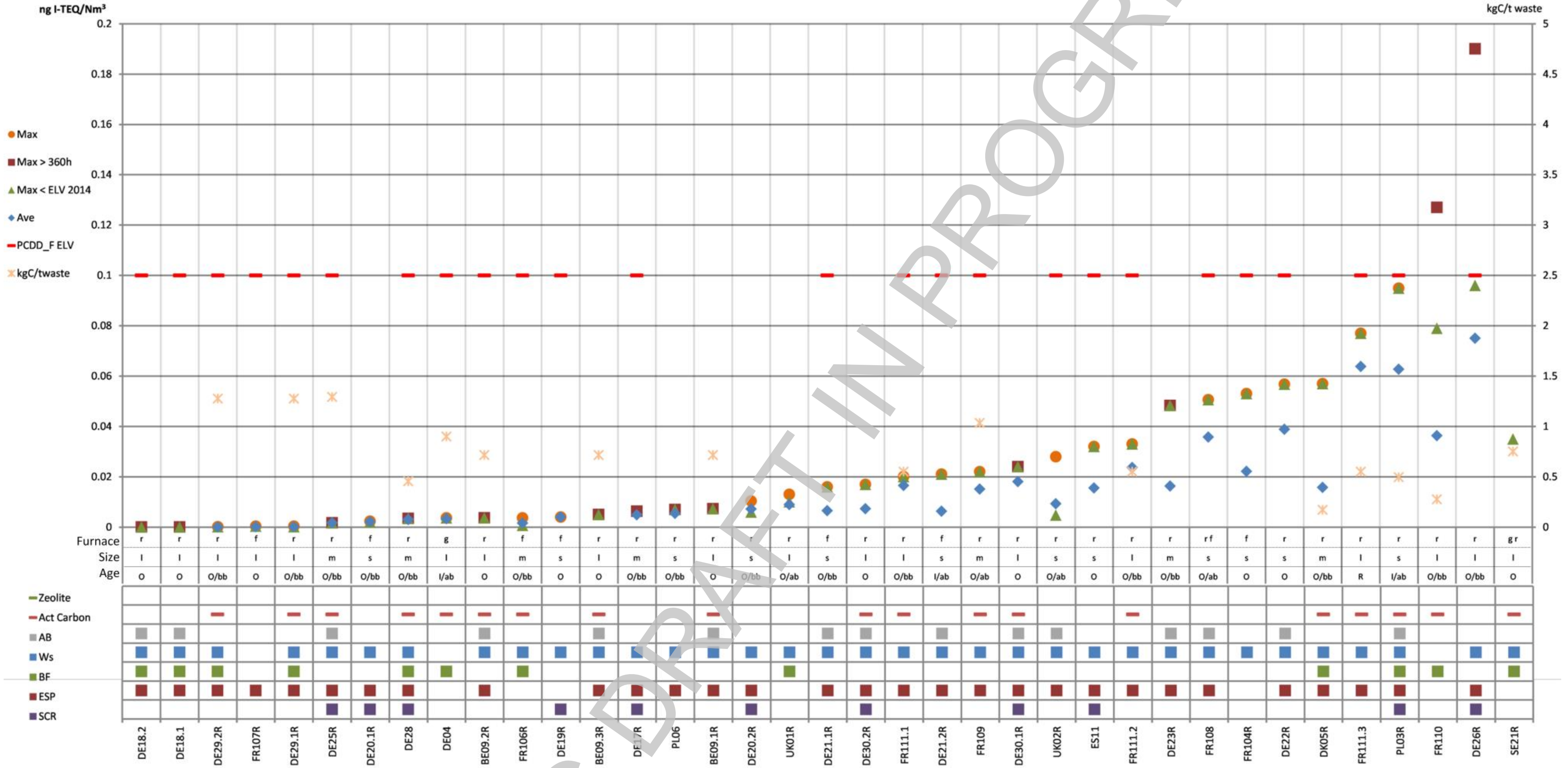
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: DSI = Dry Sorbent Injection; AB = Adsorption Bed
Source: [81, TWG 2016].

Figure 3.110:Continuously monitored TVOC emissions to air from plants incinerating predominantly hazardous waste



Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Techniques installed: Primary T = Primary Technique.
Source: [81, TWG 2016].

Figure 3.111:Continuously monitored CO emissions to air from plants incinerating predominantly hazardous waste

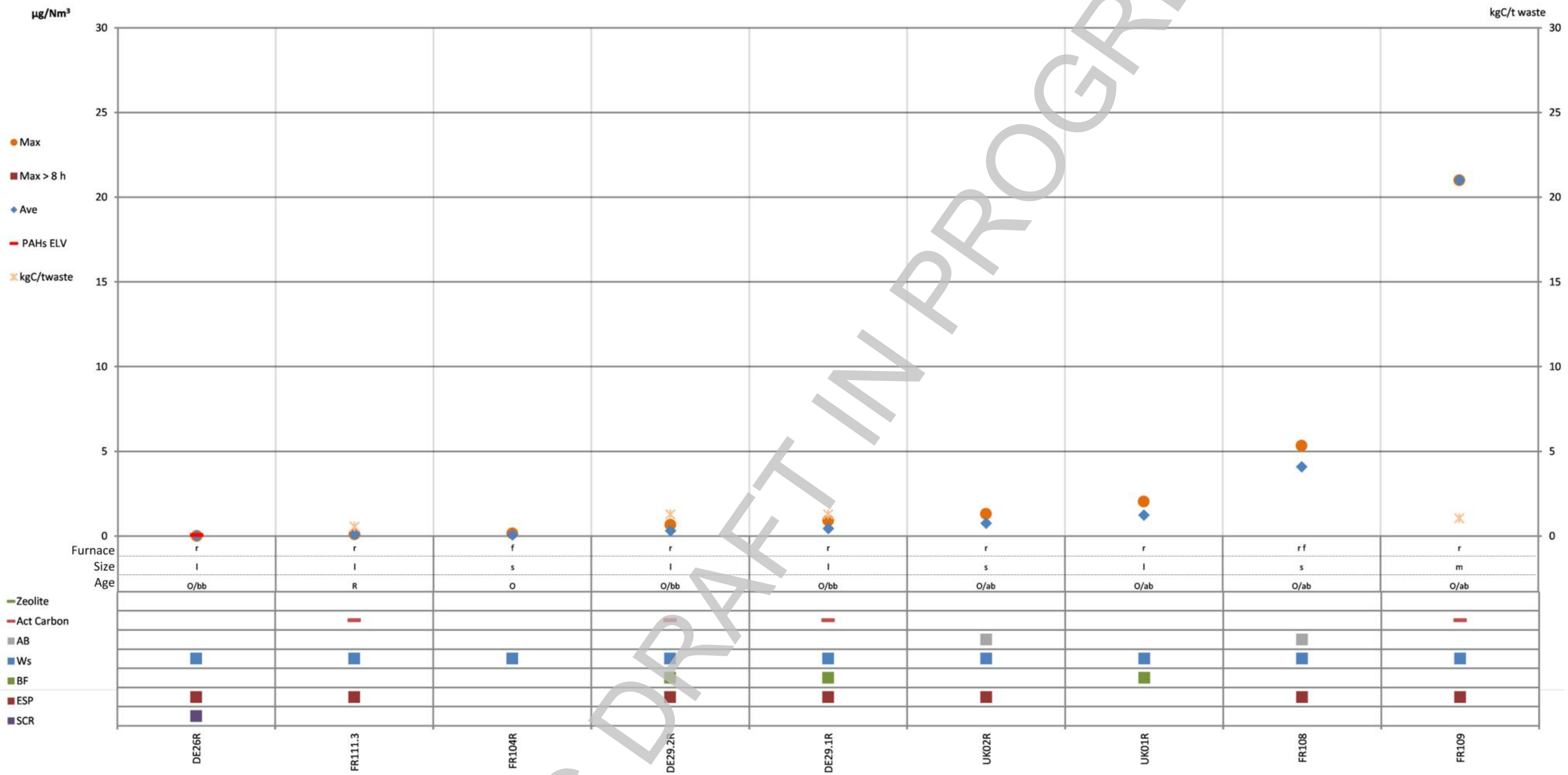


Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction.
Source: [81, TWG 2016].

Figure 3.112:Discontinuously monitored PCDD/F emissions to air from plants incinerating predominantly hazardous waste

Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction
Source: [81, TWG 2016].

Figure 3.113:Discontinuously monitored PCBs emissions to air from plants incinerating predominantly hazardous waste

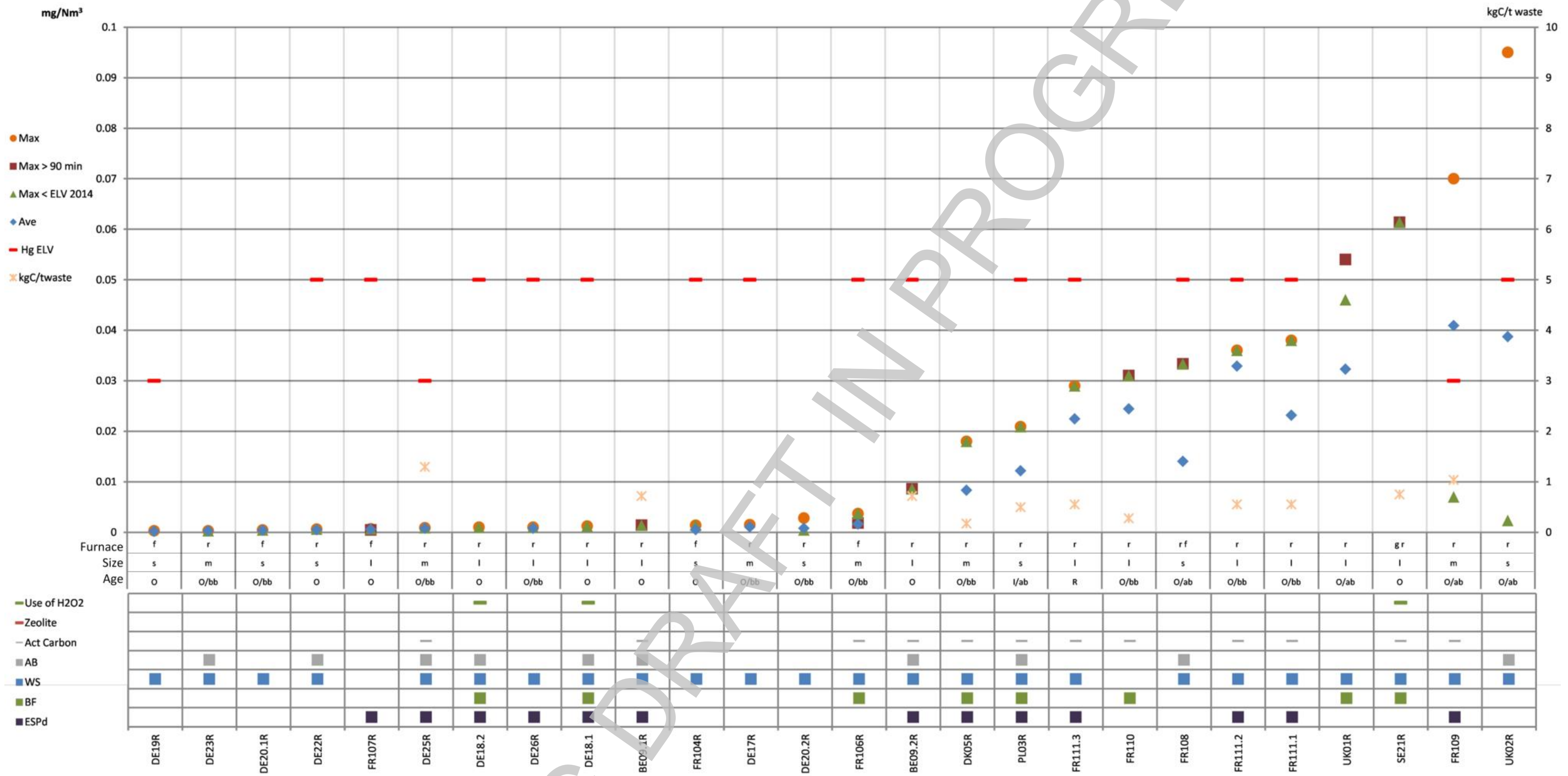


Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction.
Source: [81, TWG 2016].

Figure 3.114:Discontinuously monitored PAHs emissions to air from plants incinerating predominantly hazardous waste

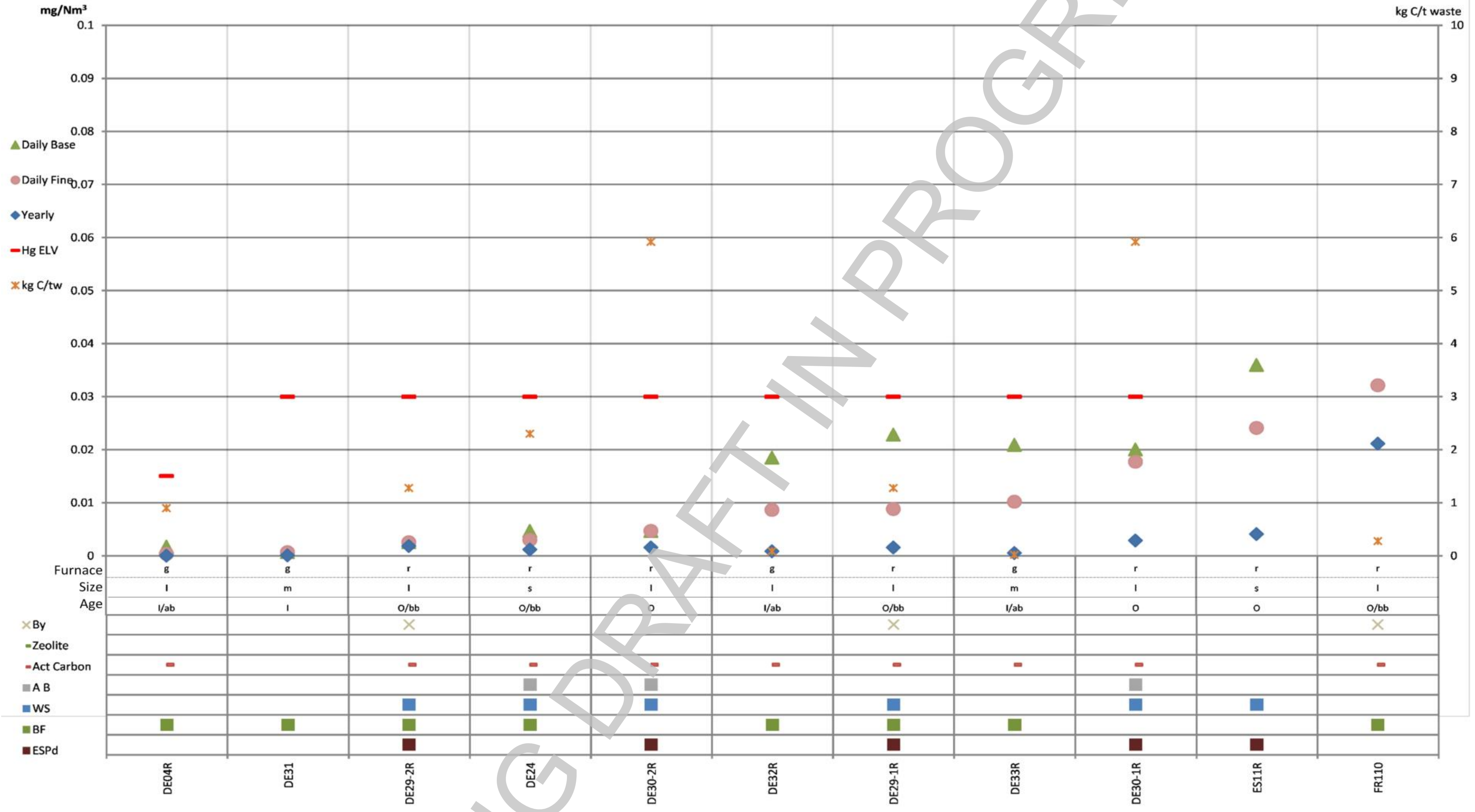
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator; SCR = Selective Catalytic Reduction.
Source: [81, TWG 2016].

Figure 3.115:Discontinuously monitored BaP emissions to air from plants incinerating predominantly hazardous waste



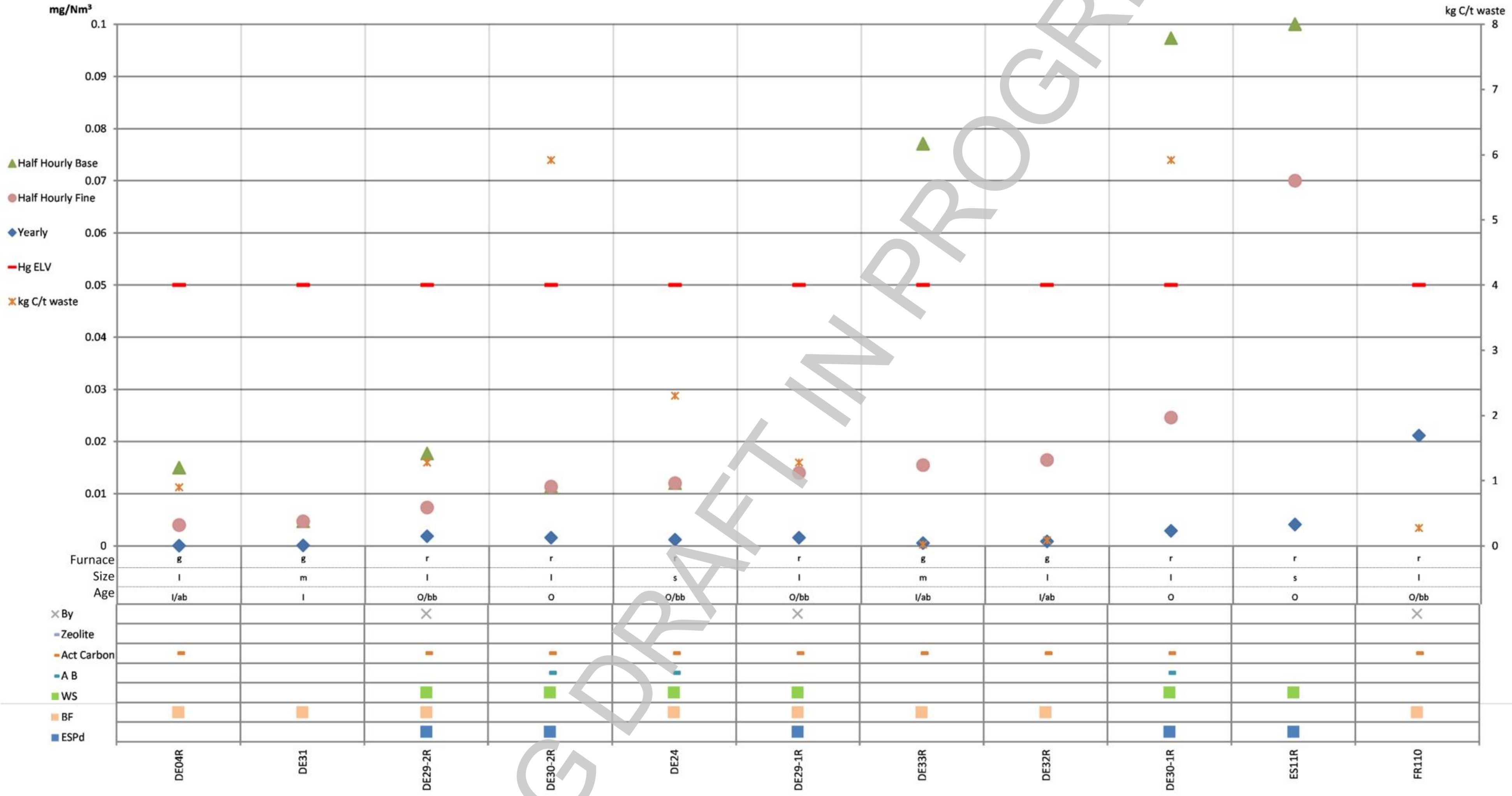
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: H2O2 = peroxide; Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.116:Discontinuously monitored Hg emissions to air from plants incinerating predominantly hazardous waste



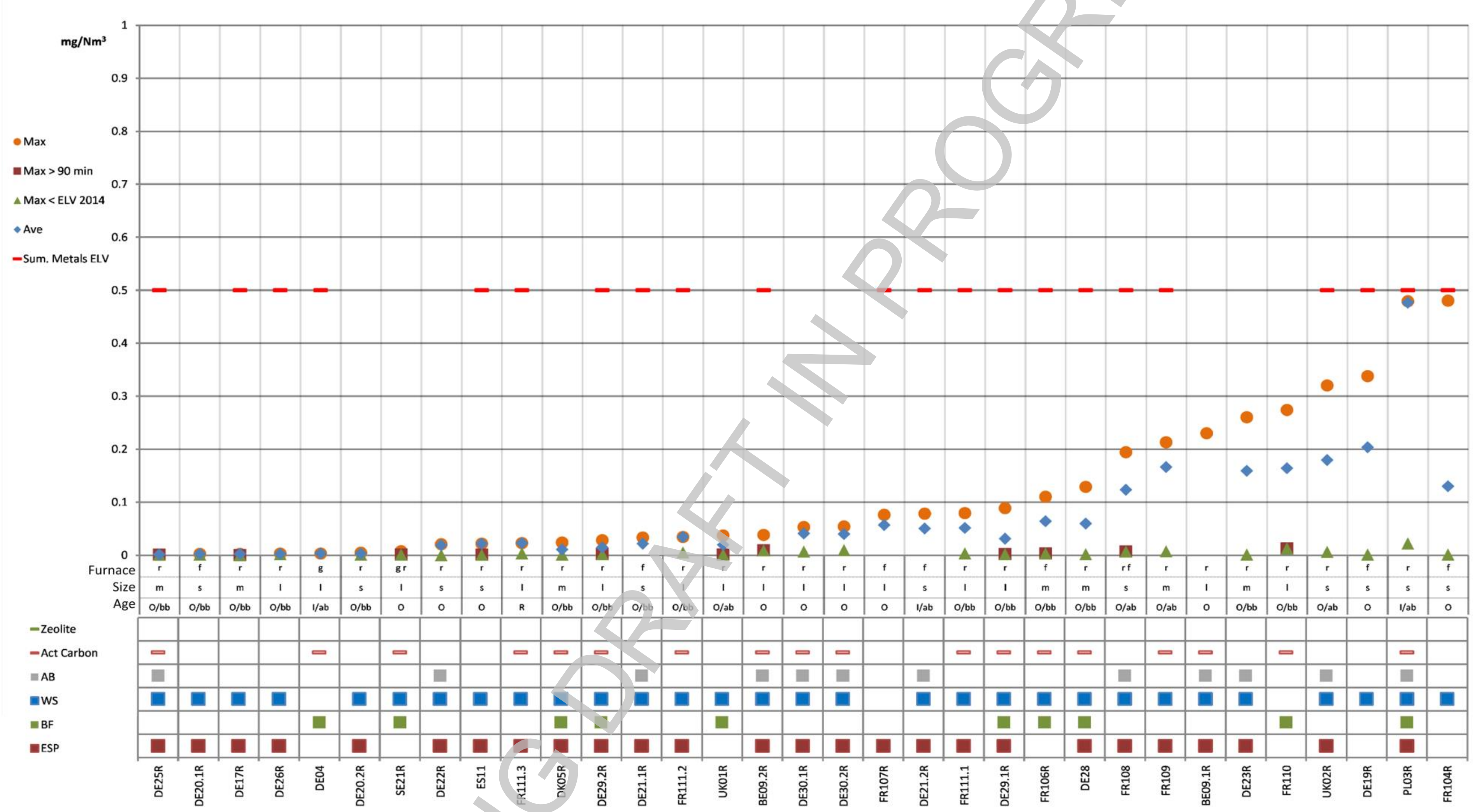
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.117:Continuously monitored Hg emissions to air from plants incinerating predominantly hazardous waste



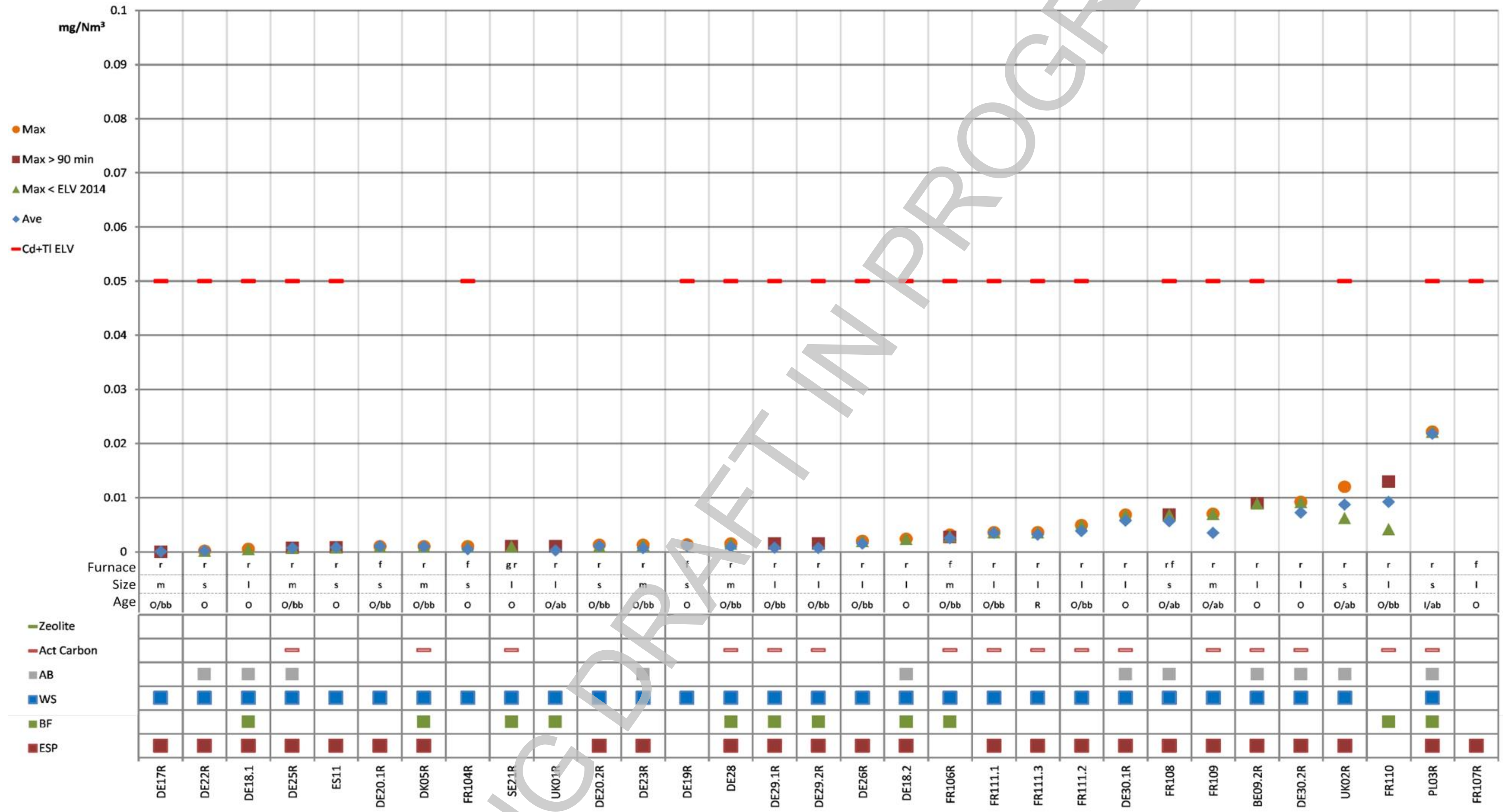
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
BY = ByPass.
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESPd = Dry Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.118:Half-hourly monitored Hg emissions to air from plants incinerating predominantly hazardous waste



Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.119: Discontinuously monitored Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V emissions to air from plants incinerating predominantly hazardous waste



Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Reagents Used: Act Carbon = Activated Carbon.
Techniques installed: AB = Adsorption Bed; WS = Wet Scrubber; BF = Bag Filter; ESP = Electrostatic precipitator.
Source: [81, TWG 2016].

Figure 3.120: Discontinuously monitored Cd+Tl emissions to air from plants incinerating predominantly hazardous waste

3.2.2.5 Emissions to air from the incineration of clinical waste

The 2016 data collection includes three reference lines incinerating predominantly clinical waste. Only one of them provided sufficiently complete continuous monitoring data.

Table 3.23 summarises the ercury nt monitored data from a clinical waste incineration plant.

Table 3.23: Continously monitored emissions from reference lines incinerating predominantly clinical waste

Ref. line	Techqniques	NO_X (mg/Nm^3)			CO (mg/Nm^3)			Dust (mg/Nm^3)		
		Max. Daily Base	Max. Daily Fine	Yearly	Max. Daily Base	Max. Daily Fine	Yearly	Max. Daily Base	Max. Daily Fine	Yearly
NL04	BF, WS, DSI, SCR	91.7	91.7	63.9	46.5	23.0	10.5	0.14	0.14	0.09
NB: NL04 is a gasification plant (plant age = Old installation / Plant size = small). Techniques installed: BF = Bag filter; WS = Wet scrubber; DSI = Dry sorbent injection; SCR = Selective catalytic reduction.										

The plant is a gasification plant fitted with a SCR for the reduction of NO_X formation, achieving a value under 100 mg/Nm^3 as a maximum daily average.

The yearly average CO emission level is 10.5 mg/Nm^3 and the maximum daily average is 23 mg/Nm^3 as obtained with 'fine' data filtering and 46.5 mg/Nm^3 with 'base' data filtering.

Reported dust emissions are extremely low and stable, with a minimal difference between the yearly average (0.09 mg/Nm^3) and the maximum daily average (0.14 mg/Nm^3). The reference line is fitted with a bag filter.

Table 3.24 and Table 3.25 summarise the discontinuously monitored emission data from the three reference lines incinerating predominantly clinical waste that participated in the 2016 data collection.

Table 3.24: Discontinuously monitored emissions from reference lines incinerating predominantly clinical waste (1)

Ref. line	Techniques	Reagents used	Hg (mg/Nm^3)		Cd+Tl (mg/Nm^3)		Sum. Metals (mg/Nm^3)		NH_3 (mg/Nm^3)	
			Max.	Avg.	Max.	Max.	Max.	Avg.	Max.	Avg.
UK14.1	BF, DSI	Lime, Active Carb.	0.02	0.0003	0.004	0.202	0.202	0.160	NI	NI
UK14.2	BF, DSI	Lime, Active Carb.	0.02	NI	0.004	0.202	0.202	NI	NI	NI
NL04	BF, WS, DSI, SCR	NI	0	NI	0	NI	0	NI	0	NI
NB: See Table 3.25. NI: No Information										

Table 3.25: Discontinously monitored emissions from reference lines incinerating predominantly clinical waste (2)

Ref. line	Techniques	Reagents used	HF (mg/Nm^3)		PCCD/F (ng I-TEQ/Nm^3)		PCBs (ng WHO-TEF/Nm^3)		PAH (µg/Nm^3)	
			Max	Ave	Max	Ave	Max	Ave	Max	Ave
UK14.1	BF, DSI	Lime, Active Carb.	1.2	0.4	0.02	0.006	0.011	0.006	3.2	1.9
UK14.2	BF, DSI.	Lime, Active Carb.	1.2	NI	0.02	NI	0.011	NI	3.2	NI
NL04	BF, WS, DSI, SCR	No info provided	0	NI	0.01	NI	NI	NI	NI	NI

NB:
NI: No Information
Emission data not provided: NH_3, BaP.
UK14.1 and UK 14.2 are reference lines with a furnace type = other, plant age = Old installation / retrofitting to the current configuration after 2006 and Size = small.
NL04 is a gasification plant (plant age = Old installation / Plant size = small).
Techniques installed: BF = Bag filter; WS = Wet scrubber; DSI = Dry sorbent injection; SCR = Selective catalytic reduction.

3.3 Emissions to water

3.3.1 Volumes of waste water arising from flue-gas treatment

[1, UBA, 2001]
The incineration process only produces a significant amount of waste water from ~~generally only arises to any significant degree from~~ wet FGC systems. Other types of flue-gas cleaning systems (dry and semi-dry) do not usually give rise to any effluent. *(From Section 2.6.1)* ~~Water is used in waste incineration for various purposes. Wet flue-gas cleaning systems give rise to waste water whereas semi-wet and dry systems generally do not.~~ In some cases the waste water from wet FGC systems is evaporated and in others it is treated and reused and/or discharged.

Table 3.26 shows examples of the typical quantities of scrubbing water arising from the flue-gas cleaning of waste incineration plants.

Table 3.26: Typical values of the amount of scrubbing water arising from FGC at waste incineration plants treating wastes with a low chlorine content

Plant type and waste throughput	Type of flue-gas cleaning	Approx. quantity of waste water (m^3/tonne of waste)
Municipal waste incineration plant with a throughput of 250 000 t/yr	2 stages, with lime milk	0.15 (design value)
Municipal waste incineration plant with a throughput of 250 000 t/yr	2 stages, with sodium hydroxide (before condensation facility)	0.3 (operating value)
Hazardous waste incineration plant with a throughput of 60 000 t/yr	2 stages, with lime milk	0.15 (annual average)
Hazardous waste incineration plant with a throughput of 30 000 t/yr	2 stages, with sodium hydroxide	0.2 (annual average)
Source: [1, UBA, 2001]		

3.3.2 Other potential sources of waste water from waste incineration plants

[1, UBA, 2001]
Besides the waste water from the flue-gas cleaning, waste water can also arise from a number of other sources. ~~Regional rainfall variations can have a great effect. Owing mainly to differences on installation design, not all of these waste water streams will arise at all plants and those given here are streams which may arise:~~
(From Section 2.6.1)

Bottom ash ~~waste water from~~ collection, treatment and ~~(open air-)~~ storage ~~of bottom ash~~

~~This type of~~ Waste water from ash handling activities can normally be reused as the water supply for a wet bottom ash discharger ~~de-slaggers~~, ~~and therefore, normally~~ so it will not need to be discharged. It is, however, important to have sufficient storage (and treatment) capacity, ~~in order to be able~~ to cope with fluctuations in storage levels caused by rainfall. Generally, the treatment options for excess water are: discharge to an available process waste water treatment system; discharge to the local sewerage system; and/or special disposal. This type of waste water can be reused in the FGC system if the quality is suitable, generally after treatment by sedimentation, filtration, etc.

Boiler operations ~~water other less specific process~~

~~For example,~~ Waste water from the boilers ~~water/steam cycle~~ (resulting from the preparation of boiler feed water and~~,~~ boiler drainage~~, and cooling water discharge~~) can normally~~. In many~~

~~practical situations, these water flows can~~ be reused in the incineration and ~~flue-gas treatment process~~ FGC system so it will not need to be discharged. ~~(e.g. as make-up water) and therefore will not lead to emissions to the environment.~~ However, the recycling of waste water to the FGC system is only possible in the case of semi-wet or wet systems if the quality ~~of waste water~~ is suitable; otherwise, the waste water is discharged (mainly due to the high salt content).

Sanitary waste water

This originates from toilets, kitchens and cleaning. It is normally discharged to the sewerage system, for treatment in a municipal ~~communal~~ waste water treatment plant. A septic tank may be used if connection to the local sewage system is not possible. ~~Here is no other possibility.~~ As this category of waste water is not specific for waste incineration, it is not discussed further in this document.

Clean rainwater

This arises from rain falling on non-polluted surfaces, such as roofs, service roads and parking places. Normally this 'clean' water is collected separately from process water and ~~discharged by a "clean" water collection system and is~~ discharged directly to the local surface water or via soakaways. Pretreatment may be required for rainwater from roads or parking areas.

Polluted rainwater

This arises from rain falling on polluted surfaces, such as unloading areas ~~activities etc)~~. It is usually segregated from clean rainwater and may be treated before use or discharge.

~~Used~~ Cooling water

By far the largest cooling capacity is required where water condenser cooling is used, i.e. for electricity production with a steam turbine. Depending on the design of the plant, various ~~types of~~ cooling water streams will need to be disposed of, including:
~~These include:~~

- water from convection cooling of the condenser, which is connected to the steam turbine;
- water drained off from an evaporation cooling water system~~, as used for condenser cooling~~;
- water from various other equipment ~~parts~~ which require cooling; waste chute, hydraulic systems, strippers, etc.

~~Because~~ These cooling water streams are not specific for waste incineration; they are described in the ~~discussed in the European~~ 'Reference document on the application of Best Available Techniques to Industrial Cooling Systems', published in December 2001.

Condensed waste water from the partial pre-drying of sewage sludge

This type of waste water is specific to sewage sludge incineration, although it does not arise in all cases as the steam generated during drying is sometimes evaporated with the incinerator flue-gas instead of being condensed. It generally has a high chemical oxygen demand (COD) and contains substantial concentrations of nitrogen (mainly NH_3), as well as other pollutants that were originally present in the treated sludge. The high nitrogen content can form a bottleneck for treatment; in this case stripping of nitrogen may be used, although there may be a risk of fouling and additional energy requirements for its operation. A solution in this case may be recycling into the furnace, when the recovered ammonia solution (concentration approximately 10 %) can be used for SNCR $deNO_X$ feed.

In Table 3.27 the amount of waste water generated from some of the sources described above is presented.

Table 3.27: Other possible waste water sources, and their approximate quantities, from waste incineration plants

Waste water	Approx. amount	Occurrence
Chimney condensates after wet scrubbing	- 20 m^3/d - 6 600 m^3/yr	Continuous
Wet ash removal/wet declining	- 5 m^3/d - 1 650 m^3/yr	
Reversible flow water from ion exchanger	- 1 $m^3/month$ - 120 m^3/yr	Discontinuous
Boiler water	- 500 m^3/yr	
Water from the cleaning of storage containers	- 800 m^3/yr	
Other cleaning water	- 300 m^3/yr	
Contaminated rainwater	- 200 m^3/yr (Germany)	
Laboratory water	- 200 m^3/yr	
NB: Data calculated on the basis of 330 operating days per year. *Source:* [1, UBA, 2001]		

3.3.3 Installations free of process water releases

[1, UBA, 2001]
In some incineration plants, waste water arising from wet gas scrubbing is evaporated in the incineration process using a spray dryer. This can eliminate the need for effluent releases from the process.

In such cases, the waste water is generally pretreated in an waste water treatment plant (WWTP) ~~Effluent Treatment Plant (ETP)~~, before it is fed to the spray dryer. Treatment in a~~n~~ WWTP ~~ETP~~ can help to prevent the recirculation and accumulation of some substances. Mercury recirculation is of particular concern, and specific reagents are usually added to provide a means for removal of mercury from the system.

Salt (NaCl) can be recovered from the treated effluent for possible industrial uses, or may be collected in the FGC residues.

3.3.4 Plants with ~~ercur-chemical~~ waste water discharges ~~treatment~~

[1, UBA, 2001]
The treatment of waste water from the flue-gas cleaning in waste incineration plants is not fundamentally different from the treatment of waste water from other industrial processes.

Waste water from municipal waste incineration plants mainly contains the following substances~~, which require treatment~~:

- ~~heavy~~ metals, including mercury;
- inorganic salts (chlorides, sulphates etc.) ;
- organic compounds (phenols, PCDD/F).

The following table shows typical contamination levels of waste water from flue-gas cleaning facilities of municipal and hazardous waste incineration plants before the treatment of waste water.

Table 3.28: Typical contamination of waste water from wet FGC facilities of waste incineration plants before treatment

Parameter	Municipal waste incineration			Hazardous waste incineration for common commercial plants		
	Minimum	**Maximum**	**Average**	**Minimum**	**Maximum**	**Average**
pH value	< 1		NA	No data	No data	n/a
Conductivity (μS)	No data	> 20 000	No data	No data	No data	No data
COD (mg/l)	140	390	260	No data	No data	22
TOC (mg/l)	47	105	73	No data	No data	No data
Sulphate (mg/l)	1 200	20 000	4 547	615	4 056	No data
Chloride (mg/l)	85 000	180 000	115 000	No data	No data	No data
Fluoride (mg/l)	6	170	25	7	48	No data
Hg (μg/l)	1 030	19 025	6 167	0.6	10	No data
Pb (mg/l)	0.05	0.92	0.25	0.01	0.68	No data
Cu (mg/l)	0.05	0.20	0.10	0.002	0.5	No data
Zn (mg/l)	0.39	2.01	0.69	0.03	3.7	No data
Cr (mg/l)	< 0.05	0.73	0.17	0.1	0.5	No data
Ni (mg/l)	0.05	0.54	0.24	0.04	0.5	No data
Cd (mg/l)	< 0.005	0.020	0.008	0.0009	0.5	No data
PCDD/F (ng/l)	No data	No data	No data	No data	No data	No data

NA: not applicable
Source: [1, UBA, 2001]

~~The following two tables show:~~

- ~~Table 3.29 shows the annual specific emissions to surface water and/or sewer from various waste incinerators in the Netherlands in 1999.~~
- ~~Table 3.30 shows the impact of waste water treatment on the effluent from a MSWI and provides a comparison of this performance with various standards.~~

~~Table 3.29: Releases to surface water and sewers from Dutch waste incinerators in 1999~~

~~Site~~	~~Incinerated~~	~~As~~	~~Cd~~	~~Cr~~	~~Cu~~	~~Hg~~	~~Pb~~	~~Ni~~	~~Zn~~	~~Chlorides~~	~~Sulphates~~	~~COD~~	~~N-Kjeldahl~~
	~~(kt/yr)~~	~~mg/t)~~	~~mg/t)~~	~~mg/t)~~	~~mg/t)~~	~~mg/t)~~	~~mg/t)~~	~~mg/t)~~	~~mg/t)~~	~~(g/t)~~	~~(g/t)~~	~~(g/t)~~	~~(g/t)~~
~~Municipal Waste Incineration~~													
~~Gevudo~~	~~171~~	~~23.2~~	~~9.1~~	~~17~~	~~115~~	~~3.04~~	~~72~~	~~39.9~~	~~552~~	~~4 990~~	~~2 070~~	~~298~~	~~46~~
~~AVR Rotterdam~~	~~386~~	~~0.5~~	~~0.3~~	~~5~~	~~6~~	~~0.10~~	~~9~~	~~8.6~~	~~4~~	~~n/a~~	~~n/a~~	~~15~~	~~1~~
~~AVR-Botlek~~	~~1 106~~	~~0.6~~	~~2.7~~	~~2~~	~~4~~	~~0.72~~	~~5~~	~~2.1~~	~~20~~	~~n/a~~	~~n/a~~	~~34~~	~~4~~
~~AVR-AVIRA~~	~~301~~	~~0.0~~	~~2.0~~	~~2~~	~~6~~	~~0.07~~	~~2~~	~~1.6~~	~~26~~		~~0~~	~~133~~	~~10~~
~~AVI Roosendaal~~	~~55~~	~~4.4~~	~~0.1~~	~~7~~	~~62~~	~~0.02~~	~~16~~	~~4.9~~	~~45~~	~~0~~	~~0~~	~~24~~	~~1~~
~~ARN~~	~~250~~	~~3.7~~	~~1.3~~	~~43~~	~~25~~	~~0.71~~	~~23~~	~~44.4~~	~~181~~	~~708~~	~~111~~	~~207~~	~~131~~
~~AVI Amsterdam~~	~~789~~	~~0.0~~	~~0.0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~		~~0~~	~~0~~	~~0~~
~~AVI Noord-~~	~~452~~	~~0.1~~	~~0.1~~	~~1~~	~~3~~	~~0.02~~	~~4~~	~~0.4~~	~~27~~	~~1~~	~~n/a~~	~~n/a~~	~~n/a~~
~~AVI Wijster~~	~~433~~	~~23.1~~	~~0.0~~	~~30~~	~~58~~	~~0.16~~	~~53~~	~~36.9~~	~~226~~	~~335~~	~~84~~	~~380~~	~~44~~
~~AZN~~	~~603~~	~~0.2~~	~~0.2~~	~~0~~	~~2~~	~~0.17~~	~~0~~	~~0.3~~	~~23~~	~~4 602~~	~~254~~	~~18~~	~~4~~
~~AVI Twente~~	~~285~~	~~n/a~~	~~0.0~~	~~0~~	~~0~~	~~n/a~~	~~0~~	~~0.0~~	~~1~~	~~2~~	~~n/a~~	~~12~~	~~1~~
~~Hazardous Waste Incineration~~													
~~AVR-Chemie DTs~~	~~44~~	~~4.6~~	~~4.6~~	~~14~~	~~25~~	~~6.84~~	~~23~~	~~18.3~~	~~228~~	~~n/a~~	~~n/a~~	~~319~~	~~26~~
~~Clinical Waste Incineration~~													
~~ZAVIN~~	~~7~~	~~191.1~~	~~632.1~~	~~658~~	~~2 694~~	~~4 391~~	~~11 680~~	~~459.0~~	~~72 830~~	~~n/a~~	~~n/a~~	~~658~~	~~16~~
~~Sewage Sludge Incineration~~													
~~DRSH~~	~~368~~	~~21.4~~	~~3.5~~	~~5~~	~~79~~	~~5.97~~	~~15~~	~~3.0~~	~~92~~	~~1 560~~	~~4 560~~	~~1 830~~	~~n/a~~
~~SNB~~	~~406~~	~~5.8~~	~~0.6~~	~~18~~	~~17~~	~~1.23~~	~~8~~	~~12.3~~	~~51~~	~~725~~	~~31~~	~~816~~	~~768~~
~~V.I.T.~~	~~89~~	~~1.9~~	~~1.5~~	~~3~~	~~14~~	~~0.51~~	~~19~~	~~6.0~~	~~56~~	~~n/a~~	~~56 080~~	~~155~~	~~30~~
~~*Source:* [2, infomil, 2002]~~													

~~**Table 3.30: Waste water quality (after treatment with Trimercaptotriazine) – Comparison between raw and treated waste water and various standards**~~

~~**Contaminant**~~	~~**Waste water**~~														
	~~**Limit values**~~			~~**Input**~~			~~**Treated effluent (Trimercaptotriazine add. 150 ml/m^3)**~~			~~**Input**~~			~~**Treated effluent (Trimercaptotriazine add. 55 ml/m^3)**~~		
				~~First stage wet scrubber 289 l/t waste input~~						~~Second stage scrubber 55 l/t waste input~~					
		~~German 33Abw~~	~~EC Dir. 2000/76~~	~~Range~~		~~Avg.~~	~~Range~~		~~Avg.~~	~~Range~~		~~Avg.~~	~~Range~~		~~Avg.~~
				~~Min.~~	~~Max.~~		~~Min.~~	~~Max.~~		~~Min.~~	~~Max.~~		~~Min.~~	~~Max.~~	
		~~mg/l~~	~~mg/l~~	~~mg/l~~	~~mg/l~~	~~mg/l~~	~~mg/l~~	~~mg/l~~	~~mg/l~~	~~mg/l~~	~~mg/l~~	~~mg/l~~	~~mg/l~~	~~mg/l~~	~~mg/l~~
~~pH~~				~~0.3~~	~~0.6~~	~~0.5~~	~~6.7~~	~~8.3~~	~~7.6~~	~~7.4~~	~~8.4~~	~~8.1~~	~~9.4~~	~~11.1~~	~~10.3~~
~~Susp. Solids~~	~~95 %~~ ~~100 %~~	~~30~~ ~~45~~	~~30~~ ~~45~~										~~1~~ ~~1~~	~~56 (1)~~ ~~56 (1)~~	~~23.8~~ ~~23.8~~
~~Hg~~		~~0.03~~	~~0.03~~	~~1.8~~	~~5.7~~	~~3.6~~	~~<0.001~~	~~0.013~~	~~0.01~~	~~0.04~~	~~1.42~~	~~0.82~~	~~<0.001~~	~~0.013~~	~~<0.003~~
~~Cd~~		~~0.05~~	~~0.05~~	~~<0.01~~	~~0.76~~	~~0.45~~	~~<0.01~~	~~<0.01~~	~~<0.01~~	~~0.1~~	~~0.62~~	~~0.37~~	~~<0.01~~	~~0.02~~	~~<0.01~~
~~Tl~~		~~0.05~~	~~0.05~~	~~<0.01~~	~~0.03~~	~~0.028~~	~~<0.01~~	~~0.013~~	~~<0.01~~	~~<0.01~~	~~0.02~~	~~0.016~~	~~<0.01~~	~~0.023~~	~~<0.013~~
~~As~~		~~0.15~~	~~0.15~~	~~<0.03~~	~~0.1~~	~~0.05~~	~~<0.05~~	~~<0.05~~	~~<0.05~~	~~<0.05~~	~~0.08~~	~~0.06~~	~~<0.03~~	~~<0.10~~	~~<0.04~~
~~Pb~~		~~0.1~~	~~0.2~~	~~1.2~~	~~24~~	~~8.8~~	~~0.03~~	~~1.2~~	~~0.13~~	~~0.7~~	~~9.2~~	~~3.5~~	~~<0.05~~	~~1.4 (2)~~	~~<0.11~~
~~Cr~~		~~0.5~~	~~0.5~~	~~0.46~~	~~1.3~~	~~0.7~~	~~<0.02~~	~~<0.02~~	~~<0.02~~	~~0.02~~	~~0.14~~	~~0.06~~	~~<0.02~~	~~0.03~~	~~<0.02~~
~~Cu~~		~~0.5~~	~~0.5~~	~~1.9~~	~~29~~	~~8.6~~	~~0.1~~	~~0.32~~	~~0.23~~	~~0.81~~	~~3.1~~	~~1.4~~	~~0.02~~	~~0.79 (3)~~	~~0.10~~
~~Ni~~		~~0.5~~	~~0.5~~	~~1.9~~	~~4.5~~	~~2.5~~	~~0.23~~	~~0.64~~	~~0.41~~	~~0.02~~	~~0.13~~	~~0.08~~	~~<0.02~~	~~0.83 (4)~~	~~<0.20~~
~~Zn~~		~~1.0~~	~~1.5~~	~~4.1~~	~~67~~	~~24~~	~~0.17~~	~~0.25~~	~~0.22~~	~~6.9~~	~~36~~	~~17~~	~~0.01~~	~~1.7 (5)~~	~~0.19~~
~~Dioxin~~	~~ng/l~~	~~0.3~~	~~0.3~~	~~In liquids~~		~~0.01~~			~~<0.01~~			~~<0.01~~			~~<0.01~~
~~Dioxin~~	~~ng/l~~			~~In solids~~		~~11.7~~			~~0.25~~			~~15.9~~			~~0.32~~

~~NB:~~
~~1. 1 in excess of 24 measurements in 2001~~
~~2. 5 in excess of 104 measurements 0.18 – 0.27 (1 x 1.4) mg/l in 2001~~
~~3. 2 in excess of 104 measurements 0.66 and 0.79 mg/l in 2001~~
~~4. 3 in excess of 104 measurements 0.57- 0.83 mg/l in 2001~~
~~5. 1 in excess of 104 measurements in 2001~~
~~*Source:* [52, Reimann, 2002]~~

~~3.3.5 Hazardous waste incineration plants – European survey data~~

~~[EURITS, 2002 #41]~~

This section describes the emissions to water arising from treated flue-gas waste water streams. ~~The data are taken from a survey of European merchant hazardous waste incinerators as reported by [EURITS, 2002 #41]~~.

The amount of information available is less than for emissions to air, reflecting the fact that most WI plants have no waste water emissions arising from the flue-gas cleaning system. The graphs show the maximum, the average and the minimum concentrations of the flow-proportional representative samples of the discharge over a period of 24 hours performed in 2014. The pollutant load emitted in 2014 is also shown.

The following contextual information is also shown in the graph: techniques in use relevant for the pollutant represented; prevalent waste burnt; plant size; plant age; number of samples considered for the emission values reported.

Water emissions are shown only for direct discharges.

~~3.3.5.1 General overview of emissions to water from European HWI~~

~~An overview of the yearly average minimum and maximum concentrations for the different installations is given in~~
~~Table~~ 3.31~~.~~

~~The concentration of most parameters varies a lot between the different installations, as does the water flow (expressed in litre per kilogram of waste incinerated).~~

~~Table 3.31: Annual average range of concentrations of the emissions to water after treatment from merchant hazardous waste installations that discharge waste water~~

~~**Parameter**~~ ~~all mg/l~~ ~~(unless stated)~~	~~**Yearly average**~~	
	~~**Minimum**~~	~~**Maximum**~~
~~Suspended solids~~	~~3~~	~~60~~
~~COD~~	~~<50~~	~~<250~~
~~Cd~~	~~0.0008~~	~~0.02~~
~~Tl~~	~~0.01~~	~~0.05~~
~~Hg~~	~~0.0004~~	~~0.009~~
~~Sb~~	~~0.005~~	~~0.85~~
~~As~~	~~0.0012~~	~~0.05~~
~~Pb~~	~~0.001~~	~~0.1~~
~~Cr~~	~~0.001~~	~~0.1~~
~~Co~~	~~<0.005~~	~~<0.05~~
~~Cu~~	~~0.01~~	~~0.21~~
~~Mn~~	~~0.02~~	~~0.2~~
~~Ni~~	~~0.004~~	~~0.11~~
~~V~~	~~<0.03~~	~~0.5~~
~~Sn~~	~~<0.02~~	~~<0.5~~
~~Zn~~	~~<0.02~~	~~0.3~~
~~Cl^-~~	~~3 000~~	~~72 000~~
~~SO_4^{2-}~~	~~300~~	~~1 404~~
~~Dioxins (ng TEQ/l)~~	~~0.0002~~	~~<0.05~~
~~Flow of water (l/kg waste)~~	~~0.2~~	~~20~~

~~*Source:* [EURITS, 2002 #41]~~

~~Table 3.32 below shows the emissions to water as the mass flow of these components in mg/kg of waste input:~~

~~Table 3.32: Mass flows of the emissions to water from surveyed merchant HWIs in Europe~~

	~~mg/kg waste incinerated)~~	
~~Parameter~~	**~~Minimum~~**	**~~Maximum~~**
~~Suspended solids~~	~~2.4~~	~~325~~
~~COD~~	~~76.5~~	~~1040~~
~~Cd~~	~~0.001~~	~~0.16~~
~~Hg~~	~~0.00048~~	~~0.112~~
~~Sb~~	~~0.0325~~	~~0.72~~
~~As~~	~~0.001~~	~~0.325~~
~~Pb~~	~~0.0084~~	~~0.65~~
~~Cr~~	~~0.0024~~	~~2~~
~~Co~~	~~0.045~~	~~0.325~~
~~Cu~~	~~0.0085~~	~~4.2~~
~~Mn~~	~~0.023~~	~~1~~
~~Ni~~	~~0.0042~~	~~2~~
~~V~~	~~0.325~~	~~0.6~~
~~Sn~~	~~0.09~~	~~0.565~~
~~Zn~~	~~0.0226~~	~~1.95~~
~~Cl~~	~~4 520~~	~~60 000~~
~~SO_4^{2}~~	~~240~~	~~6 572~~
~~*Source:* [EURITS, 2002 #41]~~		

~~3.3.5.2 Overview by parameter of emissions to water from European HWI~~

Total suspended solids

Figure 3.121 ~~In the graph below~~ shows the TSS emissions to water measured in 2014. ~~Yearly average values for suspended solids released for all of the surveyed installations are given as suspended solids in mg/l effluent.~~

For each installation, the type of waste water treatment technique in use for the reduction of suspended solids is shown; these are:

- ~~the use of a sand~~ filtration; ~~or~~
- sedimentation; ~~the separate treatment of the acidic and alkali scrubber waters – in this case no forced precipitation, nor post precipitation of $CaSO_4$ is performed, and higher loads of sulphate are discharged~~
- flotation;
- coagulation;
- flocculation;
- no additional water treatment step specific for the reduction of TSS emissions.

~~From the graph on heavy metals (Figure 3.99) it can be seen that these metals are only a marginal constituent of the suspended solids.~~

The residual suspended solids in the discharged effluent may have the following three main origins:

- residual fractions of the precipitated components which are not removed by decantation or filtration;

- when groundwater containing Fe(II) is used in wet flue-gas cleaning, a slow oxidation of Fe(II) to Fe(III) and subsequent precipitation of $Fe(OH)_3$ can result in suspended solids where the residence time in the waste water treatment plant is shorter than the time the reaction needs to be completed;
- in other cases, the suspended solids can originate from post-precipitation reactions of sulphates and carbonates with Ca^{2+} which is present in the effluent or in other water streams which come into contact with the effluent before discharge and when the residence time is shorter than the time the reaction needs to be completed.

The emission levels range between close to the limit of quantification and 25 mg/l as an average of all the measurements in 2014 and 43 mg/l as a maximum. Three plants reported higher maximum emissions.

The reported data do not show a clear correlation between the achieved emission levels and the size of the plant, the prevalent type of waste incinerated, or the applied techniques. However, it can be noted that lower emission levels are achieved by plants fitted with filtration (three plants have an average below 3 mg/l).

~~General conclusions from the graph:~~

- ~~all the installations perform below 60 mg/l~~
- ~~the installations that have separate treatments for the acidic and alkali scrubber waters achieve the lowest emissions of suspended solids (3 mg/l)~~.

Mercury

Figure 3.122 ~~the graph below,~~ shows the mercury emissions to water measured in 2014 ~~yearly average mercury values for all installations are given~~. ~~And given as:~~

- ~~the average concentration in mg/l, for 24 hour representative samples for continuous discharge (90 % of installations) or for batch representative samples for batch discharge (10 % of installations)~~
- ~~the 95 percentile in mg/l, if daily values or several values a week are available~~
- ~~the 99 percentile in mg/l, if daily values or several values a week are available.~~

~~For five of the waste water streams, Hg is measured daily (or several times a week) and for four installations data are obtained weekly or monthly. It can be concluded that the data in the graph are representative of a complete working year.~~

For each installation, the type of waste water treatment technique in use for the reduction of ~~is shown, so far as it has an influence on~~ mercury is shown; these are ~~emissions. In this case, there is~~:

- chemical precipitation;
- ion exchange;
- adsorption;
- filtration and sand filtration;
- sedimentation;
- flocculation;
- coagulation;
- ~~the precipitation of mercury as a M-sulphide or a M-trimercaptotriazine component~~
- ~~the precipitation as M-sulphide component and subsequently the use of an activated carbon filter~~
- no additional water treatment step specific for the reduction of mercury emissions.

Mercury in the effluent originates~~, of course,~~ from mercury contained in the waste. It is common practice that incinerators apply an input limit for the content of mercury in the waste incinerated ~~over a time period~~.
For one installation incinerating hazardous waste and equipped with wet gas scrubbing, it is calculated that the total mercury input via the waste amounts to 2 000 kg/yr ~~for an installation~~ with an incineration capacity of 100 000 t/yr. Taking into account a maximum yearly emitted mercury flow via the waste water of less than 4 kg/yr, a removal efficiency higher than 99.8 % can be reached based on M-trimercaptotriazine precipitation and subsequent efficient removal of the precipitate.

The emission levels range between close to the limit of quantification and 0.006 mg/l as an average and 0.027 mg/l as a maximum. Higher emissions have been reported by six plants, probably because they use a different unit to express the concentration of this pollutant.

The graph shows that plants fitted with ion exchange and/or adsorption generally achieve lower emission levels (mostly below 0.001 mg/l as an average and 0.004 mg/l as a maximum). In general, plants incinerating predominantly hazardous waste have higher emissions than plants incinerating the other types of waste.

The reported data do not show a clear correlation between the achieved emission levels and the size of the plant.

~~General conclusions from the graph:~~

- ~~all the installations perform below 0.01 mg/l~~
- ~~the 95 and 99 percentile values vary from one installation to another~~
    ~~in three cases occasional peak values of Hg are detected (average <P95 <P99) which can amount to 50 µg/l and higher; the reason for this is unexpected situations, e.g. unexpectedly high input or failures of the treatment installation~~
    ~~in two cases no peak values are detected (P99= P95 = average); the reason for this is in one case that discharges are made periodically and not continuously, and in the other case the fact that no Hg is present in the raw alkaline scrubber water~~
- ~~there is no direct relationship visible between the abatement technique and the annual average emission of mercury.~~

Metal and metalloid emissions

~~In the graph below the yearly average metal emissions for all installations are given and given as:~~

- ~~average concentrations in mg/l, for 24 hour representative samples in the case of continuous discharges (90 % of installations) or for batch representative samples in the case of batch discharges (10 % of installations)~~
- ~~the 95 percentile in mg/l, if daily values or several values a week are available~~
- ~~the 99 percentile in mg/l, if daily values or several values a week are available.~~

Metals in the effluent originate from the metals contained in the waste. The waste water treatment technique used to decrease the metal emissions consists of chemical precipitation of metals as hydroxides and/or as metal sulphide components. Flocculation additives are used to optimise the precipitation. Filtration is generally used in addition to coagulation and sedimentation or chemical precipitation. For further reduction of their concentration, adsorption and ion exchange are used.

Source: [41, EURITS, 2002]

~~Figure 3.12: Graph of annual average discharges of various metals to water at European HWIs~~

~~General conclusions from the graph:~~

- ~~almost all the individual metal emissions are below 0.1 mg/l~~
- ~~only higher values are registered for Zn and Cu in specific cases.~~

~~In the following graphs a more detailed overview is given per parameter with 95- and 99-percentile values. From these graphs it can be seen that, in some cases, higher values are sometimes registered.~~

Figure 3.123 shows antimony emissions to water measured in 2014.

Only 13 plants have reported data on direct antimony emission to water. Almost half of them are Austrian plants. The emission levels range between close to the limit of quantification and 0.6 mg/l as an average of all the measurements in 2014 and 0.9 mg/l as a maximum. Three plants reported higher emissions.

The reported data do not show a clear correlation between the achieved emission levels and the size of the plant or the applied techniques. However, it can be noted that higher emission levels are reported by plants incinerating hazardous waste (two plants have a maximum between 0.9 mg/l and 20 mg/l).

Figure 3.124 shows arsenic emissions to water measured in 2014.

The emission levels range between close to the limit of quantification and 0.06 mg/l as an average of all the measurements in 2014 and 0.3 mg/l as a maximum. Five plants reported higher emissions, probably because they reported the data in a different unit.

The reported data show that larger plants achieve lower emissions than medium or smaller plants. The reported data do not show a clear correlation between the achieved emission levels and the prevalent type of waste incinerated or the size of the plant. It can be noted that, in general, lower emission levels are reported by plants using adsorption.

Figure 3.125 shows cadmium emissions to water measured in 2014.

The emission levels range between close to the limit of quantification and 0.03 mg/l as an average of all the measurements in 2014 and 0.07 mg/l as a maximum. Four plants reported higher maximum emissions, probably because they reported the data in a different unit. *(To the TWG: please check)*

The reported data do not show a clear correlation between the achieved emission levels and the size of the plant, the prevalent type of waste incinerated, or the applied techniques.

Figure 3.126 shows chromium emissions to water measured in 2014.

The emission levels range between close to the limit of quantification and 0.16 mg/l as an average of all the measurement in 2014 and 0.21 mg/l as a maximum. Three plants reported higher maximum emissions, probably because they reported the data in a different unit. *(To the TWG: please check)*

The reported data do not show a clear correlation between the achieved emission levels and the size of the plant, the prevalent type of waste incinerated, or the applied techniques.

Figure 3.127 shows copper emissions to water measured in 2014.

The emission levels range between close to the limit of quantification and 0.3 mg/l as an average of all the measurement in 2014 and 0.5 mg/l as a maximum. Four plants reported higher maximum emissions, probably because they reported the data in a different unit. *(To the TWG: please check)*

The graph shows that plants using adsorption and/or ion exchange generally achieve emission levels below 0.5 mg/l.

The reported data do not show a clear correlation between the achieved emission levels and the size of the plant or the prevalent type of waste incinerated.

Figure 3.128 shows lead emissions to water measured in 2014.

The emission levels range between close to the limit of quantification and 0.2 mg/l as an average of all the measurement in 2014 and 0.5 mg/l as a maximum. Four plants reported higher maximum emissions, probably because they reported the data in a different unit. *(To the TWG: please check)*

The graph shows that plants using adsorption and ion exchange generally achieve emission levels below 0.05 mg/l.

The reported data do not show a clear correlation between the achieved emission levels and the size of the plant or the prevalent type of waste incinerated.

Figure 3.129 shows molybdenum emissions to water measured in 2014.

Only three plants have reported data on direct molybdenum emission to water. The emission levels range between 0.02 mg/l and 0.4 mg/l as a maximum of all the measurements in 2014.

The reported data do not show a clear correlation between the achieved emission levels and the size of the plant, the applied techniques or the prevalent type of waste incinerated.

Figure 3.130 shows nickel emissions to water measured in 2014.

The emission levels range between close to the limit of quantification and 0.4 mg/l as an average of all the measurements in 2014 and 0.8 mg/l as a maximum. Two plants reported higher maximum emissions, probably because they reported the data in a different unit. *(To the TWG: please check)*

The reported data do not show a clear correlation between the achieved emission levels and the applied techniques, the size of the plant or the prevalent type of waste incinerated.

Figure 3.131 shows thallium emissions to water measured in 2014.

The emission levels range between close to the limit of quantification and 0.025 mg/l as an average of all the measurement in 2014 and 0.05 mg/l as a maximum. Two plants reported higher maximum emissions, probably because they reported the data in a different unit.

The reported data do not show a clear correlation between the achieved emission levels and the applied techniques, the size of the plant or the prevalent type of waste incinerated.

Figure 3.132 shows zinc emissions to water measured in 2014.

The emission levels range between close to the limit of quantification and 0.45 mg/l as an average of all the measurements in 2014 and 3.5 mg/l as a maximum. Three plants reported higher maximum emissions, probably because they reported the data in a different unit. *(To the TWG: please check)*

The graph shows that plants using adsorption and ion exchange generally achieve emission levels below 0.4 mg/l.

The reported data do not show a clear correlation between the achieved emission levels and the size of the plant or the prevalent type of waste incinerated.

Total organic carbon (TOC)

In order to reduce emissions to water of TOC, primary techniques (e.g. reduction of the emitted load of organic carbon by optimisation of the incineration process) are applied. In addition to these, adsorption with activated carbon and filtration are also used as specific techniques for the abatement of TOC, .

Figure 3.133 shows TOC emissions to water measured in 2014.

The emission levels range between 1.4 mg/l and 12 mg/l as an average of all the measurements in 2014 and 38 mg/l as a maximum. One plant reported an average of 364 measurements of 6.4 mg/l and a maximum of 86 mg/l.

The graph shows that plants using a combination of adsorption and filtration achieve emission levels about 9 mg/l.

The reported data do not show a clear correlation between the achieved emission levels and the size of the plant or the prevalent type of waste incinerated.

Polychlorinated dibenzo-dioxins and furans (PCDD/F)

In order to reduce the water emissions of PCDD/F, primary techniques such as the optimisation of the incineration process and/or avoidance of the conditions for *de novo* synthesis are applied. In addition to these, adsorption with activated carbon is also used as a specific technique for the abatement of PCDD/F.

Figure 3.134 shows PCDD/F emissions to water measured in 2014.

The emission levels range between close to the limit of quantification and 0.09 ng/l as an average of all the measurements in 2014 and 0.35 ng/l as a maximum.

The graph shows that plants using microfiltration achieve emission levels about 0.009 ng/l.

The reported data do not show a clear correlation between the achieved emission levels and the size of the plant or the prevalent type of waste incinerated.

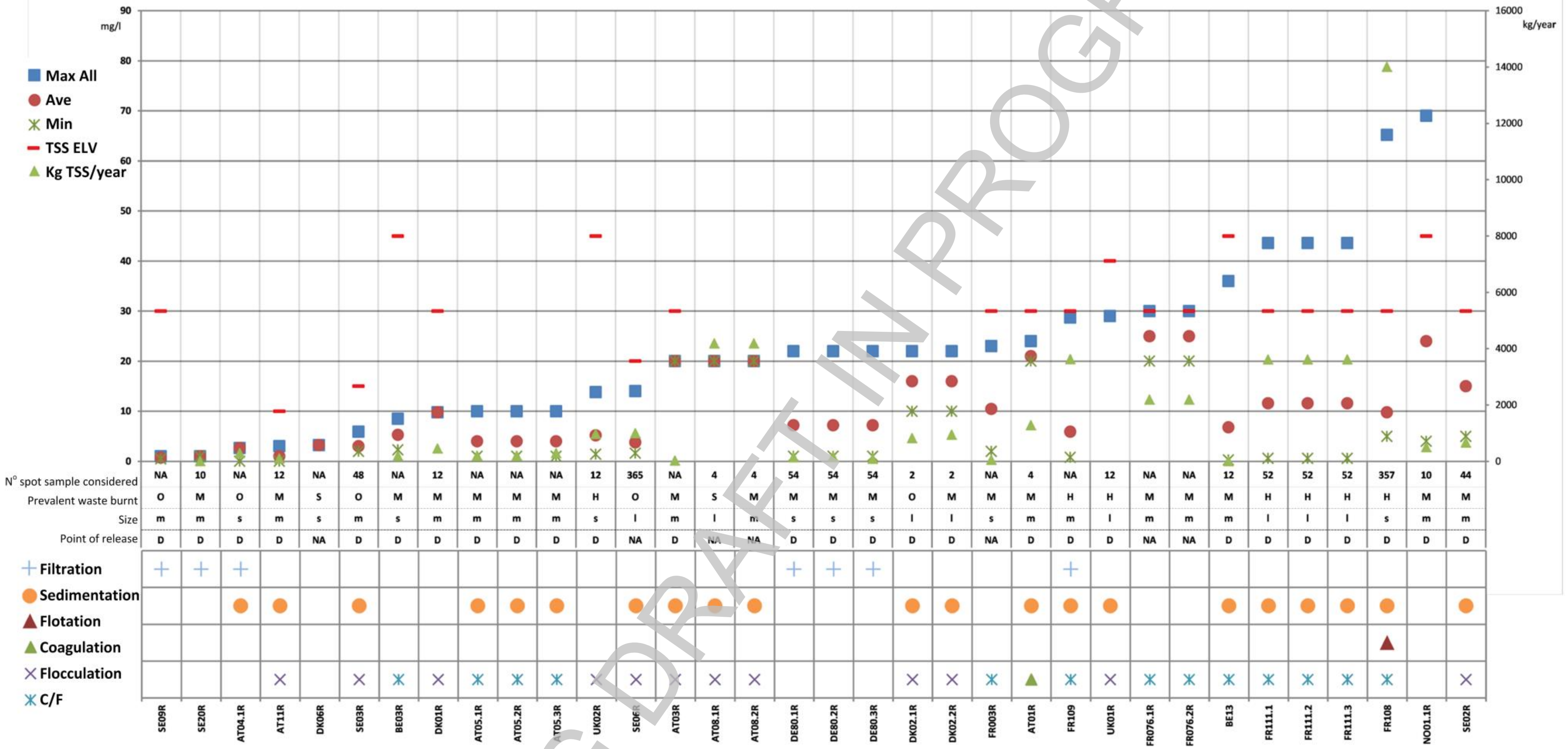
Chloride and sulphate content

[EURITS, 2002 #41] The amount of **chloride** in the effluent demonstrates a linear relationship to the amount of chlorine in the waste in the input to the incinerator. ~~Most incinerators discharge their waste water into, or near, the sea. A concentration of 3 – 72 g/l of effluent is quoted.~~

~~One surveyed installation discharges the effluent containing salt into the fresh water of a river.~~

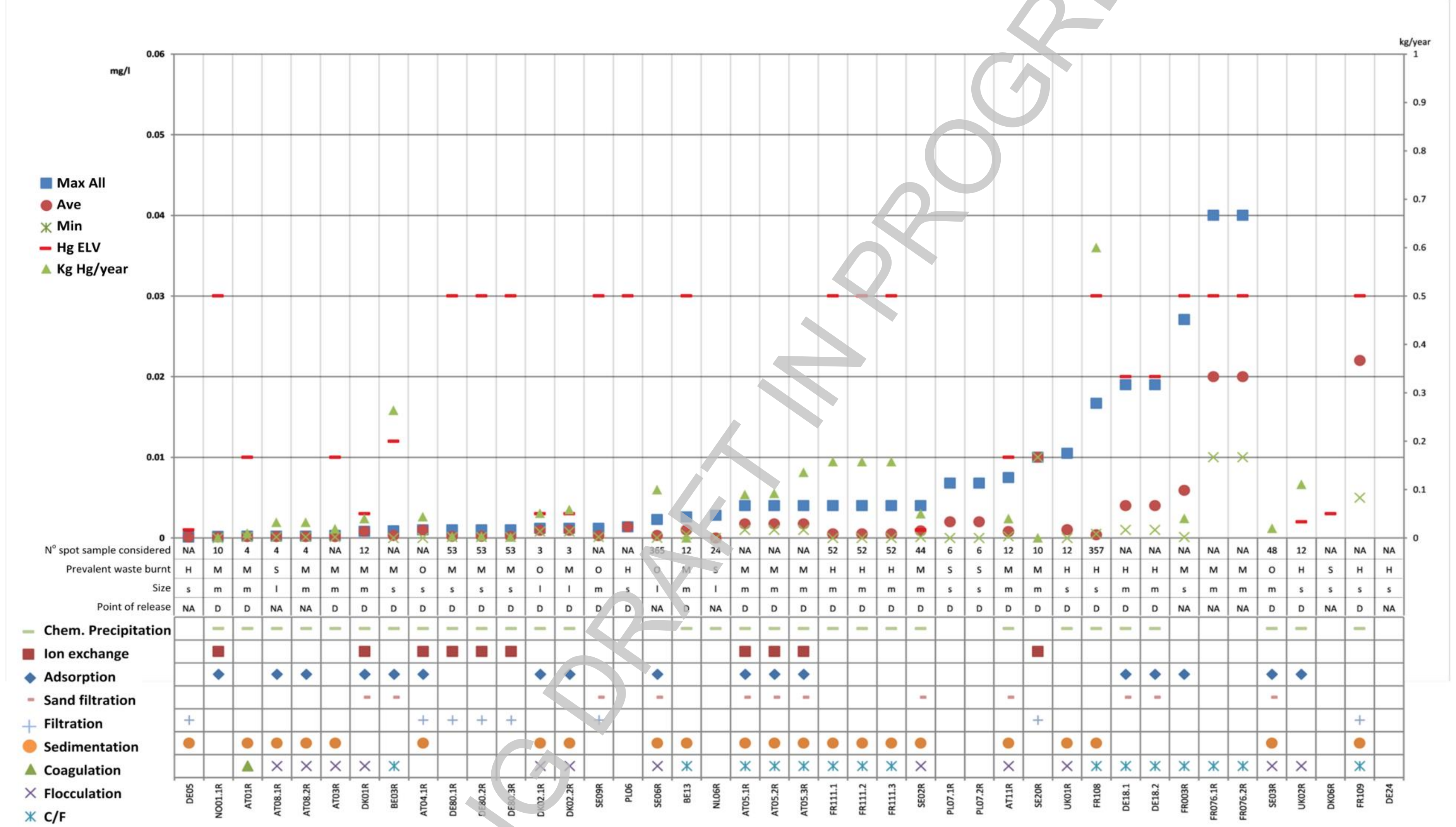
The **sulphate** content in the effluent is reduced ~~controlled~~ in most installations by the partial precipitation of gypsum, so the discharged concentration of SO_4^{2-} is between 1 g/l and 2 g/l [83 WI BREF 2006].

~~There is one installation which treats the acidic and alkali scrubber waters separately, without precipitation of gypsum, leading to a higher load of sulphate, which is discharged to the sea in this case.~~



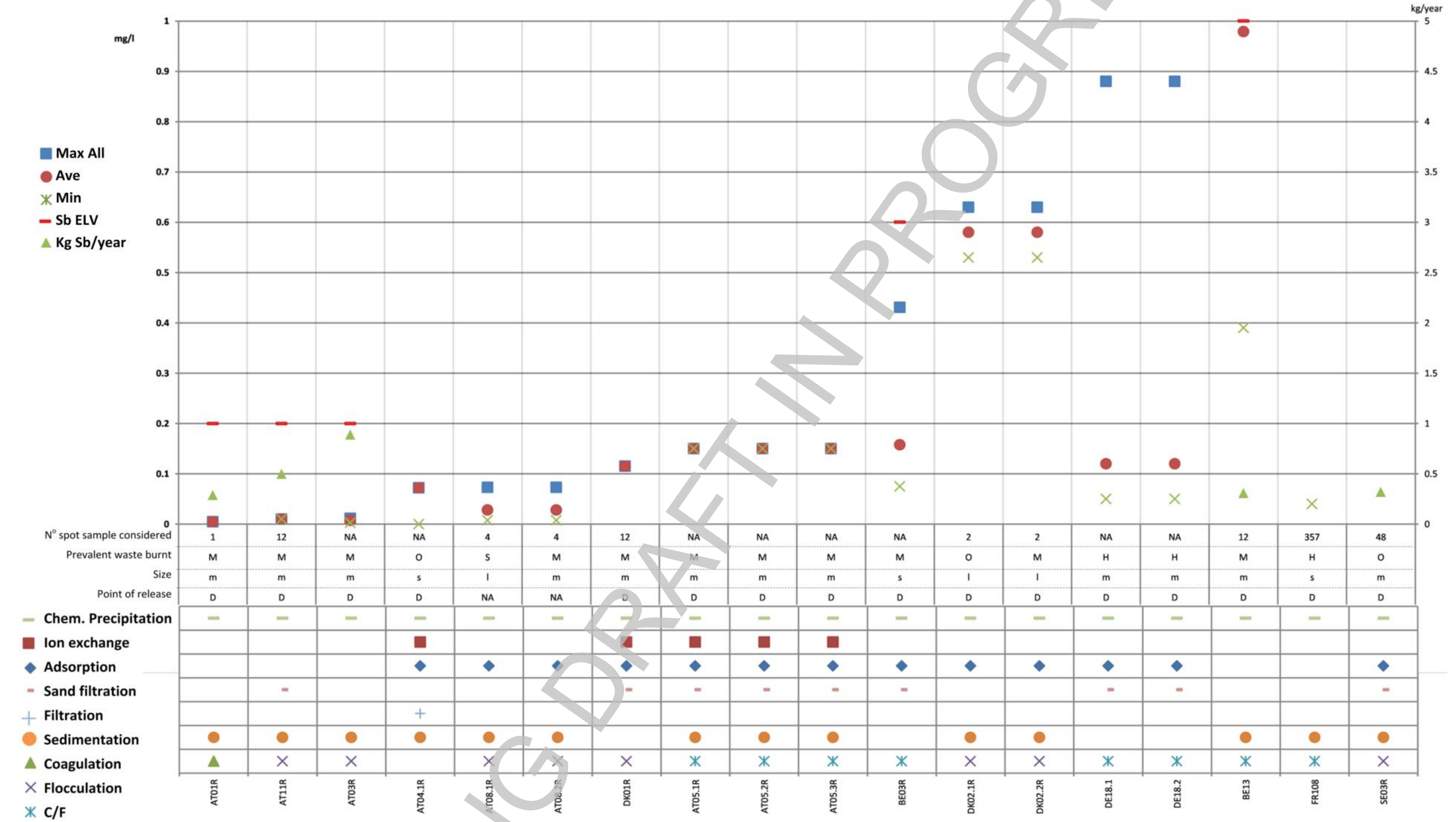
Note:
N° spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.121:~~Graph of annual average~~ Total suspended solid emissions ~~discharges~~ to water and abatement techniques applied ~~at European HWIs~~



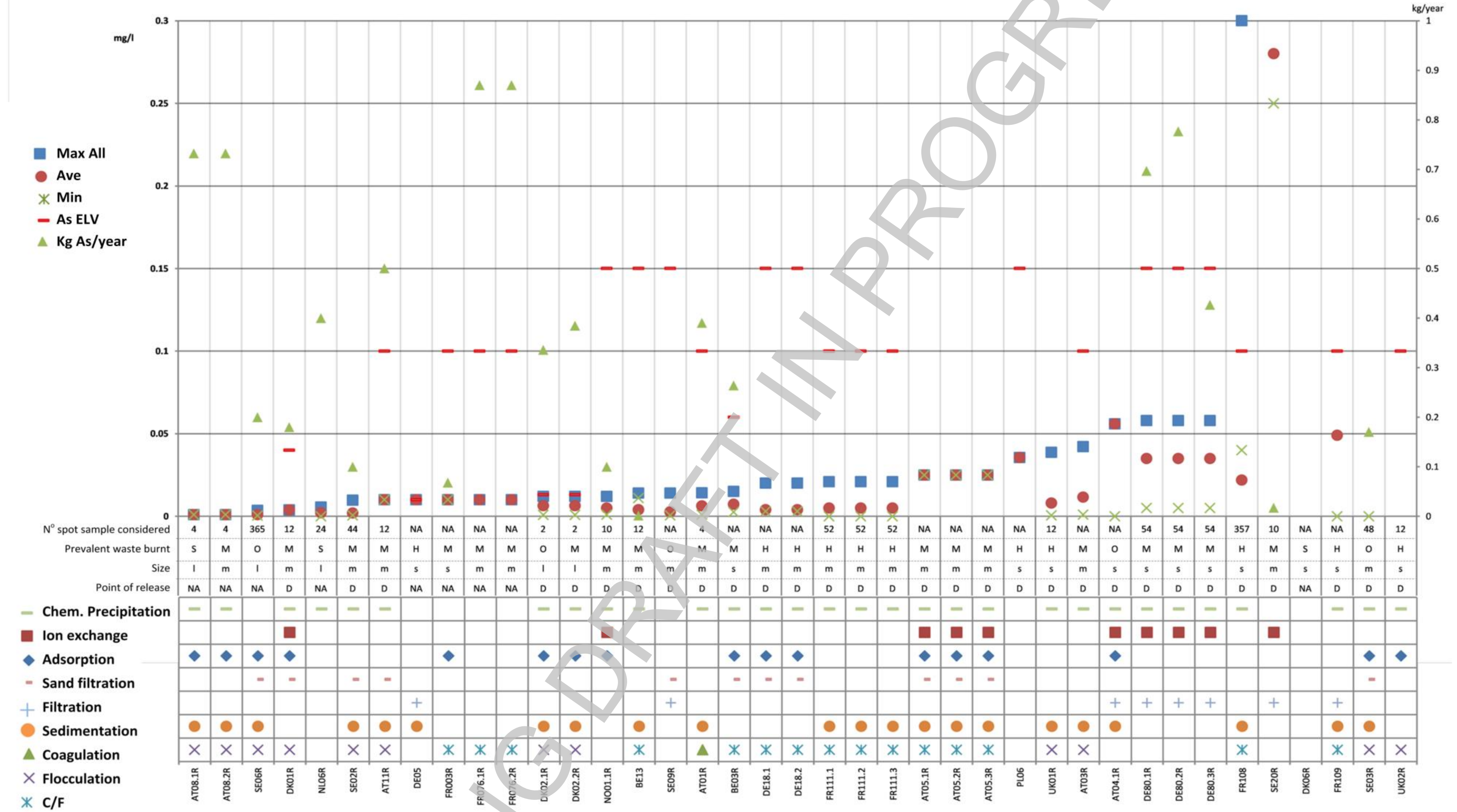
Note:
Nº spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.122:~~Graph of annual average~~ Mercury emissions ~~discharges~~ to water and abatement techniques applied ~~at European HWIs~~



Note:
Nº spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

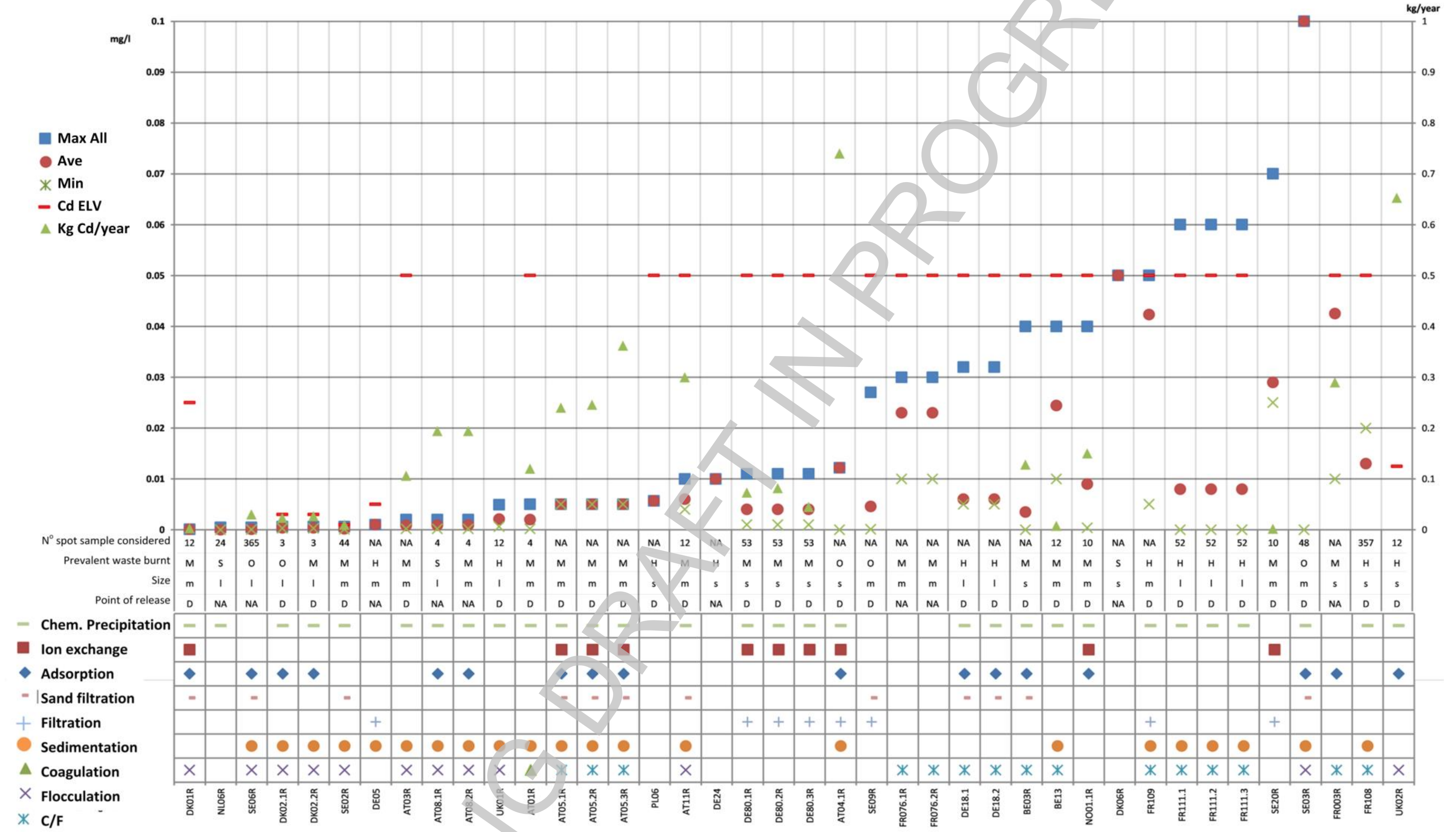
Figure 3.123:~~Graph of~~ Antimony emissions to water and abatement techniques applied



Note:
N° spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation

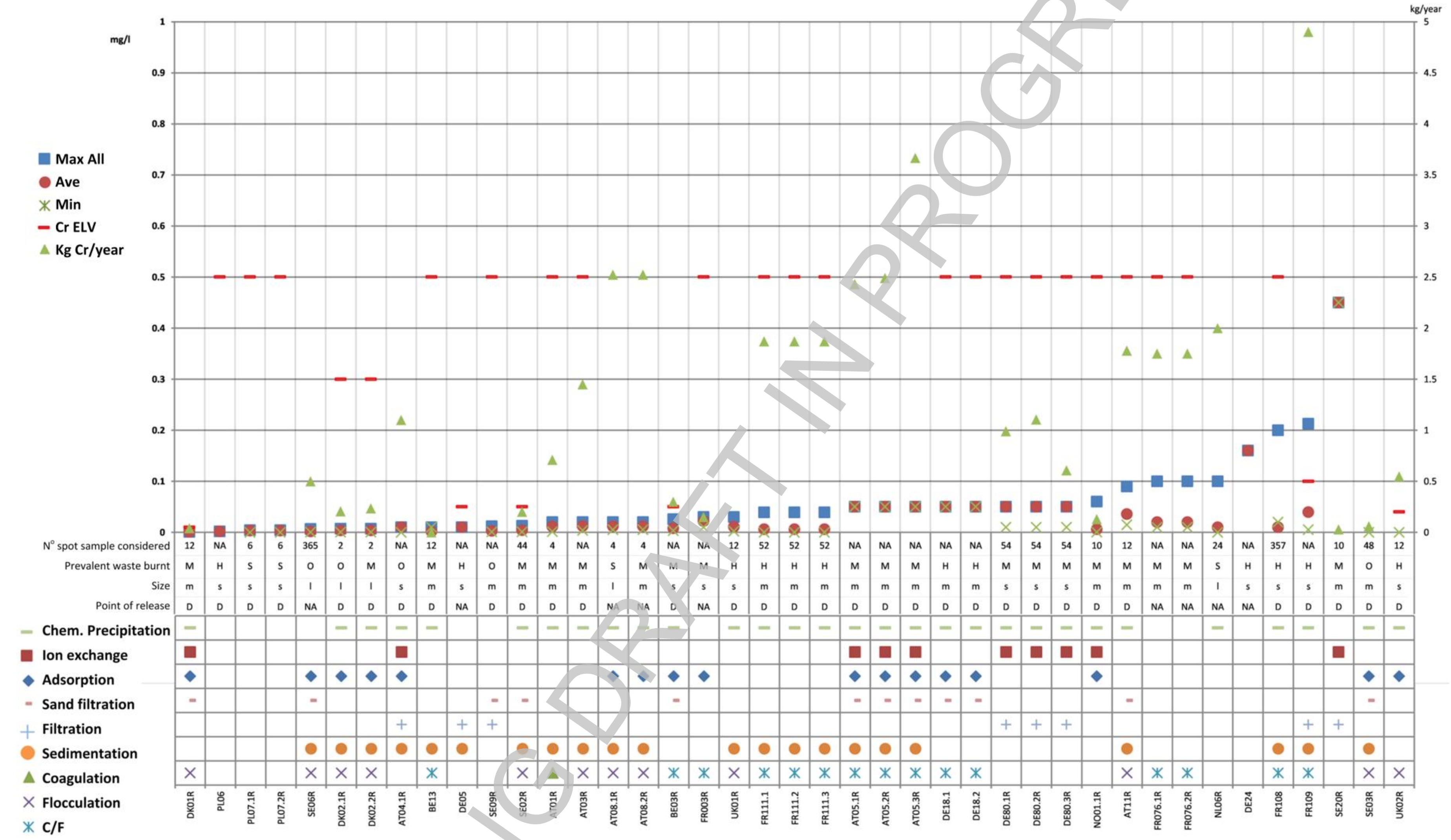
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.124:~~average~~ Arsenic emissions ~~discharges~~ to water and abatement techniques applied ~~at European HWIs~~



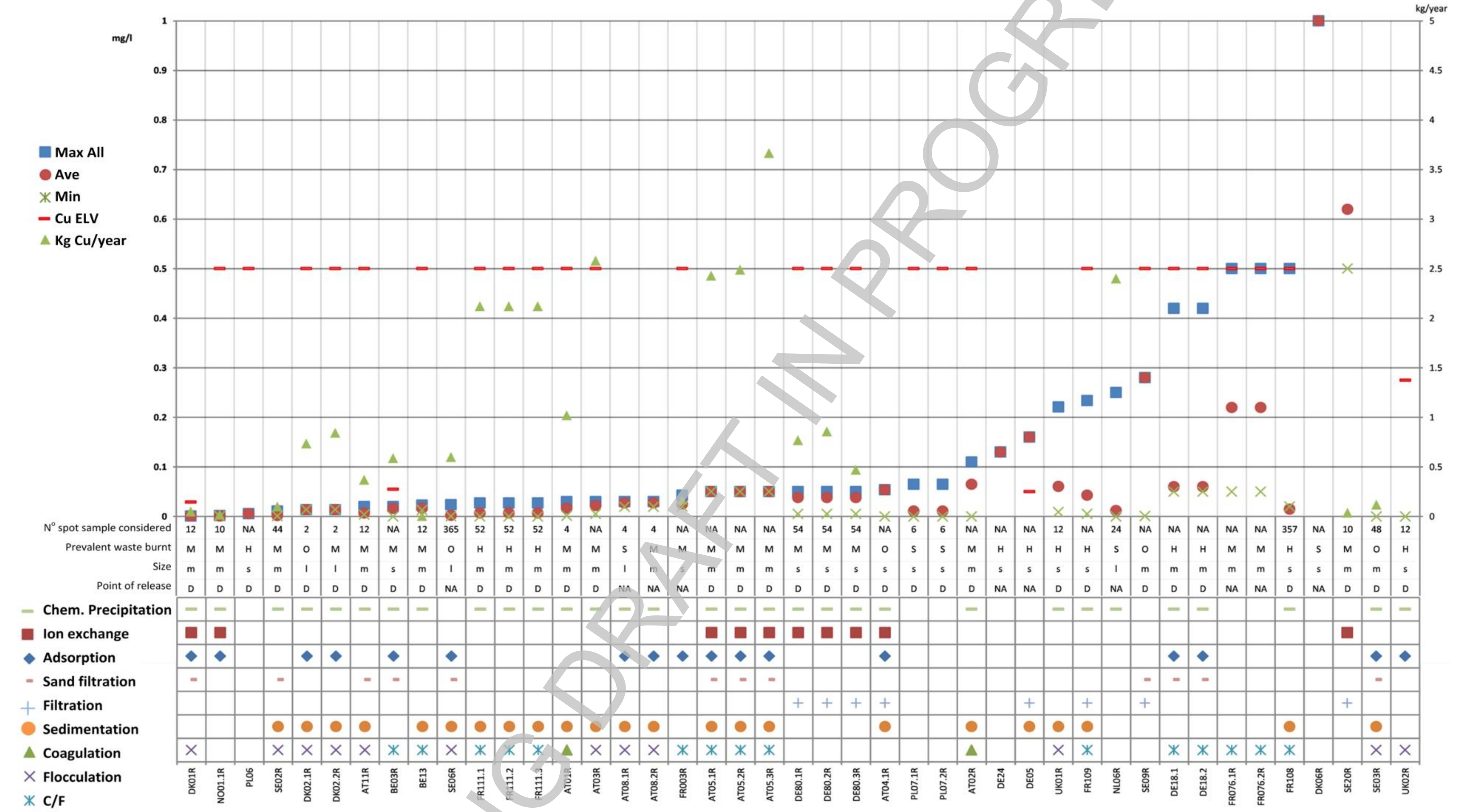
Note:
Nº spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.125:~~annual average~~ Cadmium emissions ~~discharges~~ to water and abatement techniques applied ~~at European HWIs~~



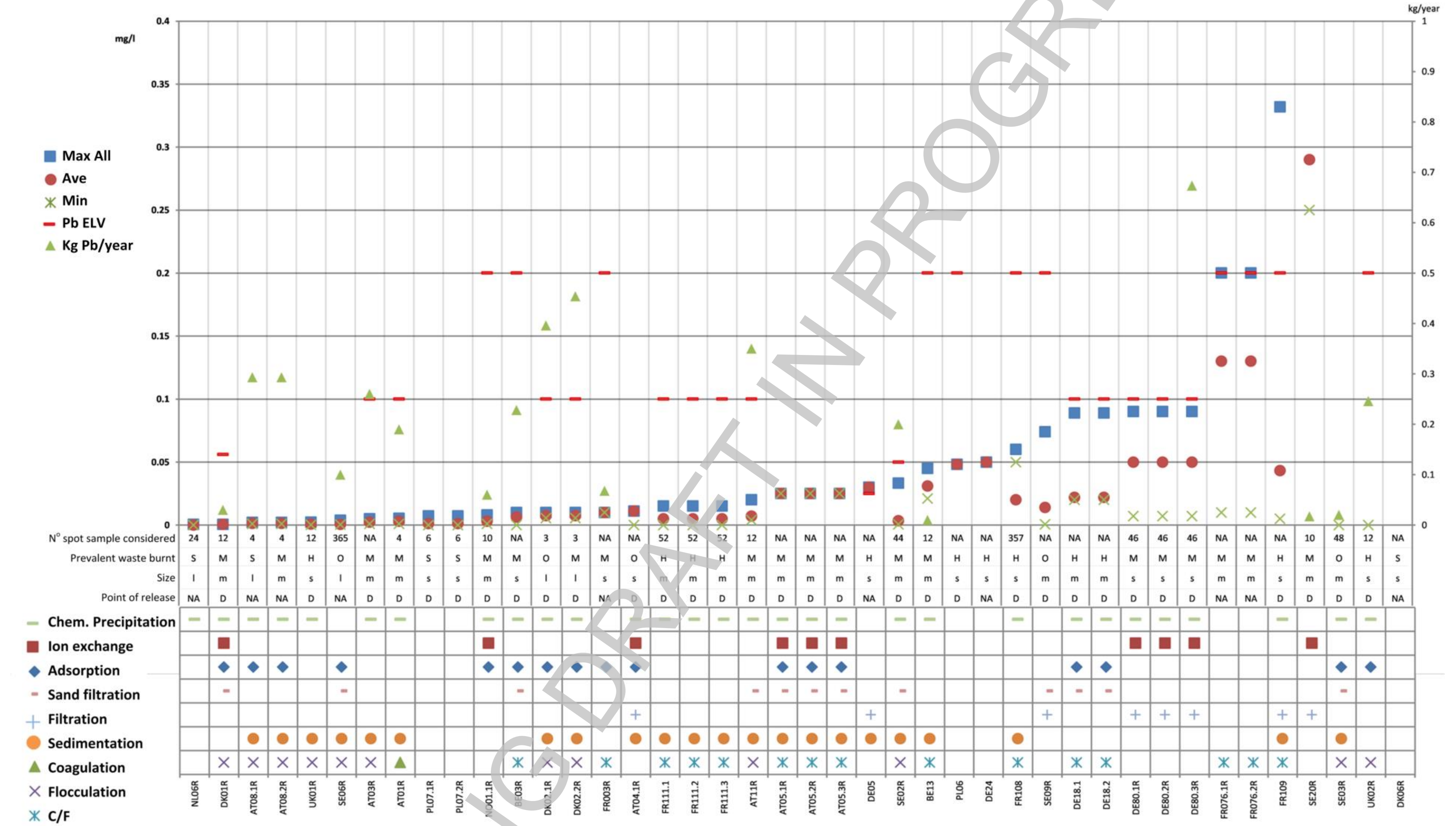
Note:
Nº spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.126:~~annual average~~ Chromium ~~discharges~~ emissions to water and abatement techniques applied ~~at European HWIs~~



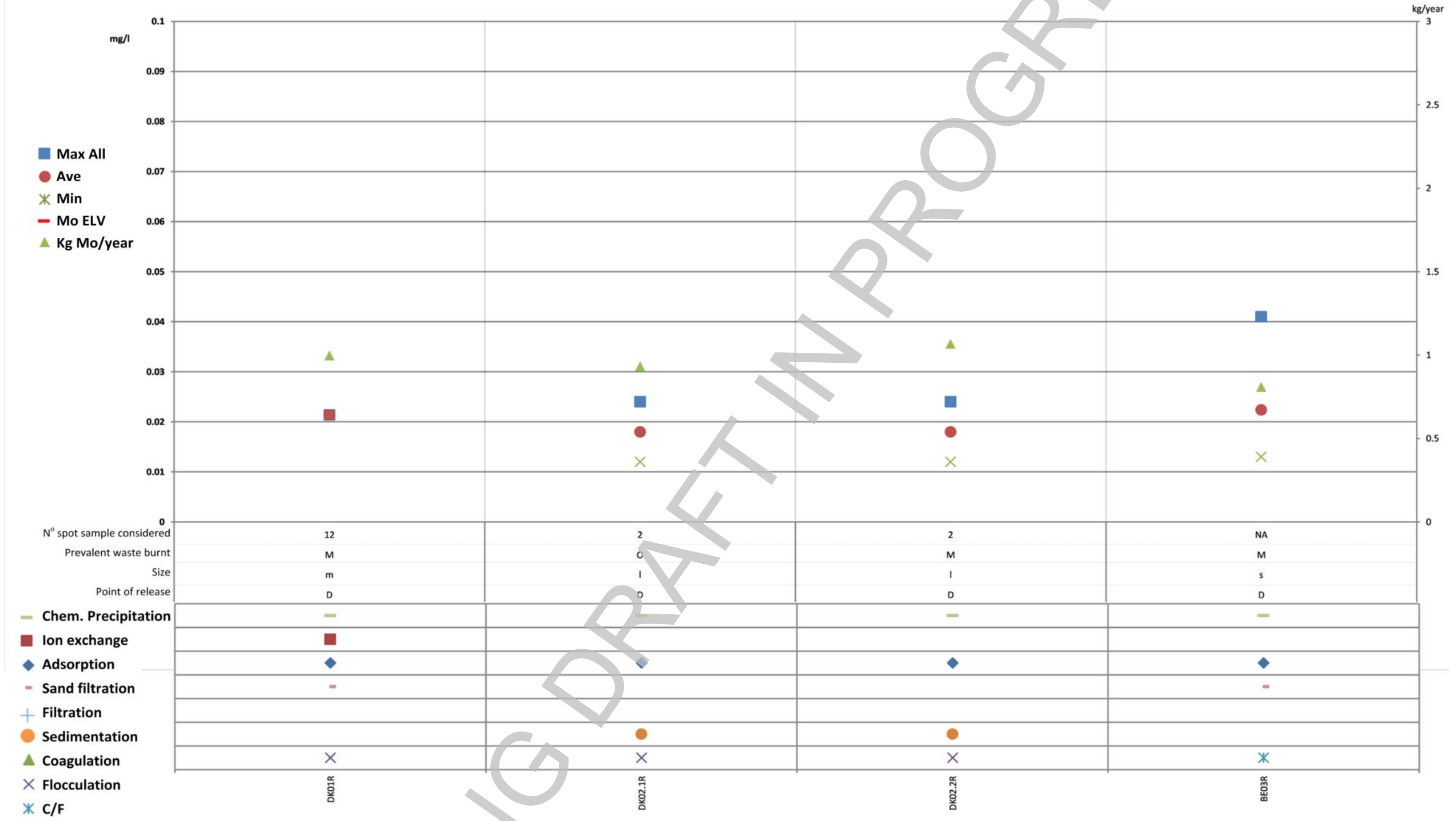
Note:
Nº spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.127:~~annual average~~ Copper emissions ~~discharges~~ to water and abatement techniques applied ~~European HWIs~~



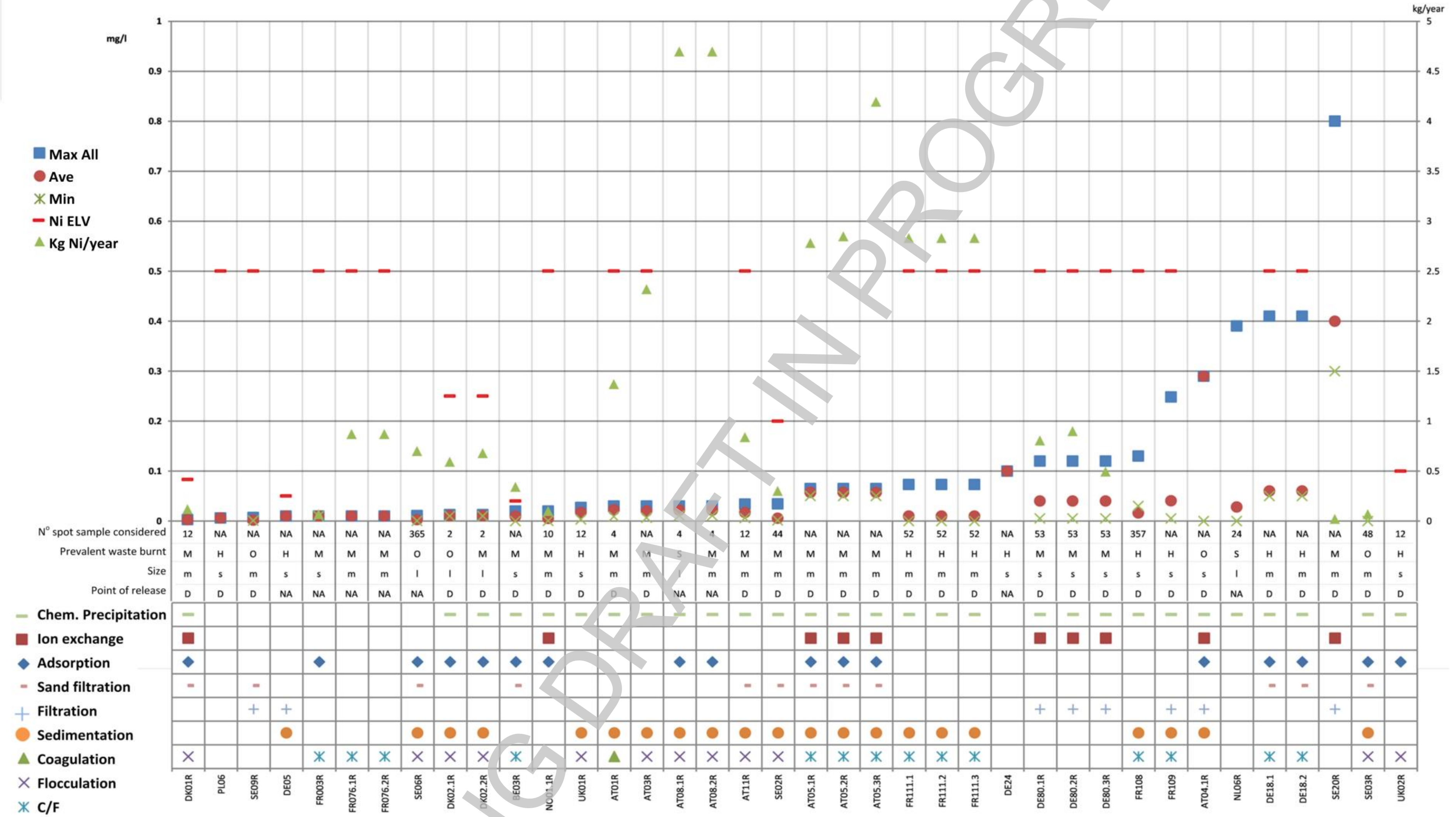
Note:
Nº spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.128:~~annual average~~ Lead emissions ~~discharges~~ to water and abatement techniques applied ~~at European HWIs~~



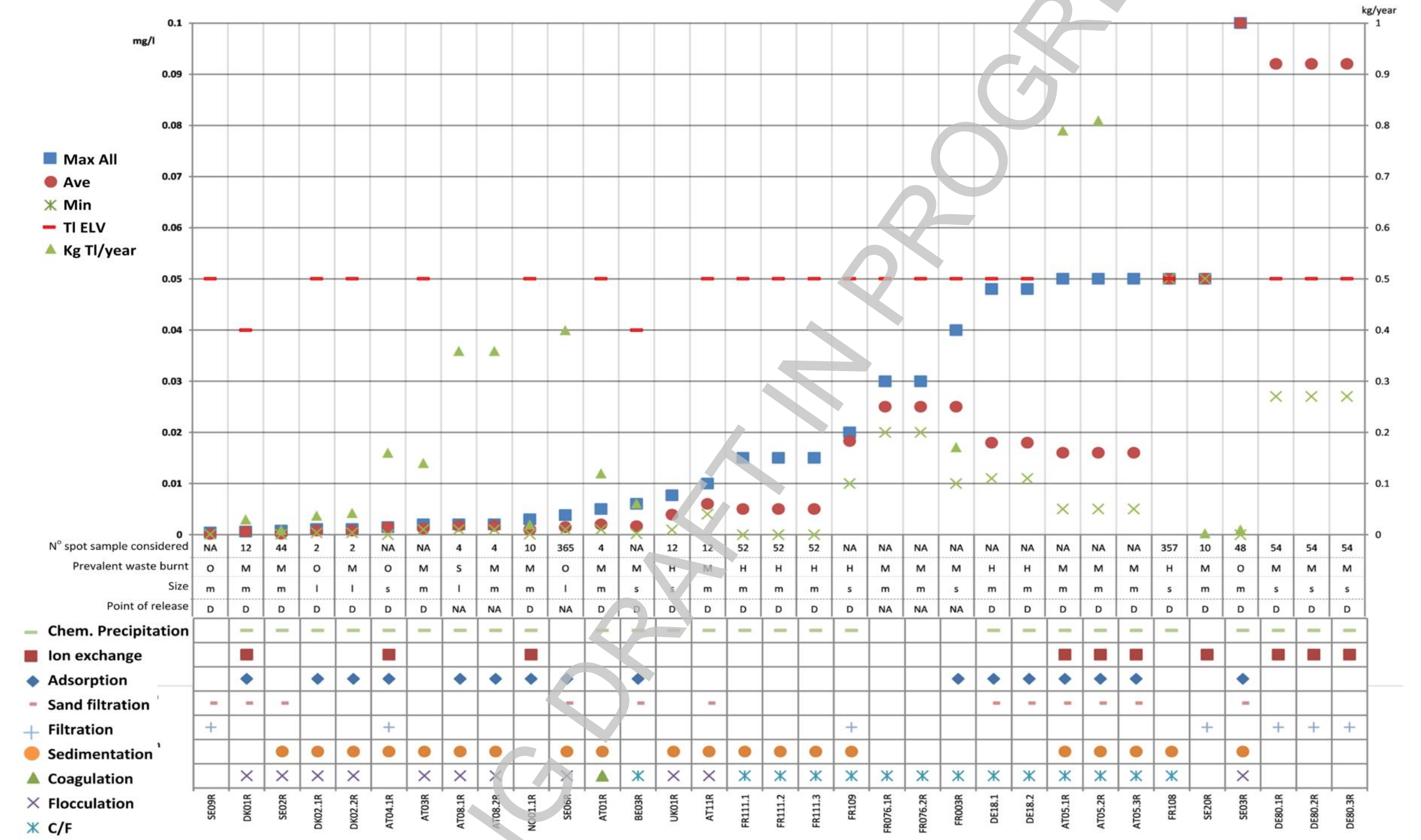
Note:
Nº spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.129: Molybdenum emissions to water and abatement techniques applied



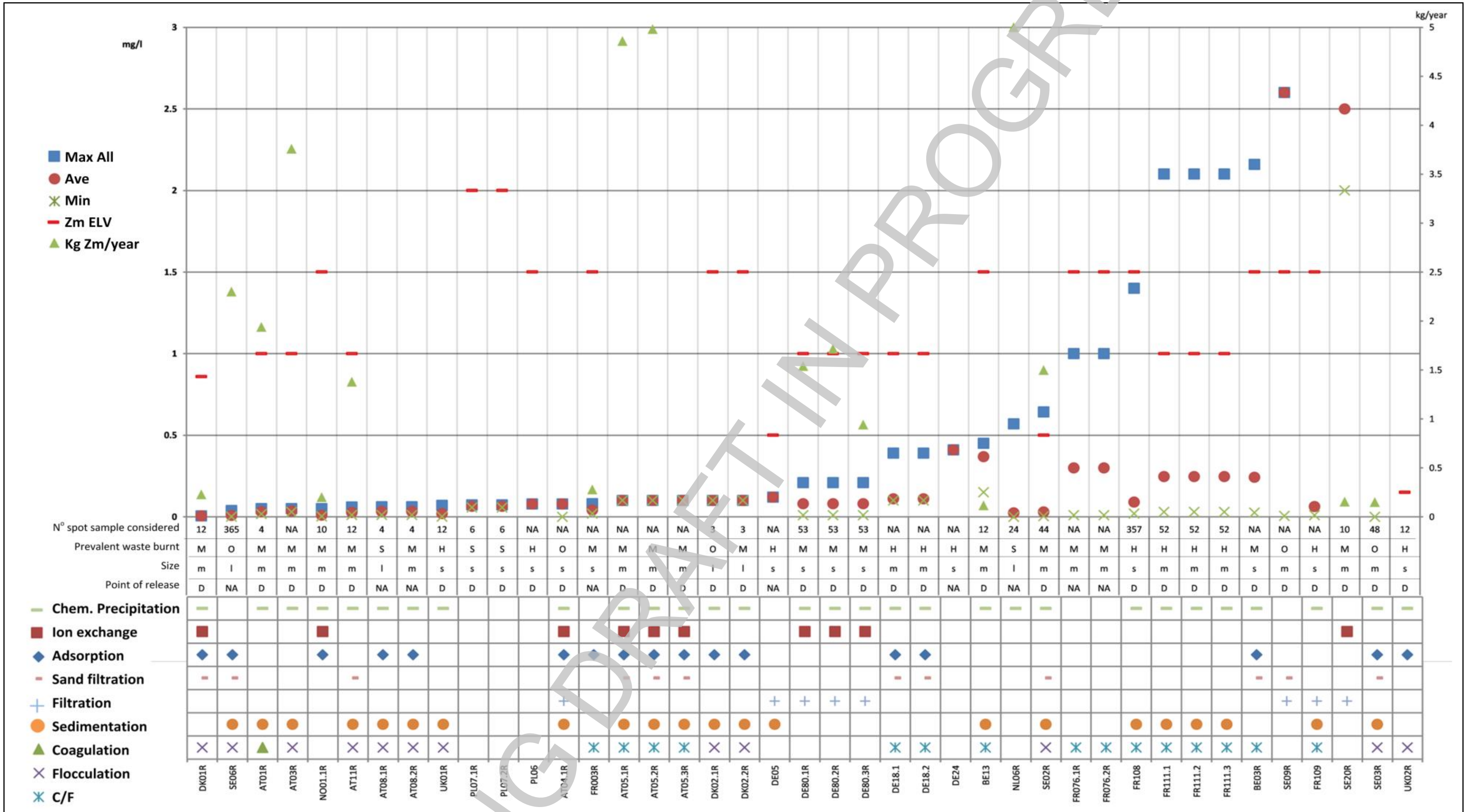
Note:
N° spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.130:~~annual average~~ Nickel emissions ~~discharges~~ to water and abatement techniques applied ~~at European HWIs~~



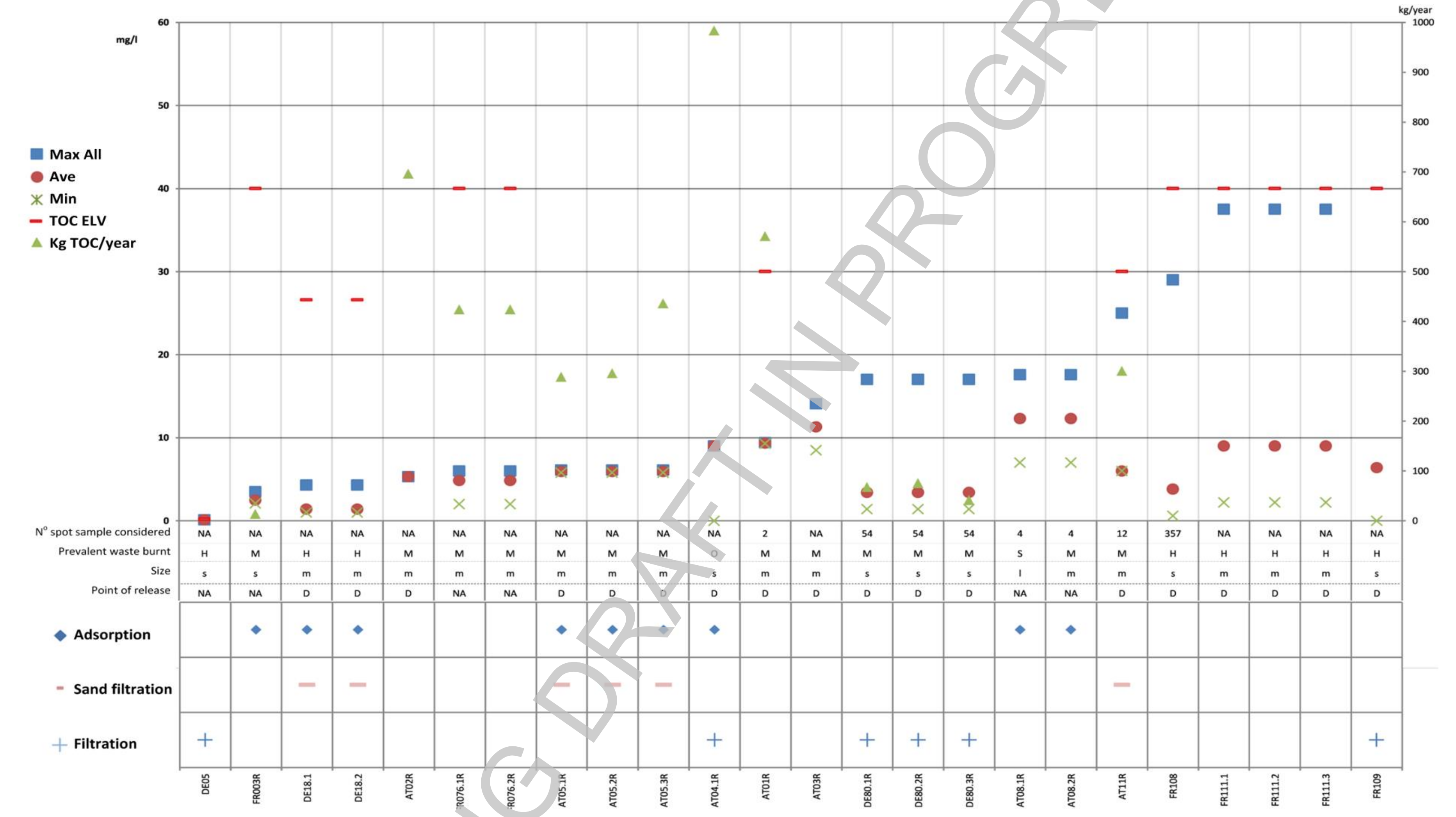
Note:
Nº spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.131: Thallium emissions to water and abatement techniques applied



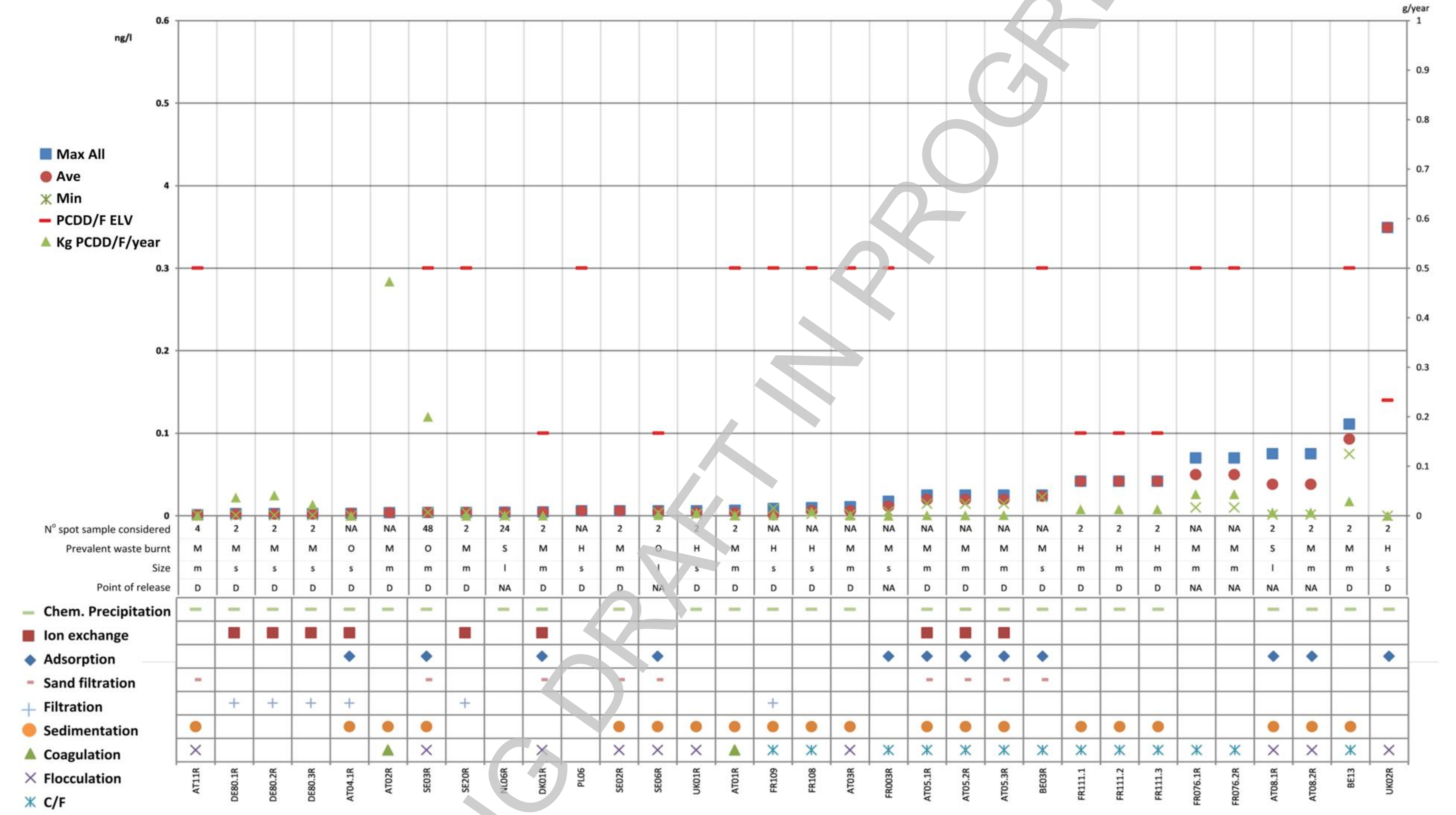
Note:
Nº spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.132:~~annual average~~ Zinc emissions ~~discharges~~ to water and abatement techniques applied ~~at European HWIs~~



Note:
Nº spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.133: Total organic carbon emissions to water and abatement techniques applied



Note:
Nº spot sample considered: NA = Not available.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
Point of Release: D = Direct discharge; NA = Not available.
Techniques installed: C/F = Coagulation and Floculation; Chem Precipitation = Chemical Precipitation
Source: [81, TWG 2016]. ~~[41, EURITS, 2002]~~

Figure 3.134: PCDD/F emissions to water and abatement techniques applied

3.4 Solid residues

3.4.1 Mass streams of solid residues ~~in MSWI~~

In Table 3.33, some typical data on residues from ~~municipal~~ waste incineration plants are summarised.

Table 3.33: Typical data on the quantities of residues arising from municipal waste incineration plants

Types of waste	Specific amount (dry) (kg/t of waste)
Slag / Bottom ash ~~(including grate siftings/riddlings)~~	150~~200~~–350
Dust from boiler ~~and dedusting~~	20–40 (1)
Fly ash ~~FGC residues, reaction products only:~~	
Wet FGT ~~sorption~~	15~~8 – 15~~40
Semi-wet FGT ~~sorption~~	20~~15 – 35~~50
Dry FGT ~~sorption~~	15~~7 – 45~~60
Sludge from waste water treatment	1–15
~~Reaction products, and filter dust, from:~~	
~~Wet sorption~~	~~30 – 50~~
~~Semi-wet sorption~~	~~40 – 65~~
~~Dry sorption~~	~~32 – 80~~
~~Loaded activated carbon~~	~~0.5 – 1~~

(1) Fluidised bed furnaces produce a higher amount of boiler ash.
~~It can be up to wet sorption residue has a specific dryness (e.g. 40 – 50 % d.s.) [74, TWGComments, 2004]~~
Source: [81, TWG 2016] ~~[1, UBA, 2001]~~

~~State-of-the-art~~ MSWI plants ~~typically produce~~ generate between 200 kg and 350 kg bottom ashes per tonne of waste treated. This figure ~~Most published numbers~~ includes the grate siftings~~, which only recently (and only in some countries) have been kept separate from the bottom ash~~. The mass flow of siftings depends on the type of grate and its time of operation. The siftings ~~may~~ increase the amount of unburned matter in the bottom ash and can contribute to leaching of copper. Concerning bottom ash reuse, ferrous and non-ferrous materials (e.g. aluminium) can be easily separated ~~may be segregated~~. However, the inventory of metallic Al, which drips through the grate voids, is of higher concern (e.g. it can cause grate blockage). [74, TWGComments, 2004]

The ~~production~~ generation of boiler ash depends on the type of boiler and on the amount of dust originally released from the furnace~~ grate~~. ~~Few~~ Limited data are available on boiler ash production in fluidised bed furnaces, but they show a clear tendency ~~at a higher level of boiler ash produced by~~ for this type of furnace to produce a higher level of boiler ash.

~~[Vehlow, 2002 #38] The mass flow of flue-gas treatment residues shows the highest variation of all residues. 10 – 12 kg/t is a mean value for wet systems, which operate close to stoichiometry. This figure comprises the dry neutral sludge (2 – 3 kg/t) and the soluble salts (8 – 9 kg/t). In semi-wet or dry lime systems the amount is increased because of unreacted additives, while the dry sodium bicarbonate process gives the lower values [64, TWGComments, 2003]. Table 3.34 below, gives mass streams of solid residues for various substances per tonne of MSW incinerated. The data given is average data for 12 MSWI in the Flanders Region of Belgium in 1999:~~

Table 3.34: Mass streams of solid residues from MSWI expressed per tonne of MSW incinerated

~~**Type of solid residue**~~	~~**Percentage (%)**~~
~~Bottom ash~~	~~21~~
~~Fly ash + gas cleaning residue + sludge from wet scrubbers~~	~~4.2~~
~~Scrap recuperated from bottom ash~~	~~1.2~~
Source: [64, TWGComments, 2003]	

3.4.2 ~~Bottom ash~~ Solid residues' composition and leachability

~~Requirements concerning the quality of the residues from the incineration process are included in European incineration legislation. Directive 2000/76/EC (Art. 6.1) includes an operational condition requiring that incineration plants achieve a level of incineration such that, in slag and bottom ashes, the loss on ignition is ≤5 % or the TOC is ≤3 %.~~

~~In modern well-operated MSWI plants the TOC in bottom ashes can be below 1 wt %.~~ Combustion trials have demonstrated that an increase in the heating value of the waste feed and the resulting higher bed temperatures improve the burnout of bottom ash. [Vehlow, 2002 #38]

In Figure 3.135 and in Figure 3.136 data on the maximum percentage of the TOC content of the bottom ash/slag coming from the incineration of waste measured in 2014 are shown, while Figure 3.137 and Figure 3.138 show the maximum percentage of the loss on ingnition (LOI) measured in 2014. The figures also show the prevalent type of waste burnt, the plant size, the type of furnace used and whether the waste residue has been classified by the operator as slag, bottom ash or fluidised bed combustion ash.

The information gathered through questionnaires does not show a correlation between theTOC and LOI reported and the type of furnace, the plant size or the prevalent type of waste burnt.

~~Only data from modern facilities have been used in this table.~~ TOC determination in accordance with the standard EN 13137 also detects elementary carbon as TOC, which does not cause any problems on landfills. The TOC of bottom ashes comprises mainly elementary carbon, but, to a certain extent, organic compounds are also found (e.g. from sifting of plastics). These cover the spectrum from short-chain compounds up to low volatile species such as PAHs or PCDD/F. ~~The I-TEQ levels detected in the bottom ashes of modern incineration plants are in the same order of magnitude as those found in some urban and industrial soils.~~

~~Typical~~ Concentrations of organic compounds in the various solid residues are reported ~~compiled~~ Table 3.35~~,~~ Table 3.36 and Table 3.37.

Table 3.35: Concentration of organic compounds in the solid residues from the flue-gas cleaning system

Plant code	Prevalent waste	Furnace type	FGC system	Residue description	PAHs (mg/kg)	PCBs (mg/kg)	PCDD/F (ng I-TEQ/kg)
DE54	O	g	Wet	NA	NA	NA	3.4
NL05	S	fb	Wet	NA	NA	NA	3
AT08.1	S	r fb	Wet	Boiler ash	NA	NA	186
AT08.2	M	fb	Wet	Boiler ash	NA	NA	0.14
DE26	H	r	Wet	Boiler ash	NA	NA	3.4–9.5
DE76	O	g	Dry	Boiler ash	NA	NA	41
DK05	H	r	Wet	Boiler ash	NA	NA	17
FI01	M	g	Wet	Boiler ash	NA	< 0.021	150–180
IT01	M	g	Wet	Boiler ash	NA	NA	22
IT13	O	g	Dry	Boiler ash	0.68	0.011	285.1
IT14	M	g	Dry	Boiler ash	< 0.5	NA	63–190
IT15	M	g	Dry	Boiler ash	< 0.5	NA	0.11–0.17
IT16R	O	fb	Wet	Boiler ash	1.98–327	0.0093–0.01	1360–41400
IT17	O	g	Wet	Boiler ash	0.5	0.002–0.0024	0.35–0.4
IT18	M	g	Dry	Boiler ash	< 1	0.00003	1524
IT22	O	g	Dry	Boiler ash	< 0.5	NA	0.377
IT23	M	g	Dry	Boiler ash	NA	0.01	1200
DE67	M	g	Semi	Catalyst	NA	NA	231
UK08	M	g	Dry	Catalyst	NA	0.022–0.357	176.3–328.5
AT02	M	g	Wet	Fly ash	NA	NA	440
DE25	H	r	Wet	Fly ash	NA	NA	205
DE26	H	r	Wet	Fly ash	NA	NA	50.1–63.4
DE29	H	r	Wet	Fly ash	NA	NA	90
DE39	M	g	Wet	Fly ash	NA	NA	1037
DE51	O	g	Wet	Fly ash	NA	NA	114
DE56	M	g	Dry	Fly ash	NA	NA	151
DE74	O	g	Wet	Fly ash	NA	NA	2 500 700
DE76	O	g	Dry	Fly ash	NA	NA	224
DE80	M	g	Wet	Fly ash	0.54	NA	427
DE86	M	g	Wet	Fly ash	< 0.05	NA	487
FI01	M	g	Wet	Fly ash	NA	< 0.021	250–700
IT02	M	g	Dry	Fly ash	0–0.2	0–0.1	0.0004–0.001
IT11	M	g	Wet	Fly ash	< 2	< 5	0.12-0.04
UK09.1	M	g	Semi	Fly ash	NA	NA	21.6–346
UK09.2	M	g	Semi	Fly ash	NA	NA	21.9–57.4
UK09.3	M	g	Semi	Fly ash	NA	NA	20.2–60.4
UK14	C	o	Dry	Fly ash	NA	13.8–51 (ng/kg)	3671–7633

NB: Prevalent type of waste incinerated: M = MSW; O = ONHW; S = SS; H = HW; C = CW.
Furnace type: g = grate; fb = fluidised bed; r = rotary kiln.
Source: [81, TWG 2016]

Table 3.36: Concentration of organic compounds in the bottom ash/slag

Plant code	Prevalent waste	Furnace type	FGC system	PAHs (mg/kg)	PCBs (mg/kg)	PCDD/F (ng I-TEQ/kg)
AT02	M	g	Wet	NA	< 0.93	2.73
AT08.1	S	r fb	Wet	0.52	< 0.64	0.82
AT08.2	M	fb	Wet	NA	NA	21.1
DE15	S	fb	Wet	NA	< 0.01	15–23
DE16	S	fb	Wet	< 0.1	NA	57–55
DE23	H	r	Wet	0.2	< 0.1	< 5
DE25	H	r	Wet	NA	NA	79.3
DE29	H	r	Wet	< 1	< 0.1	0.01–46
DE30	H	r	Wet	0–60	NA	10–1000
DE31	H	g	Semi	6.2 POPs	NA	< 0.02
DE39	M	g	Wet	2.7–12.5	n/a	n/a
DE55	M	g	Wet	NA	NA	478.3
DE56	M	g	Dry	NA	NA	0.6–9.3
DE69	M	g	Dry	NA	> 1	NA
DE74	O	g	Wet	NA	NA	10678
DE80	M	g	Wet	NA	NA	13.8
DE86	M	g	Wet	0.74	NA	4.71
DK05	H	r	Wet	NA	NA	58
FI01	M	g	Wet	NA	< 0.021	7.6–13
FR108	H	r f	Wet	NA	3519	NA
IT01	M	g	Wet	NA	NA	1.1–54
IT02	M	g	Dry	0.1	0.0000001	5.92E-6 – 4.13E-5
IT11	M	g	Wet	< 2	< 5	< 0.02
IT13	O	g	Dry	0.40	1.40	6.0
IT14	M	g	Dry	< 0.5	NA	1.1–8.6
IT15	M	g	Dry	< 0.5	NA	0.0014–0.003
IT16	O	fb	Wet	< 0.5	< 0.01	1.3–6.78
IT17	O	g	Wet	0.5–0.96	0.0096–0.028	0.0035–0.008
IT18	M	g	Dry	< 1	< 1	42826
IT22	O	g	Dry	< 5	NA	3.6
IT23	M	g	Dry	NA	0.01	9.3
UK07.1	M	fb	Dry	NA	0.000017	443
UK07.1	M	fb	Dry	NA	0.0000001–0.00000086	1.1–6.6
UK07.2	M	fb	Dry	NA	0.000011	340
UK07.3	M	fb	Dry	NA	0.000016	494
UK08	M	g	Dry	1.15–1.39	0.003–0.197	4.14–8.39
UK09.1	M	g	Semi	NA	NA	2.46–6.1
UK09.2	M	g	Semi	NA	NA	1.5–10.6
UK09.3	M	g	Semi	NA	NA	2.39–13.4
UK14	C	o	Dry	NA	0.22–2.5 ng/kg	13.7–53.9

NB: Prevalent type of waste incinerated: M = MSW; O = ONHW; S = SS; H = HW; C = CW.
Furnace type: g = grate; fb = fluidised bed; r = rotary kiln.
Source: [81, TWG 2016]

Table 3.37: Concentration of organic compounds in the solid residues from the waste water treatment plant

Plant code	Prevalent waste	Furnace type	Description	PAH (mg/kg)	PCB (mg/kg)	PCDD/F (ng I-TEQ/kg)
DE30	H	r	Gypsum	0–0.6	below LOD	150–170
DE51	O	g	Gypsum	NA	NA	11.2
DE74	O	g	Gypsum	NA	NA	266 550
DE86	M	g	Gypsum	0.82		9.29
DE25	H	r	Sludge	NA	NA	11971
DE39	M	g	Sludge	n/a	n/a	592
DE80	M	g	Sludge	NA	NA	14
FR108	H	r f	Sludge	NA	0.186	NA
IT02	M	g	Sludge	0.1	0.000002	6.73E-5 – 4.16E-6
IT11	M	g	Sludge	< 1	< 5	< 0.02–0.1
IT17	O	g	Sludge	0.5	0.0072–0.022	0.098–0.14

NB: Prevalent type of waste incinerated: M = MSW; O = ONHW; S = SS; H = HW.
Furnace type: g = grate; fb = fluidised bed; r = rotary kiln.
Source: [81, TWG 2016]

~~Table 3.38: Concentration ranges of organic compounds in bottom, boiler and filter ashes~~

~~Parameter~~	~~Bottom ash~~	~~Boiler ash~~	~~Filter ash~~
~~PCDD/F (I-TEQ)~~	~~<0.001 – 0.01~~	~~0.02 – 0.5~~	~~0.2 – 10~~
~~PCB~~	~~<5 – 50~~	~~4 – 50~~	~~10 – 250~~
~~PCBz~~	~~<2 – 20~~	~~200 – 1 000~~	~~100 – 4 000~~
~~PCPh~~	~~<2 – 50~~	~~20 – 500~~	~~50 – 10 000~~
~~PAH~~	~~<5 – 10~~	~~10 – 300~~	~~50 – 2 000~~

~~NB: All values in ng/g~~
~~*Source:* [Vehlow, 2002 #38]~~

~~Table~~ 3.39 ~~below shows data for PCDD/F for 10 MSWI in Netherlands over 5 years (2000 – 2004):~~

~~Table 3.39: PCDD/F concentrations in various MSWI incineration residues in NL (data 2000 – 2004)~~

~~Residue~~	~~Average value in ng/kg I-TEQ~~	~~Max value in ng/kg I-TEQ~~	~~Number of samples~~	~~Total amount in 2003/tonnes~~
~~Bottom ash~~	~~46~~	~~46~~	~~1~~	~~110 0000~~
~~Fly ash~~	~~2 950~~	~~16 900*~~	~~34~~	~~82 200~~
~~Boiler ash~~	~~42~~	~~86~~	~~3~~	~~2 900~~
~~Wet FGC salts~~	~~636~~	~~5 400~~	~~16~~	~~25 500~~
~~Filter cake~~	~~17 410~~	~~66 000*~~	~~30~~	~~8 300~~

~~* This is a relatively old installation with modern FGC equipment that prevents dioxin emissions to air. The residue is land filled on a hazardous waste landfill site.~~
~~*Source:*~~

~~Table 3.40 below gives survey data of an overview of the PCDD/F content in residues from MSWI plants. The data excludes peak high and low results:~~

~~**Table 3.40: Range of PCDD/F concentrations in MSWI residues (excluding peak high and low values)**~~

~~**Residue**~~	~~**Range of values**~~	~~**units**~~
~~Bottom ash~~	~~1 – 68~~	~~ng TEQ/kg dry solid~~
~~Boiler ash~~	~~<40 – 600~~	~~ng TEQ/kg dry solid~~
~~Fly ash (ESP)/filter dust~~	~~140 – 5 720~~	~~ng TEQ/kg dry solid~~

~~NB: In this table the peak high and low values have been removed~~
~~*Source:*~~

Bottom ashes from the incineration of MSW

Table **3.41** shows the ercur-chemical characteristics of this waste from MSW incinerators.

Table 3.41: Characterisation of bottom ash from MSW incinerators

Properties	**Compounds**	**Values**
pH	NA	11–12.5–13
Soluble salts content	Cl, sulphates	Up to 70 %
Eluate conductivity	NA	1 000–16 000–25 000 µS/cm
Heavy metals	Pb, Zn, Cd, Cr	Up to several %
Inert compounds	Silica, alumina, lime	NA
Fine particulates	NA	< 100 µm
Density	NA	0.9–1.2–1.5
Hygroscopic material	Salts, excess lime content	
Leaching test before treatment	Solubles Cr Cd Pb Zn As	10–80 % 5–60 µg/l 0.1–100 µg/l 5–6 000 µg/l 0.6–1 000 µg/l 0.4–10 µg/l

NB: The middle number in ranges corresponds to the average.
NA: Not Applicable

Source: [82, Germany, 2014]

The mineral fraction, scrap metals and the non-incinerated fraction are the main components of bottom ash from MSW incineration. The mineral fraction mainly contains silicates, alkaline earth and salts.

The relative partitioning of elements into bottom ash depends mainly on the composition of the MSW fed to the incinerator, the volatility of the elements it contains, the type of incinerator and grate system applied and the operation of the combustion system. [4, IAWG, 1997]

The mass and volume reduction of waste incineration causes an enrichment of a number of ~~heavy~~ metals in the bottom ashes compared to their concentration in the waste feed. Some ~~heavy~~ metals, e.g. arsenic, cadmium or mercury, are, to a great extent, volatilised out of the fuel bed. It is evident that, with the exception of the mainly lithophilic copper, all selected ~~heavy~~ metals are highly enriched in filter ashes.

The scrap metal components are ferrous (mainly ferrous scrap and stainless steel) and non-ferrous metals (mainly aluminium, brass and copper) (see Table 3.42).

Table 3.42: Main components of raw bottom ash

Categories	Percentage by weight (mass-%)
Mineral fraction	85–90
Non-incinerated fraction	< 3
Ferrous metal scrap	7–10
Non ferrous metal scrap	0.5–2

Source: [82 Germany 2014]

~~Note:~~ It is important to note that the risks associated with bottom ash are not indicated only by the presence or absence of substances – their chemical and physical form, as well as the nature of the environment where the material will be used, are also important to prevent emissions from the ashes to the environment. [64, TWGComments, 2003] ~~The important thing is, therefore, not the fact that the bottom ashes contain pollutants but to check possible emissions from the ashes to the environment.~~ In **Table 3.43**, the bottom ash composition is reported.

Table 3.43: Chemical composition of bottom ash from the incineration of MSW

Values in wt-%	Bottom ash (raw)			Bottom ash after storage (ageing time of 3 months)		
Parameter	**Min.**	**Average**	**Max.**	**Min.**	**Average**	**Max.**
SiO2	42.91	49.2	64.84	39.66	49.2	60.39
Fe2O3*	9.74	12	13.71	8.41	12.7	17.81
CaO*	10.45	15.3	21.77	10.42	15.1	23.27
K2O*	0.83	1.05	1.36	0.84	0.91	1.42
TiO2*	0.65	1.03	1.33	0.65	0.88	1.12
MnO*	0.06	0.14	0.22	0.1	0.17	0.26
Al2O3*	6.58	8.5	10.79	7.43	8.83	10.45
P2O5*	0.55	0.91	1.49	0.5	1.04	2.61
MgO*	1.79	2.69	3.4	1.84	2.59	3.51
Na2O*	1.86	4.3	5.81	2.05	4.15	7.49
CO_2	2.56	5.91	10.96	NA	NA	NA
Sulphates	2.5	15.3	28.3	5.8	12.5	22.5
Chloride	1.3	3.01	7	1.5	2.71	4.6
Cr (ppm)	174	648	1 035	295	655	1 617
Ni (ppm)	55	215	316	90	165	260.2
Cu (ppm)	935	2 151	6 240	1 245	2 510	5 823
Zn (ppm)	1 200	2 383	4 001	1 795	3 132	5 255
Pb (ppm)	497	1 655	3 245	1 108	2 245	3 900

NB: * These values are calculated using analysis procedures based on X-ray fluorescence.
NA: Not Applicable
Source: [82, Germany, 2014]

Usually two different types of bottom ash analysis are performed. The first method analyses the available mobile compounds (eluate analysis (i.e. leachate)) of the bottom ash fraction. The second method analyses the complete compounds of the bottom ash (solids analysis). The use of the methods is determined by the way that the mineral fraction is used. However, the eluate analysis is more important when assessing the possibility of material recovery, [75, FEAD 2014] because almost all regulations for the disposal or utilisation of waste products are based on standardised leaching tests. ~~However, different tests are used in different countries. Harmonisation and standardisation of the testing procedures is under development within CEN (European Committee for Standardisation TC 292). Hence the testing is done under country specific conditions and the interpretation of the results of various tests has to take this into account.~~

Table 3.44 gives the ~~average~~ leaching values for ~~Dutch MSW incinerator~~ untreated bottom ashes as reported in the WI BREF review data collection. ~~After mechanical treatment, as measured from 1993 to 1997. Data have been taken from regular quality controls performed by the national organisation of waste managers (VVAV) at all MSW incinerators and from the National Institute for Environmental Protection (RIVM).~~

Table 3.44: Leaching properties of ~~mechanically~~ untreated bottom ash~~, measured using NEN7343~~

Compound	Minimum leaching value (mg/kg)	Maximum leaching value (mg/kg)
$(SO_4)^{2-}$	200	10 000 ~~5 058~~
As	0.00045 ~~0.022~~	28
Ba	0.05 ~~0.6~~	38
Br^-	7.6	NA
Cd	0.002 ~~0.003~~	6.7
Cl^-	5	10 000 ~~2 615~~
CN^- (free)	0.01	NA
CN^- (total)	0.048	NA
Co	0.1 ~~0.05~~	0.2
Cr tot	0.004 ~~0.08~~	1.24
Cu	0.005 ~~3~~	20
F^-	0.2 ~~14.1~~	1300
Hg	0.0002 ~~0.001~~	0.1
Mo	0.01 ~~1.52~~	3.3
Ni	0.005 ~~0.13~~	0.3
Pb	0.005 ~~0.07~~	21
Sb	0.005 ~~0.22~~	1.2
Se	0.001 ~~0.01~~	0.13
Sn	0.04	NA
V	0.01	0.2~~3~~
Zn	0.01 ~~0.09~~	6.7

NB: Ratio l/s = 10 l/kg.
Source: [81, TWG 2016]

~~Leaching of bottom ashes can very significantly depending on the type of waste. Recent values from a wide population of MSW indicates an average leaching for Cu of 5.79 mg/kg in 2001 and 6.21 mg/kg in 2002. [74, TWGComments, 2004]~~
As compared to stony or inert materials, the following compounds may be considered critical for MSW bottom ash: copper, zinc, antimony, molybdenum, chloride, and sulphate. Treatment techniques aim to reduce the leachability of these critical compounds.

Residues from the incineration of hazardous waste ~~incineration plants~~

Residues from hazardous waste incineration are not fundamentally different from those of municipal waste incineration plants. However, the following differences can be observed:

- In the case of ash and slag: the incineration of hazardous waste in drums is usually performed at temperatures higher than those used for municipal waste incineration. This can result in different metal partitioning.
- Owing to variations in waste type and content, the specific amount of bottom ash can be subject to variations much greater than those in municipal waste incineration plants. These variations can be seen within the same plant according to the wastes fed, as well as between different plants and technologies.
- In the case of filter dust/FGC residues, as the concentration of heavy metals is normally higher in hazardous waste, the solid residues produced may also contain considerably higher concentrations of heavy metals.

~~Table 3.45 below gives data from a European survey of merchant HWI operators concerning the total production of various residues:~~

~~Table 3.45: Quantities of the main waste streams produced by HWI (European survey data)~~

	~~Residue production (kg/t waste input)~~			~~(Tonnes)~~
	~~Minimum~~	~~Maximum~~	~~Average~~	~~Total annual amount (recorded)~~
~~Bottom ash~~	~~83~~	~~246~~	~~140~~	~~193 372~~
~~Boiler ash + fly ash + solid flue-gas cleaning residue~~	~~32~~	~~177~~	~~74~~	~~79 060~~
~~Filter cake from WWTP~~	~~9~~	~~83~~	~~30~~	~~16 896~~
~~*Source:* [EURITS, 2002 #41]~~				

The following table gives an overview of the parameters measured by some plants incinerating hazardous waste to check the desctruction efficiency and/or to ensure the effective destruction of the hazardous components of the waste.

Table 3.46: Methods and paramenters used by the waste incineration plants to check the distruction efficiency of the hazardous waste compounds

Plant and furnace type		Waste burned (t) in 2014	Parameters to measure the destruction efficiency of the hazardous compounds of the burned waste	Method	Other parameters to measure the quality of the bottom ash/slag generated and the method used
DE15	fb	162500	CO emission after incineration	Laser method	Not measured
DE18	r	105000	TOC	Not reported	Not measured
DE20	f	33700	Water content/dry residue; TOC; LOI	105 °C; DIN EN 13137; DIN EN 15169	Some graphite material is burned. As the 'TOC' value in the bottom slag obtained by the standard method includes the inorganic carbon, TIC is measured as well if the TOC limit is reached. The difference is the 'real' TOC.
DE21	f	12696	Temperature at the end of the furnace, oxygen in the furnace, minimum combustion air flow, flame detection and the AMS for air emissions	Thermocouples, Infrared, flow meters, etc.	Not measured
DE23	r	55223	None	Not applicable	Eluate with DIN 38404-C5/ DIN 10523
DE25	r	56478	None	Not applicable	Leaching test
DE26	r	137966	CO emission after incineration	Laser method	Measurement of metal content from mixed samples 12 times a year
DE28	r	55006	Ash content	Not reported	Not measured
DE29	r	117629	None	Not	Extractable lipophile matters in

				applicable	original substance; method: German LAGA Guideline KW/04 (2009); result: 0.044 % (yearly average; 21 measurements)
DE38	g	580746	None	Not applicable	Leaching test
DE39	g	302749	As, Cd, Cr tot, Cu, Hg, Ni, Pb, Zn, PAHs	ISO11885-E22, ISO16772, ISO18287	Not measured
DE44	g	494815	Not measured	Not applicable	Due to LAGA – rule with catalogue of critical value, LAGA 20 = Z 2
DE52	g	187311	None	Not applicable	EOX, heavy metal, dioxin
DE55	g	385951	Ar, Pb, Cd, Cr, Cu, Ni, Hg, Zn, Cl, SO4	DIN EN ISO 17294-2/ DIN EN ISO 12846/ DIN 38414-4/ DIN EN ISO 10304-1/ DIN ISO 18287	Not measured
DE56	g	219329	None	Not applicable	Sorted amount with DIN ISO 11464; dry residue with DIN ISO 11465; LOI with DIN 18128; EOX with DIN 38414-S17; cadmium, arsenic, lead, copper, nickel, chromium and zinc with DIN EN ISO 11885; mercury with DIN EN 1483; PAK with DIN ISO 13877
DE60	g	364133	None	Not applicable	EOX (DIN 38414 s17); PAK (DIN ISO 13877)
ES11	r	44516	Continuous/Discontinuous monitoring emissions control	Automatic measurement system	Every 3 months: metals content in bottom ash. TOC and LOI
FI01	g r	317095	None	Not applicable	TOC, PCDD/F, PCB, XRF
FR106	f	59051	None	Not applicable	Ni and Zn
FR108	r f	32930	Intrinsic PCB content	Not reported	Analysis of key parameters in the bottom slags; TOC and LOI
FR110	r	126468	TOC	TOC meter	Hourly visual inspection; TOC tested at 870 °C measuring the CO produced; Visual control at the kiln outlet with endoscope; Choice of nozzles positioning (low calorific value/high calorific value) to avoid or make a thermal barrier; Variation of the kiln rotation speed.)
FR111	r	196055	LOI and metals in the solid residues	EN 12457-2	Leaching teast
NL05	fb	360100	None	Not applicable	Phosphorus
NO01	g	185980	Not reported	Not reported	Not measured

NO02	g	141896	Flue-gas measuring	Not reported	A basiccharacterisation is performed every year on bottom ashes that have been sorted (metals sorted out)
PL03	r	28267	TOC	EN13137	LOI method EN15169
PL05	fb	15673	None	Not applicable	Measured parameters specified in Annex 1 – 3 of National Law (criteria and procedures for allowing waste to landfilling of waste like in Landfill Directive)
SE03	g	176487	Metals, TOC, etc	Test and ercury n t are carried out when new HW are incinerated but no regular tests are preformed	Not measured
SE21	g r	153249	PCBs, PAHs	Gas chromatography	X-ray fluorescence (XRF) scan of the slag and all types of ash
UK02	r	37344	LOI	BS EN 15169:2007	Not reported
UK08	g	261257	Not measured	Not applicable	pH, Alkalinity Reserve and metals

NB: g = grate furnace; fb = fluidised bed furnace; r = rotary kiln; f = other furnace.
Source: [81, TWG 2016]

Typical leaching values for bottom ashes from hazardous waste incineration are given in Table 3.47

~~. It must be noted that the German DIN-S4 leaching test was used, results are therefore given in mg/l. For comparison with the data from~~

~~Table 3.44, approximate values in mg/kg may be obtained by multiplication by a factor of 10.~~

Table 3.47: Typical leaching values of bottom ash from the incineration in hazardous waste incineration plants, measured using DIN-S4

Compound	Minimum (mg/l)	Maximum (mg/l)
As	< 0.01	16 ~~0.08~~
Ba	< 0.01	14.4
Cd	< 0.01 ~~<0.001~~	2.1 ~~0.001~~
Co	0.03	< 0.1
Cr tot	< 0.01 ~~<0.001~~	30 ~~2.87~~
Cr VI	< 0.01 ~~<0.03~~	10 ~~2.87~~
Cu	<0.01	2.15 ~~1.50~~
Hg	< 0.002 ~~0.00~~	1 ~~<0.01~~
Mn	0.008	0.68
Mo	0.01	21
Ni	<0.01	5 ~~0.02~~
Pb	<0.01	13 ~~0.18~~
Sb	< 0.005	4
Se	< 0.01	1
Tl	< 0.001	< 0.35
V	0.005	0.1
Zn	< 0.02 ~~<0.01~~	3.2 ~~0.3~~
Chloride	< 1 ~~2~~	4 700 ~~450~~
Fluoride	< 0.1 ~~0.8~~	15 ~~13~~
Sulphate	2 ~~5~~	3 600 ~~300~~
Phenol index	< 0.01	10
DOC	< 1	130
TDS	< 50	18 000
TOC	0.09	55
BTEX	0	< 0.15
PCBs 7	< 0.02	< 0.05
Mineral oil	NA	< 100
PAHs	< 0.05	6.2

NB: Ratio l/s = 10 l/kg.
Source: [81, TWG 2016] ~~[1, UBA, 2001]~~

Residues from the incineration of sewage sludge ~~incinerators~~

The chemical structure of sewage sludge ash is influenced considerably by the weather, in particular the amount of rain. In the case of rainy weather, larger amounts of clay and fine sand enter the sewerage system, pass the grit chamber, are precipitated in the preliminary sedimentation basin and reach the sludge incineration with the primary sludge. As a result, the silicate content of the ash is increased considerably, and the contents of other components are diluted in periods of rainy weather.

In addition, the type of catchment and the treatments carried out have a great effect on the sludge quality. Areas with a large number of heavy industrial connections may result in higher concentrations of heavy metals ~~(etc.)~~ being fed to the incinerator; these substances may then accumulate in bottom and fly ashes. Rural areas, with little industry, may give rise to less polluted ~~a cleaner~~ sludge and hence a lower contamination of incinerator residues.

Another point of major influence is the nature of the treatment (and therefore of the reagents: mineral, polymeric, etc.) that is applied in order to purify the waste water.
[74, TWGComments, 2004]

Information on the content of phosposrous and of some hazardous organic substances in the solid residues coming from the incineration of waste is reported in the Table 3.48 below.

Table 3.48: Content of phosphorous, PAHs, PCBs and PCDD/Fs in the solid residues coming from the incineration of waste

Plant code	Prevalent waste	Furnace type	FGC Type	Residue type	P (mg/kg)	PAHs (mg/kg)	PCBs (mg/kg)	PCDD/F (ng I-TEQ/kg)
NL05	S	fb	Wet	NA	1 500	NA	NA	3
DE26	H	r	Wet	Boiler ash	14 800–35 700	NA	NA	3.4–9.5
SE20	M	g	Wet	Boiler ash	2 870	NA	NA	NA
DE15	S	fb	Wet	Bottom ash/slag	29 200–38 700	NA	< 0.01	15–23
DE16	S	fb	Wet	Bottom ash/slag	28 000–46 000	< 0.1	Not determined	57–55
DE26	H	r	Wet	Bottom ash/slag	2 700–5 500	NA	NA	NA
DE70	M	g	Dry	Bottom ash/slag	70	NA	NA	NA
DE73	M	g	Semi	Bottom ash/slag	< 0.1–1.1	NA	NA	NA
DE74	O	g	Wet	Bottom ash/slag	2 300	NA	NA	10 678
DE87	S	fb	Wet	Bottom ash/slag	90 000	NA	NA	NA
NL05	S	fb	Wet	Bottom ash/slag	113 000	NA	NA	0
NL06	S	fb	Wet	Bottom ash/slag	87 000	NA	NA	NA
DE26	H	r	Wet	Fly ash	19 000–29 800	NA	NA	50.1–63.4
DE73	M	g	Semi	Fly ash	< 0.1–0.66	NA	NA	NA
DE74	O	g	Wet	Fly ash	5 700	NA	NA	2 500 700
DE74	O	g	Wet	Gypsum	230	NA	NA	266 550

NB: Prevalent type of waste incinerated: M = MSW; O = ONHW; S = SS; H = HW.
Furnace type: g = grate; fb = fluidised bed; r = rotary kiln.
Source: [81, TWG 2016]

Issues with other waste types

Clinical waste issues are that:

- burnout needs to be thorough to ensure destruction of infective agents and to disguise recognisable body parts;
- the partitioning of radioactive isotopes used in medicines that give rise to wastes may be to the bottom ash or fly ashes – this may result in additional disposal/recycling considerations;
- hypodermic needles and other sharp materials in the bottom ash may give rise to additional handling risks.

Quality of solid residue from fluidised beds

Because of differences in the process, the waste properties and the combustion temperatures, the quality of ashes is very different to that of ashes of grate incinerators. Generally, the lower (but more even) operational temperatures, the nature of the fuel and the process in fluidised beds mean that:

- a greater proportion of volatile metals remain in the bottom ash – consequently, concentrations of heavy metals in the flue-gas residues are reduced; however, sometimes there are problems with Cr^{VI} levels in the soluble part of the bottom ash;
- the degree of vitrification of the ash may be reduced;
- burnout may be improved.

When recovered fuel is produced for fluidised bed boilers, the ash content is usually 1–10 %, and with construction and demolition waste it is normally 1–7 %. [33, Finland, 2002].

Household waste burnt in rotating fluidised bed incinerators has an ash content of up to 30 % and ~~with RDF~~ up to 15 % in the case of RDF.

The majority of solid residue from fluidised bed incineration is fly ash, which, according to conditions and applied fluidised bed technology, can form up to 90 % of the total ash residue. The bottom ash is also mixed with fluidised bed material (e.g. sand, additives for desulphurisation). When waste or RDF is burnt in a rotating fluidised bed, the ratio of bottom ash to fly ash is about 50:50.

When waste originating from construction and demolition is used, a small increase can be found in the heavy metal content of both ashes compared to wood combustion. When the recovered fuel is made of household waste, there is a greater increase in heavy metals. The amount of the increase depends on the type of household waste used. If all the household waste is combusted, the increase is high. If source separation is used, and only combustible packaging material is combusted, the increase of heavy metals is less. Recovered fuels made of industrial wastes can be very variable and therefore result in a wide range of ash qualities.

Table 3.49: Leaching values of bottom ash from fluidised bed furnaces

Compound (unit)	Plant code and prevalent waste burned									
	AT08.1	AT08.2	BE08	DE02	IT16	PL01	PL05	UK07	UK17	UK18
	S	M	O	O	O	S	S	M	O	O
As (mg/kg)	< 0.01	< 0.01	0	24.5	0.001	1.72	0.042–6.09	< 0.008	< 0.02–0.142	< 0.02–< 0.03
Ba (mg/kg)	22	2.1	1.6		0.307–.784	1	0.307–0.428	1.52	1–10.2	1.49–2.84
Cd (mg/kg)	0.019	0.02	0	16.4	0.005	0.13	< 0.005	< 0.001	< 0.01	< 0.003–< 0.01
Co (mg/kg)	< 0.5	< 0.5	0		NA	NA	NA	< 0.006	< 0.1	< 0.1–< 0.2
Cr tot (mg/kg)	< 0.3	< 0.3	1.4	180	0.042–0.081	0.1	< 0.030	2.26	0.028–0.69	0.2–0.69
Cr VI (mg/kg)	< 0.3	< 0.3	0.6		NA	NA	NA	NA	0.37–0.6	NA
Cu (mg/kg)	< 0.5	< 0.5	0.47	491	0.005–0.097	0.28	0.059–< 0.040	0.13	< 0.1–0.44	< 0.1–< 0.2
Hg (mg/kg)	< 0.001	< 0.001	0	0.986	0.0005	0.005	< 0.005–< 0.005	< 0.0001	< 0.0002	< 0.0002–< 0.0003
Mn (mg/kg)	< 0.1	< 0.1	0		NA	NA		< 0.04	< 0.1	< 0.1–< 0.2
Mo (mg/kg)	22.3	0.3	2.19		0.009–0.019	3.98	< 0.040–11	0.4	0.028–0.12	0.32–0.85
Ni (mg/kg)	< 0.3	< 0.3	0	36	0.005	0.25	< 0.040	< 0.01	< 0.1	< 0.1–< 0.2
Pb (mg/kg)	1.7	< 0.3	71.9	1240	0.005–0.011	0.31	< 0.100	0.2	0.09–4.3	0.016–1.27
Sb (mg/kg)	< 0.3	0.4	0		0.024–0.157	0.099	< 0.010–< 0.50	< 0.17	0.065–0.25	0.12–0.31
Se (mg/kg)	< 0.1	< 0.1	0		0.001	3.69	0.015–21.4	< 0.01	< 0.02	< 0.02–< 0.03
Tl (mg/kg)	< 0.5	< 0.5	0	0.38	NA	NA	NA	< 0.01	0.024–0.87	< 1–< 2
V (mg/kg)	0.15	0.2	0		NA	NA	NA	0.24	0.012–0.19	< 0.1–< 0.2
Zn (mg/kg)	0.6	< 0.1	0.4	3 500	0.05	1	< 0.050	0.53	< 0.1–27.3	< 0.2–0.2
Chloride (mg/kg)	3 240	909	1 915	NA	81–122	6 568	< 50–26 900	1210	12–29.2	263–707

Fluoride (mg/kg)	19	3	5	NA	NA	2251	< 1.0–1 269	< 0.96	0.88–1.16	0.1–1.52
Sulphate (mg/kg)	1 600	13 000	10 024	NA	11232	60 000	186–296 350	1610	30.4–64	206–853
Phenol index (mg/kg)	1.1	< 0.1	NA	NA	NA	NA	NA	NA	< 0.1	NA
DOC (mg/kg)	NA	NA	NA	NA	20	1366	28.9–36.2		1.68–9	NA
TDS (mg/kg)	NA	NA	NA	NA	1620–4270	596 352	1 440–722 220	3030	760–3 468	5 700–7 500
TOC (mg/kg)	302	25	36.9	NA	NA	0.43	NA		NA	5.2–10.6
BTEX (mg/kg)	NA	NA	NA	NA	NA	NA	NA		NA	NA
PCBs 7 (mg/kg)	NA	NA	NA	NA	NA	NA	NA	0.0001	NA	NA
Mineral oil (mg/kg)	1	< 1	NA	NA	NA	NA	NA		NA	NA
PAHs (mg/kg)	NA	NA	NA	NA	NA	NA	NA	< 2.4	NA	NA
PCDD/F mg/kg)	NA	NA	NA	NA	NA	NA	NA	0.00000198	NA	NA

3.4.3 Incineration bottom ash/slag treatment

According to the data gathered, all plants in Europe treat the incineration bottom ash/slag with ferromagnetic separation to recover iron and most use eddy current separation to recover the non-ferrous metals.

Table 3.50 reports the main features of the incineration slag and/or bottom ash treatment plants that participated in the data collection exercise.

Table 3.50: Incineration bottom ash treatment plants' characteristics

Plant	**Capacity (t/year)**	**Throughput (t/h)**	**Within WIP**	**Treatment type**	**Process used**
AT.B-01	40 000	90	No	Dry, Wet, Wash	M,F,E,Dw,SS
BE.B-01	100 000	25	Yes	Dry, Wash	F,E,A,B,SS
BE.B-02	NA	75	Yes	Wet	M,F,E,S,Dw,SS
CZ.B-01	120 000	50	Yes	Wet	M,F,E,
DE.B-01	180 000	100	No	Dry, Wash	M,F,E,A,SS
DE.B-02	400 000	90	NA	Wet, Dry, Wash	M,F,E,A,Dw,SS
DE.B-03	300 000	120	No	Wet	M,F,E,SS
DE.B-04	600 000	130	No	Dry, Wash	M,F,E,I,N,O,A,SS
DE.B-05	340 000	120	No	Dry, Wash	M,F,E,A,SS
DE.B-06	216 000	100	No	Dry, Wash	M,F,E,A,SS
DE.B-07	450 000	120	No	Dry, Wash	M,F,E,A,SS
DE.B-08	250 000	80	No	Dry, Wash	M,F,E,I,A,SS
DE.B-09	70 000	37	Yes	Dry, Wash	M,F,E,SS
DE.B-10	90 000	100	Yes	Dry, Wash	M,F,E,
DE.B-11	90 000	100	Yes	Dry, Wash	M,F,E,A
DE.B-12	79 000	55	Yes	Dry, Wash	F,E,A,SS
DE.B-13	140 000	100	Yes	Wet	M,F,E,I,A,B,SS
DE.B-14	NA	NA	Yes	Dry, Wash	M,F,E,B,SS
DK.B-01	125 000	100	No	Wet	M,F,E,I,A,SS
DK.B-02	750 000	120	No	Wet	M,F,E,I,A,SS
DK.B-03	180 000	90	No	Wet	M,F,E,A,SS
ES.B-01	200 000	120	Yes	Dry, Wash	M,F,E,A,SS
FR.B-01	5 500	1.2	Yes	Dry, Wash	F,E,SS

FR.B-02	12 000	3	Yes	Dry, Wash	F,E,SS
FR.B-03	90 000	90 000	Yes	Dry, Wash	F,E,A,SS
FR.B-04	87 000	100	Yes	Dry, Wash	M,F,E,SS
FR.B-05	54 250	80	Yes	Dry, Wash	F,E,A,SS
FR.B-06	200 000	100	No	Dry, Wash	M,F,E,A,SS
FR.B-07	120 000	92	No	Dry, Wash	M,F,E,A,SS
FR.B-08	100 000	40	No	Dry, Wash	M,F,E,SS
FR.B-09	7 000	0.84	Yes	Dry, Wash	F,SS
FR.B-10	20 000	35	No	Dry, Wash	F,E,SS
IT.B-01	250 000	110	No	Dry, Wash	M,F,E,A,SS
IT.B-02	620 000	160	No	Wet, Dry, Wash	M,F,E,I,A,S,Dw,Dd,SS
NL.B-01	180 000	100	Yes	Dry, Wash	F,E,A,B,SS
NL.B-02	320 000	130	No	Dry, Wash	F,E,A,B,SS
NL.B-03	700 000	200	No	Dry, Wash	M,F,E,A,B,SS
PT.B-01	200 000	60	No	Dry, Wash	M,F,E,A,SS
PT.B-02	NA	NA	Yes	Dry, Wash	F
SE.B-01	87 000	1000	Yes	Dry, Wash	F,E,SS
SE.B-02	129 905	40	No	Dry, Wash	F,E,A,SS
SE.B-03	100 000	100	No	Dry, Wash	M,F,E,I,SS
UK.B-01	200 000	120	No	Dry, Wash	F,E,A,B,SS

To the TWG: the values highlighted are not consistent. Please check

NB: NA = not available; A = Wind shifter / air/ -aeraulic separation; B = Ballistic separation; Dd = Dry density separation; Dw = Wet density separation; E = Eddy current separation; F = Ferromagnetic separation; I = Induction all-metal separation; M = Manual sorting; N = Near-infrared separation; O = Optical separation other than NIS; S = Sink-float separation; SS = Screening / Sieving.

Source: [81, TWG 2016]

3.4.3.1 Mass streams

The quantity of ferrous and non-ferrous metals recovered from the incineration bottom ash/slag depends on the composition of the incinerated waste and on the process applied to extract this component from the IBA. The typical waste code for bottom ash from waste incineration is 19 01 12 or occasionally 19 01 11* under the European List of Waste. Table 3.51 and Table 3.52 show the quantity of bottom ash/slag treated in 2014 and the percentage of ferrous and non-ferrous metals recovered.

Table 3.51: Quantity of treated waste with European waste code 19 01 12 in 2014 with the percentage of ferrous and non-ferrous metals produced

Plant	Quantity treated (t)	Ferrous metals (%)	Non-ferrous metals (%)
AT.B-01	32 546	1.15	1.85
BE.B-01	88 655	NA	NA
BE.B-02	87 813	8	3
CZ.B-01R	59 145	6	0.3
DE.B-01	157 600	5.77	1.46
DE.B-02	276 000	NA	NA
DE.B-03	140 180	10	1
DE.B-04	322 874	4–8	0.20–1
DE.B-05	244 931	7.66	2.613
DE.B-06	141 000	4.8	3.34
DE.B-07	304 000	NA	NA
DE.B-08	46 500	NA	NA
DE.B-09	61 172	8	0.8
DE.B-10	56 476	11.47	1.45
DE.B-11	NA	9	2.9
DE.B-12	79 000	5.06	0.68
DE.B-13	104 015	6.2	1.06
DE.B-14	64 262	9.3	0.8
DK.B-01	116 161	6	1.2

DK.B-02	750 000	NA	NA
DK.B-03	11 000	3.6	1.1
ES.B-01R	114 376	8.3	0.53
FR.B-01	11 432	NA	NA
FR.B-02	11 216	NA	NA
FR.B-03	96 186	NA	NA
FR.B-04	68 838	NA	NA
FR.B-05	45 717	NA	NA
FR.B-06	127 203	1.1	1.9
FR.B-07	104 469	NA	NA
FR.B-08	80 000	NA	NA
FR.B-09	5 837	NA	NA
FR.B-10	4 810	NA	NA
IT.B-01	132 217	8	2
IT.B-02	301 288	10	1.5
NL.B-01	205 131	6.5	2.3
NL.B-02	240 559	6.2	3
NL.B-03	616 072	4.59	1.86
PT.B-01	112 506	NA	NA
PT.B-02	18 179	2.46	NA
SE.B-01	87 000	4.44	1.89
SE.B-02	129 905	4.4	1.74
SE.B-03	99 275	5.4	1.5
UK.B-01	171 196	7	2.3

For the TWG: the values highlighted have been calculated. Please check

NB: NA = not available.

The percentage of ferrous and non-ferrous metals separated from the treated waste is net. It does not take into account the impurities.

Source: [81, TWG 2016]

Table 3.52: Quantity of treated waste with European waste code 19 01 11* in 2014 with the percentage of ferrous and non-ferrous metals produced

Plant	Quantity treated (t)	Ferrous metals (%)	Non-ferrous metals (%)
DE.B-03	73025	10	1
IT.B-01	39592.81	8	2
IT.B-02	30779	10	1.5

NB:
The percentage of ferrous and non-ferrous metals separated from the treated waste is net. It does not take into account the impurities.

Source: [81, TWG 2016]

Table 3.53 gives an overview of the treatment results and of the destinations of the treated bottom ash/slag. Most of it is recovered in road construction or earthworks or sent to landfill.

Table 3.53: Input and output of European incineration bottom ash treatment plants in 2014

Plant	Waste		R/D	Grain size (mm)	Destination						
	Input (t)	Output (t)			RC	L	OS	U	RP	AF	OR
AT.B-01	32 546	31 566	D	0–50	No	Yes	No	No	No	No	No
BE.B-01	88 655	80 711	R	0–20	Yes	No	No	No	No	No	Yes
BE.B-02	87 813	71 580	R/D	< 0.67; 0.67–2; 2–6; 6–50	Yes	Yes	Yes	No	No	No	No
CZ.B-01R	59 145	59 145	R	0–16; 16–42; > 42	No	Yes	No	No	No	No	No

DE.B-01	157 600	130 000	R	0–45	Yes	Yes	Yes	No	No	No	No
DE.B-02	276 000	243 500	R/D	0–0.25; 0.25–45	No	Yes	Yes	No	No	No	No
DE.B-03	140 180 73 025	189 540	R	0–80	No	Yes	No	Yes	No	No	No
DE.B-04	522 874	411 546	R/D	0–55	Yes	Yes	No	No	No	No	No
DE.B-05	244 931	206 822	R	0–32	No	Yes	No	No	No	No	No
DE.B-06	141 000	128 116	R	0–32	Yes	Yes	Yes	No	No	No	No
DE.B-07	304 000	280 000	R	0–32	Yes	No	No	No	No	No	No
DE.B-08	46 500	41 300	R	0–2; 2–8; 8–40	Yes	Yes	Yes	No	No	No	Yes
DE.B-09	61 172	55 745	R	0–32	No	Yes	No	Yes	No	No	No
DE.B-10	56 476	47 294	R	0–32	Yes	No	Yes	No	No	No	No
DE.B-11	NA	79 412	R	0–32	Yes	No	Yes	No	No	No	No
DE.B-12	79 000	64 300	R/D	NA	No	Yes	No	No	No	No	No
DE.B-13	104 015	108 855	R/D	NA	No	Yes	No	No	No	No	No
DE.B-14	64 262	57 814	R/D	0–32; < 32	No	Yes	No	No	No	No	Yes
DK.B-01	116 161	104 540	R	0–50	Yes	No	No	No	No	No	No
DK.B-02	750 000	675 000	R	0–50	Yes	No	No	No	No	No	No
DK.B-03	11 000	30 000	R	0–50	Yes	No	No	No	No	No	No
ES.B-01R	114 376	127 998	R	0–10; 10–20; 0–20	Yes	Yes	Yes	No	Yes	No	Yes
FR.B-01	11 432	11 432	R	0–30	Yes	No	No	No	Yes	No	Yes
FR.B-02	11 216	14 339	R	NA	Yes	No	No	No	No	No	No
FR.B-03	96 186	64 969	R	0–31	Yes	No	No	Yes	No	No	No
FR.B-04	68 838	68 258	R/D	0–30	Yes	Yes	No	No	No	No	No
FR.B-05	45 717	36 021	R	NA	Yes	No	No	No	No	No	No
FR.B-06	127 203	110 545	NA	0–20	Yes	No	No	No	No	No	No
FR.B-07	104 469	98 243	R	0–20	Yes	Yes	No	No	No	No	No
FR.B-08	80 000	65 000	R	0–31	Yes	No	No	No	No	No	No
FR.B-09	5 837	4 161	R	0–45	Yes	Yes	No	No	No	No	No
FR.B-10	4 810	3 900	NA	NA	Yes	No	No	No	No	No	No
IT.B-01	132 217 39 592.81	158 900	NA	0–2; 2–4; 0–4; 4–10	No	No	Yes	No	Yes	No	No
IT.B-02	301 288 30 779	290 000	R	0–6; 0–20	Yes	Yes	No	No	No	No	Yes
NL.B-01	205 131	184 151	R	0–22	Yes	No	No	No	No	No	No
NL.B-02	240 559	150 029	R	0–40	Yes	No	No	No	No	No	No
NL.B-03	616 072	568 631	R	0–11; 0–32	Yes	No	No	No	Yes	No	No
PT.B-01	112 506	50 353	R	0–31	Yes	No	No	No			Yes
PT.B-02	18 179	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SE.B-01	87 000	87 000	NA	0–4; 4–60; > 60	Yes	No	No	No	No	No	No
SE.B-02	129 905	121 000	NA	0–50	Yes	No	No	No	No	No	No
SE.B-03	99 275	77 534	R/D	0–60; > 60	Yes	Yes	No	No	No	No	No

UK.B-01	171 196	125 806.1	R	0–40;	Yes	No	No	No	No	No

NB: NA = not available;
R = Recovery; D = Disposal;
RC = road construction or earthworks; L = landfill; OS = other structures; U = underground; RP = recovery in product; AF = recovery in agriculture or fertiliser;
OR = other recovery.
Source: [81, TWG 2016]

Table 3.54 gives an overview of the bottom ash quality after the treatment. This information can be compared with the information on leaching values of the raw bottom ash produced by incineration plants given in Section 3.4.2.

Table 3.54: Leaching values of bottom ash after treatment

Component	**Average (mg/kg)**	**Minimum (mg/kg)**	**Maximum (mg/kg)**
Chloride	1930	100	5800
Sulphate	2118	50	6410
Lead	1	0.01	11
Copper	5	0.05	80
Nickel	0.17	0.01	1
Arsenic	0.4	0.01	2
Molybdenum	0.6	0.01	5
Antimony	0.2	0.01	1
Cadmium	0.01	0.003	0.05
Zinc	1	0.005	9
Vanadium	0.1	0.03	0.2
Total chromium	0.23	0.01	2
COD	158	1	670

Note: the reported values are calculated from the comparable information provided by the following plants: AT.B-01, BE.B-02, DE.B-05, DE.B-12, DE.B-14, ES.B-01R, FR.B-01, FR.B-02, FR.B-03, FR.B-04, FR.B-05, R.B-06, R.B-08, FR.B-09, FR.B-10, IT.B-02, NL.B-01, NL.B-02, NL.B-03, PT.B-01, SE.B-03
Source: [81, TWG 2016]

3.4.3.2 Emissions to air

Emissions to air from an incineration bottom ash/slag treatment plant are likely to be dust including particles of metals. Emissions of dust and metals come mainly from the slag/ash handling, the shredding and the air separation Table 3.55 shows the achieved dust emission levels of some EU plants with the techniques applied to reduce emissions to air and the emission sources.

Table 3.55: Dust emissions to air from incineration bottom ash treatment – Periodic measurements

Plant	Channalled emission from:	Tech.	Flow rate (Nm^3/h)			Dust (mg/Nm^3)		
			Max.	Avg.	Mín.	Max.	Avg.	Min.
CZ B-01	Shredder; Sieve; Conveyor belt; Hall air suction	B	98 120	68 540	54 040	0.7	0.3	0.2
DE B-05	Air separation	B	30 000	25 750	21 500	0.9	0.5	0.1
DE.B-10	Conveyor belt; Hall air suction	NR	NR	NR	NR	3.8	2.3	0.9
IT.B-01	Shredder; Sieve; Conveyor belt	C, B	NR	52 000	NR	1.9	1.8	1.7
IT.B-02	Shredder; Sieve; Conveyor belt; Hall air suction	C, B	200 000	180 000	160 000	0.2	0.2	0.2

NB: NR = not reported; B = bag filter; C = cyclone.
Source: [81, TWG 2016]

3.4.3.3 Emissions to water

Waste water comes mainly from the wet process and the washing process. Process waste water contains salts and metals as well as suspended solids and organic substances including PCDD/F.

Table 3.56 summarises the levels of emissions to water reported through the data collection. It also gives an indication of the applied techniques and the types of process applied.

Table 3.56: Reported emissions to water from the treatment of incineration slags and bottom ashes with the techniques used and points of release

Plant		CZ.B-01R	DE.B-03	DE.B-07	DE.B-08	DK.B-03	FR.B-03	FR.B-06	FR.B-07	FR.B-08	FR.B-09	IT.B-01	IT.B-02	NL.B-03	PT.B-01	UK.B-01
Bott. Ash Treat Plant and WIP within same plant?		Yes	No	No	No	No	Yes	No	No	No	Yes	No	No	No	No	No
Waste Water Treat. Within plant?		No	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No
Type of Treatment		Wet	Wet	Dry/Wash	Dry/Wash	Wet	Dry/Wash	Dry/Wash	Dry Wash	Dry/Wash	Dry/Wash	Dry/Wash	Wet/Dry/Wash	Dry/Wash	Dry/Wash	Dry/Wash
Techniques		Sed/Neut/Ch.T	Sed	Sed/Oil S.	Sed Oil S./Filt	Sed.	Sed/Filt.	Filt.	Sed/Neut/Ch.P/Oil S./Filt.	Neut /Ch.P/Oil S./Filt.	Oil S.	Sed/Neut/Ch.P.	Sed/Neut/Ch.P/ Oil S/Filt.	Sed/Ch.P/Filt.	Sed/Neut/Ch. P.	---
Flow rate (m^3/h)	Max	NA	NA	NA	NA	NA	NA	NA	NA	40	NA	NA	7.7	50	25.7	NA
	Ave	2.1	7	NA	0.16	NA	NA	NA	NA	10	NA	15	7.5	35	1.4	NA
	Min	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.2	19	0	NA
Conductivity (µS/cm)	Max	848	42000	8900	NA	NA	NA	NA	660	NA	NA	7120	8280	NA	16400	848
	Ave	707	21930	8500	1915	NA	NA	NA	368.55	NA	NA	4230	2020	NA	11120	707
	Min	622	8600	NA	NA	NA	NA	NA	77.1	NA	NA	NA	465	NA	8600	NA
Sulphate (mg/l)	Max	NA	1300	NA	NA	NA	NA	NA	NA	NA	NA	370	348	790	600	664
	Ave	NA	782	NA	NA	1730	NA	NA	NA	NA	NA	289	155	380	600	647
	Min	NA	39	NA	NA	NA	NA	NA	NA	NA	NA	NA	20	260	600	630
Ammonium-N (mg/l)	Max	29.3	2.6	NA	NA	NA	NA	NA	NA	NA	NA	8.4	7	40	33.2	0.18
	Ave	14.68	1.21	NA	0.16	NA	NA	NA	NA	NA	NA	4.9	1.7	13	18	0.13
	Min	6.95	0.22	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.1	6	6.2	0.0095
Lead (mg/l)	Max	0.015	0.48	NA	NA	NA	NA	0.01	0.004	1000	0.005	< 0,02	0.01	12	<0,50	0.016
	Ave	0.015	0.13	0.01	4.8	0.007	NA	0.01	0.003	70	0.005	< 0,02	0.01	11	<0,50	0.022
	Min	0.015	0.01	NA	NA	NA	NA	0.01	0.002	10	0.005	NA	0.01	10	<0,50	0.006
Total Suspended Solids (mg/l)	Max	104	2	NA	NA	NA	8	NA	5	600	6.5	< 10	22	64	140	NA
	Ave	50.5	0.85	0.1	NA	0.1	7.5	NA	3.7	400	4.75	< 10	11	24	140	65.2
	Min	28	0.2	NA	NA	NA	6	NA	2.4	10	3	NA	10	4	140	NA
TOC (mg/l)	Max	NA	NA	NA	NA	NA	NA	NA	NA	NA	9.6	NA	NA	NA	NA	NA
	Ave	NA	NA	NA	NA	NA	NA	NA	NA	NA	9.5	NA	NA	NA	NA	NA
	Min	NA	NA	NA	NA	NA	NA	NA	NA	NA	9.4	NA	NA	NA	NA	NA
PCDD/F (ng I-TEQ/l)	Max	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.017	NA	NA	NA	NA	NA
	Ave	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.0235	NA	NA	NA	NA	NA
	Min	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.03	NA	NA	NA	NA	NA
Receiving water body		Artificial water body (e.g. reservoir)	Artificial water body (e.g. reservoir)	NA	River / Stream	Artificial water body (e.g. reservoir)	NA	River / Stream	Artificial water body (e.g. reservoir)	Artificial water body (e.g. reservoir)	River / Stream	River / Stream	Lake	NA	NA	Artificial water body (e.g. reservoir)

Note: Type of Treatment: Wash = Bottom Ash Wash
Sed = Sedimentation
Neut = Neutralisation
Ch.P = Chemical Precipitation
Oil S. = Oil Separation
Filt = Filtration
NA = not available

3.4.3.4 Energy consumption

The energy input in the form of electrical power depends directly on the plant capacity, types of processes and technologies used. It is thus very specific to each individual case and is only comparable to a limited extent.

Table 3.57 reports the installed power as well as the consumption of electricity, steam, fuels and water by the plants. No data are available on the detailed monitoring/metering by process of the power (electrical and fuel consumption) used to power individual processes,

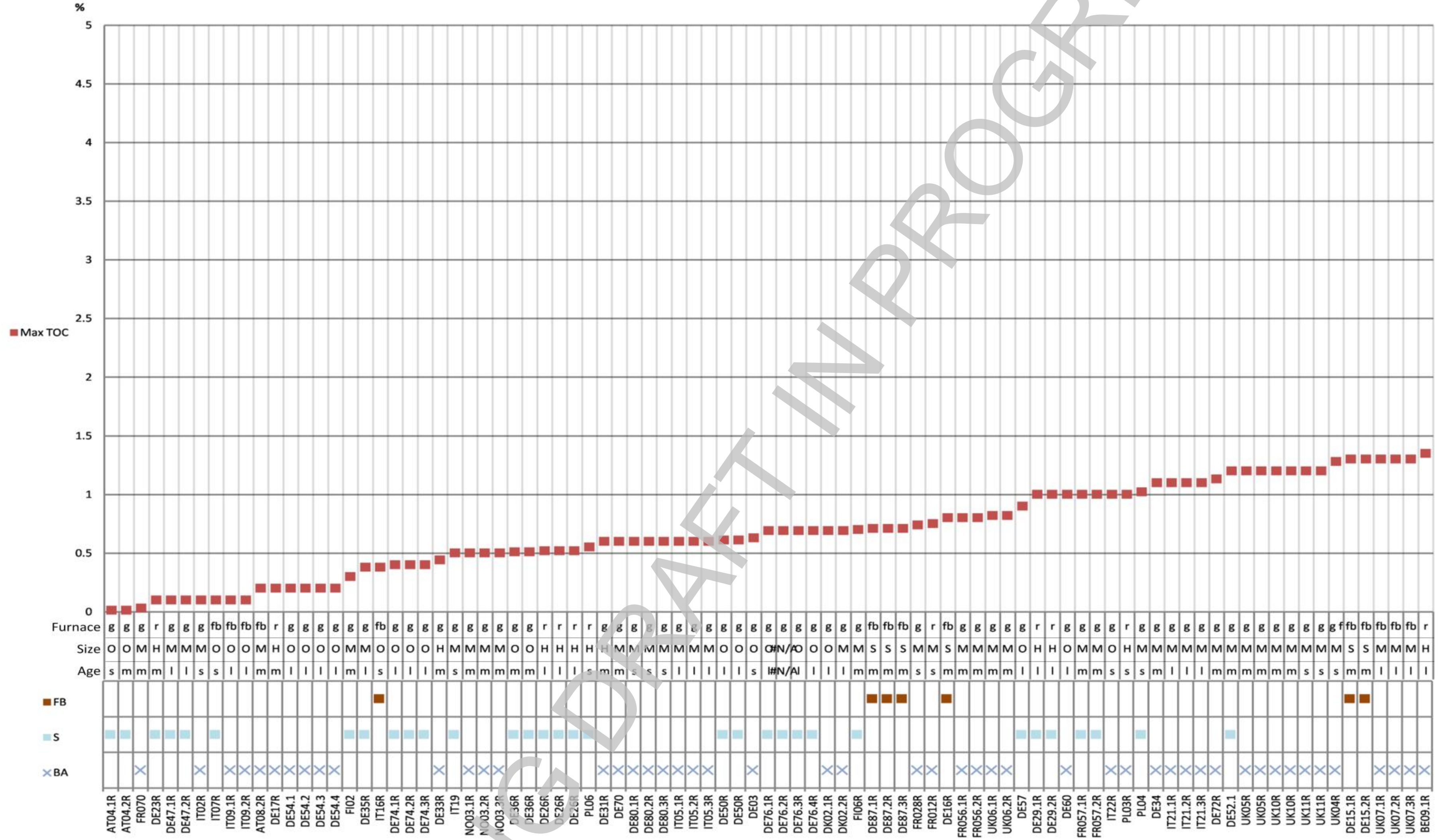
Table 3.57: Energy and water use reported in 2014 by incineration bottom ash treatment plants

Plant	Installed power (kVA)	Electricity consumption (kWh)	Liquid fuel consumption (t)	Natural gas consumption (kWh)	Steam consumption (kWh)	Water consumption (m^3)	Rainwater reused (m^3)
AT.B-01	200	NA	30 587	0	0	848	0
BE.B-01	174	295 630	0	0	0	NA	NA
BE.B-02	439	NA	0	0	0	11 415	14 050
CZ.B-01	7 550	178 38 993	0	3 031 597	302 091	3 010	13 617
DE.B-01	350	205 000	110 000	NA	NA	1 400	NA
DE.B-02	1 200	989 000	0	0	0	18 500	0
DE.B-03	175	371 000	82 900	0	0	5 896	2 495
DE.B-04	1 254.1	1 985 861	0	0	0	0	47 000
DE.B-05	640	638 216	267 132	0	0	0	13 500
DE.B-06	NA	438 000	60 000	NA	NA	NA	NA
DE.B-07	630	300 000	0	0	0	0	0
DE.B-08	400	420 000	40 000	0	0	1 200	0
DE.B-09	NA	368 000	NA	0	175 000	0	0
DE.B-10	432	1 110 000	24 000	0	0	0	0
DE.B-11	200	1 500 000	20 000	0	0	0	0
DE.B-12	NA	343 900	0	0	0	0	0
DE.B-13	800	117 023	0	0	0	323	9 270
DE.B-14	270	NA	0	0	0	300	300
DK.B-01	NA	80 000	NA	0	0	0	NA
DK.B-02	250	NA	NA	NA	NA	NA	NA
DK.B-03	280	10 000	5 000	0	0	0	4 000
ES.B-01	470	238 996	5 855	0	0	1 484.4	0
FR.B-01	32	278 400	19 100	0	0	0	0
FR.B-02	NA	NA	NA	NA	NA	NA	NA
FR.B-03	204	221 830	62 068	0	0	380	900
FR.B-04	260	125 000	42 992	0	0	46	0
FR.B-05	200	100 000	36 000	0	0	261	NA
FR.B-06	412	660 000	52 000	0	0		0
FR.B-07	630	210 360	62 540	0	0	91	0
FR.B-09	7.5	52 616.25	8 000	0	0	0	0
FR.B-10	62	NA	7 810	0	0	NA	0
IT.B-01	1 000	1 217 063	630	45 283	0	21 083	0
IT.B-02	700	1 680 000	0	0	0	3 000	3 000
NL.B-01	800	800 000	0	0	0	0	0
NL.B-02	NA	650 000	0	0	0	0	0
NL.B-03	1 070	1 115 877	157 440	0	0	20	0
PT.B-01	100	94 866	67 877	NA	NA	NA	24 304
SE.B-01	NA	80 000	0	0	0	100	0
SE.B-02	NA	NA	0	0	0	5 000	0
UK.B-01	500	212 138	NA	NA	NA	40 206	NA

For the TWG: the values highlighted have been calculated. Please check

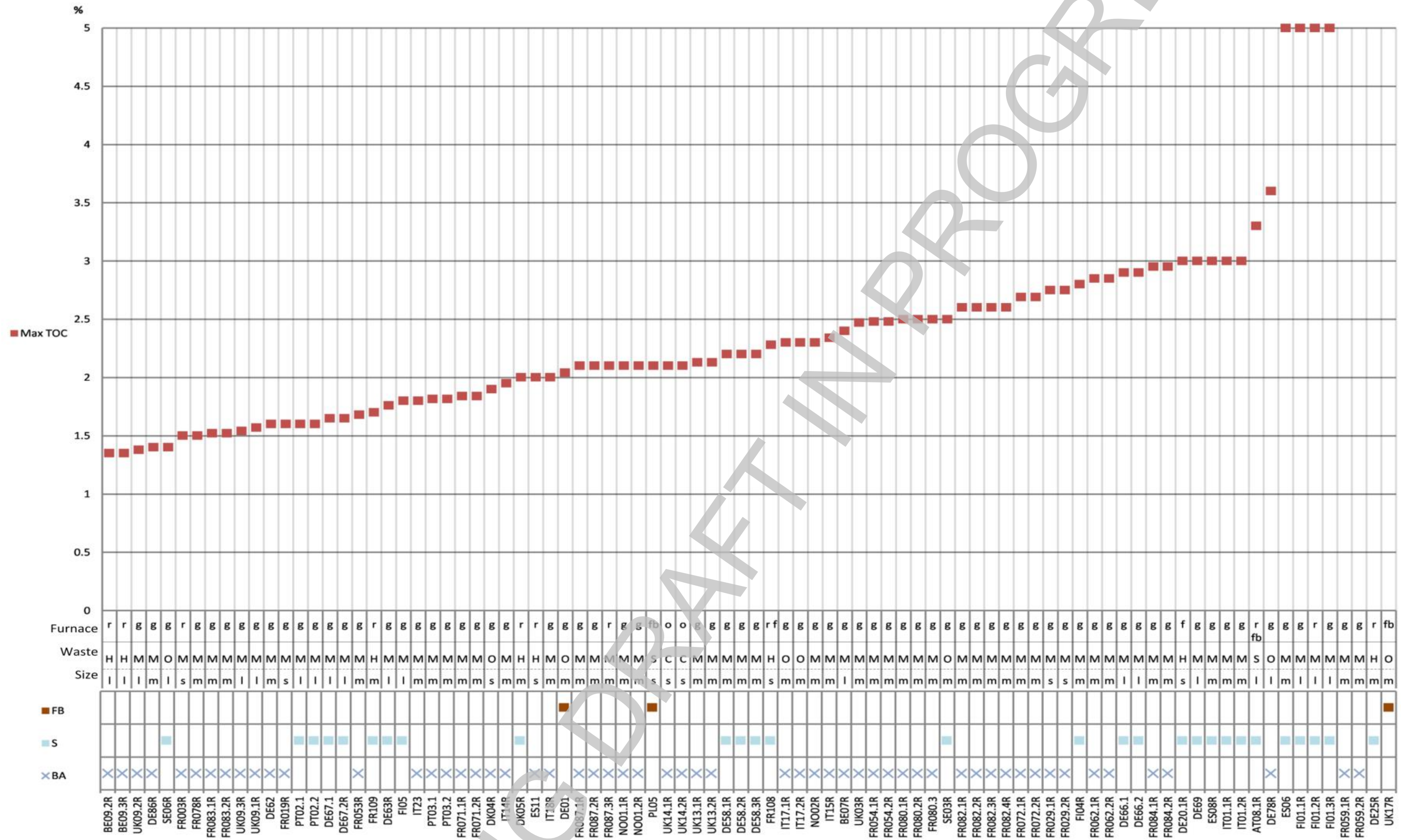
NB: NA = not available.

Source: [81, TWG 2016]



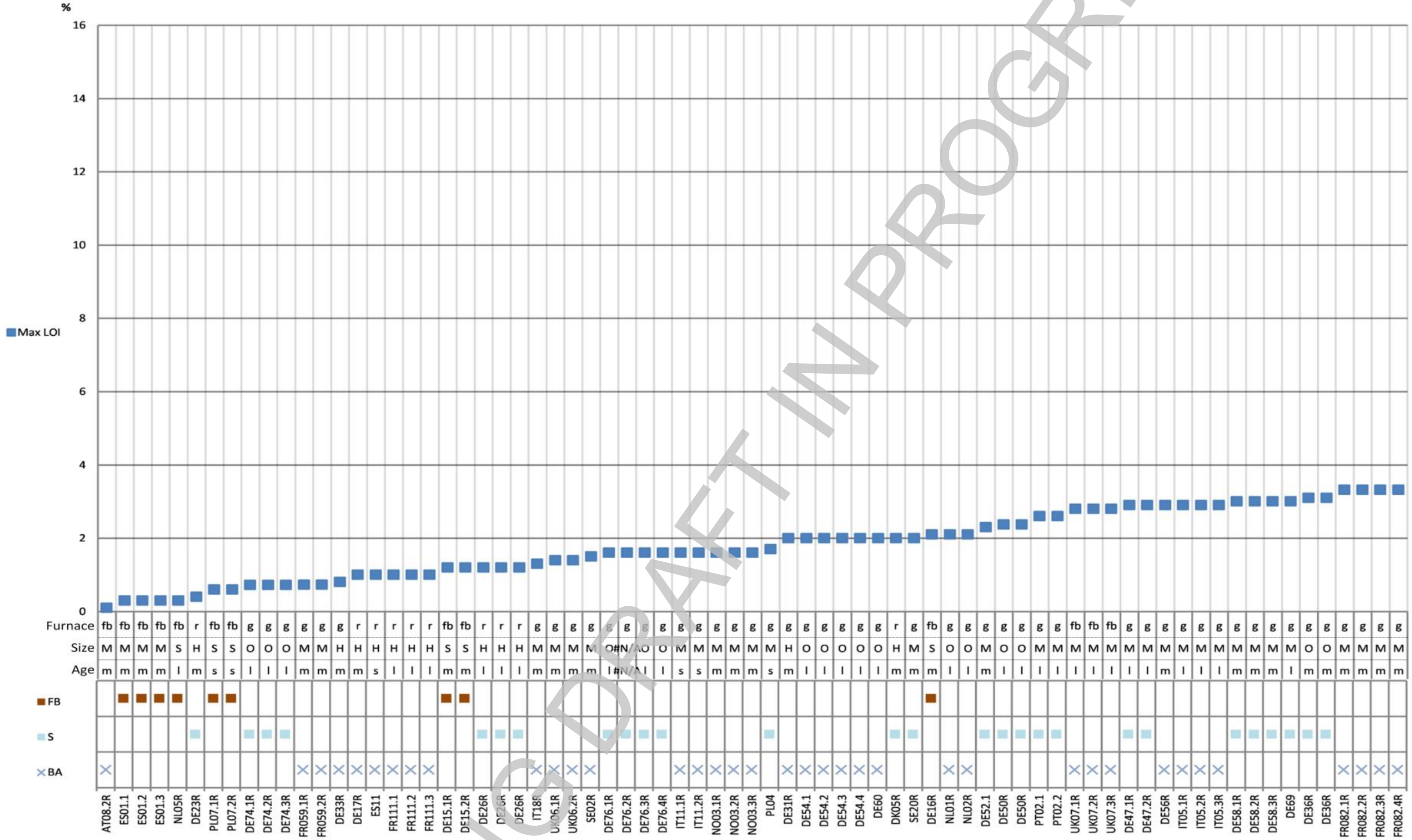
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
FB= Fluidised bed combustion ash
S= Slag
BA= Bottom ash
Source: [81, TWG 2016].

Figure 3.135:TOC content in incineration slags and bottom ashes (1/2)



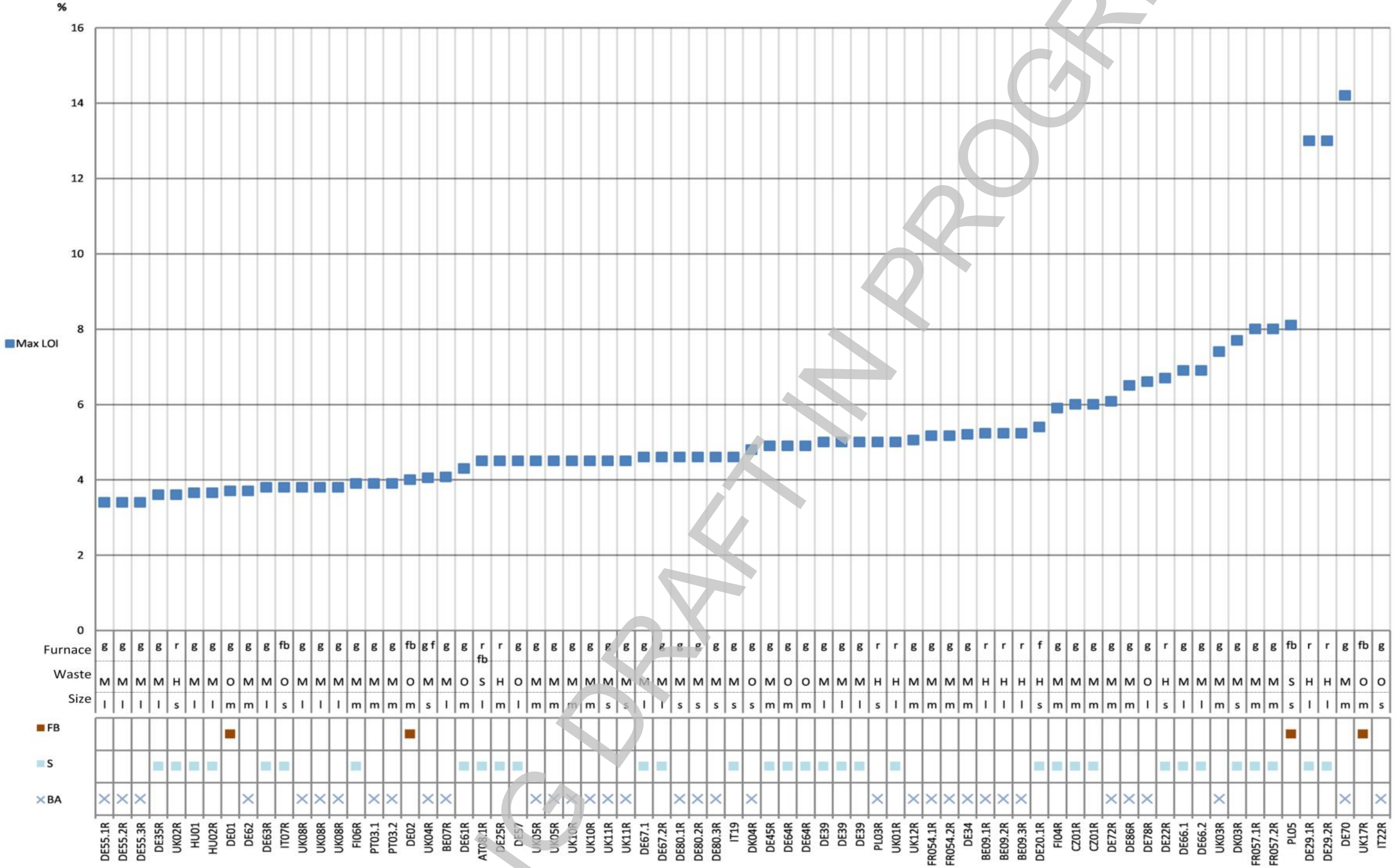
Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
FB= Fluidised bed combustion ash
S= Slag
BA= Bottom ash
Source: [81, TWG 2016].

Figure 3.136:TOC content in incineration slags and bottom ashes (2/2)



Note:
Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
FB= Fluidised bed combustion ash
S= Slag
BA= Bottom ash
Source: [81, TWG 2016]

Figure 3.137:LOI of incineration slags and bottom ashes (1/2)



Furnace type: g = grate; r = Rotary kiln; fb = Fluidised bed; f = Furnace other than the former types; gas = Gasification; O = Other.
Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste
Plant size: s = small; m = medium; l = large.
FB= Fluidised bed combustion ash
S= Slag
BA= Bottom ash
Source: [81, TWG 2016]

Figure 3.138: LOI of incineration slags and bottom ashes (2/2)

3.5 Energy consumption and production

Energy inputs to the incineration process may include:

- waste (mainly);
- support fuels (usually a very limited amount ~~few~~);
- imported electricity (if any).

Production and exports may include:

- heat (as steam or hot water);
- electricity.

Pyrolysis and gasification processes may export some of the energetic value of the incoming waste with the substances they export, e.g. syngas, chars, oils. In many cases these products are either directly or subsequently burned as fuels to utilise their energy value, although they may also be used for their chemical value as a raw material, after pretreatment if required.

~~There are a significant number~~ Most ~~of~~ incineration plants in Europe ~~that~~ produce and export electricity, heat or both. ~~Both electricity and heat.~~

The combination of energy exports ~~which is selected~~ depends on a number of factors. Often~~,~~ ~~whether a~~ the existence of local demand ~~exists~~ for steam or heat ~~is decisive for decisions concerning its~~ drives the supply. The relative prices for the supply of the energy produced and the duration of sales contracts are generally seen as key factors in determining the outcome. This, in turn, ~~has a decisive input on~~ is an important driver for the technological decisions regarding the process design. Some of these factors are described in
Table 3.58 below.

Table 3.58: Factors influencing energy recovery options

Factor	Influence
High electricity price paid for supply or reliable demand	• Encourages investment to produce electricity • Boiler cladding may be purchased to allow higher steam pressures and greater electrical outputs • Less heat will be available for supply • Plant may import electricity to ensure own produced exports can be maximised
Higher electricity price for imported electricity than that produced	• Encourages the use of own produced electricity for running the incineration process • Heat-only plants may decide to divert some energy to supply own electricity demands
Higher price paid for heat and higher reliability of demand	• Investment in distribution networks becomes more viable • Overall plant efficiency gains possible due to ability to supply more of the recovered energy
Colder climate	• Can allow heat supply over more months of the year
Hotter climate	• Less reliable heat demand for heating • May increase options to supply heat to drive chillers for air conditioning, to feed seawater thermal desalination plants, etc.
Base load energy supply contract	• Increases reliability of sales contract and encourages investment in techniques to utilise available energy (heat and electricity)
~~Very low permitted air emissions~~	~~• additional energy demand of flue-gas treatment equipment~~
Not permitted to discharge treated waste water from wet scrubbers	• Reduction in available heat for export owing to need to supply evaporation energy
Vitrification of ash required	• Higher plant energy demand results in increased self-consumption and reduced outputs
Higher incineration temperature required	• Possible need for additional fuels to obtain required ~~relevant~~ temperature
Source: [83 WI BREF 2006]	

3.5.1 Energy efficiency calculation for waste incineration installations

The energy efficiency relates the input chemical energy contained in waste (normally espressed as the LHV) with the useful energy produced (electrical and thermal) that is recovered rather then being dissipated (through the flue-gas, cooling system, etc.). The energy efficiency of a waste incineration installation is often expressed as a percentage. When considering such data, it is important to ensure that energy efficiency figures are calculated in a comparable manner.~~ The calculations that underpin these have been performed in a way that permits comparisons to be made. Failure to do so may result in inappropriate conclusions being drawn.~~ This requires taking into account the following, when calculating energy efficiency~~. Some steps that are required to avoid problems with such calculations are~~:

1. **The boundaries of the system/calculation need to be clearly defined**~~**Define the system/calculation boundary**~~

For the sake of comparability, it is necessary to take into account the type of waste incinerated and not only the waste delivered to the installation. If the incoming waste requires significant pretreatment (e.g. crushing, shredding, drying), this can result in ~~very~~ significant additional energy requirements.

2. ~~**Account for a**~~ **All energy inputs need to be accounted for**

Some installations use additional fuels to maintain combustion temperatures. The energy recovered at the installation will be partly derived from the waste and partly derived from the additional fuel.

3. **Own energy consumption and internal energy flows need to be accounted for in a consistent manner** ~~**recirculating energy flows**~~

In some cases, electricity and/or heat that is recovered from the waste~~,~~ is then used within the installation. ~~When this is carried out, the net~~ Accounting for this results in ~~is~~ a net reduction of exported energy and in an equivalent reduction of imported energy.

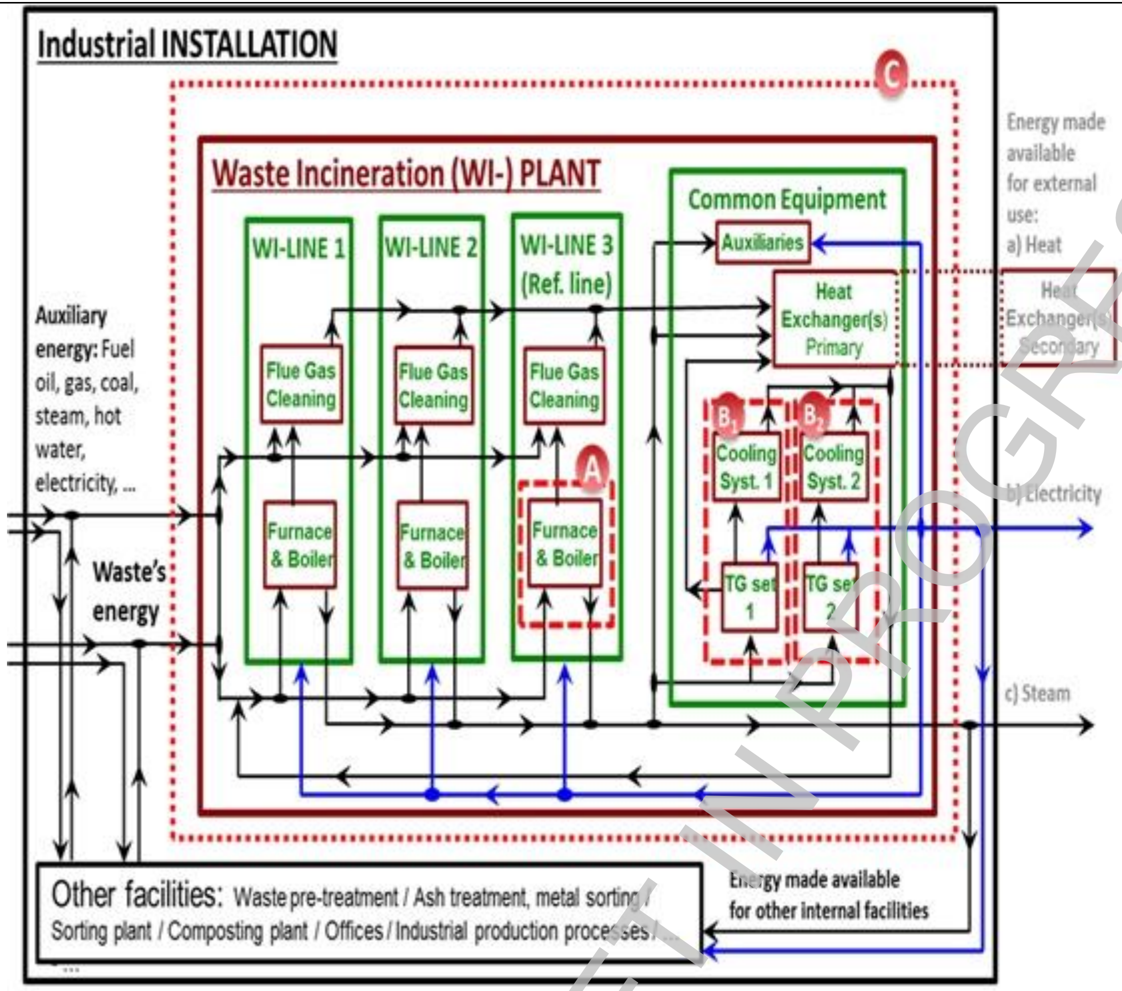
4. **All assumptions need to be made clear and consistently adhered to** ~~**Decide whether to simply add energy outputs or use equivalence factors to account for their relative value?**~~

Simple addition of the electrical and heat outputs can create difficulties when considering the relative efficiencies of installations that produce different quantities of these energy flows. The use of equivalence factors can allow consideration of the relative value of these commodities, i.e. it can allow consideration of the value of the energy production that the recovered energy displaces. The equivalence factors assigned will be dependent upon the energy mix that the energy recovered at the incineration installation replaces.

~~Where equivalence factors have been used in this document, a note of the factor used is included (see also Section 3.5.3 regarding equivalence factors).~~

~~An example an energy efficiency calculation is given in appendix 8.4. This method was developed by members of a sub-group of the TWG, and was used to provide some of the summary survey data reported in this chapter.~~

Data on energy efficiency presented in this section are derived from the performance test that the plant undergoes to check the real performance when it is first commissioned or after significant changes. The energy efficiency is assessed at the level of the waste incineration plant, with the system boundary shown in Figure 3.139.



NB:
A = Energy recovered by the boiler. Boiler performance test.
B1 & B2 = Energy generated by the Turbine generator sets. Turbine generator performance test.
C = Energy made available for use outside of the WI plant (within and/or outside the installation).
Source: [81, TWG 2016]

Figure 3.139: System boundary used for the calculation of the energy efficiency

~~3.5.2 Waste net calorific value calculation~~

~~Information regarding the typical calorific value ranges exhibited by various waste types, LHV survey and variation data and an example method for the calculation of net calorific value are included in Section 2.4.2.~~

3.5.3 Equivalence factors

[Energysubgroup, 2002 #29]

When comparing different incineration plants, a common energy unit ~~of energy measure~~ is needed. ~~Energy can be quantified in a number of ways, depending on the energy type of the resource. Fuels are usually quantified either by their heat content (joules) or in fuel equivalence values (usually, oil or hard coal equivalents).~~

The **watt-hour (Wh)** ~~**joule (J)**~~ is the ~~common~~ unit used in this document to convert the measurement units of different forms of energy into a common unit. To calculate and express energy efficiencies at WI plants, it is necessary to take into account the form of the energy consumed and produced.

~~Taking account of the~~ Comparing different energy forms~~,~~ requires the ~~comparison~~ conversion of different ~~units of~~ measurement units, such as ~~i.e.~~ MWh$_{th}$ (thermal input), MWh$_{e}$ (electricity), and MWh$_{th}$ (heat ~~thermal energy~~). The following table gives conversion factors (for externally generated sources) assuming an average of 38 % for electrical conversion efficiency (i.e. 1 MWh$_{th}$ = 0.38 MWh$_{e}$), and 91 % for external heat generation (i.e. 1 MWh$_{th}$ = 0.91 MWh$_{th}$).

Table 3.59: Energy equivalence conversion factors

From:	**Multiply by:**			
To:	**GJ$_{th}$**	**MWh$_{th}$**	**MWh$_{e}$**	**MWh$_{th}$**
GJ$_{th}$	1	0.2778	0.1056	0.2528
MWh$_{th}$	3.6	1	0.3800	0.9100
MWh$_{e}$	9.4737	2.6316	1	-
MWh$_{th}$	3.9560	1.0989	-	1
Gcal$_{th}$	4.1868	1.163	0.4421	1.0583

Source: [29, Energysubgroup, 2002, 64, TWGComments, 2003]

Note ~~It is important to understand~~ that equivalence values are not exact coefficients or conversion factors. They provide an estimate of the energy that is required to produce the energy externally.

3.5.4 Data on the recovery of energy from waste

[1, UBA, 2001]
The generation of electricity is limited by:

- the high-temperature corrosion that may occur in the heat conversion area (boiler, economiser, etc.) due to the contents of certain materials, including chlorine, in the waste;
- fouling of the boiler – above approximately 600 °C to 800 °C the ashes are sticky due to the presence of some smelting substances.

The steam parameters (and hence electrical efficiency) of incineration plants are therefore limited. A steam pressure of 90 ~~60~~ bar and a temperature of 535 ~~520~~ °C can be considered the maximum at present (2014), and only then where special measures are taken to limit corrosion.

For electricity production from MSW, typical superheated steam conditions are 40 bar to 70 ~~45~~ bar and ~~380 to~~ 400 °C to 450 °C. ~~[74, TWGComments, 2004]~~ Lower ~~figures~~ parameters, generally ~~less than~~ in the range of 30 bar and ~~300~~ 350 °C, are applied where electricity is generated from hazardous wastes owing to the increased corrosion risks (leading to operational difficulties and costs) with acidic flue-gases at higher steam parameters.

Where only heat or steam is supplied, operators tend to use lower boiler pressures and temperatures to avoid the need for the additional investment and maintenance and the more complex operation conditions associated with higher parameters. In the case where heat supply is prioritised, high pressure and temperature are not justified. Typically for heat supply, the steam will be generated at lower values, e.g. around 25 bar to 30 bar and 250 °C to 350 °C.

The majority of larger waste incinerators in Europe recover energy from the waste. ~~There are some~~ Plants without heat utilisation~~, these concerns~~ generally relate to very specific designs ~~or older/smaller plants~~. ~~For example:~~

- ~~hazardous waste incineration plants using flue-gas quenching in order to reduce risks of PCDD/F reformation (e.g. UK and France). In these cases, some heat recovery may still be made from the hot quench water that is produced by the quench scrubber~~

- ~~relatively small municipal waste incineration plants (particularly in France, but also some in Italy and Belgium).~~

The steam parameters (pressure and temperature at the turbine entrance) of the plants that participated in the data collection for the review of the WI BREF are shown in the following graphs. The size and the age of the plants are also reported, as well as the lower heating values of the incinerated waste and whether they produce only heat (H), electricity I or both (CHP).

The temperature and pressure of the steam produced by plants incinerating municipal solid waste or other non-hazardous waste are shown in graphs in Figure 3.141, Figure 3.142, Figure 3.143, and Figure 3.144. In the graphs, plants are ordered according to the date when the plant first come into operation or was retrofitted to the actual configuration (older to newer plants from left to right). The graphs do not show a clear correlation between plant age and steam parameters.

Table 3.60 shows the temperature and pressure of the steam at the turbine entrance of plants incinerating predominantly hazardous wastes.

Table 3.60: Steam parameters of plants incinerating hazardous waste at the turbine entrance

Plant	Furnace	Size	LHV (MWh/t)	Steam pressure (bar)	Steam temperature (°C)
DE04	Grate	l	NA	75	470
DE05	Grate	m	5.2	33.5	430
DE18	Rotary	l	2.9	27	270
DE26	Rotary	l	6.36	44	325
DE29	Rotary	l	NA	26	280
DE31	Grate	m	3.55	46	450
DE32	Grate	l	3.672	66	460
DE33	Grate	m	3.598	64	425
ES11	Rotary	s	NA	41	350
FR111	Rotary	l	3.3	40	360
PL03	Rotary	s	NA	20	270
SE21	Rotary	l	3.1	41	400

NB: NA = not available; size: l =large, m = medium, s = small.
Source: [81, TWG 2016]

Table 3.61 shows the temperature and pressure of the steam at the turbine entrance of plants incinerating predominantly sewage sludge. All these plants are fluidised bed incinerators.

Table 3.61: Steam parameters of plants incinerationg sewage sludge at the turbine entrance

Plant	Size	LHV (MWh/t)	Steam pressure (bar)	Steam temperature (°C)
AT08	l	1.7	53	350
NL06	l	NA	10	180
PL01	m	0.54	49	400
UK15	s	0.2	42	400

NB: NA = not available; size: l = large, m = medium, s = small.
Source: [81, TWG 2016]

In the following sections, the energy efficiency levels (electricity and heat) achieved by the plants that participated in the data collection exercise are reported. The reported energy efficiency levels refer to the ratio between the plant's gross energy output(s) and the energy input (expressed as lower heating value) into the thermal treatment unit(s), including waste and other fuels, at actual plant design and for the plant operated at full load during the performance test.

3.5.4.1 Electricity recovery data

[1, UBA, 2001]
Although there are significant local variations, typically approximately 400 kWh to 700 kWh of electricity can be generated with one tonne of municipal waste in a municipal waste incineration plant. This is dependent upon the size of the plant, steam parameters and degrees of steam utilisation and mainly on the calorific value of the waste.

The amount of energy available for export usually depends upon the amount produced and the degree of self-consumption by the installation – which can itself vary significantly. The FGC system's consumption is often significant and varies with the type of system applied (and emission levels required). In some cases, the energy required to run the installation is imported from an external supply, with all of that generated by the installation being exported – the local balance usually reflects local pricing for the electricity generated compared to general grid prices.

The following graphs and tables show the gross electrical efficiency of the waste incineration plants that participated in the data collection for the review of the WI BREF. The efficiency is presented in the graphs alongside the age and size of the plants as well as the lower heating value of the incinerated waste; plants are marked with I or I if they produce only electricity or heat and electricity, respectively.

The gross efficiency of plants incinerating predominantly municipal solid waste or other non-hazardous waste are shown in graphs in Figure 3.145, Figure 3.146, Figure 3.147 and Figure 3.148. In general, smaller plants achieve lower electrical efficiency levels than medium and large plants. The graphs do not show a clear correlation between the achieved gross electrical efficiency and the plant age or the calorific value of the waste incinerated.

Table 3.62 shows the gross electrical efficiency of plants incinerating predominantly hazardous waste.

Table 3.62: Gross electrical efficiency of plants incinerating predominantly hazardous waste

Plant	**Age**	**Size**	**LHV (MJ/kg)**	**Production**	**Efficiency (%)**
DE18	O	Large	11	Electricity	14
ES11	O	Small	11	CHP	15
DE05	O	Medium	19	Electricity	16
DE33	O	Medium	4 to be checked	CHP	27
DE31	I/ab	Medium	4 to be checked	CHP	27
DE32	I	Large	4 to be checked	Electricity	29
DE04	I/ab	Large	3 to be checked	CHP	30
DK05	I/ab	Medium	11	CHP	32

NB: Age: first entered into operation: O = older, I = intermediate; Retrofitted ab = after 2006.
LHV = lower heating value.
Source: [81, TWG 2016]

Table 3.63 shows the gross electrical efficiency of plants incinerating predominantly sewage sludge.

Table 3.63: Gross electrical efficiency of plants incinerating predominantly sewage sludge

Plant	**Age**	**Size**	**LHV (MJ/kg)**	**Production**	**Efficiency (%)**
NL06	O/ab	Large	2	Electricity	12
DE16	O/ab	Medium	4	Electricity	20.5
UK15	I	Small	0 to be checked	Electricity	85 to be checked
DE87	O/ab	Medium	1	CHP	100 to be checked

NB: Age: first entered into operation: O = old, I = intermediate; Retrofitted ab = after 2006.
LHV = lower heating value.
Source: [81, TWG 2016]

~~A survey of eight investigated MSW plants (2001 data) carried out by the TWG energy sub-group gave the following results:~~

~~**Table 3.64: Electricity production and export rates per tonne of MSW**~~

~~**Electricity**~~	~~**Units**~~	~~**Minimum**~~	~~**Average**~~	~~**Maximum**~~
~~**Production**~~	~~MWh_e/t waste~~	~~0.415 (12.9 %)~~	~~0.546 (18 %)~~	~~0.644 (22 %)~~
	~~GJ_e/t waste~~	~~1.494~~	~~1.966~~	~~2.319~~
~~**Export**~~	~~MWh_e/t waste~~	~~0.279 (8.7 %)~~	~~0.396 (13 %)~~	~~0.458 (18 %)~~
	~~GJ_e/t waste~~	~~1.004~~	~~1.426~~	~~1.649~~

1. ~~Figures are given as measured (i.e. not factored equivalents)~~
2. ~~Percentage efficiencies are given in parenthesis (also not factored) and take account of energy derived from imported fuels as well as from waste~~
3. ~~Figures for production include all electricity generated~~
4. ~~Figures for export exclude electricity produced by the process but consumed in the process~~
5. ~~LHV average value was 2.9MWh/t~~

~~*Source:* [Energysubgroup, 2002 #29]~~

~~Other data supplied for French installations shows the following results:~~

~~**Table 3.65: Electricity production and export data per tonne of MSW for MSWI in France**~~

		~~**For units>3t/h**~~			~~**New Units**~~
~~**Electricity**~~	~~**Units**~~	~~**Minimum**~~	~~**Average**~~	~~**Maximum**~~	~~**Average**~~
~~**Production**~~	~~MWh_e/tonne waste~~	~~0.148 (4.6 %)~~	~~0.368 (11.4 %)~~	~~0.572 (17.8 %)~~	~~0.528 (16.4 %)~~
	~~GJ_e/tonne waste~~	~~0.5328~~	~~1.389~~	~~1.897~~	~~1.900~~
~~**Export**~~	~~MWh_e/tonne waste~~		~~0.285 (8.8 %)~~		~~0.430~~
	~~GJ_e/tonne waste~~		~~1.026~~		~~1.548~~

~~*Source:* [64, TWGComments, 2003]~~

3.5.4.2 Heat recovery data

The gross heat efficiency of the waste incineration plants that participated in the data collection for the review of the WI BREF is presented in this section alongside the age and the size of the plants as well as the lower heating value of the incinerated waste; plants are marked with (H) or I if they produce only heat or heat and electricity, respectively.

The gross heat efficiency of plants incinerating predominantly municipal solid waste or other non-hazardous waste are shown in Figure 3.149. The graph does not show a clear correlation between the gross heat efficiency and the age or the plant size or the lower heating values.

Table 3.66 shows the gross heat efficiency of plants incinerating predominantly hazardous waste. The data do not show a clear correlation between the gross heat efficiency and the age or size of the plant or the lower heating value of the waste incinerated.

Table 3.66: Gross heat efficiency of plants incinerating predominantly hazardous waste

Plant	**Age**	**Size**	**LHV (MJ/kg)**	**Production**	**Efficiency (%)**
DE30	O	Large	9	Heat	48
FR107	O	Large	4	Heat	55
DE23	O/bb	Medium	12	Heat	60
DE22	O	Small	17	Heat	66
SE21	O	Large	17	CHP	67
DE20	O/bb	Small	14	Heat	70
DE21	I/ab	Small	18	Heat	71
DE26	O/bb	Large	24	CHP	72
DE25	O/bb	Medium	17	Heat	74
FR104	O	Small	10	Heat	76
DK05	O/bb	Medium	11	CHP	80
FR111	O/bb	Large	12	CHP	89

NB: Age: first entered into operation: O = old, I = intermediate; Retrofitted bb = before 2006, ab = after 2006.
LHV = lower heating value.
Source: [81, TWG 2016]

Table 3.67 shows the gross heat efficiency of plants incinerating predominantly sewage sludge.

Table 3.67: Gross heat efficiency of plants incinerating predominantly sewage sludge

Plant	Age	Size	LHV (MJ/kg)	Production	Efficiency (%)
DE15	O/ab	Medium	2	CHP	68
AT08	O	Large	6	CHP	70

NB: Age: first entered into operation: O=old; Retrofitted ab = after 2006.
LHV = lower heating value.
Source: [81, TWG 2016]

~~A survey of fifteen investigated MSW plants (2001 data) carried out by the TWG energy sub-group gave the following results:~~

~~Table 3.68: Heat production and export rates per tonne of MSW~~

~~Heat~~	~~Units~~	~~Minimum~~	~~Average~~	~~Maximum~~
~~Production~~	~~MWh_{th}/t waste~~	~~1.376 (45.9 %)~~	~~1.992 (65.8 %)~~	~~2.511 (74.3 %)~~
	~~GJ_{th}/t waste~~	~~4.953~~	~~7.172~~	~~9.040~~
~~Export~~	~~MWh_{th}/t waste~~	~~0.952 (29.9 %)~~	~~1.786 (58.8 %)~~	~~2.339 (72.7 %)~~
	~~GJ_{th}/t waste~~	~~3.427~~	~~6.600~~	~~9.259~~

1. ~~All figures are given as measured (i.e. not factored equivalents)~~
2. ~~Percentage efficiencies are given in parenthesis (also not factored) and take account of energy derived from imported fuels as well as from waste.~~
3. ~~Figures for production include all heat produced by the boiler~~
4. ~~Figures for export exclude heat produced by the process but consumed in the process~~

~~*Source:* [Energysubgroup, 2002 #29]~~

~~Other data supplied by France show the following results:~~

~~Table 3.69: Heat production and export rates per tonnes of MSW for MSWI in France~~

		~~For units >3t/h~~		
~~Heat~~	~~Units~~	~~Minimum~~	~~Average~~	~~Maximum~~
~~Production~~	~~MWh_{th}/t waste~~	~~0.292 (9 %)~~	~~0.978 (30.4 %)~~	~~1.595 (49.6 %)~~
	~~GJ_{th}/t waste~~	~~1.051~~	~~3.502~~	~~5.742~~
~~Export~~	~~MWh_{th}/t waste~~		~~0.902 (28 %)~~	
	~~GJ_{th}/t waste~~		~~3.247~~	

~~*Source:* [64, TWGComments, 2003]~~

3.5.4.3 Combined heat and power data

[1, UBA, 2001]
In the case of combined electricity/heat generation, approximately 1250 kWh of additional heat per tonne of waste can be used at full load.

~~If a~~ Where energy can be supplied at baseload ~~supply~~ conditions ~~situation exists~~, the gross degree of utilisation (electricity + heat) can be increased to 85~~75~~ % to 88~~76~~ % of the energy waste input (as LHV) (thermal value). Higher values are achieved with the use of flue-gas condensation. [81, TWG 2016]

~~A survey of 50 investigated MSW plants (2001 data) carried out by the TWG energy sub-group gave the following percentage efficiencies for CHP:~~

~~Table 3.70: Average CHP percentage efficiency (calculated as energy equivalents) for 50 MSWI plants~~

~~CHP~~	**~~Average efficiency~~**
~~Production~~	~~59.4 %~~
~~Export~~	~~49.3 %~~
~~NB: To allow addition of heat and electricity to provide a single efficiency measure, a factor of 2.6316 is applied to electrical efficiencies. This factor takes account of the unavoidable losses of electrical energy production and allows processes producing different balances of heat and power to be compared (and hence averaged) with greater meaning.~~	
~~*Source:* [Energysubgroup, 2002 #29]~~	

~~Note: A statement about minimum and maximum efficiencies for combined heat and power production (export) is not possible and therefore not included in Table 3.70. This is because the summation of minimum heat and minimum electricity as well as of maximum values leads to misleading results.~~

~~Other data provided by France are shown below. The figures show average values:~~

~~Table 3.71: Average CHP recovery values per tonne of MSW in MSWI in France~~

	~~Units~~	**~~For installations >3t/h~~**	**~~New installations~~**
~~Electricity production~~	~~MWh$_e$/t waste~~	~~0.168~~	~~0.382~~
	~~GJ$_e$/t waste~~	~~0.604~~	~~1.375~~
~~Heat production~~	~~MWh$_e$/t waste~~	~~0.647~~	~~0.944~~
	~~GJ$_e$/t waste~~	~~2.329~~	~~3.398~~
~~Electricity exported~~	~~MWh$_e$/t waste~~	~~0.107~~	~~0.300~~
	~~GJ$_e$/t waste~~	~~0.385~~	~~1.08~~
~~Heat exported~~	~~MWh$_e$/t waste~~	~~0.546~~	~~0.578~~
	~~GJ$_e$/t waste~~	~~1.965~~	~~2.08~~
~~*Source:* [64, TWGComments, 2003]~~			

3.5.4.4 Boiler conversion efficiency data

For the TWG: text moved from Section 3.5.4

Depending on the type of furnace, the following boiler efficiencies have been ~~are~~ reported ~~to be achieved~~:

- fluidised bed:
    - small plants: up to 85 %;
    - medium-size plants: up to 89 %;
    - large plants: up to 93 %; ~~boilers with exhaust gas temperatures of about 160 °C can achieve boiler efficiencies of about 90 %.~~
- grate:
    - small plants: up to 91 %;
    - medium and large plants: up to 93 %; ~~firing furnaces have a boiler efficiency of about 80 %. [74, TWGComments, 2004]~~
- rotary kiln:
    - small and medium-size plants: up to 82 %;
    - large plants: up to 92 %.

The boiler efficiency of the plant has been calculated as the ratio between the gross heat power (steam + hot water) output and the nominal thermal input of the plant:

- Gross heat power output (steam): energy of the steam generated by each waste incineration line minus the energy of the feed water at nominal design conditions. The gross heat power output – steam of the plant is the sum of the gross heat power output – steam of the lines.
- Gross heat power output (hot water): energy of any hot water produced directly at nominal design conditions by the waste incineration lines (e.g. by the boiler if it is a hot water boiler by an exchanger on the flue-gas after the FGC system) or indirectly through auxiliary systems other than exchangers directly fed by the boiler steam (e.g. cooling system which delivers heat to the district heating system) minus the energy of return water. The gross heat power output – hot water of the plant is the sum of the gross heat power output – hot water of the lines.
- Nominal thermal input: energy of the waste entering the furnace in nominal conditions, i.e. nominal flow of waste multiplied by the nominal average LHV, plus the energy (as LHV) of any additional fuels other than waste that are continuously combusted in nominal conditions. The nominal thermal input of the plant is the sum of the nominal thermal inputs of each of its lines.

~~With such boiler efficiencies (80 – 90 %) and higher than normal steam parameters (note: actual application depends greatly on waste type owing to increased corrosivity of flue-gases with some waste types) the following approximate electrical efficiencies may result:~~

- ~~steam parameters of 60 bar and 420° about 25 % of the energy converted in the steam generator can be recovered as electrical energy (i.e. overall electrical efficiency of 20 % in the case of grate firing and 22.5 % in the case of FBR)~~
- ~~if the steam parameters are further increased to 80 bar and 500 °C an electrical efficiency of 30 % can be achieved (i.e. overall electrical efficiency of 27 % in the case of FBR).~~
  ~~[74, TWGComments, 2004]~~

~~If there is the possibility to connect the steam cycle of a waste incineration plant to the steam cycle of an adjacent power plant, the overall electrical efficiency can be as high as 35 %. [74, TWGComments, 2004]~~

~~A survey of 50 investigated MSW plants (2001 data) carried out by the TWG energy sub-group gave the following data:~~

~~Table 3.72: Survey data of MSWI boiler efficiencies~~

	~~**Minimum**~~	~~**Average**~~	~~**Maximum**~~
~~**Boiler efficiency**~~	~~75.2 %~~	~~81.2 %~~	~~84.2 %~~

1. ~~The percentages show the efficiency of transfer of energy from the hot flue-gases to the boiler steam~~
2. ~~The LHV of the waste is calculated using the method given in Section 2.3.2.1~~
3. ~~*Boiler efficiency may be lower for small units [74, TWGComments, 2004]*~~

~~*Source:* [64, TWGComments, 2003]~~

3.5.5 Data on the consumption of energy by the process

[1, UBA, 2001]
The incineration process itself requires energy for its operation, e.g. pumps and fans. The demand varies greatly depending on the construction of the plant [1, UBA, 2001]. In particular, the process demand may be increased by:

- mechanical pretreatment systems (e.g. shredders), pumping devices or other waste preparation;
- incineration air preheating;
- reheating of flue-gas (e.g. for gas treatment devices or plume suppression);

- operation of waste water evaporation plant ~~or similar~~;
- flue-gas treatment systems with high pressure drops (e.g. filtration systems) which require higher powered forced draught fans;
- decreases in the net calorific value of the waste – as this can result in the need to add additional fuels in order to maintain the ~~required~~ minimum combustion requirements ~~temperatures~~;
- sludge treatment, e.g. drying..

[64, TWGComments, 2003]

In some cases, these demands can be met partially or entirely through heat exchange with the hot incineration gases.

Older plants with retrofitted flue-gas cleaning systems may consume more electricity compared with modern plants with integrated systems. For industrial plants for hazardous waste incineration, a range of 132–476 kWh/t of waste is seen [1, UBA, 2001].

Table 3.73 below shows the specific energy demand of waste incineration plants that participated in the data collection exercise. ~~50 investigated MSW plants (2001 data), as carried out by the TWG energy sub-group.~~ The table shows the electricity demand and the heat demand ~~and the total (as equivalents) demand~~ for the entire incineration plants, expressed per tonne of treated waste.

Table 3.73: Electricity and heat and total energy demand data for 50 surveyed European MSWI per tonne of waste treated

Energy demand type	Waste incinerated	Minimum	Average	Maximum
Electricity (MWh$_{e}$/t waste)	MSW&ONHW	0.045	0.107	0.264
	SS	0.033	0.154	0.276
	CW	0.211	0.228	0.244
	HW	0.073	0.202	0.360
Heat (MWh$_{h}$/t waste)	MSW&ONHW	0.010	0.505	0.700
	SS	0.121	0.265	0.675
	CW	NA	NA	NA
	HW	0.056	0.373	0.674

NB: NA = not available.
- All figures are given as measured (i.e. not factored equivalents).
- Figures for production include all heat produced by the boiler.
- Figures for export exclude heat produced by the process but consumed in the process.

Source: **[81, TWG 2016]**

~~Energy demand type~~	~~Units~~	~~Minimum~~	~~Average~~	~~Maximum~~
~~Electricity (absolute)~~	~~MWh$_{e}$/t waste~~	~~0.062~~	~~0.142~~	~~0.257~~
	~~GJ$_{e}$/t waste~~	~~0.223~~	~~0.511~~	~~0.925~~
~~Heat (absolute)~~	~~MWh$_{th}$/t waste~~	~~0.021~~	~~0.433~~	~~0.935~~
	~~GJ$_{th}$/t waste~~	~~0.076~~	~~1.559~~	~~3.366~~
~~Total demand (equivalents)~~	~~MWh$_{eq}$/t waste~~	~~0.155~~	~~0.575~~	~~1.116~~
	~~GJ$_{eq}$/t waste~~	~~0.558~~	~~2.070~~	~~4.018~~

~~1 All figures are given as measured (i.e. not factored equivalents)~~
~~2 Percentage efficiencies are given in parenthesis (also not factored) and take account of energy derived from imported fuels as well as from waste.~~
~~3 Figures for production include all heat produced by the boiler~~
~~4 Figures for export exclude heat produced by the process but consumed in the process~~
~~*Source:* [Energysubgroup, 2002 #29]~~

The energy consumption of the installation also varies according to the calorific value of the waste. This is largely due to the increased flue-gas volumes with higher LHV waste – requiring a larger FGC capacity. The relationship is shown in the graph below.

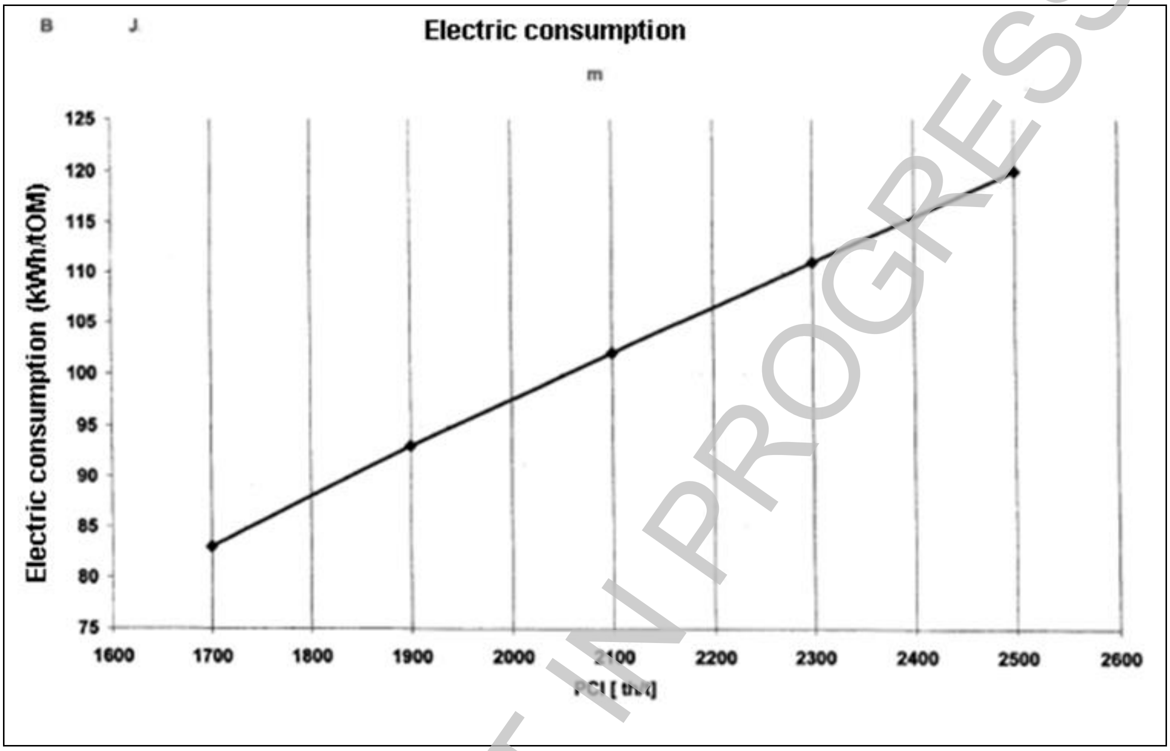


Figure 3.140: ~~Graph showing~~ Increase in installation electrical consumption with increasing waste LHV

~~3.5.6 Data comparing energy required by, and output from, the installation~~

~~A number of different methodologies may be used to compare installation consumption with overall energy recovery rates. In this example, developed by the energy sub-group of the BREF TWG the energy required to treat the waste is compare to that recovered from the waste. Other indicators are also used that compare the ratio of output to input energy.~~

~~The plant efficiency potential (Pl_{ef}) provides a figure that compares the energy exported from the process and the energy that the process itself requires for its operation:~~

$$\cancel{Pl_{ef} = (O_{exp} - (E_f + E_{imp}))/(E_f + E_{imp} + E_{circ})}$$

~~Where:~~
~~*E_f = annual energy input to the system by non-waste fuels that add to steam production (GJ/yr)*~~
~~*E_{imp} = annual imported energy (Note: energy from the treated waste (E_w) is not included)*~~
~~*E_{circ} = annual energy circulated (i.e. that generated by, but used in, the installation)*~~
~~*O_{exp} = annual exported energy (combined total of heat plus electricity as equivalents)*~~
~~*Note: Because different types of energy (electricity and heat) are added all figures calculated as equivalents at the consumption.*~~

~~The exported (e.g. sold) energy minus the imported energy is divided by the total energy demand for the waste incineration process, including flue-gas cleaning, generation of heat and electricity. Because the calculation does not take into account the energy content in the waste, it only allows efficiency comparison of incinerators processing similar wastes.~~

~~Table 3.74 below shows the results of a survey by the TWG energy sub group:~~

~~Table 3.74: Ratio of exported and consumed energy for various waste incinerators~~

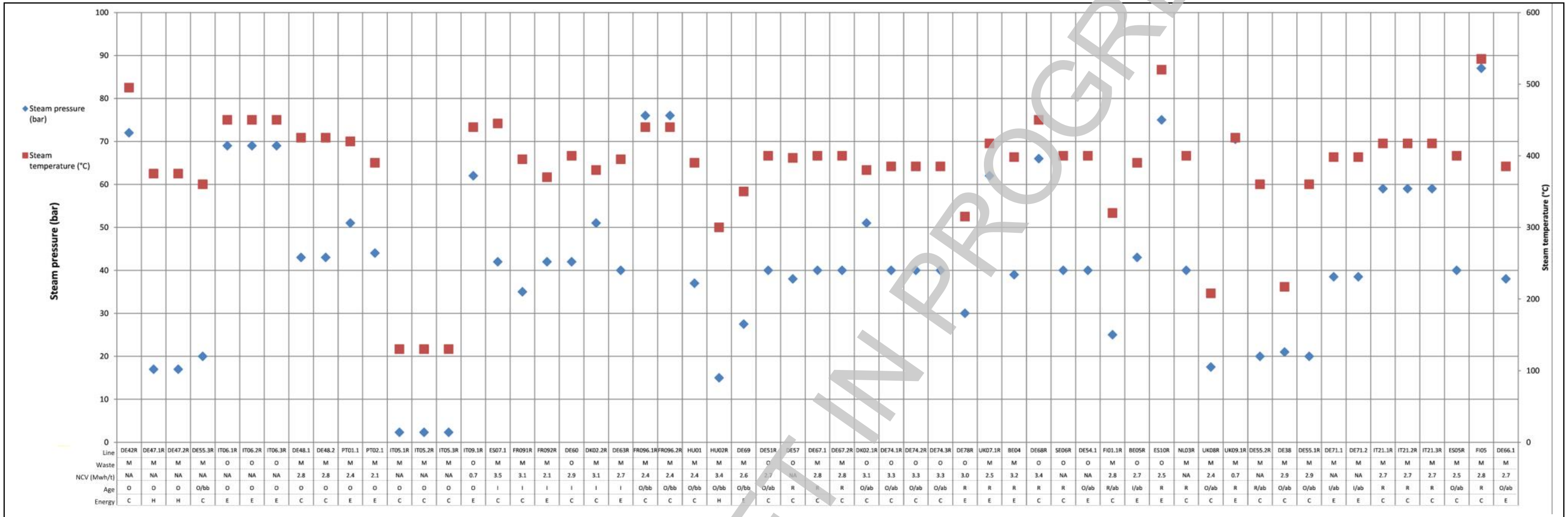
~~Process type~~	~~Number of plants surveyed~~	~~Minimum~~	~~Average~~	~~Maximum~~
~~CHP~~ ~~$PI_{ef\ (CHP)}$~~	~~50~~	~~0.6~~	~~2.0~~	~~7.1~~
~~Electricity only~~ ~~$PI_{ef\ (electr.)}$~~	~~8~~	~~0.6~~	~~1.2~~	~~1.6~~
~~Heat only~~ ~~$PI_{ef\ (heat)}$~~	~~15~~	~~1.0~~	~~2.8~~	~~7.1~~

~~NB:~~
~~Because the calculation does not take into account the energy content in the waste, it only allows efficiency comparison of incinerators processing similar (CV) wastes.~~
~~*Source:* [Energysubgroup, 2002 #29]~~

~~Where the result is higher than 1 this shows that the plant is exporting more energy gained from waste than that which is required to operate the waste incineration process.~~

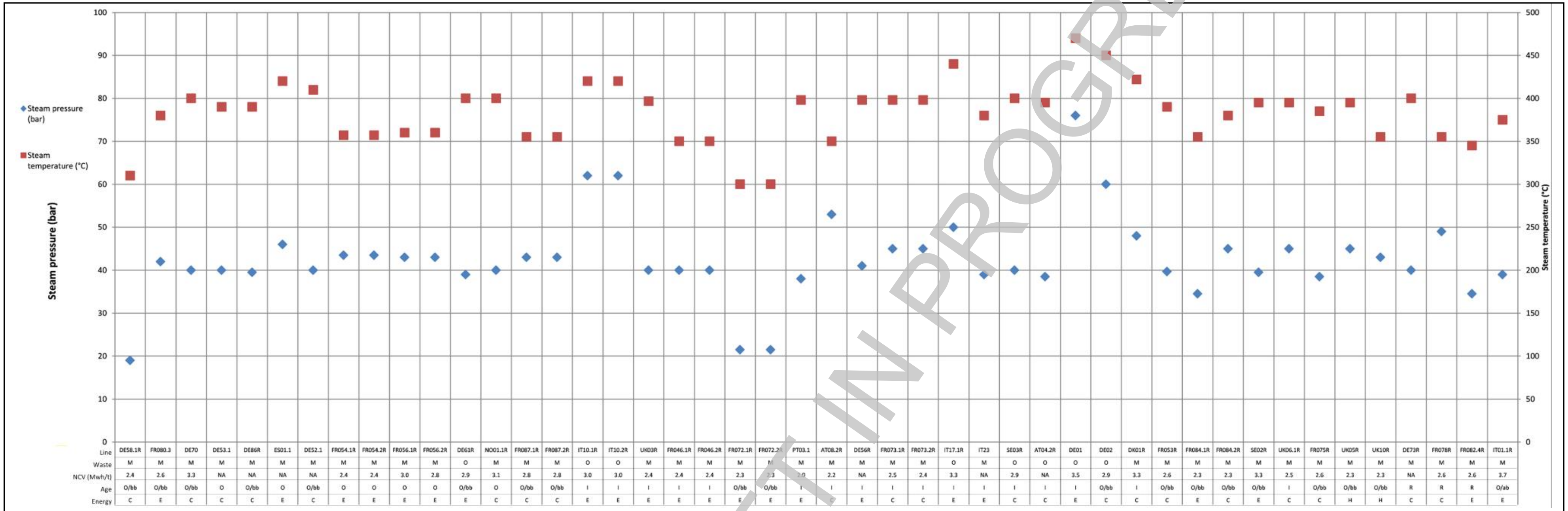
~~Where the result is below one this shows that the plant is using more energy to operate the waste incineration installation than it is recovering form the waste. Such a situation may be envisaged at an installation treating very low calorific value wastes.~~

~~This calculation does not require knowledge of the energy content of the waste. However, the result will be influenced by the waste energy content, and it can be expected that wastes with a higher energy content can result in greater energy exports, and hence higher values of $PI_{ef.}$~~



Note:
Prevalent waste burnt: M= municipal solid waste; O= other non-hazardous waste;
NCV (Net calorific value); NA = Not available
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Energy Production: E=Electricity; H=Heat; C= combined heat and electricity
Source: [81, TWG 2016].

Figure 3.141: Steam parameters from large plants incinerating municipal solid waste and other non-hazardous waste at the turbine entrance



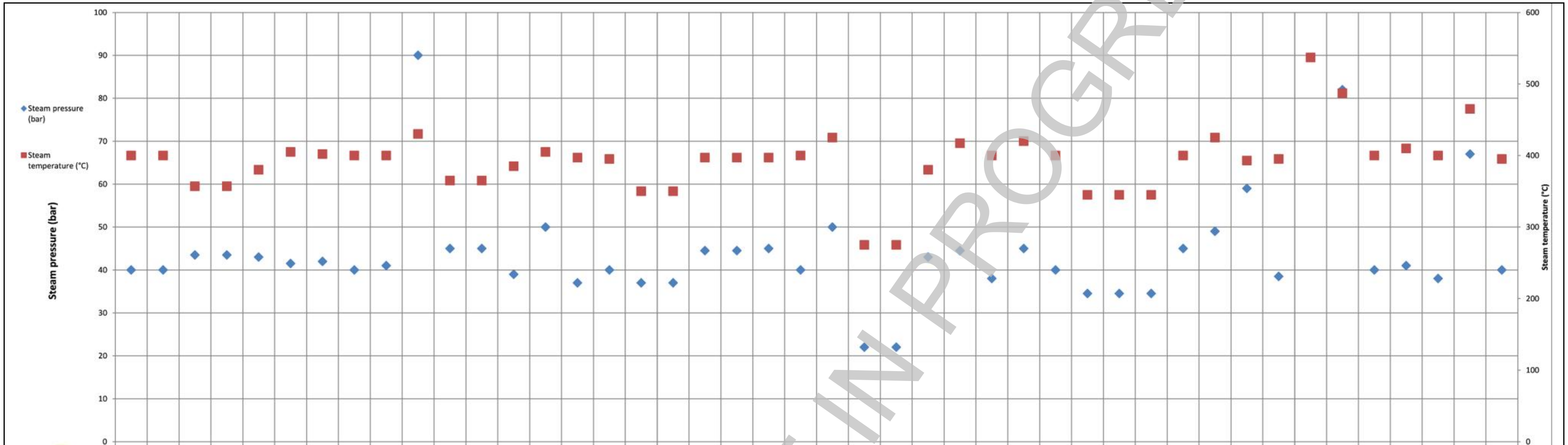
Line	DE58.1R	FR080.3	DE70	DE53.1	DE86R	ES01.1	DE52.1	FR054.1R	FR054.2R	FR056.1R	FR056.2R	DE61R	NO01.1R	FR087.1R	FR087.2R
Waste	M	M	M	M	M	M	M	M	M	M	M	O	M	M	M
NCV (Mwh/t)	2.4	2.6	3.3	NA	NA	NA	NA	2.4	2.4	3.0	2.8	2.9	3.1	2.8	2.8
Age	O/bb	O/bb	O/bb	O	O/bb	O	O/bb	O	O	O	O	O/bb	O	O/bb	O/bb
Energy	C	E	C	C	C	E	C	E	E	E	E	E	C	C	C

Line	IT10.1R	IT10.2R	UK03R	FR046.1R	FR046.2R	FR072.1R	FR072.2R	PT03.1	AT08.2R	DE56R	FR073.1R	FR073.2R	IT17.1R	IT23	SE03R
Waste	O	O	M	M	M	M	M	M	M	M	M	M	O	M	O
NCV (Mwh/t)	3.0	3.0	2.4	2.4	2.4	2.3	2.3	2.0	2.2	NA	2.5	2.4	3.3	NA	2.9
Age	I	I	I	I	I	O/bb	O/bb	I	I	I	I	I	I	I	I
Energy	E	E	E	E	E	E	E	E	C	E	C	C	E	E	C

Line	AT04.2R	DE01	DE02	DK01R	FR053R	FR084.1R	FR084.2R	SE02R	UK06.1R	FR075R	UK05R	UK10R	DE73R	FR078R	FR082.4R	IT01.1R
Waste	O	O	O	M	M	M	M	M	M	M	M	M	M	M	M	M
NCV (Mwh/t)	NA	3.5	2.9	3.3	2.6	2.3	2.3	3.3	2.5	2.6	2.3	2.3	NA	2.6	2.6	3.7
Age	I	I	O/bb	I	O/bb	O/bb	O/bb	O/bb	I	O/bb	O/bb	O/bb	R	R	R	O/ab
Energy	C	E	C	C	C	E	C	E	C	C	H	H	C	C	E	E

Note:
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Prevalent waste burnt: M= municipal solid waste; O= other non-hazardous waste;
Energy Production: E=Electricity; H=Heat; C= combined heat and electricity
Source: [81, TWG 2016].

Figure 3.142: Steam parameters from medium-size plants incinerating municipal solid waste and other non-hazardous waste at the turbine entrance (1/2)



Line	AT03R	FI02	FR059.1R	FR059.2R	FR077R	AT07R	BE06R	DE34	DE36R	DE84R	FR062.1R
Waste	M	M	M	M	M	M	O	M	O	M	M
NCV (Mwh/t)	2.4	2.9	2.3	2.4	2.5	2.9	4.0	NA	3.8	3.5	2.5
Age	R	R	O/ab	O/ab	R	R	R	O/ab	R	R	O/ab
Energy	C	C	E	E	C	E	E	C	C	C	E

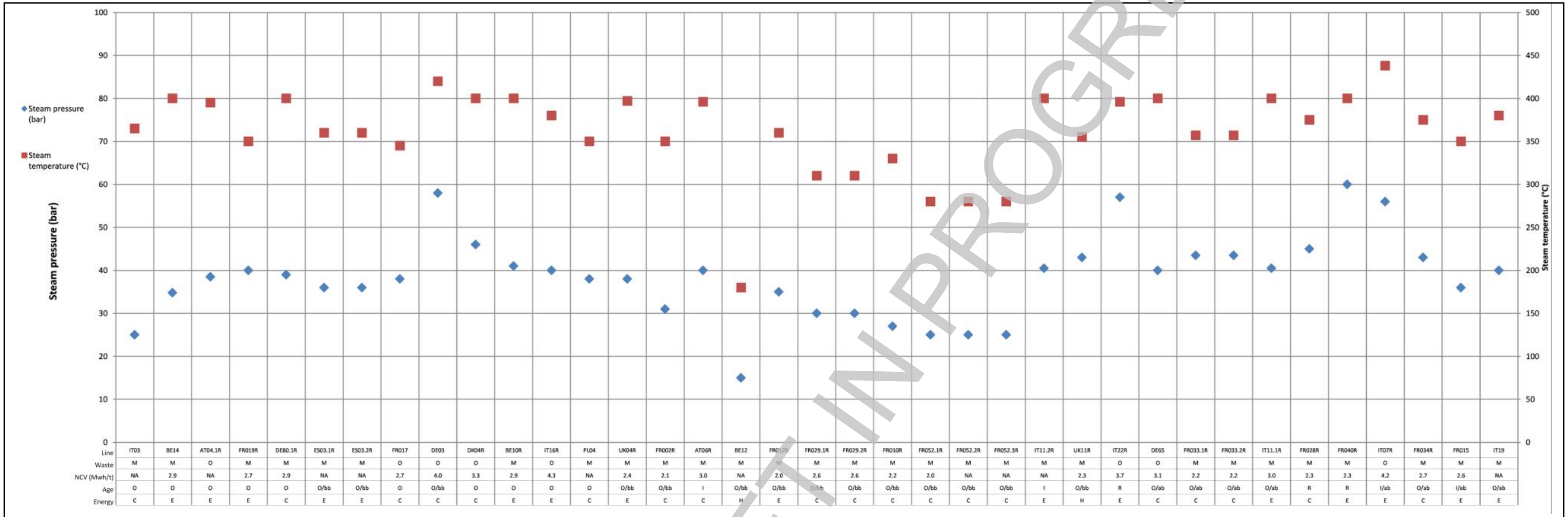
Line	FR062.2R	IT12.1R	IT14R	CZ01R	DE37R	FR076.1R	FR076.2R	FR083.1R	FR083.2R	IT15R	NO01.2R
Waste	M	M	M	M	M	M	M	M	M	M	M
NCV (Mwh/t)	2.5	2.5	2.7	2.7	11.5	2.7	2.7	1.9	1.9	2.7	3.1
Age	O/ab	I/ab	R	R	I/ab	O/ab	O/ab	I/ab	I/ab	R	R
Energy	E	E	E	C	E	E	E	E	E	E	C

Line	NO02R	FR071.1R	FR071.2R	IT18R	AT11R	DE49.1R	ES06	FI06R	FR082.1R	FR082.2R	FR082.3R
Waste	M	M	M	M	M	M	M	M	M	M	M
NCV (Mwh/t)	3.3	2.7	2.5	2.1	NA	11.6	NA	2.7	NA	NA	NA
Age	R/ab	R/ab	O/ab	O/ab	R/ab	I/ab	R	R	O/ab	O/ab	O/ab
Energy	C	C	C	E	C	E	E	C	E	E	E

Line	IT13.1	SE09R	UK12R	DE46R	FI03	UK17R	AT02R	DE45R	DE64R	DE72R	ES02.1R
Waste	O	O	M	O	M	O	M	M	O	M	M
NCV (Mwh/t)	3.2	NA	NA	10.8	NA	3.7	2.8	10.5	2.9	3.4	2.4
Age	R	R/ab	R	R/ab	R/ab	R	O/ab	O/ab	O/ab	R/ab	O/ab
Energy	C	C	E	E	H	C	C	E	E	E	E

Note:
Prevalent waste burnt: M= municipal solid waste; O= other non-hazardous waste;
NCV (Net calorific value); NA = Not available
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Energy Production: E=Electricity; H=Heat; C= combined heat and electricity
Source: [81, TWG 2016].

Figure 3.143: Steam parameters from medium-size plants incinerating municipal solid waste and other non-hazardous waste at the turbine entrance (2/2)

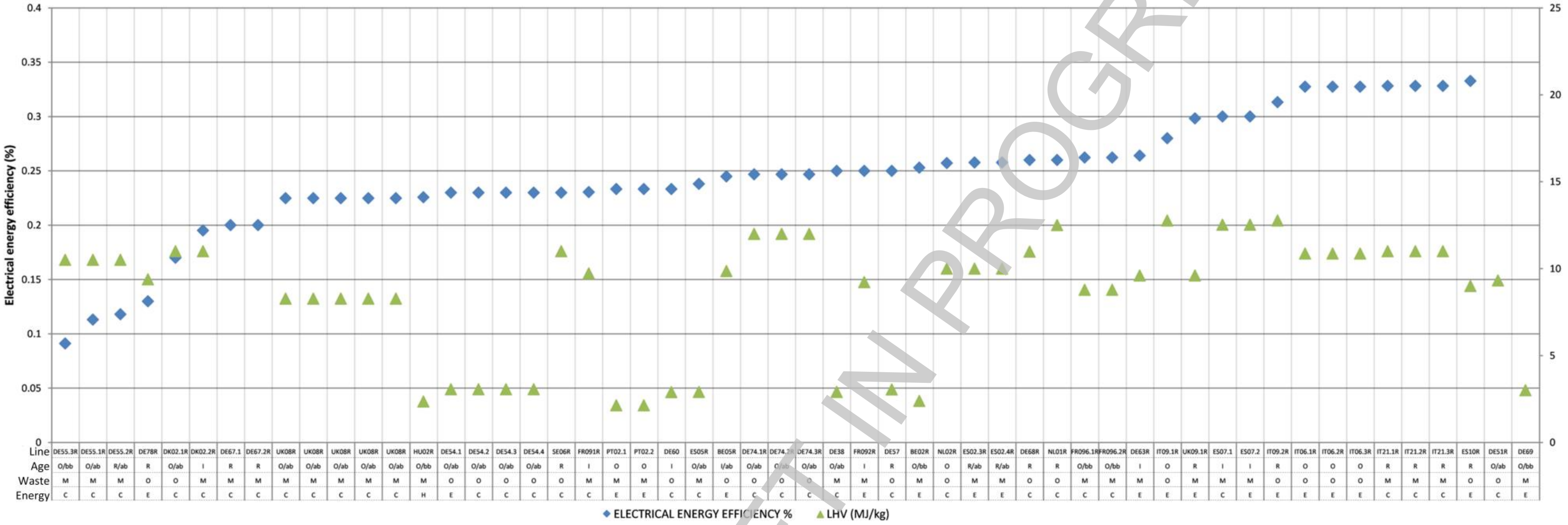


Line	IT03	BE14	AT04.1R	FR019R	DE80.1R	ES03.1R	ES03.2R	FR017	DE03	DK04R	BE10R	IT16R	PL04	UK04R	FR002R	AT06R	BE12	FR012R	FR029.1R
Waste	M	M	O	M	M	M	M	O	O	O	M	O	M	M	M	M	M	M	M
NCV (Mwh/t)	NA	2.9	NA	2.7	2.9	NA	NA	2.7	4.0	3.3	2.9	4.3	NA	2.4	2.1	3.0	NA	2.0	2.6
Age	O	O	O	O	O	O/bb	O/bb	O	O/bb	O	O	O	O	O/bb	O/bb	I	O/bb	O/bb	O/bb
Energy	C	E	E	E	C	E	E	C	C	C	E	E	C	E	C	C	H	E	C

Line	FR029.2R	FR010R	FR052.1R	FR052.2R	FR052.3R	IT11.2R	UK11R	IT22R	DE65	FR033.1R	FR033.2R	IT11.1R	FR028R	FR040R	IT07R	FR034R	FR015	IT19
Waste	M	M	M	M	M	M	M	O	O	M	M	M	M	M	O	M	M	M
NCV (Mwh/t)	2.6	2.2	2.0	NA	NA	NA	2.3	3.7	3.1	2.2	2.2	3.0	2.3	2.3	4.2	2.7	2.6	NA
Age	O/bb	O/bb	O/bb	O/bb	O/bb	I	O/bb	R	O/ab	O/ab	O/ab	O/ab	R	R	I/ab	O/ab	I/ab	O/ab
Energy	C	C	C	C	C	E	H	E	C	C	C	E	C	E	E	C	E	E

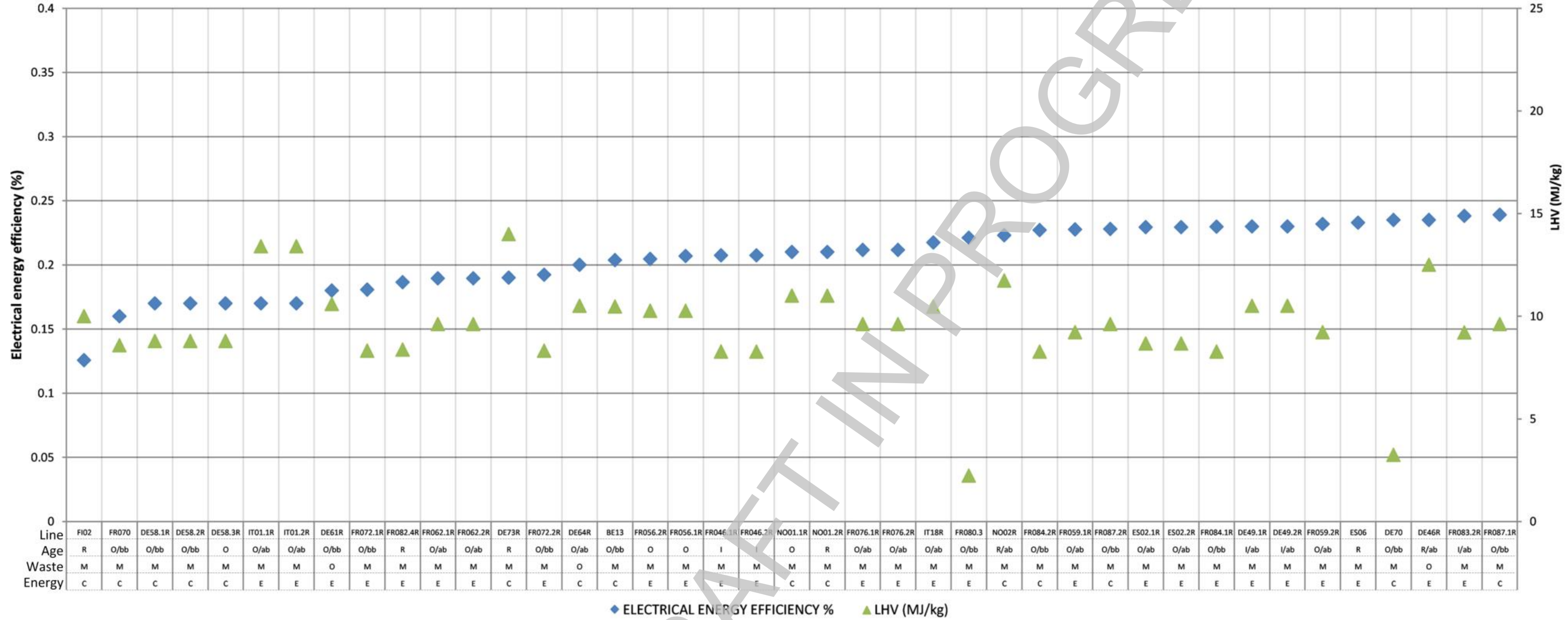
Prevalent waste burnt: M= municipal solid waste; O= other non-hazardous waste;
NCV (Net calorific value); NA = Not available
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Energy Production: E=Electricity; H=Heat; C= combined heat and electricity
Source: [81, TWG 2016].

Figure 3.144: Steam parameters from small plants incinerating municipal solid waste and other non-hazardous waste at the turbine entrance



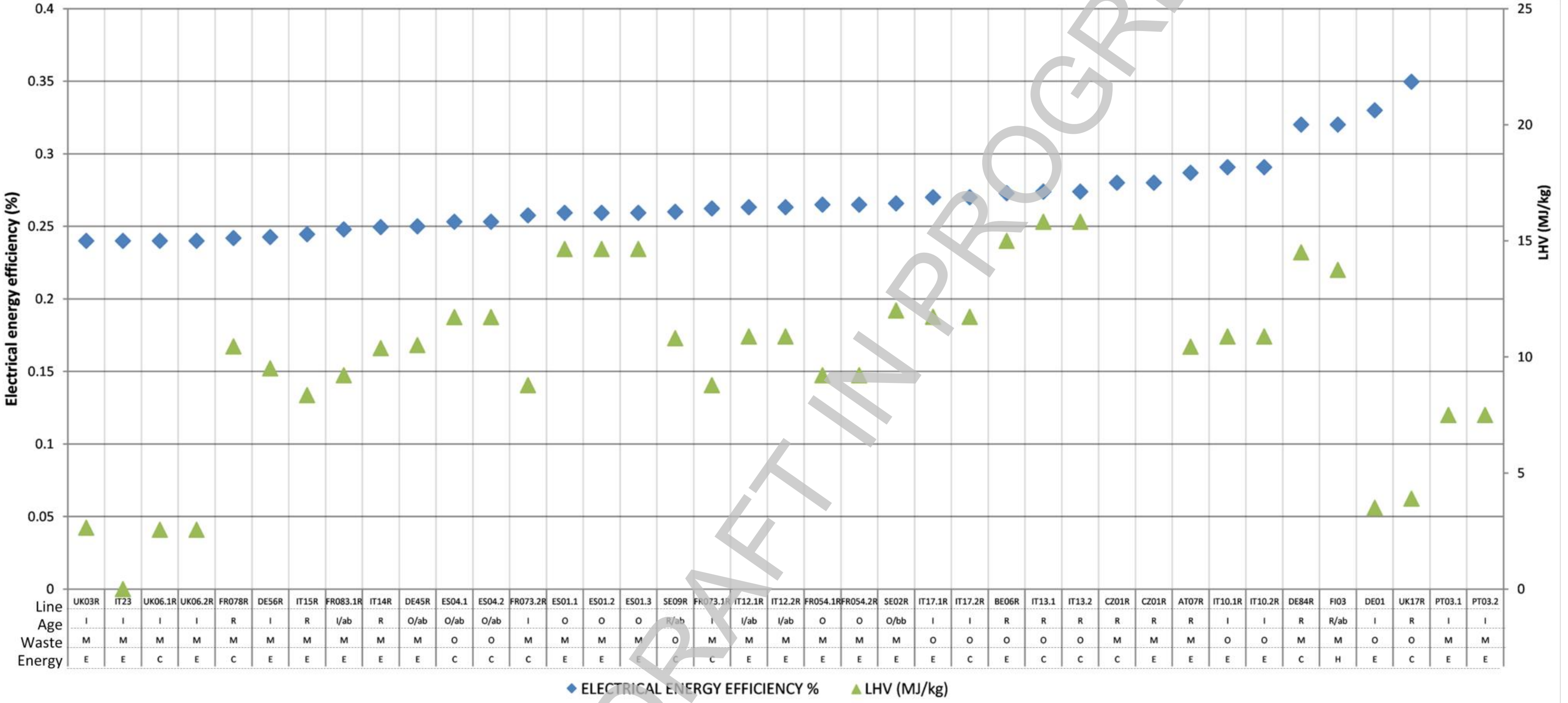
Note:
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Prevalent waste burnt: M= municipal solid waste; O= other non-hazardous waste;
Energy Production: E=Electricity; H=Heat; C= combined heat and electricity
Source: [81, TWG 2016].

Figure 3.145: Gross electrical efficiency from large plants incinerating municipal solid waste and other non-hazardous waste



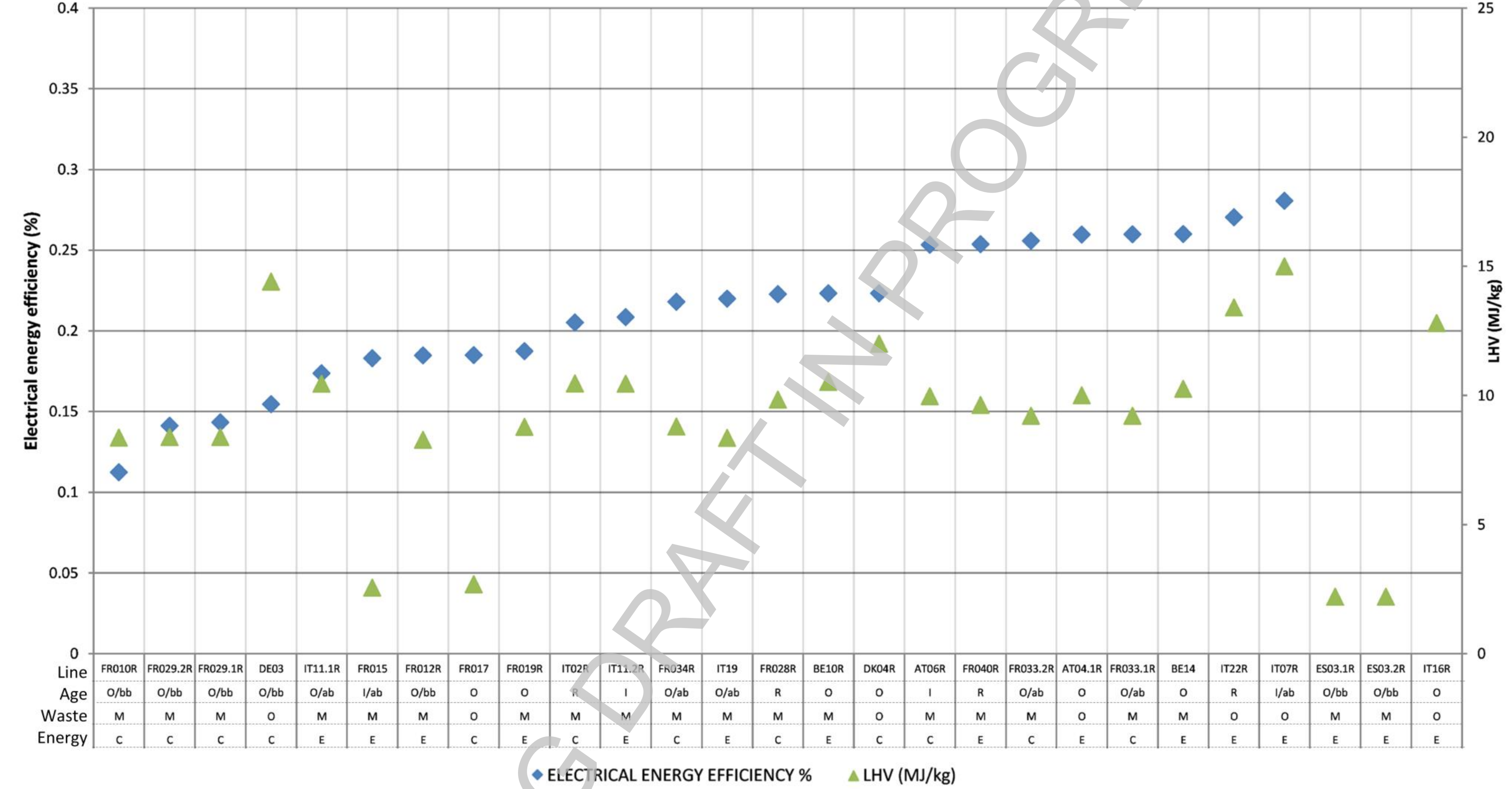
Note:
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Prevalent waste burnt: M= municipal solid waste; O= other non-hazardous waste;
Energy Production: E=Electricity; H=Heat; C= combined heat and electricity
Source: [81, TWG 2016].

Figure 3.146: Gross electrical efficiency from medium-size plants incinerating municipal solid waste and other non-hazardous waste (1/2)



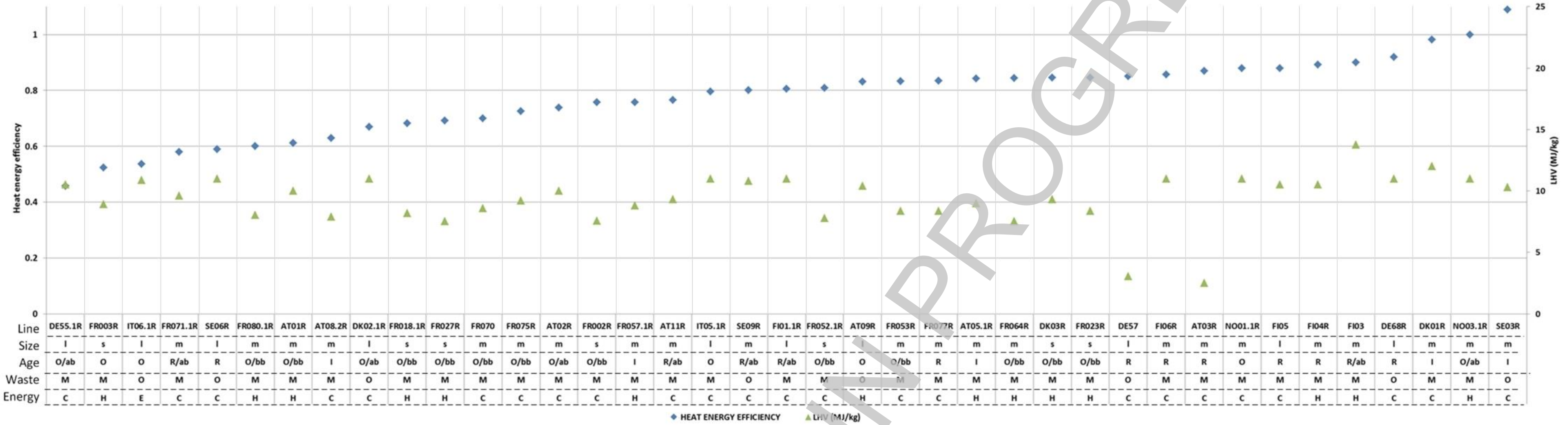
Note:
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Prevalent waste burnt: M= municipal solid waste; O= other non-hazardous waste;
Energy Production: E=Electricity; H=Heat; C= combined heat and electricity
Source: [81, TWG 2016].

Figure 3.147: Gross electrical efficiency from medium-size plants incinerating municipal solid waste and other non-hazardous waste (2/2)



Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Prevalent waste burnt: M= municipal solid waste; O= other non-hazardous waste;
Energy Production: E=Electricity; H=Heat; C= combined heat and electricity
Source: [81, TWG 2016].

Figure 3.148: Gross electrical efficiency from small plants incinerating municipal solid waste and other non-hazardous waste



Line	DE55.1R	FR003R	IT06.1R	FR071.1R	SE06R	FR080.1R	AT01R	AT08.2R	DK02.1R	FR018.1R	FR027R	FR070	FR075R
Size	l	s	l	m	l	m	m	m	l	s	s	m	m
Age	O/ab	O	O	R/ab	R	O/bb	O/bb	I	O/ab	O/bb	O/bb	O/bb	O/bb
Waste	M	M	O	M	O	M	M	M	O	M	M	M	M
Energy	C	H	E	C	C	H	H	C	C	H	H	C	C

Line	AT02R	FR002R	FR057.1R	AT11R	IT05.1R	SE09R	FI01.1R	FR052.1R	AT09R	FR053R	FR077R	AT05.1R	FR064R
Size	m	s	m	m	l	m	l	s	l	m	m	m	m
Age	O/ab	O/bb	I	R/ab	O	R/ab	R/ab	O/bb	O	O/bb	R	I	O/bb
Waste	M	M	M	M	M	O	M	M	O	M	M	M	M
Energy	C	C	H	C	C	C	C	C	H	C	C	H	H

Line	DK03R	FR023R	DE57	FI06R	AT03R	NO01.1R	FI05	FI04R	FI03	DE68R	DK01R	NO03.1R	SE03R
Size	s	s	l	m	m	m	l	m	m	l	m	m	m
Age	O/bb	O/bb	R	R	R	O	R	R	R/ab	R	I	O/ab	I
Waste	M	M	O	M	M	M	M	M	M	O	M	M	O
Energy	H	H	C	C	C	C	C	H	H	C	C	H	C

Plant size: s = small; m = medium; l = large.
Plant age: O = Old installation; I = Intermediate Installation; R = Recent Installation // year of retrofitting: bb = Before previous WI BREF (2006); ab = After previous WI BREF (2006).
Prevalent waste burnt: M= municipal solid waste; O= other non-hazardous waste;
Energy Production: E=Electricity; H=Heat; C= combined heat and electricity
Source: [81, TWG 2016].

Figure 3.149: Gross heat efficiency from plants incinerating municipal solid waste and other non-hazardous waste

3.6 Noise

Table 3.75 below described the sources and levels of noise generated at waste incineration installations, along with some of the reduction measures used.

Table 3.75: Sources of noise at waste incineration plants

Area relevant to noise/ main emitters	Reduction measures	Noise L_{WA} [dB(A)]
Delivery of waste, i.e. noise from lorries, etc.	Tipping hall closed to all sides	104–109
Shredding	Scissors in tipping hall	95–99
Waste bunker	Noise insulation of the building with gas concrete, gates with tight design	79–81
Boiler building	Enclosure with multi-shell construction or gas concrete, ventilation channels with connecting link silencers, tight gates	78–91
Machine building	Use of low-noise valves, noise-insulated tubes, noise insulation of the building as described above	82–85
Flue-gas cleaning:	Noise insulation, enclosure of the facility, e.g. with sheets with trapezoidal corrugations, use of blimps for the suction draught and silencer for the chimney	
- ESP		82–85
- Scrubbing		82–85
- Suction draught		82–84
- Chimney		84–85
- Total flue-gas cleaning system		89–95
Disposal of residues:	Enclosure, loading in the bunker	
- Bottom ash discharge		71–72
- Loading		73–78 (day)
- Transportation from the plant		92–96 (day)
- Total waste management residues		92–96 (day) 71–72 (night)
Air cooler	Silencers on the suction and pressure sides (see also ICS BREF for further information)	90–97
Energy transformation facility	Low-noise design, within specially constructed noise-proofed building	71–80
Total L_{WA} of the plant		
Day		**105–110**
Night		**93–99**
NB: Day/night indicates that the operation is usually carried out during the day or at night. *Source:* [1, UBA, 2001]		

With the noise reduction measures described above, the noise emission limits, given for a specific project based on the local conditions, can be safely met, by day and by night.

Noise is also generated during the construction phase. This may result in considerable noise exposure in neighbouring residential areas, depending mainly on the location. Three main construction stages are all equally relevant as noise sources:

- digging the excavation;
- laying the foundations (including piledriving); and
- erecting the outer shell of the building.

Appropriate measures, such as restrictions on operating hours, particularly during the night, use of low-noise construction machinery and temporary structural sound insulation measures, may be taken. In some MS, specific legislation also exists for this.

[1, UBA, 2001], [2, infomil, 2002], [64, TWGComments, 2003]

3.7 Other ~~operating~~ resources used

This section describes some of the substances consumed by the incineration process and gives available data. Table 3.77 at the end of this section provides data regarding the quantities of various substances consumed by hazardous waste incinerators.

3.7.1 Water

The main consumption of water in waste incineration plants is for flue-gas cleaning. Dry systems consume the least water and wet systems generally the most. Semi-wet systems fall in between.

Typical effluent rates at a MSWI are around 250 kg per tonne of waste treated (in the case of wet scrubbing~~, other FGC technologies provide different figures~~).

It is possible for wet systems to reduce consumption greatly by recirculating treated effluent as a feed for scrubbing water. This can only be performed to a certain degree as salt can build up in the recirculated water.

The use of cooled condensing scrubbers provides a further means by which water can be removed from the flue-gas stream, which then, after treatment, can be recirculated to the scrubbers. Salt build-up remains an issue.

Processes without energy recovery boilers may have much higher water consumption. This is because the required flue-gas cooling is carried out using water injection. Consumption rates of up to 3.5 tonnes water/tonne of waste are seen in such cases (Belgium 2002). Installations with a rapid quench system (such as those operated in the UK for HWI) may use up to 20 tonnes of water per tonne of waste incinerated.

The water consumption for FGC in HWI is about 1–6 m^3 per tonne of waste; and for sewage sludge it is about 15.5 m^3 per tonne of waste.
[74, TWGComments, 2004]

3.7.2 Other operating resources

[1, UBA, 2001]
The following consumption (and residual products) rates can be calculated for their **stoichiometric reaction** during flue-gas cleaning.

Table 3.76: Stoichiometric calculation of amounts of lime used for absorption during flue-gas cleaning (reactants expressed at 100 % concentration and purity)

Pollutant		$Ca(OH)_2$	Residual products	
	kg	kg		kg
HCl	1	1.014	$CaCl_2$	1.521
HF	1	1.850	CaF_2	1.950
SO_2	1	1.156	$CaSO_4$	2.125
Pollutant		**NaOH**	**Residual product**	
HCl	1	1.097	NaCl	1.600
HF	1	2.000	NaF	2.100
SO_2	1	1.249	Na_2SO_4	2.217
Pollutant		**Sodium bicarbonate**	**Residual product**	
HCl	1	2.301	NaCl	1.603
HF	1	4.200	NaF	2.100
SO_2	1	2.625	Na_2SO_4	2.219
Pollutant		**Ammonia**	**Residual product**	
NO	1	0.370	Not applicable	
NO_2	1	0.739		
Pollutant		**Urea**	**Residual product**	
NO	1	0.652	Not applicable	
NO_2	1	1.304		

NB:

1. To establish accurate reagent ratios, it is necessary to take into account the initial emission level and the targeted emission level.
2. Reactants may be supplied at varying concentrations and this may therefore alter overall mixed reagent consumption rates.

Source: [1, UBA, 2001] [74, TWGComments, 2004]

3.7.2.1 Neutralisers

[1, UBA, 2001]
To neutralise the acids contained in the flue-gas, either NaOH, hydrated lime milk of lime or sodium bicarbonate is used. Its consumption depends on the specific structure of the waste (and hence the raw gas content) as well as the technical equipment used (contact, mixing, etc.).

For hydrated lime, 6 kg to 22 kg are consumed per tonne of waste depending on flue-gas cleaning type and other factors. For NaOH, this figure is 7.5–33 kg per tonne of waste.
[74, TWGComments, 2004]

3.7.2.2 NO_X removal agents

Typical reagents for the removal of NO_X from the flue-gas are ammonia, ammonia water (25 % NH_3) and urea solution. The latter in particular is, depending on the producer, often supplemented by additional ingredients.

If upstream NO_X concentrations are known, this helps achieve a well-controlled process. [74, TWGComments, 2004]

These materials must be used in a targeted manner and well controlled to prevent excessive formation of ammonia or the direct slippage of the excess ammonia.

For ammonia water, a consumption rate of 2.5 kg per tonne of waste is ~~quoted~~ typical. ~~Research has shown a~~ Literature values are in the range of 0.5 kg to 5 kg per tonne of waste.

3.7.2.3 Fuel oil and natural gas

Light fuel oil (diesel), heavy fuel oil (about 0.03–0.06 m^3 per tonne of waste) and natural gas (in Austrian plants between 4.5 m^3 and 20 m^3 per tonne of waste) are used for process heating and support burners. [74, TWGComments, 2004]

Waste solvents (typically with a thermal value of > 25 MJ/kg) are also used as support fuels in some plants.

High calorific wastes (e.g. oils and solvents, typically those with a thermal value of > 15 MJ/kg) are routinely used as support fuels in rotary kiln hazardous waste incineration plants.

If the flue-gas is reheated for individual process steps (e.g. SCR), this is mainly done with natural gas.

3.7.2.4 Merchant hazardous waste incinerator plant survey data

[EURITS, 2002 #41]
An overview is given below of the minimum and the maximum amounts of additives in kilograms per tonne of incinerated waste for surveyed merchant hazardous waste installations.

Table 3.77: Amount of additives used by merchant hazardous waste incineration processes

	kg/t waste		
Additives	**Minimum**	**Maximum**	**Average**
CaO + $Ca(OH)_2$ (100 %), as CaO	1.33	97	28.6
NaOH (50 %)	0.40	41.67	15.5
$CaCO_3$	11.9	23.76	17.4
HCl (33 %)	0.14	10	1.5
TMT-15 or other sulphide treatment	0.0085	0.98	0.23
Na_2S	0.008	0.83	0.44
$Na_2S_2O_3$	0.08	4.2	1.7
$FeCl_3$	0.049	0.50	0.27
$FeClSO_4$	0.15	0.96	0.55
Fe Al chloride	1.75	1.75	1.75
PE	0.01	1.30	0.3
Activated carbon	0.3	19.31	3.7
Urea (45 %)	3.1	3.1	3.1
NH_4OH	0.50	3.33	2.1
$CaCl_2$	2.36	2.36	2.36

NB: This table gives only some reference values and may not be representative for a specific installation or technique.
Source: [EURITS, 2002 #41]

4 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT

This chapter ~~sets out~~ describes techniques (or combinations thereof), and associated monitoring, considered ~~generally~~ to have the potential for achieving a high level of environmental protection in the ~~industries~~ activities within the scope of this document. The techniques described will include both the technology used and the way in which the installations are designed, built, maintained, operated and decommissioned.

It covers environmental management systems, general process-integrated techniques and general end-of-pipe measures~~ are included~~. Waste prevention and management, including waste minimisation and recycling procedures, are also considered, as well as techniques that reduce the consumption of raw materials, water and energy by optimising use and reuse. ~~Prevention, control, design, management and re-cycling procedures are considered as well as the re-use of materials and energy.~~ The techniques described also cover measures used to prevent or to limit the environmental consequences of accidents and incidents, as well as site remediation measures. They also cover measures taken to prevent or reduce emissions under other than normal operating conditions (such as start-up and shutdown operations, leaks, malfunctions, momentary stoppages and the definitive cessation of operations).

Annex III to the Directive lists a number of criteria for determining BAT, and the information within this chapter will address these considerations. ~~Techniques may be presented singly or as combinations to achieve the objectives of IPPC. Annex IV to the Directive lists a number of general considerations to be taken into account when determining BAT and techniques within this chapter will address one or more of these considerations.~~ As far as possible, the standard structure in Table 4.1 is used to outline the information on each technique, to enable a comparison of techniques and ~~an objective~~ the assessment against the definition of BAT in the Directive.

This chapter does not necessarily provide an exhaustive list of techniques which could be applied in the sector. Other techniques may exist, or may be developed, which could be considered in the determination of BAT for an individual installation.

~~Because it is not possible to be exhaustive and because of the dynamic nature of industry, and the momentary nature of this document, it is possible that there may be additional techniques not described but which may also be considered BAT. These are likely to be techniques that meet or exceed the BAT criteria established here and in Chapter 5, applied locally as thus provide particular advantages in the situation in which they are used.~~
~~[64, TWGComments, 2003]~~

Table 4.1: Information breakdown for each technique described in this chapter 4

Heading within the sections	**Type of information included**
Description	A brief description of the technique with a view to being used in the BAT conclusions.
Technical description	A more detailed and yet concise technical description using, as appropriate, chemical or other equations, pictures, diagrams and flow charts.
Achieved environmental benefits	The main potential environmental benefits to be gained through implementing the technique (including reduced consumption of energy; reduced emissions to water, air and land; raw material savings; as well as production yield increases, reduced waste, etc.).
Environmental performance and operational data	Actual and plant-specific performance data (including emission levels, consumption levels – of raw materials, water, energy – and amounts of residues/wastes generated) from well-performing installations/plants (with respect to the environment taken as a whole) applying the technique accompanied by the relevant contextual information. Any other useful information on the following items: • how to design, operate, maintain, control and decommission the technique • emission monitoring issues related to the use of the technique • sensitivity and durability of the technique • issues regarding accident prevention. Links between inputs (e.g. nature and quantity of raw material and fuel, energy, water) and outputs (emissions, residues/wastes, products) are highlighted, in particular where relevant to enhancing an understanding of different environmental impacts and their interaction, for example where trade-offs have been made between different outputs such that certain environmental performance levels cannot be achieved at the same time. Emission and consumption data are qualified as far as possible with details of relevant operating conditions (e.g. percentage of full capacity, fuel composition, bypassing of the (abatement) technique, inclusion or exclusion of other than normal operating conditions, reference conditions), sampling and analytical methods, and statistical presentation (e.g. short- and long-term averages, maxima, ranges and distributions). Information on conditions/circumstances hampering the use of the (abatement) technique at full capacity and/or necessitating full or partial bypassing of the (abatement) technique and measures taken to restore full (abatement) capacity.
Cross-media effects	Relevant negative effects on the environment due to implementing the technique, allowing a comparison between techniques in order to assess the impact on the environment as a whole. This may include issues such as: • consumption and nature of raw materials and water • energy consumption and contribution to climate change • stratospheric ozone depletion potential • photochemical ozone creation potential • acidification resulting from emissions to air • presence of particulate matter in ambient air (including microparticles and metals) • eutrophication of land and waters resulting from emissions to air or water • oxygen depletion potential in water • persistent/toxic/bioaccumulable components (including metals) • generation of residues/waste

	• limitation of the ability to reuse or recycle residues/waste • generation of noise and/or odour • increased risk of accidents. The Reference Document on Economics and Cross-media Effects (ECM) should be taken into account.
Technical considerations relevant to applicability	It is indicated whether the technique can be applied throughout the sector. Otherwise, the main general technical restrictions on the use of the technique within the sector are indicated. These may be: • an indication of the type of plants or processes within the sector to which the technique cannot be applied; • constraints to implementation in certain generic cases, considering, e.g.: ○ whether it concerns a new or an existing plant, taking into account factors involved in retrofitting (e.g. space availability) and interactions with techniques already installed ○ plant size, capacity or load factor ○ quantity, type or quality of product manufactured ○ type of waste, fuel or raw material used ○ climatic conditions. These restrictions are indicated together with the reasons for them. These restrictions are not meant to be a list of the possible local conditions that could affect the applicability of the technique for an individual plant.
Economics	Information on the costs (capital/investment, operating and maintenance including details on how these costs have been calculated/estimated) and any possible savings (e.g. reduced raw material or energy consumption, waste charges, reduced payback time compared to other techniques), or revenues or other benefits including details on how these have been calculated/estimated. Cost data are preferably given in euro (EUR). If a conversion is made from another currency, the data in the original currency and the year when the data were collected is indicated. The price/cost of the equipment or service is accompanied by the year it was purchased. Information on the market for the sector in order to put costs of techniques into context. Information relevant to both newly built, retrofitted and existing plants. This should allow assessment, where possible, of the economic viability of the technique for the sector concerned. Information on the cost-effectiveness of the technique (e.g. in EUR per mass of pollutant abated) and related assumptions for their calculation can be reported. The Reference Document on Economics and Cross-media Effects (ECM) and the Monitoring of emissions to Air and Water from IED installations (ROM) are taken into account with regard to economic aspects and monitoring costs, respectively.
Driving force for implementation	Where applicable, specific local conditions, requirements (e.g. legislation, safety measures) or non-environmental triggers (e.g. increased yield, improved product quality, economic incentives – e.g. subsidies, tax breaks) which have driven or stimulated the implementation of the

	technique to date. This subsection should be very short using bullet point lists.
Example plants	Reference to a plant(s) where the technique has been implemented and from which information has been collected and used in writing the section. An indication of the degree to which the technique is in use in the EU or worldwide.

~~Organisation of Chapter 4:~~

~~This chapter groups the techniques in approximately the order in which they would appear in the majority of waste incineration installations. Thus it highlights the specific techniques that can be applied at **each stage** of the incineration process, and that can lead to improved environmental performance or other benefits that are of relevance to determining BAT.~~

~~Table 4.2 gives the title of the sections and indicates the grouping to which the techniques have been divided for BREF purposes.~~

~~**Table 4.2: Organisation chart for the information in Chapter 4**~~

~~**Chapter 4 section number (and hyperlink to section)**~~	~~**Title of section**~~
~~4.1~~	~~General practices applied before thermal treatment~~
~~4.3~~	~~Thermal processing~~
~~4.4~~	~~Energy recovery~~
~~4.5~~	~~Flue-gas treatment~~
~~4.6~~	~~Process water treatment and control~~
~~4.7~~	~~Treatment techniques for solid residues~~
~~4.8~~	~~Noise~~
~~**Error! Reference source not found.**~~	~~Environmental management tools~~
~~4.9~~	~~Good practice for public awareness and communication~~

~~Description:~~

~~Each technique described includes relevant information, made available by the TWG, on the consumption and emission levels considered achievable by using the technique, some idea of the costs and the cross-media issues associated with the technique and information on the extent to which the technique is applicable to the range of installations requiring IPPC permits, for example new, existing, large or small installations, and to various waste types.~~

~~As far as possible, a standard structure is used to outline each technique, as shown in the following table, to enable comparisons of techniques and an objective assessment against the definition of BAT given in the Directive. BAT determination itself is not covered here but is covered in Chapter 5.~~
~~Table 4.3 below shows the structure of the information that is included where possible, for each technique in this chapter:~~

~~**Table 4.3: Information breakdown for each technique described in this Chapter 4**~~

~~**Type of information considered**~~	~~**Type of information included**~~
~~**Description**~~	~~Technical description of the technique~~
~~**Achieved environmental benefits**~~	~~Main environmental impact(s) to be addressed by the technique (process or abatement), including emission values~~

	~~achieved and efficiency performance (see also IPPC Directive annexe IV). Environmental benefits of the technique in comparison with others~~
~~**Cross-media effects**~~	~~Any side-effects and disadvantages caused by implementation of the technique. Details on the environmental problems of the technique in comparison with others~~
~~**Operational data**~~	~~Performance data on emissions/wastes and consumption (raw materials, additives, water and energy). Any other useful information on how to operate, maintain and control the technique, including safety aspects, operability constraints of the technique, output quality, etc.~~
~~**Applicability**~~	~~Consideration of the factors involved in applying and retrofitting the technique (e.g. space availability, process specific)~~
~~**Economics**~~	~~Information on costs (investment and operation) and any possible savings (e.g. reduced raw material consumption, waste charges) also as related to the capacity of the technique~~
~~**Driving force for implementation**~~	~~Reasons for implementation of the technique (e.g. other legislation, improvement in production quality)~~
~~**Example plants**~~	~~Reference to a plant where the technique is reported to be used~~
~~**Reference literature**~~	~~Literature for more detailed information on the technique~~

~~When possible, this chapter provides information on actual activities that are being, or can be implemented by this sector, including actual associated costs. Where possible, the information provided also gives the context in which the technique can be used effectively.~~

4.1 Organisational techniques to improve environmental performance

4.1.1 Environmental management ~~tools~~ system (EMS)

Description
A formal system to demonstrate compliance with environmental objectives.

Technical description
The Directive defines 'techniques' (under the definition of 'best available techniques') as 'both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned'.

In this respect, an environmental management system (EMS) is a technique allowing operators of installations to address environmental issues in a systematic and demonstrable way. EMSs are most effective and efficient where they form an inherent part of the overall management and operation of an installation.

An EMS focuses the attention of the operator on the environmental performance of the installation; in particular through the application of clear operating procedures for both normal and other than normal operating conditions, and by setting out the associated lines of responsibility.

All effective EMSs incorporate the concept of continuous improvement, meaning that environmental management is an ongoing process, not a project which eventually comes to an end. There are various process designs, but most EMSs are based on the plan-do-check-act cycle (which is widely used in other company management contexts). The cycle is an iterative dynamic model, where the completion of one cycle flows into the beginning of the next (see Figure 4.1).

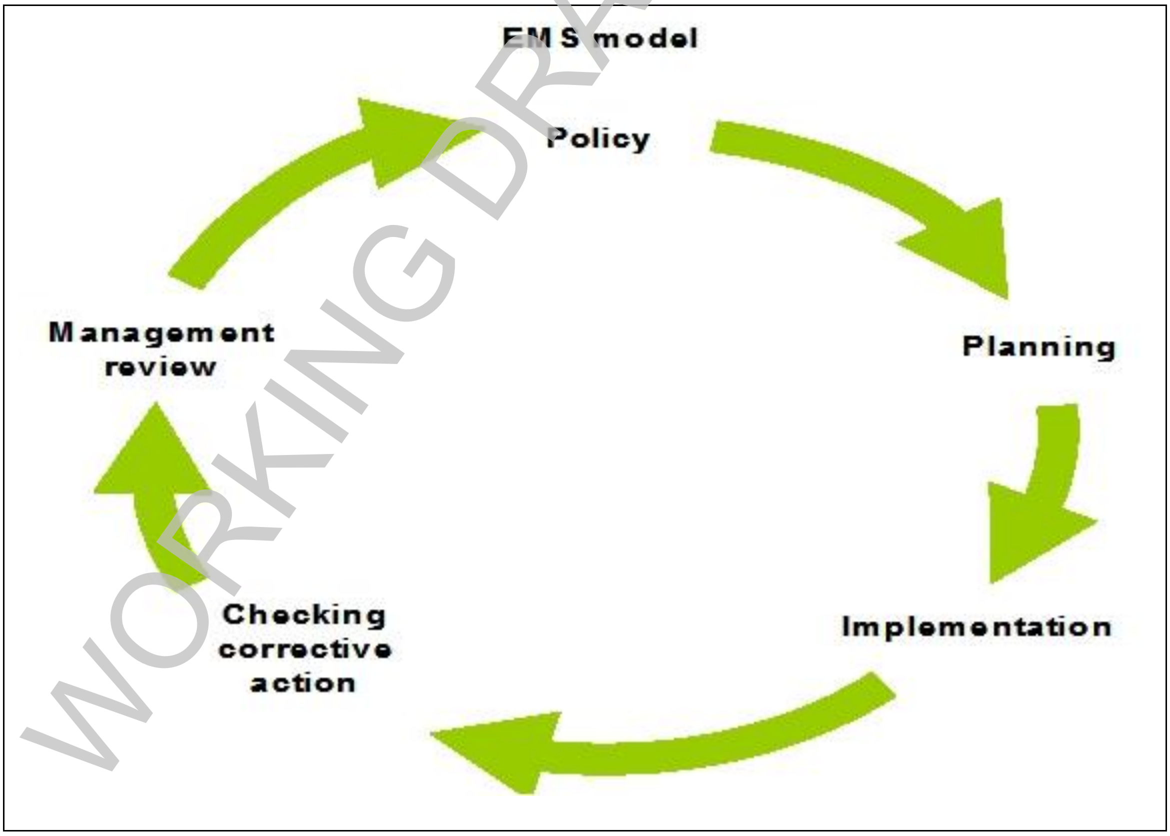


Figure 4.1: Continuous improvement in an EMS model

An EMS can take the form of a standardised or non-standardised (‘customised’) system. Implementation and adherence to an internationally accepted standardised system, such as EN ISO 14001, can give higher credibility to the EMS especially when subjected to a properly performed external verification. EMAS provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can, in principle, be equally effective provided that they are properly designed and implemented.

While both standardised systems (EN ISO 14001 or EMAS) and non-standardised systems apply in principle to organisations, this document takes a narrower approach, not including all activities of an organisation, e.g. with regard to their products and services, due to the fact that the Directive only regulates installations/plants.

An EMS can contain the following components:

i. commitment of the management, including senior management;
ii. definition, by the management, of an environmental policy that includes the continuous improvement of the environmental performance of the installation;
iii. planning and establishing the necessary procedures, objectives and targets, in conjunction with financial planning and investment;
iv. implementation of procedures paying particular attention to:
    a) structure and responsibility;
    b) recruitment, training, awareness and competence;
    c) communication;
    d) employee involvement;
    e) documentation;
    f) effective process control;
    g) planned regular maintenance programmes;
    h) emergency preparedness and response;
    i) safeguarding compliance with environmental legislation;
v. checking performance and taking corrective action, paying particular attention to:
    a) monitoring and measurement (see also the JRC Reference Report on Monitoring of emissions to air and water from IED-installations – ROM);
    b) corrective and preventive action;
    c) maintenance of records;
    d) independent (where practicable) internal and external auditing in order to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;
vi. review, by senior management, of the EMS and its continuing suitability, adequacy and effectiveness;
vii. following the development of cleaner technologies;
viii. consideration for the environmental impacts from the eventual decommissioning of the installation at the stage of designing a new plant, and throughout its operating life including:
    a) avoiding unnecessary underground structures;
    b) incorporating features that facilitate dismantling;
    c) choosing surface finishes that are easily decontaminated;
    d) using an equipment configuration that minimises trapped chemicals and facilitates drainage or cleaning;
    e) designing flexible, self-contained equipment that enables phased closure;
    f) using biodegradable and recyclable materials where possible;
ix. application of sectoral benchmarking on a regular basis.

Specifically for incineration plants and, where relevant, IBA treatment plants, the following features can also be incorporated in the EMS:

x. waste stream management plan;
xi. residues management plan including measures aiming to:
    a) minimise the generation of residues;
    b) optimise the reuse, regeneration, recycling and/or energy recovery of the residues;
    c) ensure the proper disposal of residues;
xii. OTNOC management plan;
xiii. accident management plan;
xiv. odour management plan where odour nuisance at sensitive receptors is expected and/or has been substantiated, including:
    a) a protocol for conducting odour monitoring in accordance with EN standards (e.g. EN 13725); it may be complemented by measurement/estimation of odour exposure (e.g. according to EN 16841-1 or EN 16841-2) or estimation of odour impact;
    b) a protocol for response to identified odour incidents, e.g. complaints;
    c) an odour prevention and reduction programme designed to identify the source(s); to measure/estimate odour exposure; to characterise the contributions of the sources; and to implement prevention and/or reduction measures;

xv. noise management plan where noise nuisance at sensitive receptors is expected and/or has been substantiated, including;
    a) a protocol for conducting noise monitoring;
    b) a protocol for response to identified noise and vibration incidents;
    c) a noise and vibration reduction programme designed to identify the source(s), to measure/estimate noise and vibration exposure, to characterise the contributions of the sources and to implement prevention and/or reduction measures.

Achieved environmental benefits

An EMS promotes and supports the continuous improvement of the environmental performance of the installation. If the installation already has a good overall environmental performance, an EMS helps the operator to maintain the high performance level.

Environmental performance and operational data

No information provided.

Cross-media effects

None reported. The systematic analysis of the initial environmental impacts and scope for improvements in the context of the EMS sets the basis for assessing the best solutions for all environmental media.

Technical considerations relevant to applicability

The components described above can typically be applied to all installations within the scope of this document. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) is generally related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have (determined also by the type and the amount of waste processed).

Economics

It is difficult to determine accurately the costs and economic benefits of introducing and maintaining a good EMS. There are also economic benefits that are the result of using an EMS and these vary widely from sector to sector.

External costs relating to verification of the system can be estimated from guidance issued by the International Accreditation Forum [84, IAF 2010].

Driving force for implementation

The driving forces for the implementation of an EMS include:

- improved environmental performance;
- improved insight into the environmental aspects of the company which can be used to fulfil the environmental requirements of customers, regulatory authorities, banks, insurance companies or other stakeholders (e.g. people living or working in the vicinity of the installation);
- improved basis for decision-making;
- improved motivation of personnel (e.g. managers can have confidence that environmental impacts are controlled and employees can feel that they are working for an environmentally responsible company);
- additional opportunities for operational cost reduction and product quality improvement improved company image;
- reduced liability, insurance and non-compliance costs.

Example plants

EMSs are applied in a number of installations throughout the EU.

Reference literature

[85, COM 2014], [86, EC 2009], [87, DG Environment 2010], [88, CEN 2015], [89 European Commission 2015]

~~**Description**~~

~~The best environmental performance is usually achieved by the installation of the best technology and its operation in the most effective and efficient manner. This is recognised by the IPPC Directive definition of 'techniques' as *"both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned"*.~~

~~For IPPC installations an Environmental Management System (EMS) is a tool that operators can use to address these design, construction, maintenance, operation and decommissioning issues~~

~~in a systematic, demonstrable way. An EMS includes the organisational structure, responsibilities, practices, procedures, processes and resources for developing, implementing, maintaining, reviewing and monitoring the environmental policy. Environmental Management Systems are most effective and efficient where they form an inherent part of the overall management and operation of an installation.~~

~~Within the European Union, many organisations have decided on a voluntary basis to implement environmental management systems based on EN ISO 14001:1996 or the EU Eco-management and audit scheme EMAS. EMAS includes the management system requirements of EN ISO 14001, but places additional emphasis on legal compliance, environmental performance and employee involvement; it also requires external verification of the management system and validation of a public environmental statement (in EN ISO 14001 self-declaration is an alternative to external verification). There are also many organisations that have decided to put in place non-standardised EMSs.~~

~~While both standardised systems (EN ISO 14001:1996 and EMAS) and non-standardised ("customised") systems in principle take the *organisation* as the entity, this document takes a more narrow approach, not including all activities of the organisation e.g. with regard to their products and services, due to the fact that the regulated entity under the IPPC Directive is the *installation* (as defined in Article 2).~~

~~An environmental management system (EMS) for an IPPC installation can contain the following components:~~
~~(a) definition of an environmental policy~~
~~(b) planning and establishing objectives and targets~~
~~(c) implementation and operation of procedures~~
~~(d) checking and corrective action~~
~~(e) management review~~
~~(f) preparation of a regular environmental statement~~
~~(g) validation by certification body or external EMS verifier~~
~~(h) design considerations for end-of-life plant decommissioning~~
~~(i) development of cleaner technologies~~
~~(j) benchmarking.~~

~~These features are explained in somewhat greater detail below. For detailed information on components (a) to (g), which are all included in EMAS, the reader is referred to the reference literature indicated below.~~

~~(a) Definition of an environmental policy~~

~~Top management are responsible for defining an environmental policy for an installation and ensuring that it:~~

- ~~is appropriate to the nature, scale and environmental impacts of the activities~~
- ~~includes a commitment to pollution prevention and control~~
- ~~includes a commitment to comply with all relevant applicable environmental legislation and regulations, and with other requirements to which the organisation subscribes~~
- ~~provides the framework for setting and reviewing environmental objectives and targets~~
- ~~is documented and communicated to all employees~~
- ~~is available to the public and all interested parties.~~

~~(b) Planning~~

- ~~procedures to identify the environmental aspects of the installation, in order to determine those activities which have or can have significant impacts on the environment, and to keep this information up-to-date~~

- ~~procedures to identify and have access to legal and other requirements to which the organisation subscribes and that are applicable to the environmental aspects of its activities~~
- ~~establishing and reviewing documented environmental objectives and targets, taking into consideration the legal and other requirements and the views of interested parties~~
- ~~establishing and regularly updating an environmental management programme, including designation of responsibility for achieving objectives and targets at each relevant function and level as well as the means and timeframe by which they are to be achieved.~~

~~(c) Implementation and operation of procedures~~

~~It is important to have systems in place to ensure that procedures are known, understood and complied with, therefore effective environmental management includes:~~

~~(i) Structure and responsibility~~

- ~~defining, documenting and communicating roles, responsibilities and authorities, which includes appointing one specific management representative~~
- ~~providing resources essential to the implementation and control of the environmental management system, including human resources and specialised skills, technology and financial resources.~~

~~(ii) Training, awareness and competence~~

- ~~identifying training needs to ensure that all personnel whose work may significantly affect the environmental impacts of the activity have received appropriate training.~~

~~(iii) Communication~~

~~establishing and maintaining procedures for internal communication between the various levels and functions of the installation, as well as procedures that foster a dialogue with external interested parties and procedures for receiving, documenting and, where reasonable, responding to relevant communication from external interested parties.~~

~~(iv) Employee involvement~~

~~involving employees in the process aimed at achieving a high level of environmental performance by applying appropriate forms of participation such as the suggestion-book system or project-based group works or environmental committees.~~

~~(v) Documentation~~

~~establishing and maintaining up-to-date information, in paper or electronic form, to describe the core elements of the management system and their interaction and to provide direction to related documentation.~~

~~(vi) Efficient process control~~

~~adequate control of processes under all modes of operation, i.e. preparation, start-up, routine operation, shutdown and abnormal conditions~~

~~identifying the key performance indicators and methods for measuring and controlling these parameters (e.g. flow, pressure, temperature, composition and quantity)~~

~~documenting and analysing abnormal operating conditions to identify the root causes and then addressing these to ensure that events do not recur (this can be facilitated by a 'no-blame' culture where the identification of causes is more important than apportioning blame to individuals).~~

~~(vii) Maintenance programme~~

~~establishing a structured programme for maintenance based on technical descriptions of the equipment, norms etc. as well as any equipment failures and consequences~~

~~supporting the maintenance programme by appropriate record keeping systems and diagnostic testing~~

~~clearly allocating responsibility for the planning and execution of maintenance.~~

~~(viii) Emergency preparedness and response~~

~~establishing and maintaining procedures to identify the potential for and response to accidents and emergency situations, and for preventing and mitigating the environmental impacts that may be associated with them.~~

~~Checking and corrective action~~

~~(i) Monitoring and measurement~~

~~establishing and maintaining documented procedures to monitor and measure, on a regular basis, the key characteristics of operations and activities that can have a significant impact on the environment, including the recording of information for tracking performance, relevant operational controls and conformance with the installation's environmental objectives and targets~~ ~~*(see also the Reference document on Monitoring of Emissions)*~~

~~establishing and maintaining a documented procedure for periodically evaluating compliance with relevant environmental legislation and regulations.~~

~~(ii) Corrective and preventive action~~

~~establishing and maintaining procedures for defining responsibility and authority for handling and investigating non-conformance with permit conditions, other legal requirements as well as objectives and targets, taking action to mitigate any impacts caused and for initiating and completing corrective and preventive action that are appropriate to the magnitude of the problem and commensurate with the environmental impact encountered.~~

~~(iii) Records~~

~~establishing and maintaining procedures for the identification, maintenance and disposition of legible, identifiable and traceable environmental records, including training records and the results of audits and reviews.~~

~~(iv) Audit~~

~~establishing and maintaining (a) programme(s) and procedures for periodic environmental management system audits that include discussions with personnel, inspection of operating conditions and equipment and reviewing of records and documentation and that results in a written report, to be carried out impartially and objectively by employees (internal audits) or external parties (external audits), covering the audit scope, frequency and methodologies, as well as the responsibilities and requirements for conducting audits and reporting results, in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained~~

~~completing the audit or audit cycle, as appropriate, at intervals of no longer than three years, depending on the nature, scale and complexity of the activities, the significance of associated environmental impacts, the importance and urgency of the problems detected by previous audits and the history of environmental problems – more complex activities with a more significant environmental impact are audited more frequently~~

~~having appropriate mechanisms in place to ensure that the audit results are followed up.~~

~~(v) Periodic evaluation of legal compliance~~

~~reviewing compliance with the applicable environmental legislation and the conditions of the environmental permit(s) held by the installation~~

~~documentation of the evaluation.~~

~~(d) Management review~~

- ~~reviewing, by top management, at intervals that it determines, the environmental management system, to ensure its continuing suitability, adequacy and effectiveness~~
- ~~ensuring that the necessary information is collected to allow management to carry out this evaluation~~
- ~~documentation of the review.~~

~~(e) Preparation of a regular environmental statement~~

- ~~preparing an environmental statement that pays particular attention to the results achieved by the installation against its environmental objectives and targets. It is regularly produced – from once a year to less frequently depending on the significance of emissions, waste generation etc. It considers the information needs of relevant interested parties and it is publicly available (e.g. in electronic publications, libraries etc.).~~

~~When producing a statement, the operator may use relevant existing environmental performance indicators, making sure that the indicators chosen:~~

  i. ~~give an accurate appraisal of the installation's performance~~
  ii. ~~are understandable and unambiguous~~
  iii. ~~allow for year on year comparison to assess the development of the environmental performance of the installation~~
  iv. ~~allow for comparison with sector, national or regional benchmarks as appropriate~~
  v. ~~allow for comparison with regulatory requirements as appropriate.~~

~~(f) Validation by certification body or external EMS verifier~~

- ~~having the management system, audit procedure and environmental statement examined and validated by an accredited certification body or an external EMS verifier can, if carried out properly, enhance the credibility of the system.~~

~~(g) Design considerations for end-of-life plant decommissioning~~

- ~~giving consideration to the environmental impact from the eventual decommissioning of the unit at the stage of designing a new plant, as forethought makes decommissioning easier, cleaner and cheaper~~
- ~~decommissioning poses environmental risks for the contamination of land (and groundwater) and generates large quantities of solid waste. Preventive techniques are process-specific but general considerations may include:~~
  i. ~~avoiding underground structures~~
  ii. ~~incorporating features that facilitate dismantling~~
  iii. ~~choosing surface finishes that are easily decontaminated~~
  iv. ~~using an equipment configuration that minimises trapped chemicals and facilitates drain-down or washing~~
  v. ~~designing flexible, self-contained units that enable phased closure~~
  vi. ~~using biodegradable and recyclable materials where possible.~~

~~(h) Development of cleaner technologies~~

- ~~environmental protection should be an inherent feature of any process design activities carried out by the operator, since techniques incorporated at the earliest possible design stage are both more effective and cheaper. Giving consideration to the development of cleaner technologies can for instance occur through R and D activities or studies. As an alternative to internal activities, arrangements can be made to keep abreast with – and where appropriate – commission work by other operators or research institutes active in the relevant field.~~

~~(i) Benchmarking, i.e.~~

- ~~carrying out systematic and regular comparisons with sector, national or regional benchmarks, including for energy efficiency and energy conservation activities, choice of input materials, emissions to air and discharges to water (using for example the European Pollutant Emission Register, EPER), consumption of water and generation of waste.~~

~~Standardised and non-standardised EMSs~~
~~An EMS can take the form of a standardised or non-standardised ("customised") system. Implementation and adherence to an internationally accepted standardised system such as EN ISO 14001:1996 can give higher credibility to the EMS, especially when subject to a properly performed external verification. EMAS provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.~~

~~Main achieved environmental benefits~~
~~Implementation of and adherence to an EMS focuses the attention of the operator on the environmental performance of the installation. In particular, the maintenance of and compliance with clear operating procedures for both normal and abnormal situations and the associated lines of responsibility should ensure that the installation's permit conditions and other environmental targets and objectives are met at all times.~~

~~Environmental management systems typically ensure the continuous improvement of the environmental performance of the installation. The poorer the starting point is, the more significant short-term improvements can be expected. If the installation already has a good overall environmental performance, the system helps the operator to maintain the high performance level.~~

~~Cross-media effects~~
~~Environmental management techniques are designed to address the overall environmental impact, which is consistent with the integrated approach of the IPPC Directive.~~

~~Operational data~~
~~No specific information reported.~~

~~Applicability~~
~~The components described above can typically be applied to all IPPC installations. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.~~

~~Economics~~
~~It is difficult to accurately determine the costs and economic benefits of introducing and maintaining a good EMS. A number of studies are presented below. However, these are just examples and their results are not entirely coherent. They might not be representative for all sectors across the EU and should thus be treated with caution.~~

~~A Swedish study carried out in 1999 surveyed all 360 ISO-certified and EMAS-registered companies in Sweden. With a response rate of 50 %, it concluded among other things that:~~
- ~~the expenses for introducing and operating EMS are high but not unreasonably so, save in the case of very small companies. Expenses are expected to decrease in the future~~
- ~~a higher degree of co-ordination and integration of EMS with other management systems is seen as a possible way to decrease costs~~

- ~~half of all the environmental objectives and targets give payback within one year through cost savings and/or increased revenue~~
- ~~the largest cost savings were made through decreased expenditure on energy, waste treatment and raw materials~~
- ~~most of the companies think that their position on the market has been strengthened through the EMS. One-third of the companies report increasing revenue due to EMS.~~

~~In some Member States reduced supervision fees are charged if the installation has a certification.~~

~~A number of studies[1] show that there is an inverse relationship between company size and the cost of implementing an EMS. A similar inverse relationship exists for the payback period of invested capital. Both elements imply a less favourable cost-benefit relationship for implementing an EMS in SMEs compared to larger companies.~~

~~According to a Swiss study, the average cost for building and operating ISO 14001 can vary:~~

- ~~for a company with between 1 and 49 employees: CHF 64000 (EUR 44000) for building the EMS and CHF 16000 (EUR 11000) per year for operating it~~
- ~~for an industrial site with more than 250 employees: CHF 367000 (EUR 252000) for building the EMS and CHF 155000 (EUR 106000) per year for operating it.~~

~~These average figures do not necessarily represent the actual cost for a given industrial site because this cost is also highly dependent on the number of significant items (pollutants, energy consumption...) and on the complexity of the problems to be studied.~~

~~A recent German study (Schaltegger, Stefan and Wagner, Marcus, *Umweltmanagement in deutschen Unternehmen – der aktuelle Stand der Praxis*, February 2002, p. 106) shows the following costs for EMAS for different branches. It can be noted that these figures are much lower than those of the Swiss study quoted above. This is a confirmation of the difficulty to determine the costs of an EMS.~~

~~Costs for building (EUR):~~

~~minimum - 18750~~
~~maximum - 75000~~
~~average - 50000~~

~~Costs for validation (EUR):~~

~~minimum - 5000~~
~~maximum - 12500~~
~~average - 6000~~

~~A study by the German Institute of Entrepreneurs (Unternehmerinstitut/Arbeitsgemeinschaft Selbständiger Unternehmer UNI/ASU, 1997, *Umweltmanagementbefragung – Öko-Audit in der mittelständischen Praxis – Evaluierung und Ansätze für eine Effizienzsteigerung von Umweltmanagementsystemen in der Praxis*, Bonn.) gives information about the average savings achieved for EMAS per year and the average payback time. For example, for implementation costs of EUR 80000 they found average savings of EUR 50000 per year, corresponding to a payback time of about one and a half years.~~
~~External costs relating to verification of the system can be estimated from guidance issued by the International Accreditation Forum (http://www.iaf.nu).~~

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1) E.g. Dyllick and Hamschmidt (2000, 73) quoted in Klemisch H. and R. Holger, *Umweltmanagementsysteme in kleinen und mittleren Unternehmen - Befunde bisheriger Umsetzung,* KNI Papers 01/02, January 2002, p 15; Clausen J., M. Keil and M. Jungwirth, *The State of EMAS in the EU.Eco-Management as a Tool for Sustainable Development - Literature Study,* Institute for Ecological Economy Research (Berlin) and Ecologic - Institute for International and European Environmental Policy (Berlin), 2002, p 15.

~~Driving forces for implementation~~

~~Environmental management systems can provide a number of advantages, for example:~~

- ~~improved insight into the environmental aspects of the company~~
- ~~improved basis for decision-making~~
- ~~improved motivation of personnel~~
- ~~additional opportunities for operational cost reduction and product quality improvement~~
- ~~improved environmental performance~~
- ~~improved company image~~
- ~~reduced liability, insurance and non-compliance costs~~
- ~~increased attractiveness for employees, customers and investors~~
- ~~increased trust of regulators, which could lead to reduced regulatory oversight~~
- ~~improved relationship with environmental groups.~~

~~Example plants~~

~~The features described under (a) to I above are elements of EN ISO 14001:1996 and the European Community Eco-Management and Audit Scheme (EMAS), whereas the features (f) and (g) are specific to EMAS. These two standardised systems are applied in a number of IPPC installations. As an example, 357 organisations within the EU chemical and chemical products industry (NACE code 24) were EMAS registered in July 2002, most of which operate IPPC installations.~~

~~In the UK, the Environment Agency of England and Wales carried out a survey among IPC (the precursor to IPPC) regulated installations in 2001. It showed that 32 % of respondents were certified to ISO 14001 (corresponding to 21 % of all IPC installations) and 7 % were EMAS registered. All cement works in the UK (around 20) are certified to ISO 14001 and the majority are EMAS registered. In Ireland, where the establishment of an EMS (not necessarily of a standardised nature) is required in IPC licenses, an estimated 100 out of approximately 500 licensed installations have established an EMS according to ISO 14001, with the other 400 installations having opted for a non-standardised EMS.~~

~~Reference literature~~

~~(Regulation (EC) No 761/2001 of the European parliament and of the council allowing voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), OJ L 114, 24/4/2001, http://europa.eu.int/comm/environment/emas/index_en.htm)~~

~~(EN ISO 14001:1996, http://www.iso.ch/iso/en/iso9000-14000/iso14000/iso14000index.html; http://www.tc207.org)~~

4.1.2 ~~Use of~~ Ensurance of continuous ~~rather than batch~~ operation of the WI plant

Description

The setting up and the implementation of operational procedures (e.g. organisation of the supply chain, continuous rather than batch operation, preventive maintenance) to limit as far as practicable the number of shutdowns and start-ups.

Technical description

Emissions at incineration plants are easier to control during routine operation than during start-up and shutdown operations. Reducing the number of start-ups and shutdowns required is, therefore, an ~~important~~ operational strategy that can reduce overall emissions and consumption. Waste collection/delivery regime and seasonal waste generation fluctuations can cause shutdowns through lack of wastes, although they are often avoided by running the plant at partial load in order to deal with such fluctuations. Running at partial load does not normally cause problems for a modern combustor. [74, TWGComments, 2004]

Factors that help to achieve continuous throughput include:

- the process design throughput rate is similar to the rate at which waste is received;
- waste storage (where possible) may cover slow periods;
- organisation of the supply chain to prevent slow periods;
- supplementing waste feed with additional fuels;
- use of online cleaning.

Sizing and maintaining plants to maximise continuous running is, therefore, important.

Good maintenance is important for avoiding/limiting shutdowns. An on-line maintenance programme can be designed into the installation so that availability is maximised.

Achieved environmental benefits
Emissions associated with shutdown and start-up operations are in part avoided. Planning for and achieving a reduced number of shutdowns is likely to reduce the annual mass emission levels of any plant.

Environmental performance and operational data
Predicting and controlling waste flows to the plant is important to ensure the steady operation of the plant.

Cross-media effects
Energy efficiency can be reduced by continuous operation on a lower load, because turbine efficiency is lower.

Technical considerations relevant to applicability
Generally applicable.

Economics
Avoiding shutdowns can reduce costs at incineration installations by:

- allowing continuous throughput and hence greater installation utilisation;
- decreasing furnace maintenance due to lower thermal stress on the process;
- avoiding capital costs of an unnecessarily large process.

Where the capacity of the installation is larger than the quantity of the waste received, and the decision is taken to supplement the throughput with other wastes or fuels, there may be costs associated with the purchase of those fuels/wastes.

Driving force for implementation
Main driving forces are operational. Consistent plant operation improves energy efficiency.

Example plants
In general, all ~~large~~ waste incineration plants are operated continuously. ~~MSWI plants of an industrial size (above ~2 t/h) can be operated continuously with a minimum number of shutdowns.~~

Reference literature
[28, FEAD, 2002] [64, TWGComments, 2003]

4.2 Operational techniques to improve environmental performance ~~General practices applied before the thermal treatment stage~~

~~4.2.1 Suitability of process design for the waste(s) received~~

To the TWG: Already covered by the definition of process input limitation

~~One of the most important decisions to be made by the waste incinerator operator relates to the selection of a combustion (or thermal treatment) stage that is technically suited to the material that will be fed to the process. Once that design has been selected, the operational objective then becomes one of managing the incoming waste so that its properties remain within the range for which the process is designed (see techniques described in 4.2.3).~~

~~In general, existing technologies have been developed in order to meet the specific waste treatment requirements of particular waste streams. The application of a technology developed for a different waste, of possibly unsuitable characteristics, can result in poor or unreliable performance. Some installations are designed as "mass burn" (i.e. to treat wastes of varying composition), others only to receive selected waste streams with narrow specifications. The design required depends on the wastes that will be received for treatment in the incinerator. Significant operational, safety and environmental consequences may result from attempting to treat the wrong waste in the wrong design of installation.~~

~~In addition to the target performance (e.g. waste destruction, energy outputs, emission levels), the choice of thermal treatment technique generally needs to take account of the following technical criteria:~~

- ~~waste chemical composition and variation~~
- ~~waste physical composition, e.g. particle size and variation~~
- ~~waste thermal characteristics, e.g. calorific value, moisture levels~~
- ~~throughput and process availability required~~
- ~~required bottom ash, and other residue(s) quality and composition~~
- ~~possibilities for use of products of partial oxidation, such as syngas or coke~~
- ~~emission level targets and selected abatement system~~
- ~~type of energy recovery (e.g. heat, electrical power, CHP).~~

~~In addition to these technical criteria, the following may also influence the final design choice:~~

- ~~degree of technical risk~~
- ~~operational experience and available skill~~
- ~~budget.~~

~~Installations that are designed to treat a narrow range of specific wastes (or highly pretreated and hence more homogeneous waste) operate within a narrower range of performance limits, than those that receive wastes with greater variability. More homogenous waste can allow improved process stability, with more even and predictable flue-gas composition. Where waste quality can be well controlled, FGT system capacity may be narrowed to some degree without increasing the risk of raw gas concentrations exceeding FGT capacity.~~

~~In practice, many waste incinerators may have only limited control over the precise content of the wastes they receive. Operators receiving such wastes thus need to design their processes to be sufficiently flexible to cope with the range of waste inputs that could be fed to the process.~~
~~[64, TWGComments, 2003]~~

~~4.2.2 General housekeeping measures~~

To the TWG: alredy part of the EMS

~~General tidiness and cleanliness contribute to an enhanced working environment and can allow potential operational problems to be identified in advance.~~

~~The main elements of good housekeeping are:~~

- ~~the use of systems to identify and locate/store wastes received according to their risks~~
- ~~the prevention of dust emissions from operating equipment~~
- ~~effective waste water management, and~~
- ~~effective preventive maintenance.~~

~~[64, TWGComments, 2003]~~

4.2.3 Quality control of incoming wastes

This section covers those techniques that help the operator to characterise the waste input to be treated. General techniques applied to control that the incoming wastes are compatible with the plant characteristic are outlined in the WT BREF and can be referred to for general guidance.

4.2.3.1 Establishment of plant ~~installation~~ input limitations and identification of key risks

Description
Identification of the types of waste which can be accepted, considering the characteristics of the waste incineration plant, in terms of calorific value, humidity, ash content, physical state, size, etc.

Technical description
Every installation has limitations on the characteristics of the wastes that can be fed to the incinerator itself. From knowledge of the incineration process input limitations, it is possible to derive a waste input specification that highlights the maximum and desirable system input rates. It is then possible to identify the key risks, and procedural controls required to prevent or reduce operation outside these limitations.

Factors that set such boundaries include:

- design of waste feed mechanism and the physical suitability of waste received;
- waste flow rate and heat throughput rating of the furnace;
- ~~emission limit values~~ required environmental performance ~~to be reached~~ (i.e. pollutant reduction required expressed as a percentage);
- flue-gas cleaning technology capacity for individual pollutant removal (e.g. limit on flue-gas flow rate, pollutant loading).

Examples of key risks identified can be:

- high mercury input, leading to high raw flue-gas concentrations;
- high iodine or bromine input, leading to high raw flue-gas concentrations;
- high variability in moisture content or CV, leading to combustion irregularities;
- high chlorine loading exceeding FGC capacity;
- high sulphur loading exceeding FGC capacity;
- rapid change in flue-gas chemistry which ~~e~~affects FGC function;
- physically large items blocking feed systems – leading to an interruption of regular operation;
- excessive slagging/fouling of boiler components when certain types of waste are being fed, e.g. high Zn concentration sources (contaminated wood waste) have been reported to cause abnormal slagging in the first boiler pass.

Once the theoretical and actual (i.e. those occurring at ~~operational~~ plants in operation) risks have been established, the operator can ~~then~~ develop a targeted control strategy to reduce those risks, e.g. if ~~operator~~ experience shows that the ~~installation may experience exceedences of~~ HCl emission limit values may be exceeded, then the operator may decide to attempt to control chlorine sources and peak concentrations in the waste ~~as~~ fed to the combustion stage and/or to improve the design and operational practice ~~features~~ of the acid gas FGC ~~applied~~.

Achieved environmental benefits
The use of this technique helps ensure the smooth and stable operation of the incinerator and reduces the requirement for reactive and emergency process intervention.

Environmental performance and operational data
The definition of process input limitation is applied by ~~Applicable to~~ all waste incineration plants, particularly those that receive wastes from diverse sources and of a wide or difficult to control specification (e.g. merchant hazardous waste plants).

Existing ~~installations~~ plants will have the advantage of experience and knowledge from previous situations encountered during the operational lifetime of the installation. New plants may be able to learn from the operational experience of similar existing plants and then adapt and develop their own procedures according to their specific operational experiences.

Installations with extensive storage and pretreatment facilities may be able to accept wastes that are initially outside the normal combustor specification and then treat the waste to meet the combustor requirements.

While merchant HWIs are often built to treat a large variety ~~be able to~~ ~~receive any kind~~ of hazardous waste, this is not the case for many other installations including MSWIs. However, some types of waste which are similar in nature to MSW are treated in some MSWIs, e.g. commercial waste, some clinical wastes and sewage sludges. The installation may require some adaptation to be suitably equipped to treat wastes that differ in nature from the main type received. This would generally include the provision of adequate reception, storage and handling systems. If the waste is significantly different then more extensive adaptations may also be required, e.g. to the furnace type, FGC, waste water treatment system, specific safety measures and laboratory/testing equipment. [64, TWGComments, 2003]
~~See description above~~.

Cross-media effects
The implementation of process input limitation ~~procedures~~ results in the removal of wastes which fall outside the established specification. Those wastes are then diverted ~~from the incineration process~~ to other waste treatment plants ~~options~~. The type and magnitude of cross-media effects that result are therefore dependent upon the type and performance of the alternative treatment option.

Technical considerations relevant to applicability
Generally applicable.

Economics
~~Costs are not precisely quantifiable.~~ Excluding some waste sources/types may reduce income. In addition, specific investment may be required to introduce techniques to identify and manage such wastes, e.g. analysis, pretreatment.

Driving force for implementation
A good knowledge of process limitations is required in order to assess and select procedures to control input and hence the overall process performance.

Example plants

This is a widely employed practice at hazardous waste incineration plants in particular. The technique is also applied at many European MSWIs in order to identify and possibly exclude undesired waste types.

Reference literature
[55, EIPPCBsitevisits, 2002] [64, TWGComments, 2003]

4.2.3.2 Communication with waste suppliers to improve incoming waste quality control

Description
The quality assurance of the incoming waste

Technical description
Wastes are commonly received from a wide variety of sources over which the operator may have only limited control. Where the operator has identified specific wastes, substances or properties of wastes, or individual sources that can or do cause operational problems, the communication of the operator's concerns to those persons producing and supplying the waste can help to assure quality in the overall chain of waste management. An example is the separate collection of mercury-containing wastes such as batteries, or dental amalgam so that the mercury content of the MSW stream is reduced.

The type of techniques used and the degree to which they are employed depend upon the degree of risk and the frequency and nature of any operational difficulties encountered. In general, the greater the variability of the waste types, compositions and sources, the more effort is required in waste input control.

Achieved environmental benefits
Avoiding the receipt of unsuitable wastes or controlling the delivery of wastes that are difficult to treat or that require special care can reduce operational difficulties and hence avoid additional releases.

Environmental performance and operational data
This technique ~~can be applied to all waste incineration plants, but~~ is of most use at those plants receiving wastes from diverse sources and of a wide, or difficult to control, specification (e.g. merchant hazardous waste plants).

Processes that are designed to receive a narrow range of well-defined wastes may need to take particular care to ensure key substances are controlled.

Existing plants will have the advantage of learning from the real situations already encountered. For instance:

- At the SELCHP (South East London, UK) MSWI, sources of gypsum (Calcium Sulphate) which were disturbing the operation were identified.
- In Caen (France), a successful information campaign to reduce the mercury content in MSW was carried out.

Cross-media effects
Some wastes may need to be diverted from the incinerator to other waste treatment options.

Technical considerations relevant to applicability
Generally applicable.

Economics
Savings may arise from avoiding operational difficulties.

Driving force for implementation
Procedures to control input can reduce the risks of operational upsets and associated releases.

Example plants
This is a widely employed practice at hazardous waste incineration plants in particular.

Reference literature
[64, TWGComments, 2003]

For the TWG: 4.1.3.3, 4.1.3.4 and 4.1.3.5 can be merged.

4.2.3.3 Control of waste feed quality on the incinerator site

Description
The control of the waste feed quality on the incineration site.

Technical description
To help control the waste feed quality, and hence stabilise the combustion process within design parameters, a set of quality requirements can be derived for the waste fed to the combustor. The waste quality requirements can be derived from an understanding of the process' operational limitations, such as:

- thermal throughput capacity of the incinerator;
- physical requirements of the feed (particle size);
- controls used for the incineration process (e.g. using LHV, steam production, O_2 content);
- capacity of the flue-gas treatment system and the derived maximum raw gas input concentrations/rates;
- the emission limit values that need to be met;
- bottom ash quality requirements.

Wastes can be stored, mixed or blended (this is restricted by some national legislation) to ensure that the final waste that is fed to the combustor falls within the derived set of quality requirements.

The key substances/properties that will usually require particular procedures to be put in place for their management relate to variations in the concentration and distribution in the waste of the following:

- mercury, alkali metals and heavy metals;
- iodine and bromine;
- chlorine and sulphur;
- variations in heat values/moisture content;
- critical organic pollutants, e.g. PCBs;
- physical consistency of waste, e.g. sewage sludge;
- mixability of different kind of waste.

The results of CEN/TC 292 and CEN/TC 343 can be relevant for carrying out the sampling of these substances in the waste.

Achieved environmental benefits
Reduced emissions to in the flue-gas through:

- smooth process operation;
- effective combustion;
- improved energy recovery;

- more even raw gas concentrations and hence improved operation of flue-gas cleaning plant;
- reduced fouling in the boiler by reducing the dust release.

Environmental performance and operational data
All waste incineration plants ~~installations~~ have ~~need to derive~~ their own set of key process input limitations and then adopt suitable receipt restrictions and possible pretreatment to ensure that these limitations are not exceeded.

This is ~~A requirement to do so will be~~ especially the case ~~necessary~~ where highly variable waste compositions are encountered (e.g. merchant HWIs), and at smaller capacity plants as these have less operational "buffering" capacity than larger plants.

[64, TWGComments, 2003] This technique finds its main application and benefits at hazardous waste incinerators, although in some countries (e.g. Austria) it is performed at every waste incineration plant.
~~No information.~~

Cross-media effects
The preparation and storage of wastes can give rise to fugitive emissions that themselves require management.

Technical considerations relevant to applicability
Generally applicable. For clinical waste, sampling is not applicable due to the risk of infections.

Economics
No information provided ~~not supplied~~.
Driving force for implementation
The driving force is to help ensure that the feedstock material is suited to the processes used, and hence to allow emissions and consumption to be controlled within required parameters.

Example plants
This technique is applied in particular at hazardous waste incineration plants in the EU-28.

Reference literature
[25, Kommunikemi, 2002] [64, TWGComments, 2003]

4.2.3.4 Checking, sampling and testing of incoming wastes

Description
The checking, sampling and testing of the incoming wastes.

Technical description
This technique involves the use of a suitable regime for the assessment of incoming waste. The assessments carried out are selected to ensure:

- that the wastes received are within the range suitable for the installation;
- whether the wastes need special handling/storage/treatment/removal for off-site transfer;
- whether the wastes are as described by the supplier (for contractual, operational or legal reasons).

The techniques adopted vary from simple visual assessment to full chemical analysis. The extent of the procedures adopted will depend upon:

- nature and composition of waste;
- heterogeneity of the waste;
- known difficulties with wastes (of a certain type or from a certain source);

- specific sensitivities of the installation concerned (e.g. certain substances known to cause operational difficulties);
- whether the waste is of a known or unknown origin;
- existence or absence of a quality controlled specification for the waste;
- whether the waste has been dealt with before and experiences with it.

Specific techniques applied are listed in Table 4.4.
~~Example procedures are provided under Operational data below.~~

Table 4.4: Techniques applied for checking and sampling of various waste types

Waste type	~~Example~~ Techniques applied	Comments
Mixed municipal wastes	• Visual inspection in bunker • Spot checking of individual deliveries by separate ~~off-~~unloading • Weighing the waste as delivered • Radioactive detection	Industrial and commercial loads may have elevated risks and require greater attention
Pretreated municipal wastes and RDF	• Visual inspection • Periodic sampling and analysis for key properties/substances	None
Hazardous wastes	• Visual inspection • Control and comparison of data in the declaration list in comparison with delivered waste • Sampling/analysis of all bulk tankers • Random checking of drummed loads • Unpacking and checking of packaged loads • Assessment of combustion parameters • Blending tests on liquid wastes prior to storage • Control of flashpoint for wastes in the bunker • Screening of waste input for elemental composition ~~e.g. by EDXRF~~	Extensive and effective procedures are particularly important for this sector. Plants receiving mono-streams may be able to adopt more simplified procedures
Sewage sludges	• Periodic sampling and analysis for key properties and substances • Checking for hard materials, e.g. stones/metal/wood/plastics, prior to pumping transportation, dewatering and drying stages • Process control to adapt to sludge variation	The suitability of the techniques is dependent on the kind of sewage sludge e.g. raw sludge, digested sludge, oxidised sludge ~~etc~~.
Clinical wastes	• Control and comparison of data in the declaration list in comparison with delivered waste • Screening for radioactivity	Infection risk makes sampling inadvisable. Control is required by waste producer
~~**Animal by-products**~~	~~• control and comparison of data in the declaration list in comparison with delivered waste~~ ~~• sampling/testing of low risk material for fat, moisture content~~	~~Sampling not advisable for high risk material for safety reasons~~

Source : [1, UBA, 2001, 2, infomil, 2002, 41, EURITS, 2002], [64, TWGComments, 2003]

Achieved environmental benefits

Advanced identification of unsuitable wastes, substances or properties can reduce operational difficulties and hence avoid additional releases.

Environmental performance and operational data

Examples of tests performed on the incoming waste, depending the type of waste treated, are shown in Table 4.4.

The most extensive sampling and analysis regimes are ~~appropriate~~ used where waste compositions and sources are most variable (e.g. merchant hazardous waste plants) or where there are known difficulties, e.g. a history of problems with a particular waste type or source.

Cross-media effects

No significant ~~negative~~ cross-media effects.

Technical considerations relevant to applicability
Genarally applicable. Sampling is not possible for clinical waste due to the risk of infection.

Economics
The cost of applying these techniques increases rapidly with the extent and complexity of the procedures adopted.

The costs for the sampling, analysis, storage and additional processing time required can represent a significant proportion of the operational costs at hazardous waste plants in particular, where the most extensive sampling and analysis regimes are applied.

Driving force for implementation
To enable better process control and for plant protection.

Example plants
Widely used throughout the EU-28.

Reference literature
[40, EURITS, 2003], and discussions during site visits. [64, TWGComments, 2003]

4.2.3.5 Detectors for radioactive materials

Description
The use of detectors for radioactive materials.

Technical description
~~Although radioactive materials are not specifically regulated by IPPC,~~ The inclusion of radioactive sources or substances in waste can lead to operational and safety problems. ~~Very low "background" levels of radioactivity are present throughout the natural environment and are also be found in wastes – such levels do not require specific measures for their detection and control. However,~~ Some wastes are at risk of containing higher levels, particularly those arising from activities that use radioactive materials. Some clinical ~~hospital~~ and industrial wastes may therefore routinely or occasionally contain specific radioactive sources or contamination, although the inclusion of such wastes with municipal waste, and the difficulties of controlling mixed waste collections, can lead to radioactivity in other wastes.

Radioactive materials can often be detected using specific detectors situated at, for example, the entrance to the plant. Tests of waste loads that may have a higher risk of contamination are ~~can also be~~ carried out. Such tests are specifically carried out where loads are accepted on the basis of a maximum level of contamination. Such maximum levels are derived from knowledge of the fate of the isotopes treated, and of the particular process receiving them, and on consideration of the limits set on the contamination levels allowed in releases to land, air and water.

Plastic scintillation detectors are one type of detector used; these measure photons from gamma-emitting radionuclides and to a lesser extent from beta emitters. Radionuclides are regularly detected in clinical waste, laboratory waste and technically enhanced naturally occurring radioactive material. Also important are the controls put in place to prevent the mixing of radioactive waste with regular waste (sometimes done so as to avoid the high treatment cost associated with radioactive waste).

Achieved environmental benefits
Benefits include the prevention of plant contamination and release of radioactive substances. Contamination of the installation can result in lengthy and costly shutdowns for decontamination.

Environmental performance and operational data

Some plants report good experiences of using gate controls for radioactive material, after they recognised that the MSW they receive may occasionally contain radioactive materials. [64, TWGComments, 2003]

This technique is applied by ~~Applicable to incineration~~ plants where heterogeneous wastes are received from a wide variety of suppliers. It is applied less when the sources and variability of the waste are well known and controlled, or where the risk of receiving radioactive materials is judged to be low.

Cross-media effects

The main concern is how to manage waste that is identified as radioactive – as neither its transport nor treatment may be permitted. Developing plans and procedures in advance of such situations for managing any radioactive wastes identified is advantageous.

Technical considerations relevant to applicability

Generally applicable.

Economics

In 2006, the investment cost for installing detectors was approximately EUR 25 000–50 000 [83 WI BREF 2006].

Driving force for implementation

Reductions in the tolerable threshold for low-level radioactive contamination encourage the use of the technique. These thresholds may vary from one MS to another according to legislative requirements. [64, TWGComments, 2003]

In some Member States, e.g. France, the regulation on MSWI enforces the implementation of detectors for radioactive materials (with a few exceptions).

Example plants

Hazardous waste and some municipal waste installations.

Reference literature

[40, EURITS, 2003], ~~and discussions during site visits.~~ [64, TWGComments, 2003]

4.2.4 Waste storage

The basic principles of storage outlined in the ~~horizontal draft~~ BREF on Emissions from Storage are applicable to the storage of wastes and ~~should~~ can be referred to for general guidance on techniques. General techniques applied in waste storage are also described in the WT BREF. ~~However, because wastes often have a less well defined or even unknown composition, it is often the case that additional techniques are employed that further improve the security of the storage in order to deal with these *unknown* risks.~~ This section of the WI BREF ~~therefore~~ concentrates on the specific techniques that are relevant to waste incineration plants, rather than the more general aspects of storage.

4.2.4.1 Sealed surfaces, controlled drainage and weatherproofing

Description

Storage of waste in areas lined with sealed surfaces and fitted with segregated drainage.

Technical description

The storage of wastes in areas that have sealed and resistant surfaces and controlled drainage prevents the release of substances either directly from the waste or by leaching from the waste.

The techniques employed vary according to the type of waste, its composition and the vulnerability or risk associated with the release of substances from the waste. In general, the following storage techniques are applied. ~~Appropriate:~~

Table 4.5: Some examples of applied storage techniques for various waste types

Waste type	Storage techniques
~~General issues applicable to~~ All wastes	• Odorous materials stored inside with controlled air systems using the discharged air as combustion air (see Section 4.2.4.4) • Designated areas for loading/offloading with controlled drainage • Clearly marked (e.g. colour-coded) areas for drainage from potential areas of contamination (storage/loading/transportation) • Limitation of storage times according to waste type and risks • Adequate storage capacity • Baling or containment of some wastes for temporary storage is possible depending on the waste and location-specific risk factors • Fire protection measures, e.g. fire-resistant wall between the bunker and the furnace hall
Solid municipal and other non-hazardous ~~industrial~~ wastes	• Sealed floor bunkers or sealed level storage areas • Covered and walled buildings • Some bulk items with low pollution potential can be stored without special measures
Solid pretreated MSW and RDF	• Enclosed hoppers • Sealed floor bunkers or level storage areas • Covered and walled buildings • Wrapped or containerised loads may be suitable for external storage without special measures, depending on the nature of the waste
Bulk liquid wastes and sludges	• Attack-resistant bunded bulk tanks • Flanges and valves within bunded areas • Ducting of tank spaces to the incinerator for volatile substances • Explosion control devices in ducts, etc.
Drummed liquid wastes and sludges	• Storage under covered ~~areas~~ • Bunded and resistant surfaces
Hazardous waste	• Segregated storage according to risk assessment • Special attention to the length of storage times • Automatic handling and loading devices • Cleaning facilities for surfaces and containers
Clinical/Biohazardous wastes	• Segregated storage • Refrigerated or freezer storage for biohazardous wastes • Special attention to the reduction of storage times • Automatic handling and loading devices • Container disinfection facilities • Freezer storage, if the storage period exceeds certain time periods, e.g. 48 hours

Source: [64, TWGComments, 2003]

Achieved environmental benefits

~~Proper storing of wastes has many benefits:~~

- Reduction of risks of releases through secure containment.
- Prevention of rainwater penetrating the stored waste (and thus reduction of LCV and combustion difficulty).
- Prevention of wind scatter.
- Reduction of leachate production (and thus subsequent management requirements).
- Reduction of mobilisation of pollutants.
- Reduction of deterioration of containers (corrosion and sunlight).
- Reduction of temperature-related expansion and contraction of sealed containers.
- Reduction and management of odour releases~~ and allows their management~~.
- ~~allows m~~Management of fugitive releases.

Environmental performance and operational data

The general principle of assessing the waste types received and providing appropriate (i.e. that reduces the spread of contamination and the risks of storage and handling releases) secure storage for them is applied by ~~cable to~~ all installations.

The degree of implementation and precise methods adopted depend upon the wastes received and are outlined above in the Technical description section. In general, liquid wastes and hazardous wastes require the most attention.
~~No specific information supplied.~~

Cross-media effects

Increased energy use. ~~Additional buildings and infrastructure required.~~

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided ~~specific data supplied~~.

Driving force for implementation

- Prevention and reduction of diffuse emissions.
- Optimisation of the incineration process.
- Environmental and health regulation requirements.

Example plants

Widely applied throughout Europe. ~~Examples seen in BE, DE, DK, FR, FI.~~

Reference literature

~~Discussions during site visits.~~ [64, TWGComments, 2003]

4.2.4.2 Sufficient ~~Management of~~ storage capacity ~~times~~

Description

Techniques to consider are a combination of measures to avoid accumulation of waste such as:

- establishing a maximum waste storage capacity taking into account the characteristics of the wastes, e.g. regarding the risk of fire;
- regular monitoring of the quantity of waste stored against the maximum storage capacity;
- establishing a maximum residence time for the waste.

Technical description

Storage times can be reduced by:

- preventing the volumes of wastes stored from becoming too large;
- controlling and managing deliveries (where possible) by communication with waste suppliers, etc.

Achieved environmental benefits

~~Reducing storage times can be useful for:~~
- Prevention of the deterioration of containers (weathering, ageing, corrosion).
- Prevention of the putrefaction of organic waste (which may otherwise lead to odour releases, processing and handling difficulties, fire and explosion risks).
- Reduction of the risk of labels becoming detached.

Environmental performance and operational data

In general, MSW is stored in enclosed buildings for a period of 4 to 10 days, with the storage periods being strongly influenced by collection/delivery patterns. Because of the desire to run installations on a continuous basis, the storage capacity and hence maximum storage times will often be determined by the maximum amount of time when no waste is likely to be delivered to the plant. Holiday periods in particular can result in several days when no waste is delivered. [64, TWGComments, 2003]

A limited time for the maturation of municipal waste in the bunker may have a positive effect on the homogeneity of the waste. Feeding fresh waste immediately after it has been delivered may induce fluctuations in the process. [74, TWGComments, 2004]

Where various sources and types of waste are received and added to the furnace to meet a particular feed menu (e.g. hazardous waste installations), longer storage times for particular substances may be beneficial, even of several months in some cases. This allows time for difficult-to-treat wastes to be slowly fed into the system when sufficient compatible materials are also available. Such practices are acceptable where those particular substances are stored in such a manner that the risk of substance and container deterioration is well managed.

Cross-media effects

None reported.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

Stable plant operation.

Example plants

Widely applied throughout Europe.

Reference literature

[83 WI BREF 2006].

~~4.2.4.3 Baling or other containment of solid waste~~

~~**Description**~~

~~During peak delivery times, if the rate of waste receipt is in excess of the plant throughput, waste is wrapped in a plastic cover and stored. Waste received during maintenance or other shutdown periods can also be stored. The technique can facilitate the longer term storage of some wastes and effectively extend the storage capacity of the installation.~~

~~Stored wastes can be re-introduced into the main waste flow to the installation when the delivery rate drops, or when the heat output demand is higher, or when energy (electricity or heat) sale prices are higher.~~

~~The machinery and materials used for the baling are similar to those used in some areas for the baling of animal feeds. Waste is compacted and wrapped with plastic film in big cylinders, usually about 1 m high by 1 m diameter. The oxygen inside is quickly consumed and no more becomes available as atmospheric air cannot enter a well packed bale, even if the film is torn.~~

~~The main advantage of baling and hence the longer-term storage of wastes is that variations in the delivery rate of wastes can be accommodated, and the process can continue running at a steady rate.~~

~~Achieved environmental benefits~~
~~There are 3 main benefits:~~

- ~~minimisation of the amount of waste to be sent elsewhere – during the shut-downs of the plant or of one of its lines, the waste can be baled and burned later when the plant/line is started again~~
- ~~Optimisation of plant design. The plant can be operated at a more consistent load conditions all over the year.~~
- ~~Improvement of the valorisation of recovered energy – the stored waste can be burned when there is greater demand/price for the supplied energy.~~

~~Cross-media effects~~
~~There is a need to adopt suitable measures to manage the following storage related risks:~~

- ~~odour~~
- ~~vermin~~
- ~~litter~~
- ~~fire risks~~
- ~~leachate arising from rainwater penetration of the baled wastes.~~

~~Operational data~~
~~City centre sites or other locations where there are adjacent sensitive receptors may mean that the waste storage aspects (e.g. odours) may be more difficult or expensive to manage in an adequate way.~~

~~The technique is less likely to be required where there are multiple incineration lines, as such an arrangement can itself provide some level of flexibility of operation through the staggered scheduling of maintenance operations, so that incineration capacity is continually available.~~

~~Applicability~~
~~Applicable in circumstances where waste storage is carried out and it can be undertaken such that it does not give rise to particular concerns regarding cross-media effects (see above). May be applied to non-hazardous industrial solid wastes and either pretreated or mixed MSW, although in practice it is not widely used.~~

~~Not suitable to high hazard wastes as the risks (direct or indirect) of longer term storage are likely to outweigh the possible benefits.~~

~~Economics~~
~~Greater income possible from increased energy sales during high demand/high price periods.~~

~~The objective of the technique is to ensure that over the course of e.g. a year, costs are reduced by the additional income that is provided by incinerating waste during periods that otherwise it might not (no deliveries) or by ensuring that the waste is burned when there is a higher demand (and hence higher price) fro the energy supplied. The technique therefore is likely to find most economical benefit where (a) heat is sold, and (b) there is a variable spot market for energy.~~

~~Driving force for implementation~~
~~Varying energy prices can create a situation where it becomes desirable to bring on line additional incineration capacity to meet this demand – the stored waste can then be used during these periods.~~

~~Locations with seasonal populations (e.g. vacation areas) may produce very different amounts of combustible waste depending on the season. The storage of waste allows flexibility, so that the waste can be used when there is spare incineration capacity or additional energy demand.~~

~~Example plants~~
~~The technique is applied in various European MS e.g. Sweden, France.~~

~~Reference literature~~
~~[28, FEAD, 2002] [64, TWGComments, 2003]~~

4.2.4.4 Extraction of ~~incineration~~ air from storage areas for odour, dust and diffuse emissions ~~fugitive release~~ control

Description
Techniques to consider are:

- extraction of the air from waste storage areas and its use as primary and secondary combustiog air;
- limiting the amount of waste stored when the incinerator is not available;
- use of an alternative technique to treated the channelled emissions from the storage area when the incinerator is not available.

Technical description
The incinerator air supply (primary or secondary) can be taken from the waste (or chemical) storage areas. By enclosing the waste storage areas and limiting the size of the entrances to the waste storage areas, the whole waste storage area can be maintained under a slight negative pressure. This reduces the risk of odour releases and ensures that odorous substances ~~fugitive releases~~ are destroyed in the incinerator rather than released.

It is also possible for raw material storage to be ventilated to either the combustion chamber or to the flue-gas cleaning equipment, depending on the nature of the ~~fumes~~ air extracted.

The main techniques employed are shown in Table 4.6.

Table 4.6: Main techniques for reducing fugitive diffuse air emissions releases of odour, and GHG emissions.

Technique	Application
Solid waste in enclosed buildings from which incineration air is drawn	• Municipal wastes • Bulky solid and pasty hazardous wastes • RDF • Sewage sludges • Clinical wastes • Other odorous wastes
Ducting tank vent to incineration air feed	• Odorous and volatile hazardous wastes, e.g. solvent wastes • Odorous sludges, e.g. sewage sludge • Other odorous or volatile wastes
Source: [2, infomil, 2002] p 150, [1, UBA, 2001] p 36, [40, EURITS, 2003]	

Achieved environmental ercury
~~General~~ Reduction of diffuse emissions~~fugitive releases,~~ (e.g. odour, dust, CH_4)~~, GHG emissions, and sanitary risks~~.

Environmental performance and operational data
Typical air requirements for waste incineration processes are 3 000–10 000 m^3/tonne of treated waste, depending mainly on the LCV.

If air inlets (e.g. doorways) to waste storage areas are smaller (in terms of their combined total cross-sectional area), the inlet velocity of the air across these inlets will be higher and consequently the risk of diffuse emissions ~~fugitive releases~~ via these routes lower.

Care is required with extraction from hazardous waste (particularly flammable/volatile material) storage areas in order to avoid explosion risks.

In case of fire in the bunker, air channels must be automatically closed to prevent fire jumping from the bunker to the incineration building.

This technique is used ~~All incinerators~~ where there is a risk of odour or other substances being released from storage areas.

Plants storing volatile solvents can significantly reduce their VOC emissions using the technique.

Cross-media effects
Alternative air handling and treatment (e.g. for odour, VOCs or other substances according to the waste type) measures may be required when the incinerator is not running. Even for multiple line processes where it is usual for at least one line to be running at any particular time, provision of alternative air handling and treatment may be used since it is possible that all lines of a waste incineration plant simultaneously have to stop their operation (e.g. in case of accidents, maintenance of one line and simultaneous breakdown of the other line, end of maintenance when waste is already delivered). [74, TWGComments, 2004]

Technical considerations relevant to applicability
The applicability of limiting the amount of waste when the incinerator is not available may be limited during unplanned shutdowns.
~~Where applied only for reasons of odour control, locations that are nearer to sensitive odour receptors have a greater need for this technique.~~

Economics
There are additional ducting costs for retrofits.

The provision of a back-up system for periods when the incinerator is not available entails the additional cost of that system.

Driving force for implementation
- Control of diffuse emissions ~~fugitive releases~~, including odour.
- ~~A~~ Proximity to sensitive odour receptors ~~will increase the need for this technique, including the need for alternative measures where the incineration process is not available~~.

Example plants
The technique is widely used at waste incineration plants throughout Europe. In Germany, up to 60 MSWI plants have long-standing experience with this measure.

Reference literature
[2, infomil, 2002] p 150, [1, UBA, 2001] p 36, [40, EURITS, 2003] [64, TWGComments, 2003]

4.2.4.5 Segregation of waste types for safe processing

Description

Wastes are kept separate depending on their chemical and physical characteristics in order to enable easier and environmentally safer storage and treatment.

Technical description

Waste acceptance procedures and storage depend on the chemical and physical characteristics of the waste. Appropriate waste assessment is an essential element in the selection of storage and input operations.

This technique is strongly related to the checking, sampling and assessment of incoming wastes outlined in Section 4.2.3.4.

The segregation techniques applied vary according to the type of wastes received at the plant, the ability of the plant to treat those wastes, and the availability of specific alternative treatments or incineration pretreatment. In some cases, particularly for certain reactive mixtures of hazardous wastes, the segregation is required when the materials are packed at the production site, so that they can be packaged, transported, ~~off~~unloaded, stored and handled safely. In these cases, segregation at the incineration installation relates to maintaining the separation of these materials so that hazardous mixtures are avoided. [64, TWGComments, 2003]

Table 4.7: Some segregation techniques applied for various waste types

Waste type	Segregation techniques
Mixed municipal wastes	• Segregation is not routinely applied unless various distinct waste streams are received ~~when these can be mixed in the bunker~~ • Bulky items requiring pretreatment can be segregated • Emergency segregation areas for rejected waste • For fluidised beds, removal of metals may be required to facilitate shredding and prevent blockage
Pretreated municipal wastes and RDF	• Segregation not routinely applied • Emergency segregation areas for rejected waste
Hazardous wastes	• Extensive procedures required to separate chemically incompatible materials; examples include: ○ water from phosphides ○ water from isocyanates ○ water from alkaline metals ○ cyanide from acids ○ flammable materials from oxidising agents • Maintain separation of pre-segregated packed delivered wastes
Sewage sludges	• Wastes generally well mixed before delivery to plant • Some industrial streams may be delivered separately and require segregation for blending
Clinical wastes	• Moisture content and CV can vary greatly depending on source • Segregate different containers to allow suitable storage and controlled feeding
Source: **[2, infomil, 2002] p 150, [1, UBA, 2001] p 36, [40, EURITS, 2003] [64, TWGComments, 2003]**	

Achieved environmental benefits

Segregating incompatible wastes reduces the risk of emissions by:

- reducing accident risks (that may lead to environmentally and/or health- and safety-relevant releases);
- allowing the balanced feeding of substances, thereby avoiding system overloads and malfunctions and thus preventing plant shutdown.

Environmental performance and operational data
In France, legislation requires the storage of clean containers in a separate room to dirty ones.

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable. ~~Not applicable where waste is already collected and delivered so that further segregation is not required.~~

Economics
No information provided.

Driving force for implementation
The technique is implemented to control the hazards that may arise from the mixing of incompatible materials and to protect the installation by ensuring that the waste fed to the incinerator falls within the range for which the installation is designed.

Example plants
No information provided. ~~Supplied~~

Reference literature
[64, TWGComments, 2003]

~~4.2.4.6 Individual labelling of contained waste loads~~

To the TWG: deleted as this is for the waste providers not for WI plant operators

~~The proper labelling of the wastes (e.g. in accordance with the European Waste Catalogue) that are delivered in containers, assists their continued identification and trace-ability. Identification of wastes, and their source, has the following benefits:~~

- ~~knowledge of waste content is required for choice of handling/processing operations~~
- ~~it increases the operators ability to trace sources of problems and then to take steps to eliminate or control them~~
- ~~ability to demonstrate conformance with restrictions on waste types and quantities received/processed. [64, TWGComments, 2003]~~

~~Bar code systems and scan readers can be used for packaged and liquid wastes. The costs of such systems are low in relation to the benefits.~~

~~In general, waste delivery is accompanied by a suitable description of the waste; an appropriate assessment of this description and the waste itself forms a basic part of waste quality control. The existence of such a declaration is prescribed in European and other legislation.~~

~~An indicative list of the most important parameters for labelling includes:~~
- ~~name and address of the deliverer~~
- ~~origin of the waste~~
- ~~volume~~
- ~~water and ash content~~
- ~~calorific value~~
- ~~concentration of chlorides, fluorides, sulphur and heavy metals.~~

~~An example of an adequate description of the waste was developed by the CEN/TC 343 on "Solid Recovered Fuels".~~

~~**Applicability**~~
~~Mainly applicable to hazardous waste, clinical waste plants or other situations where wastes are held in containers and have variable/distinct compositions.~~

~~**Example plants**~~
~~Labelling is widely applied, particularly at HWIs.~~

~~**Reference literature**~~
~~Site visit discussions and [64, TWGComments, 2003]~~

4.2.4.7 Use of fire detection and control systems

Description
Techniques to consider are:

- use of an automatic fire detection and warning system;
- use of a manual and/or automatic fire intervention and control system.

Technical description
Automatic fire detection and warning systems ~~have been~~ are used in waste storage areas as well as for ~~fabric~~ bag and ~~static~~ fixed-bed coke filters, electrical and control rooms, and other identified risk areas.

Continuous automatic measurement of temperature is ~~can be~~ carried out on the surface of wastes stored in the bunkers. Temperature variations can be used to trigger an acoustic alarm.

Complementary visual control by operators can be an effective fire detection measure. [74, TWGComments, 2004]

Automatic fire intervention and control systems are applied in some cases, most commonly when storing flammable liquid waste although also in other risk areas.

Foam and carbon dioxide control systems are used ~~provide advantages in some circumstances e.g.~~ for the storage of flammable liquids. Foam nozzles are commonly used in MSW incineration plants in the waste storage bunker. Water spray systems with monitors, water cannons with the option to use water or foam, and dry powder systems are also used. Nitrogen blanketing may be used in fixed-bed coke filters, bag filters, tank farms, or for the pretreatment and kiln loading facilities for hazardous wastes. [74, TWGComments, 2004]

There are also other safety devices, such as:

- nozzles above the waste feed hoppers;
- fire-resistant walls to separate transformers and retention devices under transformers;
- gas detection above the gas distribution module.

When ammonia is used, its storage requires specific safety measures: NH_3 detection and water spray devices to absorb releases. [74, TWGComments, 2004]

The use of nitrogen blanketing requires effective operating procedures and containment to avoid operator exposure. Asphyxiation can occur outside enclosed areas as well as inside.

Achieved environmental benefits
Reduced risk of accidental fugitive releases from fires and explosions.

Environmetal performance and operational data
Containment is required to prevent the uncontrolled discharge of polluted firefighting water/chemicals.

Cross-media effects
Consumption of nitrogen for blanketing.

Technical considerations relevant to applicability
Generally applicable.
~~The selection of suitable fire prevention, detection and control systems is applicable to all installations.~~

Economics
Costs are for installation and maintenance and, where used, for nitrogen.

Prevention of damage by fire can result in significant savings. Installation of fire safety measures may reduce insurance premiums.

Driving force for implementation
Safety and safety regulation requirements~~ is a significant driver~~.

~~According to a recent European regulation, equipments located in explosive atmosphere should be explosion-proof (electrically + mechanically) [74, TWGComments, 2004]~~

Example plants
Many plants in Europe.

Reference literature
[40, EURITS, 2003], [64, TWGComments, 2003], [74, TWGComments, 2004].

4.2.5 Pretreatment of incoming waste, waste transfer and loading

4.2.5.1 Pretreatment, blending and mixing of wastes

Description
Techniques to consider are:

- mixing of incoming MSW;
- pretreatment of heterogeneous waste;
- feed equalising control system for solid hazardous waste.

Technical description
Techniques used for waste pretreatment and mixing are wide-ranging, and may include:

- mixing of liquid or solid hazardous wastes to meet input requirements for the plant ~~installation~~;
- shredding, crushing, and shearing of packaged wastes and bulky combustible wastes;
- mixing of wastes in a bunker using a grab or other machine~~ (e.g. sprelling machines for sewage sludge)~~;
- ~~different grades of shredding of MSW – from production of RDF – usually produced from source separated waste and/or other non hazardous waste. [74, TWGComments, 2004]~~

Mixing of waste may serve the purpose of improving feeding and combustion behaviour. The mixing of hazardous waste with other waste or products, prior to incineration, is done to stabilise the waste feed and process conditions, to increase burnout, to improve safe disposal of residues, and to increase the quality of recovered waste fractions [90 Eurits 2016]. Mixing of hazardous waste can involve risks. Mixing of different waste types may be carried out according to a recipe [74, TWGComments, 2004]

In any case, the mixing of waste prior to incineration should not lead to the dilution of hazardous components which were initially present at a concentration that would not have been acceptable according to the waste incinerator limits [90 Eurits 2016].

Solid heterogeneous wastes (e.g. municipal and packaged hazardous wastes) can benefit from a degree of mixing in the bunker prior to loading into feed mechanisms.

In bunkers, the mixing involves the mixing of wastes using bunker cranes in the storage bunker itself. Crane operators can identify potentially problematic loads (e.g. baled wastes, discrete items that cannot be mixed or will cause loading/feeding problems) and ensure that these are: removed, shredded or directly blended (as appropriate) with other wastes. The technique is commonly applied at municipal plants and other incinerators where batch loads are delivered for pre-incineration storage in a common bunker. Crane capacity must be designed so that it is sufficient to allow mixing and loading at a suitable rate. Usually there are two cranes, each of them sufficient to cope with the blending and feeding of all the incineration lines.

When ~~special~~ other wastes are incinerated together with MSW, they may require specific pretreatment. Clinical waste may be delivered in special packaging, while sewage sludge, when not in a relatively small proportion, may require preliminary partial or total drying, and usually a specific feeding system, e.g. in the feed hopper, in the feed chute, directly in the furnace through a side wall or above the feeder. [74, TWGComments, 2004]

The feed equaliser for solid hazardous waste consists of two screw conveyors capable of crushing and feeding solid waste and a feed hopper for receiving various types of waste. Solid bulk waste is fed to the feed hopper with a grab crane through horizontal feed gates. The feed gates are normally closed to prevent gas leakage into the ambient air.

In the bottom of the feed hopper, there are two hydraulically operated feed screws feeding the waste continuously into the feed chute through fire doors. The fire doors prevent backdraught from starting fires in the feed hopper.

The feed hopper is equipped with a level measurement for the upper and lower fill limits of the hopper. At the upper limit this provides a signal to stop the feed into the hopper while the lower limit signal slows down the operation of the screws so that there will always be some waste left at the buffer zone in the hopper to act as a barrier between the screw and the feed hopper.
The feed hopper works as a buffer zone preventing:

- nitrogen from leaking into the kiln; and
- backdraught from causing fire in the feed hoppers.

Drums ~~Barrel~~ can be fed through the front wall of the rotary kiln without a feed hopper.

Achieved environmental benefits
The burnability of the waste is improved by making it more homogeneous, thus reducing and stabilising emissions from the furnace, and leading to steadier steam/hot water generation in boilers. Although greater homogeneity generally improves the ‘smoothness’ of the operation, the degree of treatment suitable for a given waste type depends upon the nature of the waste and the receiving installation’s design (i.e. does or will the degree of heterogeneity of the waste lead to particular problems of challenges in the installation, and will the use of additional pretreatment provide sufficient benefit to outweigh the cross-media effects and costs?).

The resultant more even raw flue-gas compositions may allow closer optimisation of the flue-gas cleaning process.

Environmental performance and operational data
The safety of waste blending and crushing operations requires consideration when designing such systems and procedures. This is particularly the case for flammable, toxic, odorous and

infectious waste packed in drums. Nitrogen blanketing and airlocks for the pretreatment equipment are effective in reducing risks.

Fires and explosions at mechanical sorting and blending plants are a significant risk. However, blending of MSW in the bunker does not normally cause any particular risk. [74, TWGComments, 2004]

(*To the TWG: from Section 4.2.5.6*) At RMVA Cologne, Germany, the waste is accepted in different fractions and prepared specifically for incineration. The appropriate crushing and removal of valuable materials (primarily metal) and the merging of the individual fractions using conveyors allows the generation of a standardised, homogeneous fuel.

~~The machinery required for the sorting and shredding of heterogeneous wastes is of heavy duty. Effective management and maintenance is required to avoid breakdowns and loss of availability. For thermal processes dealing with MSW which require more than blending, the pretreatment (shredding, shearing, crushing, etc.) must be looked at carefully since it is often a weak point. Special checks should be made on the shredder output because of risk of fire in the shredded waste. [74, TWGComments, 2004]~~

~~Mixing of wastes with the objective of achieving compliance with the emission levels in permits is forbidden in some cases (e.g. in Austria).~~

Cross-media effects

Energy consumption and odour, noise and dust emissions from the operation of the pretreatment equipment can range widely depending on the nature of the waste, the technique used and the desired feed quality. ~~For example; the production of pelletised RDF from unsorted MSW can require high energy inputs (and, hence, additional costs for the pretreatment), whereas simpler shredding and mixing of selected waste streams can impose a relatively small burden.~~

Technical considerations relevant to applicability

Generally applicable.

~~All plants receiving heterogeneous solid wastes (e.g. untreated municipal and packaged hazardous wastes) can apply the technique in principle.~~

~~Significant and adequate pretreatment of municipal solid waste is a prerequisite for some thermal processes. Shredding is not widely applied on MSWI, except for specific combustion designs such as fluidised bed; sometimes double shredding (in series) may be necessary (e.g. pyrolysis plant of Arras, France).~~

~~For MSW grate incinerators, the blending of the MSW in the bunker with the crane and grab is considered essential and widely used. However, bulky objects may require removal or, if they are to be incinerated, shredding. Commercial and industrial non-hazardous wastes may require size reduction in order to homogenise the waste. [74, TWGComments, 2004]~~

Economics

Costs vary greatly depending on the nature of the waste, the technique used and the desired feed quality.

(*To the TWG: from Section 4.1.5.6*) The cost of separating mixed wastes may be significant. Costs will be reduced where efficient pre-delivery segregation schemes, perhaps coupled with some simple pretreatment, are already in place, allowing only storage and mixing to be carried out at the incineration installation.

The benefits of significant pretreatment are most likely to be realised at new plants that can design the entire incineration installation for the post-treated waste.

At existing plants that have been specifically constructed to allow for wide feedstock flexibility, and are already able to achieve ~~low emission and otherwise~~ good performance levels, the

benefits of simple pretreatment may still be seen. However, the adoption of pretreatment techniques that effectively require wholesale changes to the waste collection and pretreatment chain prior to the incineration installation are likely to involve very significant investment in infrastructure and logistics. Such decisions are likely to be beyond the scope of a single installation, and require overall consideration of the entire waste management chain in the region from which wastes are received.
~~See also comments under applicability above.~~

Driving force for implementation
Improved homogeneity of the waste to be incinerated allows better process stability, improved combustion conditions and better process optimisation. Emissions from the incineration installation may, therefore, be reduced, or more closely controlled.

The link to the local waste strategy is important when determining to what extent pretreatment needs to be carried out.

Example plants
All MSWIs in Europe blend MSW in the bunker. Numerous plants are equipped with a shear, shredder or crusher for bulky objects, e.g. Toulon.

Sewage sludge drying prior to addition to municipal waste is carried out at a number of plants in Europe, e.g. in Nice-Ariane and Bourg St Maurice (FR). It is also carried out without addition, and fed in the feed chute with MSW, e.g. Thiverval (FR), Thumaide (BE), and separately fed into the furnace, e.g. Monaco, Bordeaux Bègles, Bordeaux Cenon (FR).
[74, TWGComments, 2004]

A feed equalising system is used at Ekokem in Riihimäki (FI), at Sakab in Kumla (SE) and at A.V.R.-Chemie in Rotterdam (NL).

Reference literature
[40, EURITS, 2003] ~~and personal communications.~~ [64, TWGComments, 2003], [90 Eurits 2016], [20, EKOKEM, 2002]

~~4.2.5.2 Shredding of mixed municipal wastes~~

For the TWG: General waste treatment issue

~~**Description**~~
~~Untreated mixed municipal waste can be roughly shredded (i.e. not finely shredded) by passing delivered waste through either:~~

- ~~crocodile shears~~
- ~~shredders~~
- ~~mills~~
- ~~rotor shears~~
- ~~crushers.~~

~~**Achieved environmental benefits**~~
~~The homogeneity of the waste is improved, resulting in more even combustion and reduced and more stable emissions from the furnace. Having a more even raw gas composition may allow closer optimisation of the flue-gas cleaning process. Blockages of the feeder systems to the combustor and of bottom ash extraction and transporting systems may also be reduced, hence resulting in reduced downtime and shutdowns.~~
~~Shredding of bulky waste added to a municipal waste incineration plant has been reported to improve operation and burnout levels from 3 % TOC to closer to 1 % TOC.~~

~~**Cross-media effects**~~
~~The shredding equipment is mechanically substantial and results in:~~

- ~~increased energy consumption for shredder operation~~
- ~~potential noise – insulation of equipment is required~~
- ~~production of dusts and odour – controlled ducting of relevant air space to incinerator air supply can be applied~~
- ~~additional explosion, fire and accident risks~~
- ~~shredder jamming may cause additional start-up/shut downs and significant periods of unavailability.~~

~~Noise, odour and other releases from bulky waste shredding at MSWI plants may be reduced by placing the shredder in the waste reception hall. In some cases the shredding machinery is designed into the bunker itself so that the shredded waste falls directly into the bunker.~~

~~Operational data~~
~~Shredder systems are prone to jamming and physical damage if care is not taken to exclude certain materials.~~

~~Operators loading the shredders require specific training to identify problem materials and loads.~~

~~Where grate systems are used, the size of the post shredded material will need to be high enough to avoid excessive riddling of the grate. There is, generally, not a minimum size requirement with rotary kilns or fluidised beds. For fluidised beds oversized material tends to be the difficulty, typically due to the blockage of bottom ash extraction or waste feeders, a maximum size of about 50 mm is recommended by some manufacturers. For rotary kilns the size depends on the opening from drum feeding.~~

~~Applicability~~
~~Applicable to all plants receiving heterogeneous solid waste e.g. untreated municipal and packaged hazardous wastes.~~

~~The potential environmental benefits of producing a more homogeneous fuel are mainly accrued at the combustion and subsequent stages (e.g. FGT) and need to be weighed against the possible disadvantages of the additional waste treatment (see cross-media effects above). Whether an overall benefit is seen, is greatly dependent upon the nature of the waste received, and the combustion technology employed. At existing installations additional pretreatment may not provide any significant operational or environmental benefits. Grate incinerators are the least likely to achieve major benefits from intensive shredding of mixed MSW, other than the rough shredding of the waste, especially larger components of the waste.~~

~~Economics~~
~~Additional costs of shredding operation reported to be in the region of EUR 10 per tonne of waste for coarse shredding [16, Energos, 2002]. A higher price of EUR 30 /t is also quoted. [64, TWGComments, 2003]~~

~~Savings may be made through the optimisation of the operation of flue-gas treatment plants. Such savings will most likely be possible at new plants, by allowing the selection of smaller flue-gas treatment plants.~~

~~Driving force for implementation~~
~~Improved stability of combustion process.~~

~~Example plants~~
~~Several smaller scale (35000 tonnes/yr) municipal plants in Norway (e.g. Energos).~~

~~Reference literature~~
~~[8, Energos, 2002], [1, UBA, 2001], [64, TWGComments, 2003]~~

~~4.2.5.3 Shredding of drummed and packaged hazardous wastes~~

For the TWG: General waste treatment issue

~~**Description**~~

~~The pretreatment of liquid packaged waste and packed or bulk solid waste to produce a mixture for continuous feed to the furnace can be carried out. Suitable wastes may be treated to a pumpable state for pumped injection to the kiln or shredded for adding to the storage burner where solids and liquids separate and are then fed to the kiln separately using grabs and pumping respectively.~~

~~Pallets containing packaged liquid wastes of low to medium high viscosity are shredded to 5 to 10 cm. The shredded waste may then be screened before being transferred to tanks. Screened out plastics are passed for incineration, ferrous metals are removed using magnets for washing and recycling. In other cases the waste is not screened, and is pumped as a mixture of liquids and shredded solids to the kiln with thinning liquids e.g. waste oils.~~

~~The liquid waste is pumped to a conditioning tank where it can be mixed with solvent waste from bulk deliveries to meet viscosity requirements, before final pumping to the furnace.~~

~~Packed and bulk solid waste is shredded using a separate line and a heavy duty cutter shredder. If the power consumption of the shredder is high, this indicates that the consistency of the mixture is becoming too solid for pumping and waste oil is added through a pipeline. If the mixture becomes very thin (low viscosity), bulk solid waste can be added. Piston pumps are used to transfer the mixture to the kiln.~~

~~All equipment is sealed under a nitrogen blanket to reduce fire and explosion risks. Air lock doors are used to load the wastes.~~

~~**Achieved environmental benefits**~~

~~Use of continuous feed:~~

- ~~improves the combustion performance and reduces peaks of CO and VOCs~~
- ~~increases average heat recovery due to stable gas flow in boilers~~
- ~~stabilises conditions for operation of flue-gas cleaning equipment~~
- ~~prevents explosions in the kiln~~
- ~~reduces downtime due to refractory etc. damage.~~

~~Metals removed before the combustion (see also Section 4.2.5.5) may be of superior quality to those removed after combustion from bottom ashes. This is particularly likely to be the case for those metals removed from higher temperature operations, because of the greater deterioration in quality of post-combustion treated metals that results.~~

~~Reduction in consumption of furnace support fuel by 85 % has been achieved in one example [25, Kommunikemi, 2002].~~

~~**Cross-media effects**~~

~~Energy consumption by shredding and pumping equipment.~~

~~**Operational data**~~

~~Disadvantages are the demand for better inspection and higher requirements for the quality of the waste to prevent damage and downtime of the shredders. This downtime is compensated for by reductions in maintenance requirements of the furnace due to reduced explosion risks.~~

~~**Applicability**~~

~~Applicable to incinerators receiving packaged hazardous wastes. The general principle of increasing the homogeneity through suitable waste preparation can be applied to all incinerators where significant variations in raw gas parameters are seen post combustion.~~

~~**Economics**~~

~~In one example the recycling of packaged steel from a 35 t/d plant produced an additional income of EUR 35000/yr. The number of operators required for handling of packages was reduced from 6 to 3.~~

~~Construction costs of two line were reported:~~

- ~~35 t/d packaged liquid line = EUR 2.9 million (1990 prices)~~
- ~~75 t/d packaged and bulk solid line = EUR 5.4 million (1996 prices).~~

~~**Driving force for implementation**~~

~~Improved combustion performance leads to reduced emissions. The technique also reduces manual handling of packaged wastes, damage to and maintenance of the kiln.~~

~~**Example plants**~~

~~Kommunikemi, DK ; Ekokem, FIN~~

~~**Reference literature**~~

~~[25, Kommunikemi, 2002], [20, EKOKEM, 2002] [64, TWGComments, 2003]~~

~~4.2.5.4 Feed equalising control system for solid hazardous wastes~~

For the TWG: merged with 4.2.5.1

~~**Description**~~

~~The feed equaliser itself consists of two robust screw conveyors capable of crushing and feeding solid waste and a tailor made feed hopper for receiving various types of waste. Safety measures are designed according to plant requirements.~~

~~Solid bulk waste is fed to the feed hopper with a crab crane through the horizontal feed gates. The feed gates are normally closed to prevent gas leakage into the ambient air.~~

~~In the bottom of the feed hopper there are two hydraulically operated feed screws feeding the waste continuously into the feed chute through fire doors. The fire doors prevent back draught from starting fires in the feed hopper.~~

~~The feed hopper is equipped with a radioactive source level measurement for the upper and lower fill limits of the hopper. At the upper limit this provides a signal to stop the feed into the hopper.~~

~~The lower limit signal slows down the operation of the screws so that there will always be some waste left at the buffer zone in the hopper to act as a barrier between the screw and the feed hopper. The feed hopper works as a buffer zone preventing:~~

- ~~nitrogen from leaking into the kiln and~~
- ~~back draught from causing fire in the feed hoppers.~~

~~If there is no need for barrel feeding, the feed equalising system can also feed the waste directly through the front wall of the rotary kiln without a feed hopper.~~

~~**Achieved environmental benefits**~~

~~The feed equalising system provides a safe and reliable solution for the controlled continuous feeding of solid hazardous waste, and reduces CO peaks by ensuring uniform and stable combustion conditions inside the rotary kiln and inside the secondary combustion chamber.~~

~~In general, the main environmental benefits are:~~

- ~~continuous feeding of solid hazardous waste improves the controllability of waste feeding and reduces CO peaks compared to batch feeding~~

- ~~optimal utilisation of the incineration capacity of the rotary kiln for low calorific solid hazardous waste~~
- ~~homogenous stream of molten bottom ash is formed in the rotary kiln at high temperature~~
- ~~fire safety is improved in the hazardous bunker area by the use of automatic fire extinguishing equipment~~
- ~~installation of video monitoring equipment enable continuous observation of waste feeding into the rotary kiln.~~

~~Cross-media effects~~
~~Energy consumption by screw feeders.~~

~~Applicability~~
~~Applicable to hazardous waste incinerators receiving heterogeneous solid wastes.~~

~~Economics~~
~~Data not supplied.~~

~~Controlled continuous feeding of solid waste into the rotary kiln contributes to efficient use of the maximum incineration capacity.~~

~~Driving force for implementation~~
~~See environmental benefits above.~~

~~Example plants~~
~~Feed equalising system has been operating successfully at Ekokem in Riihimäki, Finland since 1989, at Sakab in Kumla, Sweden since 1993 and also at A.V.R. Chemie in Rotterdam, the Netherlands since 1996.~~

~~Reference literature~~
~~[20, EKOKEM, 2002]~~

~~4.2.5.5 Pre-combustion removal of recyclable metals~~

For the TWG: WT BREF issue

~~Description~~
~~Many wastes contain appreciable quantities of ferrous and non-ferrous metals. These can be an inherent part of the waste itself (e.g. food and drink containers in MSW) or arise from the packaging of waste in drums (e.g. hazardous wastes) or other metal containers.~~

~~Where the incoming wastes are shredded metals can be removed before incineration to allow recycling.~~

~~Metal separation can be achieved by using:~~

- ~~over-band magnets for large ferrous materials e.g. shredded drums~~
- ~~drum magnets for small and heavy ferrous items such as batteries, nails, coins, etc.~~
- ~~eddy current separators for non-ferrous metals – mainly copper and aluminium used for packaging and electrical components.~~

~~It may be necessary to wash the removed metals in order to remove contamination from the wastes they have been in contact with. Whether this is necessary, depends on the type of contamination, subsequent storage, transport and recycling process requirements.~~

~~Metal separation with reduced oxidation of the metals can also be achieved in fluidised bed gasification plants treating shredded mixed MSW. Here the gasification temperature of 500 – 600 °C and the action of the fluidised bed can together, allow largely un-oxidised metals to be removed from the fluidisation material (e.g. sand) using the same separation technologies described above. The cleaned bed material is re-circulated to the fluidisation chamber.~~

~~**Achieved environmental benefits**~~

~~The main achieved environmental benefits are:~~

- ~~recovery of recyclable metal streams~~
- ~~improved value of metals that have not been partially oxidised at high temperatures in the incinerator~~
- ~~reduction of content of volatile metals in the flue-gas leading to reduced contamination of flue-gas cleaning residues~~
- ~~improved bottom ash quality by reduction of metal content (non-volatile fraction).~~

~~**Cross-media effects**~~

~~Energy required for shredders and operation of separation devices.~~

~~Possible consumptions and effluents may arise from washing stages (if used). It may be possible for the contaminated washing effluent to be fed to the incineration process.~~

~~**Operational data**~~

~~Operational data regarding shredders is given where available in Sections 4.2.5.3 and 4.2.5.2.~~

~~Metal removal may be an essential requirement for certain thermal processes. This process may help preventing risk of fouling of the bed and blockage of the solid discharge due to metal fusion.~~

~~In some case. For recovery it may be better to separate the metal after thermal treatment, as the metal with low fusion point are removed. [74, TWGComments, 2004]~~

~~**Applicability**~~

~~With MSW in particular, the effective separate collection of these items may mean that greatly reduced quantities of the recoverable metals remain in the waste – making steps to remove these metal at the incineration plant less or not worthwhile.~~

~~**Economics**~~

~~There are investment and operational costs associated with the use of the shredding and separation equipment.~~

~~With FB combustors shredding may be an essential part of the installation for many waste types (e.g. MSW).~~

~~Local market prices determine the income from the recovered metals.~~

~~**Driving force for implementation**~~

~~Demand and higher prices for increased quality metal produced improve the economics of such systems. Where outlets already exist for the recovery of post-combustion metals there is a reduced incentive to adopt pre-combustion removal.~~

~~**Example plants**~~

~~Hazardous waste: shredding and removal of ferrous drums – Kommunikemi, Denmark~~
~~Municipal SW: shredding and removal of Fe and non-Fe scrap – plants in Austria~~
~~Municipal SW: example of fluidised bed with pre-shredding, metal ejection and separation – Asahi Clean Centre, Kawaguchi City, Tokyo, Japan~~

~~**Reference literature**~~

~~[64, TWGComments, 2003]~~

~~4.2.5.6 Pretreatment and targeted preparation of solid waste for combustion~~

For the TWG: merged with Section 4.2.5.1

~~**Description**~~

~~The waste is accepted in different fractions and prepared specifically for incineration. The appropriate crushing and removal of valuable materials (primarily metal) and the merging of the individual fractions using conveyors allows the generation of a standardised, homogeneous fuel.~~

~~**Achieved Environmental Benefits**~~

~~Improved combustion through homogenisation of the waste. Reduced pollutant loads, reduced heat value fluctuations and reduced emissions and consumptions from smoother operation.~~

~~The intensive mixing of waste before it enters the bunker can improve fuel qualities.~~

~~**Operational data**~~

~~Improved process operation with the potential for longer component life, particularly for the incineration stage. More even energy generation.~~

~~**Cross-media effects**~~

~~Odour, noise and dust emissions from the pretreatment and storage stages. Additional energy consumption associated with the equipment used.~~

~~**Applicability**~~

~~Mainly applicable to wastes that can be delivered in various fractions or efficiently treated to separate the fractions required.~~

~~The technique may be particularly applicable to installation designs that have narrow input specifications e.g. fluidised beds. The benefits of applying the technique may be more limited where an installation is already designed for "mass burn" e.g. grates and rotary kilns.~~

~~**Economics**~~

~~Cost of separating mixed wastes may be significant. Costs will be reduced where efficient pre-delivery segregation schemes, perhaps coupled with some simple pretreatment, and already in place, allowing only storage and mixing to be carried out at the incineration installation.~~

~~**Driving force for implementation**~~

~~Availability of pre-selected waste streams e.g. from prior segregation of the waste before delivery to the installation, which then do not need to be separated and may be stored separately.~~

~~**Example plants**~~

~~RMVA Cologne, Germany~~

~~**Reference literature**~~

~~[64, TWGComments, 2003]~~

~~**Waste transfer and loading**~~

~~4.2.5.7 Positioning and view of operator~~

To the TWG: moved to Section 4.3.6

~~The operators of waste feed systems need to have a good view of waste storage and loading areas and their mechanisms to monitor them. This can be achieved by positioning the control room with a view of the combustor loading areas and by the use of video monitors or other detection systems. The former is preferable unless there are particular safety or other technical reasons why this cannot be achieved. [64, TWGComments, 2003]~~

~~4.2.5.8 Provision of storage space for items removed from the waste~~

~~Some waste streams commonly require the removal of certain components of the waste, usually because they are unsuitable for processing in the facility. Suitable storage needs to be provided for these items. See also Section 4.2.3~~

4.2.5.9 Direct injection of liquid and gaseous ~~hazardous~~ wastes ~~in rotary kilns~~

Description
The feeding of liquid and gaseous wastes directly to the furnace.

Technical description
To prevent diffuse emissions and to safely handle these wastes, liquid, pasty and gaseous wastes are ~~can be~~ fed directly to the furnace ~~rotary kilns~~ via several direct feeding lines. In 2002, almost 8.5 % of the total waste incineration in rotary kilns consisted of liquid waste processed through direct injection lines [83 WI BREF 2006]. Each rotary kiln has several direct feeding lines.

In general, the direct injection operation is done by connecting the waste container and the feeding line and pressurising the container with nitrogen or, in the case of sufficiently low viscosity, by emptying the container with ~~appropriate~~ pumps. In this way, the liquid waste is fed into the processing line. Depending on the calorific value of the liquid waste, it is injected either at the front of the rotary kiln or into the post-combustion chamber. ~~Depending on which direct injection line is used,~~ After processing, the line can be purged with nitrogen, fuel, waste oil or steam.

Multi-purpose and/or dedicated injection lines are used, largely depending on the substances to be incinerated.

Achieved environmental benefits
Prevention of diffuse ~~air~~ emissions due to the fact that the waste is fed by a completely closed system.

Environmental performance and operational data
~~The direct injection lines allow the incineration of liquid wastes that have properties that exclude other processing possibilities.~~

Depending on the characteristics of the liquid wastes, appropriate materials/linings are required for feeder lines, with heating required for high-viscosity liquid ~~in some cases~~.

Feed rate capacity ranges depend upon incineration process factors (e.g. thermal capacity and FGC capacity) but can range from 50 kg/h to 1 500 kg/h.

Injection can be via dedicated lance or multi-fuel burner.

Cross-media effects
Use of nitrogen and steam.

Technical considerations relevant to applicability
Generally applicable.
~~Applicable to liquid hazardous wastes, particularly those that present health and safety handling risks that require minimal worker exposure.~~

Economics
The average investment price for a dedicated line amounts to EUR 100 000–200 000.

Driving force for implementation
The driving force is the need to feed toxic, odorous, reactive and corrosive liquids and gases safely.

Example plants
Indaver, Antwerp plant (BE), HIM, Biebesheim plant (DE) and GSB, Ebenhausen plant (DE).

Reference literature
[64, TWGComments, 2003]

~~4.2.5.10 Reduction of air ingress into the combustion chamber during loading~~

For the TWG: description too poor. Please improve if there si a wish to keep it, or it should be deleted

~~The use of systems that prevent air ingress to the combustion chamber helps to maintain process stability and reduce emissions.~~

~~Such systems include:~~

- ~~maintaining a filled hopper for solid wastes~~
- ~~use of enclosed screw feeders~~
- ~~use of interlocked double doors for batch loading~~
- ~~use of pumped direct injection for liquid and pasty wastes.~~

4.3 Thermal processing

~~4.3.1 Combustion technology selection~~

~~**Description**~~

The thermal treatment process used varies depending on the ercur-chemical characteristics of the waste burned. ~~A combustion (or thermal treatment) stage, that is technically suited to the material that will be fed to the process, is required. The application of a technology developed for a different waste of unsuitable characteristics can often result in poor or unreliable performance. See comments in Section 4.2.1 regarding the need for the selection of a process suited to the waste to be received.~~

Table 4.8 below provides a comparison of the main applied ~~combustion and~~ thermal treatment technologies and factors affecting their applicability and operational suitability. It is important to note that, whilst applied in the sector, the degree of utilisation ~~demonstration~~ of the technologies listed varies, as does the nature of the waste to which they have been successfully applied.

Table 4.8: Comparison of combustion and thermal treatment technologies and factors affecting their applicability and operational suitability

Process ~~Technique~~	Key waste characteristics and suitability	Throughput per line	Operational/Environmental information		Bottom ash quality	Flue-gas volume	Cost information
			Advantages	Disadvantages/ limitations of use			
Moving grate – air-cooled	• Low to medium heat values (LCV 5–16.5 GJ/t) • Municipal and other heterogeneous solid wastes • Can accept a proportion of sewage sludge and/or medical waste with municipal waste • Applied at most modern MSW installations	1–50 t/h with most projects 5–30 t/h. Most industrial applications not below 2.5 or 3 t/h.	• Very widely proven on large scales • Robust – low maintenance cost • Long operational history • Can take heterogeneous wastes without special preparation	Generally not suited to powders, liquids or materials that melt through the grate	TOC 0.5–3 %	4 000–7 000 Nm^3/t waste input. Depends on the LCV. Typically 5 200 Nm^3/t.	High capacity reduces specific cost per tonne of waste
Moving grate – liquid cooled	Same as air-cooled grates except: • LCV 10–20 GJ/t	1–50 t/h with most projects 5–30 t/h. Most industrial applications not below 2.5 or 3 t/h	Same as air-cooled grates but: • higher heat value waste treatable • better combustion control possible	Same as air-cooled grates but: • risk of grate damaging leaks • higher complexity	TOC 0.5–3 %	4 000–7 000 Nm^3/t waste input. Depends on the LCV. Typically 5 200 Nm^3/t.	Slightly higher capital cost than air-cooled
Grate plus rotary kiln	Same as other grates except: • can accept very heterogeneous waste and still achieve effective burnout • not widely used	1–10 t/h	• Improved burnout of bottom ash possible	• Throughput lower than grate only • Maintenance of rotary kiln	TOC 0.5–3 %	4 000–7 000 Nm^3/t waste input. Depends on the LCV. Typically 5 200 Nm^3/t.	Higher capital and revenue costs
Static grate with ash/waste transport mechanism	• Municipal wastes require selection or some shredding • Less problems with powders etc. than moving grates	Generally low < 1 t/h	• Lower maintenance – no moving parts	• Only for selected/pretreated wastes • Lower throughput • Some static grates require support fuel	< 3 % with prepared waste	Slightly lower than other grate systems where staged combustion is used (higher if support fuel used)	Competitive with moving grates on small scales (< 100 kt/yr).
Rotary kiln	• Can accept liquids and pastes • Solid feeds more limited than grate (owing to refractory damage) • Often applied to hazardous wastes	< 10 t/h	• Very well proven • Broad range of wastes • Good burnout – even of HW	• Throughput lower than with grates	TOC < 3 %	6 000–10 000 m^3/t waste input	Higher specific cost due to reduced capacity
Rotary kiln (cooled jacket)	Same as rotary kiln but: • higher CV wastes possible due to greater temperature tolerance	< 10 t/h	• Very well proven • Can use higher combustion temperatures (if required) • Better refractory life than uncooled kiln	• Throughput lower than with grates	Low leaching vitrified slag	6 000–10 000 m^3/t waste input	Higher specific cost due to reduced capacity

Process ~~Technique~~	Key waste characteristics and suitability	Throughput per line	Operational/Environmental information		Bottom ash quality	Flue-gas volume	Cost information
			Advantages	Disadvantages/ limitations of use			
Fluidised bed – bubbling	• Only finely divided consistent wastes. Limited use for raw MSW • Often applied to sludges	1–10 t/h	• Good mixing • Fly ashes of good leaching quality	• Careful operation required to avoid clogging bed • Higher fly ash quantities	TOC < 3 %	Relatively lower than grates	FGC cost may be lower. Costs of waste preparation
Fluidised bed – Rotating	• Wide range of heat values (7–18 MJ/kg) • Coarsely shredded MSW may be treated • Combined incineration of sludge	3–22 t/h	• Good mixing/high turbulence • Wide range of LCV • High burnout, dry bottom ash	• Shredding of MSW required • Higher fly ash quantity than grates	TOC < 3 %, often 0.5–1 %	4 000–6 000 Nm^3/t	
Fluidised bed – circulating	• Only finely divided consistent wastes. Limited use for raw MSW • Often applied to sludges/RDF	1–20 t/h most used above 10 t/h	• Good mixing • Greater fuel flexibility than BFB • Fly ashes of good leaching quality	• Cyclone required to conserve bed material • Higher fly ash quantities	TOC < 3 %	Relatively lower than grates	FGC cost may be lower. Costs of waste preparation.
Oscillating furnace	• MSW • Heterogeneous wastes	1–10 t/h	• Robust – low-maintenance • Long history • Low NO$_x$ level • Low LOI of bottom ash	• Higher thermal loss than with grate furnace • LCV under 15 G/t	TOC 0.5–3 %	~~Information not supplied~~ NA	Similar to other technologies
Pulsed hearth	• Only higher CV waste (LCV > 20 GJ/t) • Mainly used for clinical wastes	< 7 t/h	• Can deal with liquids and powders	• Bed agitation may be lower	Dependent on waste type	~~Information not supplied~~ NA	Higher specific cost due to reduced capacity
Stepped and static hearths	• only higher CV waste (LCV > 20 GJ/t) • Mainly used for clinical wastes	~~Information not supplied~~ NA	• Can deal with liquids and powders	• Bed agitation may be lower	Dependent on waste type	~~Information not supplied~~ NA	Higher specific cost due to reduced capacity
Spreader – stoker combustor	• RDF and other particle feeds • Poultryy manure • Wood wastes	~~Information not supplied~~ NA	• Simple grate construction • Less sensitive to particle size than FB	• Only for well-defined mono-streams	~~Information not supplied~~ NA	~~Information not supplied~~ NA	~~Information not supplied~~ NA
Gasification – fixed bed	• Mixed plastic wastes • Other similar consistent streams • Gasification less widely used/proven than incineration	Up to 20 t/h	• Low leaching residue • Good burnout if oxygen blown • Syngas available • Reduced oxidation of recyclable metals	• Limited waste feed • Not full combustion • High skill level • Tar in raw gas • Less widely proven	• Low leaching bottom ash Good burnout with oxygen	Lower than straight combustion	High operating/ maintenance costs
Gasification – entrained flow	• Mixed plastic wastes • Other similar consistent streams • Not suited to untreated MSW • Gasification less widely	Up to 10 t/h	• Low leaching slag • Reduced oxidation of recyclable metals	• Limited waste feed • Not full combustion • High skill level • Less widely proven	Low leaching slag	Lower than straight combustion	High operating/ maintenance costs pretreatment costs high

Process ~~Technique~~	Key waste characteristics and suitability	Throughput per line	Operational/Environmental information		Bottom ash quality	Flue-gas volume	Cost information
			Advantages	Disadvantages/ limitations of use			
	used/proven than incineration						
Gasification – fluidised bed	• Mixed plastic wastes • Shredded MSW • Shredder residues • Sludges • Metal-rich wastes • Other similar consistent streams • Gasification less widely used/proven than incineration	5–20 t/h	• Can use low reactor temperatures, e.g. for Al recovery • Separationn of main non-combustibles • Can be efficiently combined with ash melting • Reduced oxidation of recyclable metals	• Limited waste size (< 30 cm) • Tar in raw gas • Higher UHV raw gas • Less widely proven	• If combined with ash melting, chamber ash is vitrified • Ash quality without ash chamber: NA info. Not supplied	Lower than straight combustion	Lower than other gasifiers
Pyrolysis – short drum	• Pretreated MSW • High metal inert streams • Shredder residues/plastics Pyrolysis is less widely used/proven than incineration	~ 5 t/h	• No oxidation of metals • No combustion energy for metals/inert • In reactor acid neutralisation possible • Syngas available	• Limited wastes • Process control and engineering critical • High skill level • Not widely proven • Need market for syngas	• Dependent on process temperature • Residue produced requires further processing, and sometimes combustion	Very low due to low excess air required for gas combustion	High pretreatment, operating and capital costs
Pyrolysis – medium drum		5–10 t/h					
Source: [24, CEFIC, 2002] [2, infomil, 2002] [10, Juniper, 1997] [8, Energos, 2002] [1, UBA, 2001] [64, TWGComments, 2003]							

4.3.2 Use of flow modelling

Description
The use of flow modelling.

Technical description
Physical and/or computer models can ~~may~~ be used to investigate the effects of design features. Various parameters are ~~may be~~ investigated including gas velocities and temperatures inside the furnace and boiler. The gas flow through FGC systems can ~~may~~ also be studied with a view to improving their efficiency, e.g. SCR units.

Computerised Fluid Dynamics (CFD) is an example of a modelling tool that is ~~may be~~ used to predict gas flows. Using such techniques can assist in the selection of a design that will allow optimisation of the gas flows, so as to encourage effective combustion conditions and avoid long gas residence times in those temperature zones which may otherwise increase the risks of PCDD/F formation. By applying the technique to FGC systems' design, it is ~~may be~~ used to improve performance, e.g. by ensuring an even flow across the SCR catalyst mesh.

Modelling has been successfully used at both new and existing incineration plants to:

- optimise furnace and boiler geometry;
- optimise the positioning of secondary and/or flue-gas recirculation air (if used);
- optimise the reagent injection points for SNCR NO_X reduction;
- optimise the gas flow through SCR units.

Achieved environmental benefits
The optimisation of the furnace design may enhance the combustion performance and therefore prevent ~~limit~~ the formation of CO, TOC, PCDD/F and/or NO_X (i.e. combustion-related substances). There is no effect on other pollutants contained in waste. [64, TWGComments, 2003]

Reduction of fouling due to excessive local flue-gas velocities by using CFD modelling can increase the availability of plants and improve the energy recovery over time.

Another benefit if is the improvement in performance of abatement equipment.

Environmental performance and operational data
The improvements of the flue-gas flow distribution along the boiler helps to reduce erosion and fouling leading to corrosion. The technique is used:

- in new waste incineration projects, to optimise design;
- in existing plants where concerns exist regarding the combustion and boiler design, to allow the operator to investigate and prioritise optimisation possibilities;
- in existing plants undergoing alterations in the furnace/boiler;
- in new and existing plants investigating the positioning of secondary/flue-gas recirculation air injection equipment;
- in installations installing or using SCR, to optimise the SCR unit itself.

Cross-media effects
None reported.
~~Improving performance at the combustion stage may allow the selection of gas cleaning equipment with reduced emissions and consumptions.~~

Technical considerations relevant to applicability
Generally applicable to new plants. Only applicable to existing plants during the design of major palnt upgrades.

Economics
In 2006~~ Tipically~~, a computer optimisation study ~~will~~ cost in the region of EUR 10 000 to EUR 30 000, depending on the scope of the study and the number of modelling runs required.

Savings in investment and operational costs may arise from:

- selection of alternative abatement system technology options;
- smaller/less complex abatement systems;
- lower consumption by the abatement system.

The savings noted above are less likely to be realised where the key design issue for the selection of the abatement system is the presence of heavy metals or halogens, e.g. hazardous waste plants. This is because the driver for FGC system design in these cases is normally the loading of intractable substances rather than combustion-related substances.

Significant costs can be associated with modifying the furnace or boiler design of existing installations.

Driving force for implementation
The driving forces are the optimisation of the combustor design for low raw gas pollutant concentrations and possible reduced emissions and consumption.

Example plants
The technique has been used at:

- the application stage in the UK to demonstrate the effective combustion design of a proposed installation;
- to optimise the combustion-stage design at small municipal plants in Norway;
- for some new and existing municipal plants in Belgium;
- French plants: Saint-Ouen (1989), Nancy (1995), Toulouse, and St. Germain.

Reference literature
[15, Segers, 2002], [16, Energos, 2002], [17, ONYX, 2000], [64, TWGComments, 2003]

~~4.3.3 Combustion chamber design features~~

To the TWG: moved to Section 2.3.1.4

~~Description~~
~~For some furnace types, including grates and static kilns, options exist regarding the positioning and shape of the exit from the primary combustion chamber to secondary combustion zones. A design that is not appropriate would lead to poor retention of combustible gases in the combustion zones, poor gas phase burnout and higher emissions.~~

~~The design of the exit from the first stage of the furnace to the gas combustion and burnout zone (the throat) should be selected to compliment the waste composition and other components of the furnace e.g. grate type. See text in Section 0 and Figure 2.8.~~

~~For grate incineration, the design of the combustion chamber is closely linked to the supplier of the grate. Suppliers can optimise the combination of grate and combustion chamber, based on the individual performance of their system and experience. There is, generally, no overall advantage/disadvantage from one design of combustion chamber to the other – all can be applied. Furthermore, combustion chamber design cannot usually be chosen independently from grate selection; together these form a clear and non-separable unit. [64, TWGComments, 2003]~~

~~CFD modelling (see 4.3.2) may be helpful in designing the combustion chamber.~~

~~**Table 4.9: A comparison of the features of some different furnace geometries**~~

~~**Type**~~	~~**Design features**~~	~~**Comments**~~
~~Co-current or parallel flow~~	• ~~exit to combustion chamber at end of furnace~~ • ~~gas flow in same direction as waste movement~~	• ~~suited to higher LHV wastes~~ • ~~all evolved gases must pass through maximum temperature zone and have long retention time~~ • ~~primary air heating required in ignition zone~~
~~Countercurrent or counter-flow~~	• ~~exit to combustion chamber at start of furnace~~ • ~~gas flow in opposite direction to the waste~~	• ~~suited to low LHV/high moisture/high ash waste (as hot gases from volatilisation zone pass over the drying zone)~~ • ~~higher secondary air requirements to ensure gas burnout~~
~~Central current or central flow~~	• ~~exit to combustion~~ • ~~chamber in middle of furnace~~	• ~~compromise of the above for wide spectrum of waste~~ • ~~furnace configuration/secondary air important to ensure gas burnout.~~
~~Split flow~~	• ~~exit from combustion chamber in mid position but split by central section~~	• ~~central section aids retention of gases and allows secondary air to be injected from additional locations~~ • ~~mainly used for very large dimension furnace~~
~~*Source*: [1, UBA, 2001, 2, infomil, 2002, 4, IAWG, 1997, 15, Segers, 2002]~~		

~~**Achieved environmental benefits**~~
~~Improved combustion results in lower emissions to all media and reduced consumptions.~~

~~**Operational data**~~
~~The combustion chamber is usually supplied with the grate and optimised for the particular grate type that is selected. Combustion chamber design is therefore dependent upon the grate selection. Each system described in Table 4.9 can result in operational improvements when suitably applied.~~

~~**Cross-media effects**~~
~~No significant negative effects identified.~~

~~**Applicability**~~
~~These techniques are generally applicable to most incinerator designs, except rotary kilns where the exit to the secondary combustion chamber is always at the end of the kiln. However with rotary kilns, the sizing and shape of the connection to the secondary chamber and the positioning of the secondary air injection should also be such that it provides for sufficient gas retention and mixing to encourage gas burnout (as indicated by low and steady PIC concentrations).~~

~~Split flow systems are mainly applicable to larger dimension furnaces because of the additional secondary air mixing it allows in central positions of the furnace. In smaller furnaces, adequate mixing may be achieved using sidewall injection of the secondary air.~~

~~A balanced overall combustion chamber design ensures that gases evolved from the waste are well mixed and retained at sufficient temperature in the combustion chamber to allow the combustion process to be fully completed. This principle is applicable to all incineration processes.~~

~~**Economics**~~
~~At new plants the combustion chamber design features can be optimised at the outset. The additional costs of such design refinements may then be small in relation to the overall cost of the project.~~

~~At existing plants the cost of redesigning (usually this means replacing) the furnace is very high and may often outweigh the benefits to be achieved unless there are very serious difficulties with the combustion stage, or the relevant equipment is due to be replaced for other reasons.~~

~~**Driving force for implementation**~~
~~Reductions in emissions from effective combustion.~~

~~**Example plants**~~
~~All plants select one of these options.~~

~~Split flow has been applied at: Indaver, BE, AZN (Afvalverbranding Zuid-Nederland, Moerdijk, The Netherlands) as well as the Bonn plant (Germany) and the Mke-line of MVV (Mannheim, Germany).~~

~~**Reference literature**~~
~~[1, UBA, 2001, 2, infomil, 2002, 4, IAWG, 1997, 15, Segers, 2002, 64, TWGComments, 2003]~~

4.3.4 Design to increase turbulence in the secondary combustion area ~~chamber~~

Description
Design of the secondary combustion chamber to increase the flue-gas turbulence.

Technical description
See also related techniques in Sections 4.3.9 (Secondary air injection, optimisation and distribution) and 4.3.12 (Replacement of part of the secondary air with recirculated flue-gas). ~~4.3.19 Optimisation of time, temperature, turbulence of gases in the combustion zone, and oxygen concentrations~~

This technique relates to design features that increase the turbulence and hence mixing of combustion gases in the area ~~zone~~ after the primary combustion zone, but before or at the start of the main heat recovery areas when the gas temperatures will generally still exceed approximately 850 ºC. After the zone considered here, as the combustion gases may pass onwards through the main heat recovery areas (exchangers), stable and even gas velocity and flow are required to prevent gas counter-flow and circulation that might lead to heat exchange problems and pollutant generation.

In some cases, special configurations of the secondary combustion area ~~(SCA)~~ can be used to increase turbulence in the secondary combustion chamber. Examples of designs include:

- vortex chambers;
- inclusion of baffles (cooling required);
- several passes and turns in the chamber;
- tangential secondary air input;
- location and position of the secondary air injection systems (nozzles).

The use of additional physical features to increase mixing is currently mainly used for the incineration of hazardous waste ~~applied in the HWI industry~~.

Achieved environmental benefits
Benefits include improved combustion, leading to lower raw gas concentrations of combustion-related parameters.

This technique can reduce the volume of secondary air required, and hence reduce overall flue-gas volumes and NO_X production. Effective turbulence will also result in improved burnout of combustion gases with reduced VOC and CO levels

Environmental performance and operational data
No information provided. ~~Not supplied~~

Cross-media effects
None identified.

Technical considerations relevant to applicability
Generally applicable.
~~The SCC is designed by the supplier at the design stage. Additional features might appear necessary with some furnace designs for some type of waste. [74, TWGComments, 2004]~~

Economics
No information provided. ~~Not supplied~~

Driving force for implementation
No information provided. ~~Not supplied~~

Example plants
Hazardous wastes – Cleanaway UK.

Reference literature
[40, EURITS, 2003] [64, TWGComments, 2003]

~~4.3.5 Use of continuous rather than batch operation~~

For the TWG: Moved under environmental management system

~~**Description**~~
~~Emissions at incineration plants are easier to control during routine operation than during start-up and shutdown operations. Reducing the number of start-ups and shutdowns required is, therefore, an important operational strategy that can reduce overall emissions and consumptions. Waste collection/delivery regime and seasonal waste generation fluctuations can cause shutdowns through lack of wastes, although they are often avoided by running the plant at partial load in order to deal with such fluctuations. Running at partial load normally does not cause problems for a modern combustor. [74, TWGComments, 2004]~~

~~Factors that help to achieve continuous throughput include:~~

- ~~the process design throughput rate is similar to the rate at which waste is received~~
- ~~waste storage (where possible) may cover slow periods~~
- ~~organisation of the supply chain to prevent slow periods~~
- ~~supplementing waste feed with additional fuels~~
- ~~use of online cleaning.~~

~~Sizing and maintaining plants to maximise continuous running is, therefore, important.~~

~~**Achieved environmental benefits**~~
~~Consistent plant operation improves energy efficiency.~~

~~**Cross-media effects**~~
~~Energy efficiency can be reduced by continuous operation on a lower load, because turbine efficiency is lower.~~

~~**Operational data**~~
~~Predicting and controlling waste flows to the plant are important.~~

~~Good maintenance is important for avoiding/limiting shut downs. On line maintenance programme can be designed into the installation so that availability is maximised.~~

~~Applicability~~
~~Planning for and achieving a reduced number of shutdowns is likely to reduce the annual mass emission levels of any plant.~~

~~Economics~~
~~Avoiding shutdowns can reduce costs at the incineration installations by:~~

- ~~allowing continuous throughput and hence greater installation utilisation~~
- ~~decreasing furnace maintenance due to lower thermal stress on the process~~
- ~~avoiding capital costs of an unnecessarily large processes.~~

~~Where the capacity of the installation is larger than the quantity of the waste received, and the decision is taken to supplement the throughput with other wastes or fuels, there may be costs associated with the purchase of those fuels/wastes.~~

~~Driving force for implementation~~
~~Main driving forces are operational.~~

~~Example plants~~
~~In general all large waste incineration plants are operated continuously. MSWI plants of an industrial size (above ~2 t/h) can be operated continuously with a minimum number of shutdowns.~~

~~Reference literature~~
~~[28, FEAD, 2002] [64, TWGComments, 2003]~~

4.3.6 Selection and use of suitable combustion control systems and parameters

Description
The use of an advanced control system for the combustion and for the FGC system.

Technical description
[2, infomil, 2002]
The incineration of wastes of variable composition requires a process that can cope with large variations in process conditions. When unfavourable process conditions occur, interventions in operational control are required.

In order to be able to control the incineration process, detailed process information is required, an advanced control system ('philosophy') must be designed, and it is necessary to be able to intervene in the process. The details of the systems used vary from plant to plant. The following provides an overview of process information, control philosophy systems and process interventions that can be used.

Process information may include:

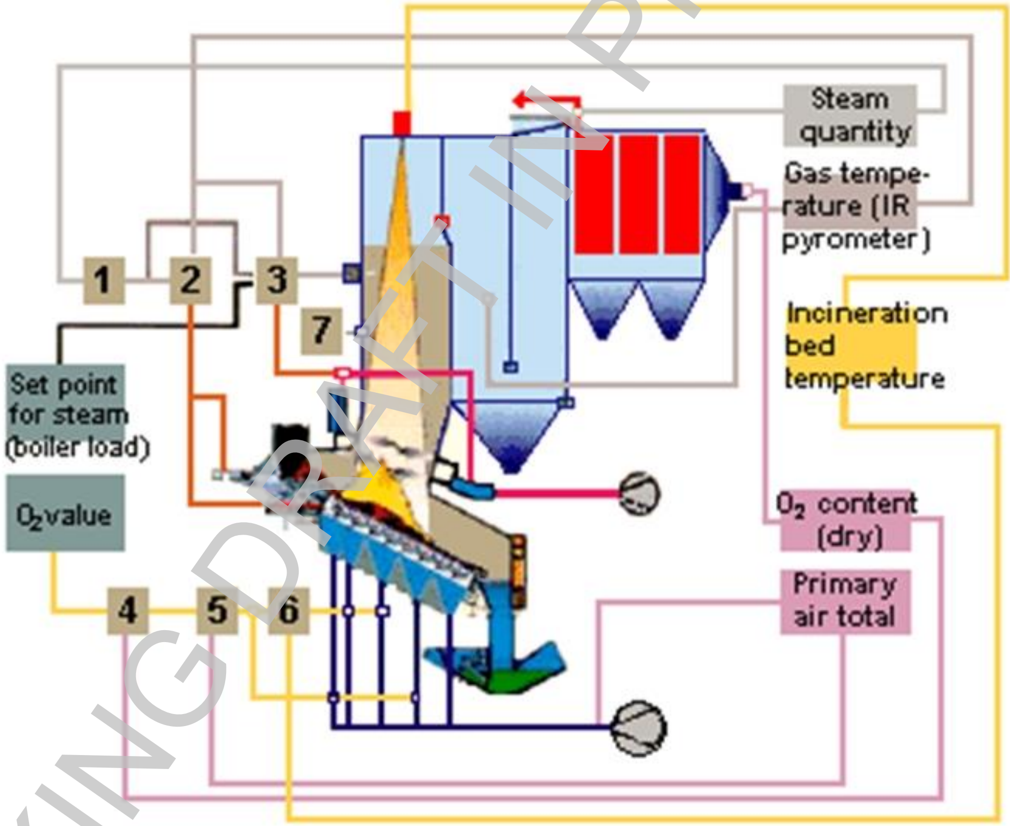
- grate temperatures for various positions;
- thickness of waste layer on the grate (visual control);
- pressure drop over the grate;
- furnace and flue-gas temperatures at various positions;
- determination of temperature distribution over the grate surface by optic or infrared measurement systems;
- CO, O_2, CO_2 and/or H_2O measurements (at various positions);
- steam production data (e.g. temperature, pressure);
- openings in the combustion wall for visual observation by individuals or camera;

- length and position of the fire in the furnace;
- emissions data for combustion-related substances (unabated levels).

[74, TWGComments, 2004]

The continuous adaptation of the distribution and amount of incineration air to match the precise incineration reaction requirements in the individual zones of the furnace can improve the incineration process. An infrared camera is an example of a techniques that is ~~can be~~ used to create a thermal image of the burning waste bed. Ultrasound and visual cameras are also used. The temperature distribution on the grate appears on a screen as an isothermal field graduated in coloured areas.

For the subsequent furnace performance control, the characteristic temperatures of the individual grate zones may be determined and passed on to the furnace performance controller as input parameters for furnace variables. Using fuzzy logic, some variables (e.g. temperature, CO, O_2 content) and a sequence of rules can be determined to maintain the process within these settings. In addition, flue-gas recirculation and tertiary air addition can be controlled.



Source: [1, UBA, 2001]

Figure 4.2: Example of the components of a furnace control system

By computer-controlled image processing, the video images provided by the IR camera can be transformed into signals which are coupled, in the furnace control system, with parameters such as the oxygen content in the flue-gas and the steam quantity.

The charging of the incineration chamber can then be controlled by recording the average temperature of the waste bed at the ~~foremost part~~ front of the grate and evaluation of the O_2 value at the end of the boiler. With the help of camera-controlled incineration bed temperature recording over the first three grate zones, primary air can be added according to demand (air quantity and distribution), which helps to even out the incineration process in the main incineration zone. In grate zone 2 (ignition zone), the air demand is controlled, as a function of the incineration bed surface temperature, and a more constant temperature profile may be reached. Adapting the air quantity in grate zones 3 and 4, and the temperature of the incineration surface, leads to steady incineration and efficient bottom ash burnout.

The control philosophy may be a classic control system, which may already be included in the process control computer. Additionally, fuzzy control systems are applicable.

Control interventions include adjusting:

- the dosing system for the waste;
- frequencies and speed of grate movements in various parts of the grate;
- amount and distribution of primary air;
- temperature of the primary air (if preheating facilities are available);
- amount and distribution of secondary air in the furnace (and, if available, of recirculation gas);
- the primary to secondary air ratio.

[74, TWGComments, 2004]

Achieved environmental benefits

The use of ~~sophisticated~~ advanced control systems can result in an incineration process that has less variations in time (i.e. improved stability) and space (i.e. more homogeneous), thus allowing for an improved overall combustion performance and reduced emissions to all media.

Improved process control has the following specific advantages:

- better bottom ash quality (due to sufficient primary air distribution and a better positioning of the incineration process on the grates);
- less fly ash production (due to less variations in the amount of primary incineration air);
- better fly ash quality (less unburned material, due to more stable process conditions in the furnace);
- less CO and VOC formation (due to more stable process conditions in the furnace; i.e. no ‘cold’ spots);
- less NO_X formation (due to more stable process conditions in the furnace; i.e. no ‘hot’ spots)
- less risks of formation of dioxins (and precursors) due to a more stable process in the furnace;
- better utilisation of the capacity (because the loss of thermal capacity by variations is reduced)
- better energy efficiency (because the average amount of incineration air is reduced);
- better boiler operation (because the temperature is more stable, there are less temperature ‘peaks’ and thus less risk of corrosion and of clogging fly ash deposits ~~formations~~);
- better operation of the flue-gas treatment system (because the amount and the composition of the flue-gases are more stable);
- higher destruction potential, combined with more effective combustion of the waste. [74, TWGComments, 2004]

The indicated advantages also result in less maintenance and thus better plant availability.

Environmental performance and operational data

In a project, incineration tests were run with oxygen-conditioned primary and secondary air and additions of nitrogen in the secondary air. A ~~favourable influence on~~ decrease of dust, CO and ~~the~~ total VOC concentrations in the raw flue-gas ~~behind the steam generator~~ was recorded, in particular with oxygenated primary air (O_2 content of supplied enriched air between 25 vol-%

and 28 vol-%). Moreover, the NO_X content in the flue-gas could be reduced due to the addition of nitrogen to secondary air.

The results from this investigation have led to the development of a system combining the following process steps:

- fully automatic incineration control through an infrared camera and fuzzy logic;
- flue-gas recirculation to the furnace via a secondary air system; and
- oxygenation of the primary incineration air in the main incineration zones.

Measures introduced at another existing plant with a feed grate included:

- graded addition of incineration air;
- constant dosing of waste through height of layer control;
- incineration monitoring by optic sensors (so-called incineration sensors) in different grate zones;
- flue-gas recirculation.

Compared to the plant's conventional operation, the combustion-related pollutants were reduced.

The grate bar temperature may be measured using thermocouples. Flue-gas temperatures are more difficult to measure due to the severe conditions – high level of dust, risk of metal melting, etc. Measurements at the furnace outlet are also not easy to implement due to operational conditions (dust, acid, etc.), in particular for CO and CO_2 measurements. For control purposes, quick measurements are required. It is very difficult to measure H_2O accurately. [64, TWGComments, 2003]

The results from the tests with normal operation and with incineration control with the IR camera and with oxygen addition are shown in Table 4.11 below.

Table 4.10: Crude flue-gas measurements at a test plant under normal operation, with IR camera and O_2 conditioning

Flue-gas component (~~crude~~ raw flue-gas ~~behind steam generator~~)	**Normal operation**	**IR camera plus fuzzy logic**	**O_2 conditioning**
Oxygen content (vol-%)	9.1–9.3	8.9–9.3	6.2–10.9
Carbon monoxide (mg/m^3)	12–32	9–26	20–27
Dust (g/m^3)	0.7–1.7	0.6–1.0	0.5–1.0
Total carbon (mg/m^3)	1.1–2.4	0.9–1.0	1.0–1.2
Dioxins/furans (ng I-TEQ/m^3)	1.5–2.7	1.0–1.3	2.0–3.5

~~TWG comment~~NB: The reported increase in PCDD/F with additional oxygen ~~shown here~~ is not the theoretically expected result.
Source: [1, UBA, 2001]

The technique is of particular benefit where the waste fed to the furnace is highly heterogeneous in nature, i.e. of variable composition, or its quality is difficult to predict or assure.

(To the TWG: from section 4.2.5.7) To achieve a stable plant operation it is also important that the operator of the waste feed systems has a good view of waste storage and loading areas. This can be achieved by positioning the control room with a view of the combustor loading areas and by the use of video monitors or other imaging systems. [64, TWGComments, 2003]

Cross-media effects
None identified.

Technical considerations relevant to applicability

Generally applicable.

The use of infrared cameras is generally applicable to grate incinerators. This technique is only applicable ~~if can be applied~~ when the furnace design (in particular the throat) is such that the camera can view the relevant areas of the grate. Moreover, the application is limited, in general, to larger scale furnaces, with several grate lines (e.g. > 10 t/h). [74, TWGComments, 2004]

~~Selection and use of suitable combustion control systems and parameters is applicable to all waste incineration installations. The detailed components of such a system will vary from one process design to another. Most of the specific techniques in the description section above are applicable to grate rather than other incinerators.~~

Economics

The indicated advantages also result in less maintenance and, therefore, better plant availability.

The order of magnitude for one IR camera (not installed and as a stand-alone unit, i.e. not integrated in the control circuit of the plant) was reported in 2004 to be approximately EUR 50 000. However, it is also reported that one supplier quotes EUR 300 000 per line (although it is not clear if this relates to the whole system of IR plus O_2 control, etc.) [74, TWGComments, 2004].

Driving force for implementation

The improved combustion performance results in overall improvements in environmental performance.

Example plants

Widely employed throughout Europe, particularly at modern plants (e.g. Coburg (DE); Ingolstadt (DE); Fribourg (CH); Brescia (IT); Arnoldstein (AT).

Reference literature

[1, UBA, 2001],[2, infomil, 2002] [64, TWGComments, 2003]

~~4.3.7 Use of infrared cameras for combustion monitoring and control~~

For the TWG: Merged with the previous section

~~4.3.8 Optimisation of air supply stoichiometry~~

For the TWG: the section does not describe any technique to optimise the use of primary and secondary air

~~**Description**~~

~~In combustion systems, sufficient oxygen (usually from air) must be supplied to ensure that the combustion reactions go to completion.~~

~~In addition to this, the supply of air has the following roles:~~

- ~~cooling~~
- ~~avoidance of slag formation in the combustion chamber/boiler~~
- ~~mixing of gases to improve efficiency~~
- ~~influencing burnout quality.~~

~~Supplying too little, or too much air, causes difficulties. The precise amount of air required is dependent upon:~~

- ~~waste type and characteristics (CV, moisture, heterogeneity)~~
- ~~type of combustor (fluidised beds have lower overall air requirements due to increased waste agitation, which increases exposure of the waste to the air)~~
- ~~ensuring the air is supplied in the correct locations and quantities.~~

~~In general, the over-supply of air should be avoided, but importantly, it must still be sufficient to ensure effective combustion (as demonstrated by low and stable CO concentrations downstream of the furnace). The over supply of air will result in increased flue-gas volumes and hence the increased size and associated costs of flue-gas treatment systems.~~

~~**Achieved environmental benefits**~~
~~Reduction of flue-gas volumes (and hence treatment requirements) whilst achieving effective gas burnout are the aim of the optimisation.~~

~~**Cross-media effects**~~
~~No information supplied.~~

~~**Operational data**~~
~~No information supplied.~~

~~**Applicability**~~
~~No information supplied.~~

~~**Economics**~~
~~No information supplied.~~

~~**Driving force for implementation**~~
~~Optimisation of the incineration process~~

~~**Example plants**~~
~~Most of waste incineration plants in EU~~

~~**Reference literature**~~
~~[64, TWGComments, 2003]~~

4.3.9 Primary and secondary air supply and distribution optimisation

To the TWG: This section only reports how to optimise the primary air supply for grate incineration (highlighted in light blue), while the technique is reported to be applied at all incinerators (irrespective of the combustion process). Is it possible to improve the technical description so that it also covers other furnace types as appropriate?

Description
The primary and secondary air flows and distribuition are optimised in order to be fed where they are necessary to properly incenerate the waste.

Technical description
Primary air is that which is supplied into, or directly above, the waste bed to provide the oxygen necessary for the combustion. Primary air also helps with the drying and gasifying of waste and with the cooling of some of the combustion equipment.

Secondary air is that which is injected into the flue-gas flows to complete the oxidation of the combustible species in it.

The ~~manner~~ type of primary air supply is directly related to the incineration technology.

In grate systems, it is supplied through the grate into the waste bed for the following purposes:

- To bring the necessary air to the different zones of the grate where the reactions occur (drying, gasification, volatilisation) and to ensure homogeneous and sufficient distribution inside the waste bed which improves bottom ash burnout.

- To cool down the grate bars to prevent slagging and corrosion. The cooling of fluid-cooled grates is typically achieved by means of a separate water circuit and the effect of the primary air on cooling is therefore irrelevant.
  [74, TWGComments, 2004]

In MSWI grates, the primary airflow is determined primarily by the oxygen requirement (a sizing function) and not by the grate cooling requirements. [74, TWGComments, 2004]

In rotary kilns, and stepped and static hearths, the primary air is generally introduced above the waste bed. In some stepped hearth designs, primary air can be partially introduced below the waste bed.

In fluidised bed systems, the primary air is introduced directly into the fluidisation material and also serves to fluidise the bed itself. The primary air is blown through nozzles from the bottom of the combustion chamber into the bed.

Separating the supply of the primary air (using individual wind boxes and, if suitable, multiple or distributed supply fans) to the different zones within a grate incinerator allows the separate control of the air supply to each of the zones. This allows each process that occurs on the grate (drying, pyrolysing, gasification, volatilisation, ashing out) to be optimised by provision of its own optimised air supply.

Insufficient supply of primary air to the final (ashing out) stage can result in poor ash burnout if the residence time in the chamber is not ~~high~~ enough.

If the combustion air is extracted from waste storage areas, this will help to reduce odour risks from waste storage.

The secondary air flow rate, temperature, number and position of the injection points are optimised to control the flue-gas turbulence, temperature and residence time. Because the mixing of hot gases requires sufficient mixing energy, the secondary air is blown in at a relatively high speed.

The injection point locations, directions and quantities are optimised using computerised flow modelling.

Temperatures at the nozzle heads can contribute significantly to NO_X generation. Typical temperatures are in the range of 1 300 °C to 1 400 °C. The use of special nozzles and of flue-gas recirculation to replace some of the nitrogen can reduce the nozzle temperatures and nitrogen supply which lead to higher NO_X generation.

The balance of primary and secondary air will depend upon the waste characteristics and upon which of the combustion technologies is utilised. Optimisation of this balance is beneficial for process operation and emissions. In general, higher calorific value wastes allow lower primary air ratios.

Achieved environmental benefits

- Reduction of NO_X, dust, VOC and CO emissions.
- Reduction of fly ash.
- Improved burnout of bottom ash.
- Reduction in the demand for non-waste ~~primary~~ fuels ~~for~~ to ~~the~~ support ~~of~~ combustion.
  [74, TWGComments, 2004]

~~Optimisation of air supply and distribution is beneficial for the optimisation of the combustion stage of the incineration process and for reducing overall emissions.~~

Environmental performance and operational data

The amount of secondary air used depends on the LCV. [74, TWGComments, 2004]

For grate technology, the amount of secondary air is normally between 20 % and 40 % of the total amount of incineration air, with the remainder being primary air.

There is a risk of rapid corrosion of the water walls of the post-combustion chamber and the boiler, if secondary air is too low, as the CO/CO_2 level could pulse between oxidising and reducing conditions. *(to the TWG: from Section 4.3.11)*

~~Easily installed. Primary air supply is essential for combustion process. Its optimisation differs with the combustion technique.~~

Cross-media effects
None reported. ~~Significant effects~~

Technical considerations relevant to applicability
Generally applicable.
~~Applied at every plant~~

Economics
Provided the initial design is correct and provides systems and equipment for primary and secondary air control, additional equipment is not normally necessary and therefore no additional costs are ~~not normally~~ incurred. Where intervention is required at an existing plant, additional fans and ducting may be required to control and distribute the air supply.

Reducing ~~If~~ the level of NO_X generated ~~level is reduced, it may~~ can also reduce the operating cost ~~of the corresponding treatment,~~ and improve the achievable NO_X abatement level associated with subsequent secondary techniques (SNCR or SCR)~~concerning SNCR technique~~. The secondary air optimisation might reduce the flue-gas volume and therefore correspondingly reduce the FGC plant size. [64, TWGComments, 2003] *(to the TWG: from Section 4.3.11)*

Driving force for implementation
Stable incineration conditions and ~~Where improved combustion and reduced emissions to all media, and in particular where~~ improved burnout of bottom ash ~~are drivers~~.

Example plants
All the incineration plants.

An example of a retrofit to improve this aspect is Toulon (FR), lines 1 and 2 (2 x 12 t/h), where fans and injection nozzles were changed. *(to the TWG: from Section 4.3.11)*

Reference literature
[2, infomil, 2002] [64, TWGComments, 2003]

4.3.10 Preheating of primary and secondary air

Description
Heat exchangers are used to preheat primary and secondary air, mainly for the incineration of waste with low calorific value. The preheating of primary air is used to dry waste with low calorific value, while the secondary air preheat is beneficial to ensure stable incineration conditions by keeping the temperature of the oxidation zone of the furnace at the design level.

Technical description
Heating the primary air supply can improve the combustion process by drying the waste. This is especially important where low calorific value/high moisture wastes are burned as they may require additional drying. [2, infomil, 2002, 64, TWGComments, 2003]
Heating the secondary air supply can improve the efficiency and assist the combustion process in the case of low calorific value wastes by ensuring that temperatures in the gas burnout zone are adequate and evenly distributed.

Preheating of incineration air in grate-type municipal waste incineration plants is normally done with low-pressure steam and not by heat exchange from the flue-gases (due to complicated air ducts and corrosion problems).

Preheating of air for bubbling fluidised bed incineration is normally done with flue-gas by means of heat exchange, but sometimes also with steam or supporting fuel. [64, TWGComments, 2003]

In some installations, this heat is taken from the cooling air behind the refractory material.

The heat supplied with the air supply is not lost since it may be recovered later in the boiler. [74, TWGComments, 2004]

Achieved environmental benefits
More stable combustion leads to lower emissions to air.

Upgrading of low-value steam/energy to better quality steam is possible.

Environmental performance and operational data
The heating of primary and, possibly, secondary air is of particular benefit where low calorific value wastes are burned. In the case of primary air, this is because it supports the drying and ignition of the waste; with secondary air, this is because it helps to maintain temperatures in the gas burnout zone.

Primary air is heated to 150 °C by mixing primary air with the cooling air of refractory material in the furnace. [74, TWGComments, 2004]

Cross-media effects
Where heat is taken from the incineration process, the cross-media effects will be minimal. If external fuel sources are used, the consumption of that external energy and the additional emissions (e.g. of NO_X, particulates) are a factor.

Technical considerations relevant to applicability
Plants burning high calorific value waste need the cooling effect of the air supply and will not, therefore, benefit from this technique.

Economics
The design of the system for new plants adds the cost of a heat exchanger plus the steam/condensate circuit. The impact of the additional cost depends on the plant scale.

~~Retrofitting at existing plants will require specific additional investment.~~

The capital costs of the heat-exchange equipment can be offset against the savings in ~~avoided cost of external~~ support fuels.

Driving force for implementation
Improved combustion performance, especially ~~where~~ with low calorific value wastes ~~are encountered~~.

Example plants
Applied to plants throughout Europe.

Reference literature
[2, infomil, 2002], [64, TWGComments, 2003]

~~4.3.11 Secondary air injection, optimisation and distribution~~

To the TWG: merged with Section 4.3.9

~~Description~~
~~During drying, gasifying, incineration, and burnout, the combustible waste materials are transformed into a gaseous form. These gases are a mixture of many volatile components, which must be further oxidised. For this purpose, additional air (so-called secondary air) is introduced into the furnace.~~

~~The incineration temperature can be raised by preheating the incineration air, and lowered by allowing in more incineration air (note: sufficient gas residence time mainly depends on the dimensions of the furnace). Therefore, in some cases the secondary air may provide cooling as well.~~

~~Another main function of the secondary air is to mix the hot flue-gases, for this purpose it is blown into the furnace through a large number of nozzles, which ensures that the furnace's entire cross-section is sufficiently covered. Because the mixing of hot gases requires sufficient mixing energy, the secondary air is blown in at relatively high speed. Additionally, dimensions of the furnace are selected to ensure adequate flue-gas flow patterns and sufficient overall residence times. For MSWI the flowrate is determined by the mixing requirements.~~

~~The injection port locations, directions and quantities can be studied and optimised for various furnace geometries, using for example computerised flow modelling.~~

~~Temperatures at the nozzle heads can contribute significantly to NO_X production. Typical temperatures are in the range of 1 300 to 1 400 °C. The use of special design nozzles and of FGR to replace some of the nitrogen can reduce nozzle temperatures and nitrogen supply that lead to higher NO_X production.~~

~~Achieved environmental benefits~~

- ~~low and stable emission of combustion related substances~~
- ~~improved oxidation of combustion gases produced during earlier combustion stages~~
- ~~reduced carry over of products of incomplete combustion and fly ash to gas cleaning stages.~~

~~The benefits are to reduce the quantity of combustion related substances (e.g. NO_X, CO and/or VOC). CO and VOC levels are not treated in the FGC system.~~

~~Cross-media effects~~
~~If secondary air with normal oxygen content is injected into the afterburning zone, on top of the nozzles while entering the afterburning zone, temperatures above 1 400 °C can be measured and by this thermal NO_X is produced. [74, TWGComments, 2004]~~

~~Operational data~~
~~The amount of secondary air depends on the LCV. [74, TWGComments, 2004]~~

~~For grate technology, the amount of secondary air is normally between 20 and 40 % of the total amount of incineration air, with the remainder being primary air.~~

~~There is a risk of rapid corrosion of the water walls of the post combustion chamber and the boiler, if secondary air is too low, as the CO/CO_2 level could pulse between oxidising and reducing conditions.~~

~~Applicability~~
~~All waste incineration plants.~~

~~Economics~~
~~The costs of making changes to optimise secondary air at individual existing plants will vary greatly according to specific design features. This cost is included in the design of the process of new plants. [74, TWGComments, 2004]~~

~~If the NO_X level is reduced, it may also reduce the cost of the corresponding treatment, and improve NO_X achievable level of abatement concerning SNCR technique. The secondary air optimisation might reduce the flue-gas volume and therefore reduce correspondingly the FGC plant size. However the mass flowrate of the pollutants remains similar. [64, TWGComments, 2003]~~

~~Driving force for implementation~~
~~Improvements at the combustion stage result in reductions in emissions to all media.~~

~~Example plants~~
~~Employed at the design stage of the majority of new plants.~~

~~An examples of retrofit to improve this aspect are: Toulon (F), lines 1 & 2 (2 x 12 t/h), when fans and injection nozzles were changed.~~

~~Reference literature~~
~~[2, infomil, 2002] [64, TWGComments, 2003]~~

4.3.12 Replacement of part of the secondary air with recirculated flue-gas

Description
The flue-gas is recircultated to optimise the turbulence in the combustion chamber while maintaining the optimal air to waste ratio.

Technical description
One of the purposes of the secondary air addition (apart from oxidising the combustible ~~species in the~~ flue-gas compounds) is to improve the mixing and homogeneity of the flue-gas. However, the use of more secondary air than is necessary results in higher flue-gas quantities. This reduces the energy efficiency of the plant, leading to a need for larger flue-gas treatment units and, therefore, to higher costs.

By replacing part of the secondary air with recirculated flue-gases, the flue-gas volume is reduced downstream of the extraction point and at the point of emission. The reductions in the fresh nitrogen supply (from air) to the furnace may help to reduce NO_X emissions.

In general, the recirculation extraction point is after FGC to reduce corrosion and other operational problems caused by raw flue-gas; this involves some energy losses and the FGC system must be designed for a larger flow.

However, if the flue-gases are recirculated from upstream of the FGC system then the size of the FGC system can be reduced, [64, TWGComments, 2003] although it needs to be set to treat more ~~polluted~~ flue-gases ~~because of the~~ with increased pollutant concentration and there is a higher risk of erosion, corrosion and fouling. [74, TWGComments, 2004]

See also Section ~~4.3.11~~ 4.3.9 on secondary air optimisation.

Achieved environmental benefits
- ~~reduced flue-gas volumes and hence. FGC treatment size of the FGC downstream of the flue-gas extraction point (i.e. generally where dirty gas is recirculated)~~
- Improved energy efficiency (an increase of approximately 0.75 % was ~~increases~~ reported at a CHP plant).
- Reduction in NO_X production by 10 % up to 30 % (if the raw gas is high in NO_X).
- Reduction in reagent consumption for NO_X control.

Environmental performance and operational data

At high excess air rates, approximately 50 % of the required amount of secondary air can be replaced by recirculating flue-gases. When the recirculated gas is raw flue-gas, this results in a 10–15 % reduction of the total amount of incineration air and flue-gases. The load of the flue-gas treatment system may be reduced proportionally if the concentrated pollutants in the reduced flue-gas quantity can be cleaned in the same way (resulting also in a reduction of emission loads) and the thermal efficiency of the plant may increase by approximately 1–3 %.

Corrosion in the recirculation ducting has been reported. It is also reported that this can be overcome by the elimination of joints, and using effective insulation of ducting to prevent cold spots, where condensation of the flue-gas and corrosion can rapidly occur. Corrosion may also occur in the boiler due to lower oxygen levels in the flue-gas.

[21, FNADE, 2002] ~~If the operator is not attentive, Corrosion can be very rapid. In such cases the expected operational savings are quickly turned into higher repair costs and plant availability loss.~~ The corrosion risk is reduced if the hotter parts of the boiler are covered by special cladding. However, when this cladding is installed, the excess O_2 ~~excess~~ concentration at the boiler exit can be reduced even without flue-gas recirculation ~~FGR~~. This, then, reduces the benefit of flue-gas recirculation ~~FGR~~.

In some German MSWI plants with recirculated flue-gas systems installed, the recirculation is reported to be closed or out of operation for operational reasons. The reduced flue-gas flow is in most cases not considered ~~used~~ in the sizing of the FGC plant; many operators choose to size the FGC plant with flue-gas recirculation off ~~OFF~~, so as to cover all possible operating conditions.
[74, TWGComments, 2004]

Cross-media effects

Depending on the precise furnace design, at high replacement rates the effective reduction of oxygen can result in elevated CO (and other products of incomplete combustion ~~(PICs)~~) levels. Care must therefore be taken to ensure replacement rates are optimised.

There may be a negative cooling effect in the rotary kiln, and in some cases, especially with wastes with lower calorific value, extra fuel is necessary to maintain the rotary kiln temperature.

Technical considerations relevant to applicability

This technique has been applied to new waste incineration plants. Some existing plants have retrofitted this technique, for which space is required for the ducting.

The technique has a limited applicability for HWI. In the case of rotary kiln HWIs, there ~~is a~~ need for a high O_2 content ~~and therefore the recirculation~~ limits the applicability of flue-gas recirculation ~~has a limited applicability~~. [74, TWGComments, 2004]

Economics

This technique involves additional investments for new plants and significant costs for retrofitting existing plants. [74, TWGComments, 2004]

Driving force for implementation

Reduction of NO_X using primary techniques.
~~Even with FGR, a de-NO_X device is required for reaching, under any operational condition, a level of 200 mg/Nm³.[21, FNADE, 2002]~~

Example plants

Applied at some new and existing plants throughout Europe.

Reference literature

[2, infomil, 2002], [21, FNADE, 2002] [64, TWGComments, 2003]

4.3.13 ~~Application~~ Use of oxygen-enriched air

For the TWG: The use of increased bed temperature, combustion control and oxygen-enriched air addition in a grate incinerator operated at Arnoldstein, Austria started operation in 2004 so was considered an emerging technique in the 2006 BREF (see Section 6.6). Austria now considers it to be an established technique so the information has been moved into this section.

Description

Use of oxygen-enriched air, or technically pure oxygen, as the combustion air.

Technical description

~~Replacement of air supply with (technically) pure oxygen or oxygen enriched air.~~ The municipal waste incinerator at Arnoldstein, Austria operates a process that uses oxygen-enriched air to achieve an integrated sintering of ash in the waste bed of a grate-based energy from the waste incinerator. Oxygen enrichment produces higher bed temperatures which melt or sinter 50–80 % of the bottom ash. The unmelted fraction protects the grate from clogging. An infrared camera is used to monitor and control the waste bed temperature by adjusting the under-fire air heating and oxygen enrichment. Reverse-acting grates are used because they maintain a cover of unmelted ash that protects the grate from the higher temperatures employed. The non-sintered fraction is separated by a screening and washing process and then recirculated to the combustion process. In addition, 75 % of the fly ashes (boiler ash and first-stage dust removal step ash – not FGC residues from acid gas cleaning) may be recirculated to the combustion stage. The high bed temperatures and wet mechanical treatment of the discharged granulated ash ensure that the fly ash recirculation does not contaminate the granulated product.

~~This technique is applied at some gasification and pyrolysis plants for the combustion of the gases they produce,~~ Oxygen-enriched air is also used to burn the gases produced at some gasification and pyrolysis plants. ~~Often as~~ This is often part of systems ~~that are~~ designed to raise combustion temperatures in order to melt the incinerator ashes. In such cases, the initial pyrolysis or gasification reactor is often a physically separate unit from the subsequent combustion chamber. The fuel-rich syngases pass into the combustion zone, where the oxygen-enriched air is added at a controlled rate in order to achieve the desired combustion conditions. Depending on the oxygen addition rate and gas quality, temperatures in the combustion chamber are generally between 850 °C and 1 500 °C, although in some specific cases temperatures of up to 2 000 °C (or higher) are used. At temperatures above around 1 250 °C, entrained fly ashes are melted.

~~This technique~~ Oxygen enrichment has also been applied ~~on a trial basis at existing large incineration plants in order to improve the process performance and as a specific design technology~~ at smalle~~r~~ plants that are generally dedicated to the destruction of particular (often hazardous) waste streams. In these smaller plants (e.g. trailer-mountable plants), the process may be applied on a batch basis in a sealed reactor, with elevated pressure (8 bar) and temperatures (e.g. in the range of 2 000 °C to 8 000 °C).

Achieved environmental benefits

The MWI at Arnoldstein, Austria uses oxygen-enriched air to:

- produce a completely sintered, well burned out, low leaching residue;
- reduce overall plant dioxin discharges (< 5 ug I-TEQ/t of waste input);
- reduce volumes of fly ashes.

Rapid and efficient combustion can result in very low and controllable CO and other combustion-related emissions.

Environmental performance and operational data

Replacement of the nitrogen in air with oxygen can reduce the potential for thermal NO_X formation. However, NO_X production also increases with increased ~~depends on~~ flame temperature so care is required to ensure that nitrogen replacement is sufficient to prevent the ~~combination with~~ higher temperatures from resulting in an overall increase in NO_X.

A lower volume of waste gas is produced ~~released~~ compared to air-fed combustion technologies. However, at temperatures above 1 500 °C this benefit may be reduced owing to the thermal expansion of flue-gases. ~~The more concentrated~~ The higher concentration of pollutants that result from the lower flue-gas volume can be treated using smaller FGC equipment. ~~Captured with a compact FG treatment line.~~ However, such an adaptation would require specific adaptations in the flue-gas treatment at existing plants. ~~Reduced FGT size~~ Smaller FGC equipment may reduce the raw material consumption to some extent ~~degree~~ (e.g. NH_3 used in SCR/SNCR for NO_X reduction). However, for pollutants contained in the waste feed, such as Cl_2, the quantity of pollutant produced and hence the consumption of raw materials in the FGC system are proportional to the waste feed rate and increasing the concentration of pollutants in the flue-gas may have little effect on consumption. ~~But this is largely related to pollutant load, rather than concentration, and therefore reductions may be negligible for waste contained pollutants.~~ It is reported that the boiler size may also be reduced using this technique. [74, TWGComments, 2004]

The use of temperatures in excess of 1 500–2 000 ºC are reported to have only a limited additional benefit in terms of emissions reduction. [64, TWGComments, 2003]

The MWI at Arnoldstein, Austria has been operating successfully using oxygen-enriched air since 2004. The annual throughput is about 80 000 t/yr, the average oxygen content is about 26 %, and the temperature on the grate is about 1 100–1 200 °C whereas the temperature in the combustion chamber is reduced by means of flue-gas recirculation.

The Arnoldstein incinerator produces a completely sintered, well burned out, low leaching residue, as shown in Table 4.11.

Table 4.11: Residue quality using enriched combustion air(O_2 at 25-27%)

	Untreated Bottom ash from incineration without O_2 enrichment	**Untreated Slag from incineration with O_2 enrichment**	**wet-mechanical treated Slag from incineration with O_2 enrichment**
Loss on ignition	2 %	1 %	0.1 %
Leaching of lead (mg/l)	0.2	0.05	0.01
PCDD/F content (ng TEQ/kg)	15	8	0.3
Source: [91 Austria 2015]			

Oxygen enrichment trials at an existing grate-type municipal waste incineration plant in the Netherlands encountered difficulties with locally increased temperatures and corrosion. These difficulties are reported to be overcome with better waste mixing and optimised injection. *For the TWG (especially the Netherlands): Please provide updated information*

At higher temperatures (above 1 000 ºC), furnace and refractory maintenance is generally greatly increased. The higher temperatures used can cause significant material selection and use difficulties. ~~In addition~~ Intensive gas cooling is required to reduce the flue-gas temperature to a suitable level for FGC. Molten fly ash requires systems to ensure its removal (e.g. vortex gas flow) so that it does not come into contact with downstream heat exchangers and cause clogging/erosion.

Additional safety risks result from the production, storage and use of oxygen.

Cross-media effects

- Increased energy consumption for the production of pure oxygen or oxygen-enriched air ~~is energy consuming~~.
- Increased emissions ~~Presence~~ of CO during transitory phases such as ~~:~~start-up, shutdown and emergency stops.
- ~~Problems of~~ Reduced resistance of refractory materials and ~~an~~ increased ~~of~~ corrosion of the boiler.

Technical considerations relevant to applicability

~~In general, installations require specific design adaptations to incorporate the use of this technique.. Attention is~~ The technique may not be applicable to existing plants because of the significant design modifications required to ~~most details of plant design including particular adaptations to~~ the combustion chamber, heat exchange areas, and sizing of FGC systems. At low levels of oxygen addition, the design changes may be more limited, but so too ~~then~~ are the potential benefits ~~advantages~~ of the ~~use of the~~ technique.

~~The techniquemay be applicable as a retrofit option at~~ The technique is applicable to existing plants where:

- combustion-related emissions are high or difficult to control; and
- air supply volumes are already high.

~~The high combustion efficiency can make this technique of use for~~ It is also applicable to the incineration of materials that are ~~very~~ highly resistant to combustion, e.g. PCBs, because of the high combustion efficiency.

~~In practise~~ Oxygen enrichment is not widely applied owing to the additional costs and cross-media impacts associated with the generation of oxygen, and the additional operational challenges such as handling molten fly ash ~~(e.g. higher temperatures may result leading to molten ash control issues) and the ability of air based techniques to achieve good performance levels~~.

Economics

Producing pure oxygen is expensive. ~~Costly,~~ Oxygen-enriched air is less expensive but still gives rise to additional costs over normal air. The costs ~~of both~~ may be reduced if the incinerator is on an industrial site where oxygen is already available~~ e.g. some industrial sites~~. Parasitic electrical loads for on-site oxygen generation are significant. This demand varies according to plant size, temperature and oxygen purity requirements but is generally in the order of 0.5–2 MW_e.

~~The use of this technique may add significantly to capital and operational costs.~~ The MWI in Arnoldstein, Austria reported a 5–10 % increase in capital costs and a reduction in the disposal costs for residues, with income possible from selling the granulated ash residue as an aggregate replacement.
For the TWG (especially Austria): Please provide updated information

Reductions in the flue-gas volume may reduce the size and cost of the flue-gas treatment devices required.

Driving force for implementation

The technique has been reported to be used for the treatment of some types of hazardous wastes that are otherwise expensive to dispose of.

The technique is reported to have been retrofitted at existing plants that had combustion performance difficulties.

Other driving forces are the reduction in disposal costs for sintered residues because of the low leachability, and the income possible from selling the sintered granulated ash residue as an aggregate replacement.

Example plants
A municipal waste incinerator at Arnoldstein (AT) has been operating successfully using oxygen-enriched air since 2004.
~~In Austria a municipal waste incineration plant has been commissioned at the beginning of 2004 where oxygen enriched air is applied. Annual throughput is about 80000 t/yr, average oxygen content is about 26 %, temperature on the grate is about 1100 – 1200 °C whereas the temperature in the combustion chamber is reduced by means of flue gas recirculation. No problems have been reported by the operator until now. [74, TWGComments, 2004]~~

Oxygen enrichment is applied in gasification and pyrolysis processes for municipal and industrial wastes in Japan as part of systems that are designed to melt the incinerator ashes (e.g. Asahi Clean Centre, Kawaguchi City, Tokyo).

The first full-scale unit for HW is now operating at SEABO (Municipality of Bologna (IT)). So far it has been used for treating materials such as: hardened paints, halogenated solvents, inks, refinery sludge, plastic packaging, polluted rags, oil containing PCBs, pesticides, and expired medicines, among others. *For the TWG (especially Italy): Please provide updated information*

Coburg (DE). *For the TWG (especially Germany: Please provide updated information*

Reference literature
[18, italy, 2002], [2, infomil, 2002], [64, TWGComments, 2003], [91, Austria, 2015]

~~4.3.14 Cooling of grates~~

To the TWG: moved to Section 2.3.2
~~**Description**~~
~~[19, Babcock, 2002] [64, TWGComments, 2003]~~

~~Grate cooling is carried out to control metal temperatures and thereby improve grate life. It is also used to imp The cooling medium can be air or water (other liquids may also be used, such as oils or other heat conducting fluid).~~

~~Air is supplied below the grate and passes through the grate spacings; the main function of this air is to provide the necessary oxygen for oxidation, and the flowrate is designed according to this requirement. Simultaneously, this air provides cooling to the grates, which is the source of cooling for air-cooled grates. When more excess air is introduced additional cooling is supplied, but a larger amount of flue-gas is produced.~~

~~Liquid cooled grates include a circuit inside the grate by which the liquid is flowing for cooling the grate. The higher heat transfer capacity of liquids make liquid cooled grates more suitable for situations where the cooling with air has limitations, in particular when burning high LHV wastes (e.g. >10 MJ/kg).~~

~~The liquid flows from the cool parts of the grate to the hotter ones in order to maintain a temperature differential. The temperature of the liquid can be used to monitor the reactions (some are endothermic, some exothermic, and to differing degrees) occurring in the waste bed above the grate. These reactions can then be controlled by varying the amount of air supplied through that section of the grate to the waste above. This separation of the cooling and air supply functions may increase the control of the process.~~

~~**Achieved environmental benefits**~~
~~Both air and water cooled grates can provide for effective waste burnt out.~~

~~For higher LCV wastes, using liquid cooled grates can allow slightly increased combustion process control, as the additional cooling capacity required with such wastes can be obtained from the cooling liquid instead of supplying more air so it is, therefore, possible to reduce the primary air supply and hence the overall flue-gas volumes.~~

~~Cross-media effects~~
~~No significant negative effects identified.~~

~~Operational data~~
~~Air-cooled grates are very widely used and proven for municipal wastes, and for a range of other mainly solid wastes. They are reported to be highly reliable and provide for effective performance and long operational use. Complexity of the air-cooled systems is somewhat lower than liquid cooled systems and this can have operational benefits. The use of air cooled grates in Europe is very common, with approximately 90 % of incinerated MSW being treated in plants using air-cooled grates.~~

~~The liquid-cooled grate system increases grate cooling efficiency as the liquid circulates directly inside the grate. Heat damage may be reduced, and even with the waste high in calorific value, it is possible to achieve a service life of over four years. Effective liquid-cooled grate bar fabrication is required to prevent problems of cracking and liquid leakage, and subsequent effect on installation availability. In order to increase grate temperature control, a sophisticated liquid circuit is required if all the grate bars are to be fed individually with liquid. An alternative is for zones of the whole grate system to be controlled.~~

~~In the higher temperature conditions that may arise when incinerating high heat value wastes, the liquid cooled grates can have longer life due to the reduced corrosion they experience but they may have a higher risk of grate damage through leaks of the cooling liquid than with air-cooled systems.~~

~~Operational experience has shown that, with water cooled grates, virtually all the leaks occur at the connections between the tiles or the connection between the tiles and the cooling circuit collectors. Hence, the risk on cooling circuit failures can be minimised by reducing the number of these connections. Fluid-cooled grate designs with a low number of connections are preferred. Lifetime of a water-cooled grate tile may be in excess of 35000 – 40000 operational hours.~~

~~Applicability~~
~~A specific feature of grates is that they are highly robust in nature and may be applied to almost any mainly solid waste type, including highly heterogeneous wastes. Both liquid and air-cooled grates are applied for municipal wastes, with approximately 90 % of MSWI using the air-cooled type.~~

~~In general liquid cooled grates are applied where there is a specific need for additional grate cooling i.e. where waste LCV is higher (e.g. above ~10 – 13 MJ/kg, depending on the grate type) Air-cooled systems may also be used in such circumstances, sometimes with other cooling features e.g. water walled furnaces.~~

~~Economics~~
~~Air-cooled grates are more economic to purchase than liquid cooled grates.~~

~~Risk of damage to the grate, and hence high repair costs and downtime, may be higher with non-air cooled systems as liquid leaks may cause damage (but see also Operational Data above).~~

~~Driving force for implementation~~
~~Selection of grate cooling systems is generally made on the balance of operational advantages and disadvantages depending on the heat value and composition of the waste that will be treated. Depending on the particular circumstances (i.e. notably the grate and waste type) it may~~

~~be possible to treat higher calorific value wastes with a fluid cooled grate than with an the same air-cooled grate.~~

~~Example plants~~
~~Cooling of grates is widely used in Europe and worldwide. Water cooled systems are less widely used but are reported to be applied at least in Denmark and Germany.~~

~~Reference literature~~
~~[19, Babcock, 2002], [64, TWGComments, 2003]~~

~~4.3.15 Water cooling of rotary kilns~~

To the TWG: moved to Section 2.3.2

~~Description~~
~~[20, EKOKEM, 2002]~~
~~This technique is usually used together with higher temperatures in the kiln (see Section 4.3.16) The rotary kiln cooling system consists of two cooling circuits. The primary cooling water circuit delivers primary cooling water on top of the rotary kiln and distributes it evenly to guarantee equal cooling effect all over the shell of the kiln. Water is then collected into four water collection basins located under the kiln and it continues to flow freely into the water collection tank. Water is circulated back through a filter and a heat-exchanger with a circulation pump. Evaporation is compensated with additional make-up water, which is automatically buffered with NaOH in order to avoid corrosion.~~

~~The secondary circuit removes heat from the primary circuit through heat-exchangers and transfers it for use. If there is no need for energy recovery, a multi-sectional air cooling system can be used for removing heat from the system. In order to avoid freezing, a water-glycol mixture is circulated through the liquid-air heat-exchangers.~~

~~The system delivers cooling water through hundreds of spray nozzles situated all over the shell of the kiln keeping the temperature of the shell at 80 – 100 °C, whereas, for air cooling the steel shell temperature is typically a few hundred degrees higher. The rotary kiln cooling increases the heat transfer through the refractory enough to reduce the rate of chemical erosion to minimum. Higher temperatures can be used in the kiln.~~

~~Achieved environmental benefits~~
~~The main benefit of rotary kiln water cooling is that higher combustion temperatures may be used where required (see advantages in Section 4.3.16).~~

~~The heat transfer rate through the furnace into the primary cooling fluid is increased. According to theoretical calculations and practical measurements at example installations, the heat transfer through the furnace into the cooling water varies between 0.5 MW and 3.0 MW, depending on the size of the rotary kiln and the thickness of the refractory. The thickness of the refractory includes the remaining brick lining and the solidified bottom ash layer. For example, in 1995 Kommunikemi (DK) reported an average kiln heat recovery of 2.2 MW.~~

~~Cross-media effects~~
~~No negative aspects identified.~~

~~Operational data~~
~~Operational benefits are:~~

- ~~extended refractory lifetime when operating at higher temperatures – lower maintenance~~
- ~~increased throughput rates possible – especially for higher calorific value wastes~~
- ~~better working environment – lower temperatures beside the kiln.~~

~~**Applicability**~~

~~This technique is applicable to rotary kiln incinerators with higher LHV inputs. It is mainly applied at hazardous waste plants but could also have wider applications to other waste burned in rotary kilns. The technique is especially suited to plants that require high temperatures for the destruction of particular types of wastes.~~

~~Water cooled kilns are reported to mainly offer extended refractory life for wastes with low melting mineral matter.~~

~~Where the system is combined with a high temperature kiln, water flowrates must be high to achieve sufficient heat removal rates. This will result in a larger quantity of warm water, rather than a lower quantity of hotter water. The technique is, therefore, more likely to be applicable to processes that have a demand/use for the warmed water generated.~~

~~**Economics**~~

~~Both Ekokem in Finland and Kommunekemi in Denmark, have reported a capacity of over 100 000 tonnes of incinerated hazardous waste (waste water not included) at high temperatures with the same brick lining. This equals an overall lifetime of two to three years. Both plants typically shut down the waste incineration once a year for a planned two-week pre-maintenance period and only twice a year for shorter inspections.~~

~~**Driving force for implementation**~~

~~Some operators have been required to operate high temperature slagging kilns and have, therefore, developed the water cooling system to allow economic operation in such circumstances. Where non-disposal outlets (e.g. re-cycling as aggregate replacement) exist for the semi-vitrified bottom ashes produced, this may reduce disposal costs and hence increase interest, or offset costs of the technique.~~

~~Availability of a customer for the warmed cooling water increases interest in this technique.~~

~~Availability of higher LHV wastes (e.g. solvents and oils) allows high operation temperatures which then require the additional cooling noted here. Where such wastes are diverted to other waste treatment options, their availability may be restricted and operation in higher temperature mode only possible with additional fuels/costs.~~

~~**Example plants**~~

~~Ekokem, Finland. Kommunikemi, Denmark~~

~~**Reference literature**~~

~~[20, EKOKEM, 2002], [40, EURITS, 2003] [64, TWGComments, 2003]~~

4.3.16 Higher temperature incineration (slagging)

Description

The waste is incinerated at temperatures higher than 1 100 °C to achieve high destruction efficiencies and to produce a vitrified bottom ash.

Technical description

This technique is most commonly applied in Europe to rotary kilns treating hazardous wastes. However, the principle of operating at elevated temperatures can, to some degree, be applied to other furnace types. For example, higher temperatures are sometimes used downstream of fluidised beds receiving non-hazardous wastes (see Sections 4.3.26 and 4.3.27).

~~Hazardous wastes, both solid and liquid, are fed into the process through the front wall of a rotary kiln. Only secondary air and waste water are injected into the secondary combustion chamber.~~

The incineration temperature rises to 1 100–1 400 °C for a couple of seconds, as all the high calorific wastes are introduced through the front wall of the kiln. This means that the temperature of the flue-gases remains above 1 050 °C until they pass from the outlet of the secondary combustion chamber. Next, they enter the waste heat boiler and finally flow through the flue-gas cleaning system.

Iron, glass, aluminium and other inorganic solid materials form a molten bottom ash mixture in the rotary kiln~~ when high temperature incineration is applied~~. This liquefied ash then flows slowly towards the outlet of the kiln where it falls down into a bottom ash quenching basin, positioned under the secondary combustion chamber. Here, the bottom ash is quickly solidified in ~~the~~ water. The resulting bottom ash is ~~and it becomes~~ finely granulated, ~~and~~ vitrified and has low leaching characteristics. Due to the granulation effect, the total volume of bottom ash produced is smaller than with conventional incineration.

Achieved environmental benefits

~~High temperature incineration at 1 100 – 1 400 °C has been reported to provide the following advantages compared to lower temperature (850 – 900 °C) combustion:~~

- ~~all~~ Organic materials are completely incinerated. The organic matter content in the bottom ash after incineration is typically less than 1 %.
- Lower contents of hydrocarbons and CO in flue-gases.
- Higher destruction of PCBs. ~~Molecules~~
- ~~a molten bottom ash is formed in the rotary kiln.~~

~~The slag, when quenched in water, becomes finely granulated, vitrified and has low leaching characteristics. It may be recovered or transported to landfill.~~

Environmental performance and operational data

Higher temperatures require a good quality refractory lining. Also, a constant slag layer is needed ~~should be managed~~ during the operation. In addition:

- incineration air may require preheating;
- ~~the amount of incineration air needs reducing~~
- membrane boiler walls have to be protected agaist the higher temperature ~~need removal or protection~~ with refractory;
- high-temperature corrosion may be a problem;
- molten slag/fly ash may cause operational problems in the furnace and heat-exchange areas.

Low residual hydrocarbons and CO are dependent on the combination of flue-gas mixing (turbulence), residence time and temperature. Temperatures of 900–1 000 °C have been reported to achieve very high destruction levels, similar to those achieved at the higher temperatures considered here. (*To the TWG: source is missing, do you have any plant-specific data?*) Homogeneous waste feeding is also considered an important influence. Hence, ~~very~~ higher temperature~~s~~ incineration alone ~~are~~ is not a guarantee for high gas burnout (i.e. low CO and VOCs). Also, at higher temperatures the gas velocity is higher, thus the residence time is lower. Therefore, to reach the performance level required, the optimisation of all the key ~~overall combination of~~ parameters is important.

Cross-media effects

- Increased NO_X formation, due to the higher temperatures ~~can result in additional NO_X formation and a requirement for additional control measures~~.
- Increased ~~Additional~~ non-waste fuel consumption ~~may be required, if~~ where the energy provided by the incineration ~~LHV~~ of ~~the~~ waste itself is insufficient to reach the higher incineration temperature.
- ~~Adapted~~ Increase of metals in the flue-gas ~~cleaning may be needed to deal with the higher levels of heavy metals vaporised~~. [40, EURITS, 2003]

Technical considerations relevant to applicability
The technique is mainly applicable to rotary kilns burning hazardous wastes of higher calorific values (overall average typically above 15 MJ/kg), e.g. those that include various solvents and waste oils.

Economics
Additional costs arise from:

- the need to use a water-cooled kiln in order to avoid high maintenance costs;
- the need to use a support fuel ~~s may be needed~~ to maintain high temperatures;
- the need to modify the ~~ications to~~ furnace ~~may be required~~ to retain heat;
- ~~addition of inorganic materials (glass, sand), producing more bottom ash~~
- the need to treat an increased amount of ~~scrubbing of heavy~~ metals in the flue-gas, because the ~~which~~ evaporation is ~~e more at~~ higher at higher temperatures.

[74, TWGComments, 2004]

In some cases, the use of higher temperatures has been abandoned on account of the costs associated with refractory maintenance. *(to the TWG: please provide references for such cases)*

Depending on the leaching tests or other local standards applied, the bottom ash produced in high-temperature incineration may be classified as non-hazardous material. This may then reduce the cost of disposal, since the bottom ash may then be transported to a ~~regular~~ non-hazardous waste landfill (under certain conditions), or even sold for utilisation in road construction. If used for construction, the total content of heavy metals may need to be low *(to the TWG: do you have any figures?)*, and the impact may be judged by comparison with that of other materials used normally for that purpose. [74, TWGComments, 2004]

Driving force for implementation
The technique has been implemented where:

- additional assurance of very high destruction efficiencies is required;
- vitrified bottom ash ~~residues are~~ is required.

~~Mainly employed at plants where the calorific content of the wastes are sufficiently high (overall average typically above 15 MJ/kg) to avoid the need for support fuels.~~

Example plants
Ekokem (FI) and Kommunikemi (DK).

Reference literature
[20, EKOKEM, 2002] [64, TWGComments, 2003]

4.3.17 Increase of the waste burnout ~~ncreased agitation and residence time of the waste in the furnace~~

Description
Waste burnout is increased using the following techniques:

- turning and agitation of the waste in the furnace;
- use of rotary kilns;
- use of fluidised beds;
- adequate waste residence times in the furnace burnout zone;
- design of furnace to reflect radiant heat;
- optimisation of primary air distribution and supply;
- addition of other wastes/fuels to support effective combustion;
- size reduction for bigger pieces of waste.

Technical description

Waste fed to the furnace needs to be well mixed and allowed sufficient time to react and ensure that effective burnout is achieved, thereby leaving a residue that is low in organic carbon. In addition, the supply of adequate and well-distributed primary air, which does not result in excessive cooling, will assist this process.

Longer exposure of the waste to elevated temperatures in the combustion chamber, higher bed temperatures and physical agitation of the waste all combine to ensure that ashes produced are low in organic species.

~~Burnout rates may, therefore, be improved by:~~

- ~~furnaces that turn and agitate the waste effectively;~~
- ~~use of rotary kilns;~~
- ~~pretreating waste and then using fluidised beds (where the waste is suited to this technology);~~
- ~~longer residence times in the furnace burnout zones;~~
- ~~design of furnace to reflect radiant heat and increase burnout;~~
- ~~optimising primary air distribution and supply;~~
- ~~addition of other wastes/fuels to support effective combustion;~~
- ~~disintegration of bigger pieces of waste.~~
- ~~sifting (riddling) return for repeated incineration.~~

The use of these techniques can result in organic-carbon-in-ash levels of below 1 %.

The level of burnout achievable using any technique will depend upon the characteristics of the waste being incinerated. The waste's physical characteristics will also have a critical influence on the practicality of feeding the waste type to the different designs of combustor, e.g. mixed municipal waste cannot be treated in a fluidised bed without pretreatment.

Maintaining the process within its thermal throughput capacity ~~of the process~~ also ensures that wastes are properly incinerated and that the residues produced are of a good quality, with possibilities for their use. (*from Section 4.3.18*)

Typically, better burnout will be achieved where waste is finely divided and has been homogenised (e.g. by mixing). The pretreatment of highly heterogeneous wastes can improve burnout.

Achieved environmental benefits

~~Effective burnout of the waste results in:~~

- Effective waste destruction.
- Improved characteristics of the solid residue for possible use.
- Increased energy recovery ~~extraction of the energetic value from the waste~~.

Improving the burnout will lower the residual carbon content and thus the TOC. The TOC is also related to the mobility of metals in the ash. For instance, copper leaches in the form of organo-copper complexes. Improving the burnout will, therefore, also reduce copper leaching.

Environmental performance and operational data

Achieved TOC levels in slags and bottom ashes are in the range of <1–3 wt-%. In WI plants measuring the loss on ignition, achieved LOI levels are <1–5 wt-%.

~~It should be noted that, while some technologies may incorporate greater agitation to result in better burnout and hence lower unburned matter in the residues produced, they are not generally chosen specifically for these reasons, but primarily for the their mechanical suitability to the~~

~~physical characteristics of the waste received i.e. the waste homogeneity etc. [64, TWGComments, 2003]~~

~~The levels reportedly achieved in Austrian incineration plants for a stable process are 1 % TOC (dry matter) and about 3 % TOC (dry matter) for start-up and shutdown.~~

Cross-media effects

Excessive physical agitation of the waste in the furnace can result in higher quantities of unburned material being carried into the secondary combustion chambers. This can result in additional dust and other pollutant loading on downstream abatement processes. Additionally, excessive agitation can result in more riddlings, i.e. unburnt material passing through the grate. [74, TWGComments, 2004]

An elevation of the combustion temperature, together with the fuel bed temperature, is reported to cause increased formation of CaO in the bottom ash, which increases the pH value of the bottom ash. The pH value of fresh bottom ashes often exceeds 12 [Vehlow, 2002 #38]. (*from Section 4.7.1*)

This increase of pH may also increase the solubility of amphoteric metals such as lead and zinc, which are present in high quantities in bottom ashes. The pH increase may be critical; in particular, as lead is amphoteric it can be dissolved at pH 11–12 and then be leached. The bottom ash pH may decrease after the incineration phase by ageing. (*from Section 4.7.1*)

Technical considerations relevant to applicability

Generally applicable.

~~The nature of the waste received may restrict the actual combustion technology selection (i.e. fluidised bed or grate, etc) and hence restrict the operators ability to select between technology options. However, the principles of increased agitation and of holding the waste in the furnace for sufficient time at sufficient temperature apply in all cases. Each chosen technology can, therefore, review the options described here that are available to it, to improve burnout.~~

Economics

New projects can take account of the need to ensure effective burnout without significant additional costs.

Major reconstruction of combustion chambers at existing plants is expensive. Retrofits may therefore only be possible when a complete refit is planned ~~(unless the minimum legal standard of 3 % TOC is not achieved, in which case action is mandatory)~~.

Driving force for implementation

~~The main driving forces are:~~

- Environmental legislation requirements.
- Improved waste destruction.
- Improved possibilities for residue use.
- Extraction of the full energetic value from the waste.

~~Article 6 of EC Directive 2000/76/EC requires that slag and bottom ashes have a Total Organic Carbon (TOC) content of less than 3 % or their loss on ignition is less than 5 % of the dry weight of the material.~~

Example plants

Applied throughout Europe.

Reference literature

[4, IAWG, 1997], [Vehlow, 2002 #38], [64, TWGComments, 2003]

~~4.3.18 Adjustment of throughput to maintain good burnout and combustion conditions~~

To the TWG: merged with Section 4.3.17

~~**Description**~~

~~The level of burnout achieved in the bottom ash residues is a parameter to consider when determining the throughput limitations of the process with a particular waste input.~~

~~Levels of TOC above 3 % (5 % LOI) are prohibited by European legislation. Levels of below 1 % are achieved in some circumstances (see Section 4.3.17 above).~~

~~For a given range of waste characteristics, the thermal capacity of the combustor is the limiting factor rather than the mass throughput. Exceeding the thermal capacity of the plant leads to a deterioration in combustion performance and of the quality of the residues produced.~~

~~**Achieved environmental benefits**~~

~~Maintaining the process within the thermal throughput capacity of the process ensures wastes are properly destroyed and that the residues produced are of better quality, with improved possibilities of their use.~~

~~**Cross-media effects**~~

~~Use of the technique avoids cross-media effects.~~

~~**Operational data**~~

~~Burnout levels may be reduced by increasing waste residence time in the furnace. This then results in a reduction of the throughput rate of the installation.~~

~~**Applicability**~~

~~Applicable to all waste incineration plants.~~

~~**Economics**~~

~~Restricting the waste throughput can result in lower income from waste disposal.~~

~~**Driving force for implementation**~~

- ~~ensures full waste destruction~~
- ~~improving ash quality.~~

~~**Example plants**~~

~~This is a common practice widely applied in the industry.~~

~~**Reference literature**~~

~~Discussions during site visits. [64, TWGComments, 2003]~~

~~4.3.19 Optimisation of time, temperature, turbulence of gases in the combustion zone, and oxygen concentrations~~

To the TWG: elements of this technique are already contained in several previously described techniques regarding the optimisation of the incineration process

~~**Description**~~

~~To achieve effective combustion of the gases produced during the incineration process, the gas needs to be well mixed with sufficient oxygen, at a high enough temperature and for a long enough time. Based upon these principles and practical experience of industrial scale incineration plants, minimum criteria have been established in various European and National legislation. The aim of these criteria is to ensure processes are designed and operated in such a way that they ensure that the gases produced are oxidised and that organic pollutants are destroyed, so as to reduce polluting emissions of these substances.~~

~~Table 4.12 below provides a brief summary of some specifications that have been applied to the combustion of the gases that are produced during the incineration process:~~

~~Table 4.12: Some combustion specifications applied to incineration~~

~~Parameter~~	~~Specification~~	~~Purpose~~
~~Minimum combustion temperature during gas residence time~~	• ~~at least 850 °C, or~~ • ~~at least 1 100 °C for hazardous wastes with greater than 1 % halogenated organic substances (as Cl)~~	• ~~adequate temperatures to allow oxidation~~
~~Minimum gas residence time~~	• ~~2 seconds after the last injection of combustion air~~	• ~~sufficient residence time at high enough temperature in the presence of sufficient oxygen to react and oxidise~~
~~Turbulence~~	• ~~Sufficient to ensure effective gas mixing and combustion reaction~~	• ~~mixing of gas to allow reactions to proceed across the entire gas stream~~
~~Oxygen concentration (excess)~~	• ~~greater than 6 % (note that the precise oxygen requirement was removed in most recent EU legislation)~~	• ~~sufficient oxygen must be supplied to allow oxidation~~

~~Operational experiences have shown that these criteria are generally appropriate and will achieve good levels of destruction. However, many existing plants operate with reduced temperatures, residence times and oxygen concentrations, and still achieve effective combustion and low emissions to all environmental media. Indeed, at some plants, reductions in NO_X emissions (in particular) have been achieved without significant deterioration of other performance parameters, or corrosion problems.~~

~~It is therefore possible, in some circumstances and for some waste types, that departures from these basic criteria to represent the optimal environmental outcome. If such departures are to be permitted the following aspects need to be examined to ensure effective overall performance:~~

- ~~low and stable CO concentrations in emissions to air (<50 mg/m^3 daily average)~~
- ~~burnout of bottom ashes of good quality (TOC <3 %)~~
- ~~benefits outweigh the risks (e.g. NO_X reduction achieved is significant)~~
- ~~is the waste (as fed) suitably homogeneous, consistent and quality assured to give confidence that pollutant destruction will be sufficient across the operational spectrum?~~
- ~~is the level of turbulence in the combustion zone adequate to allow reduced temperatures/residence time?~~

~~Residence time is highly dependent upon furnace size, and therefore, there are few options for increasing residence time once a plant has been constructed, unless a major rebuild is conducted, which can result in very significant expenditure. Generally, new plants are designed to assure residence times of two seconds or more except when specific specialist and highly controllable and homogeneous waste streams are burned, thereby allowing an increased certainty of achieving emission levels. [64, TWGComments, 2003]~~

~~Achieved environmental benefits~~

~~The potential benefits of reducing the minimum oxygen concentration and the minimum temperature levels are:~~

- ~~reductions in NO_X production and hence treatment requirements and/or emissions~~
- ~~reduced flue-gas volumes, which can result in reduced FGC requirements~~
- ~~improved energy efficiency.~~

~~In general, reducing the gas residence time on its own will not result in any specific environmental benefits but will result from a smaller combustion chamber.~~

~~Increasing gas turbulence generally improves mixing and, hence, the oxidation reaction rate that then leads to effective combustion. However, where turbulence is mainly achieved by secondary~~

~~air injection a balance is required because it is also necessary to avoid excessive air supply which may lead to: excessive cooling or over supply of nitrogen with the air that can increase NO_X production.~~

~~Cross-media effects~~

~~Reductions in time, temperature, oxygen and turbulence can result in increased emissions of~~ products of incomplete combustion ~~PICs if conditions are reduced to such a degree that combustion is not completed. These risks are greater where the wastes (as fed) are highly heterogeneous, of variable composition or where the waste quality is difficult to assure.~~

~~N_2O (nitrous oxide) emission concentrations (and hence global warming impacts) are increased at lower combustion temperatures. CO levels may also be increased at lower temperatures.~~

~~The use of higher temperatures than are necessary for the destruction of the type of waste being incinerated, generally results in only small reduction in the quantities of~~ products of incomplete combustion ~~PICs in the untreated raw flue-gas – after gas cleaning the relative benefit will be even smaller. On the other hand, higher temperatures may lead to a significant increase in NO_X production. Therefore, unless some other specific environmental benefit is sought (e.g. improvement in residue quality using slagging or guaranteed high destruction efficiencies for PCBs) the reduction in some emissions to air achievable through the use of higher temperatures may be outweighed by the cross-media effects of additional fuel consumption, NO_X production etc. [64, TWGComments, 2003]~~

~~EXAMPLE: Bubbling fluidised bed burning sewage sludge:~~

~~Table 4.13 below shows the relationship found between nitrous oxide emissions and process temperatures at a bubbling fluidised bed plant burning sewage sludge. It should be noted that fluidised bed combustion is very different from grate combustion, and that the nitrous oxide emissions from grate MSWI with a secondary combustion temperature over 900 ºC are generally negligible [64, TWGComments, 2003]:~~

~~Table 4.13: Relationship between nitrous oxide emissions and process temperatures for a bubbling fluidised bed plant burning sewage sludge~~

~~Bed temperature range (°C)~~	**~~Free board temperature~~**		
	~~930 °C~~	**~~910 °C~~**	**~~890 °C~~**
	~~Nitrous Oxide emission~~		
~~820 – 845~~	~~70~~	~~120~~	~~200~~
~~795 – 820~~	~~100~~	~~170~~	~~270~~
~~730 – 795~~	~~180~~	~~250~~	~~350~~

~~Data shown are for nitrous oxide concentrations in mg/m³~~
~~*Source:* [22, Mineur, 2002]~~

~~Operational data~~

~~There are several different methods for the determination of the time and temperature parameters for a given plant that use different temperature measuring devices located at different positions in boilers with different heat transfer properties: the measurements are conducted with the plant under different percentages of load, and at different times with respect to plant cleaning. These methods have associated levels of accuracy. Despite these uncertainties, modern plants generally show environmental compliance with the EU Directive 2000/76. [64, TWGComments, 2003]~~

~~Example:~~ ~~VERA Sewage sludge incinerator, Hamburg, Germany:~~

~~Studies were carried out at this fluidised bed plant to demonstrate the impact on emissions of the use of reduced temperature and oxygen in the combustion phase. For fluidised beds both the temperature in the bed and the freeboard are important for effective combustion.~~

~~Waste type:~~	~~Sewage sludge and screenings~~
~~Plant size:~~	~~79 000 t/yr~~
~~Combustor type:~~	~~bubbling fluidised bed~~

~~Combustion temp (T min) 810º Celsius (in freeboard of combustor)~~
~~Oxygen conc. (min) 4 %~~
~~Abatement systems: ESP/HCl and SO_2 scrubbers/fabric filter.~~

~~The following data/conclusions were noted from the results at this installation:~~

- ~~reducing FB temperature from 924 °C to 810 °C did not significantly change PCDD/F emissions (reported figures were a change from 0.0005 ng/m³ to 0.0008 ng/m³)~~
- ~~reducing oxygen concentration from 6.8 % to 4 % resulted in a reduction of PCDD/F (0.0015 to 0.0005 ng/m³)~~
- ~~at freeboard temperatures below 890 °C NO_X emissions were between 30 and 40 mg/Nm³ and independent of changes in bed temperature between 730 °C and 845 °C~~
- ~~increasing free board temperatures above 890 °C increased NO_X emissions – the effect was most marked at higher bed temperatures~~
- ~~at freeboard temperatures below 900 ºC, SNCR has little impact on NO_X emissions~~
- ~~emissions of N_2O are higher at lower freeboard and bed temperatures (see data shown in cross-media effects above)~~
- ~~emissions of N_2O are almost unaffected by the use of SNCR.~~

~~It is reported that lowering oxygen levels can result in increased corrosion rates requiring specific counter measures. [64, TWGComments, 2003]~~

~~**Applicability**~~
~~Mainly applicable at the design stage for new plants and for existing plants undergoing or planning significant retrofitting of the combustion chamber.~~

~~Applicable where the available space limits the size of the combustion chamber.~~
~~Less applicable where wastes (as fed) are highly heterogeneous, of variable composition or where waste quality is difficult to assure.~~

~~Existing plants may already have residence times that are below two seconds. These may be able to justify not carrying out extensive (and expensive) retrofitting by gathering and comparing real performance data concerning the levels of products of incomplete combustion PICs in the raw gas.~~

~~**Economics**~~
~~The estimated cost relevant impacts of changing these combustion parameters, compared to the normal design values, are indicated in the table below:~~

~~**Table 4.14: Estimated cost impacts of some alterations to combustion parameters**~~

~~**Parameter**~~	~~**Increase or Decrease in parameter**~~	~~**Estimated cost impact**~~
~~**Combustion temperature**~~	~~Increase~~	~~Additional cost of support fuels increased furnace maintenance costs may reduce ash disposal costs of slagged ash if product saleable~~
	~~Decrease~~	~~Reduced need for support fuels may restrict waste types that can be burned~~
~~**Gas residence time**~~	~~Increase~~	~~Larger furnace = higher cost may increase range of wastes accepted changing design of combustor expensive~~
	~~Decrease~~	~~Smaller process means lower costs may restrict wastes that can be burned~~
~~**Turbulence**~~	~~Increase~~	~~Changing design of combustor expensive increasing air injection increases flue-gas volumes and FGC costs~~
	~~Decrease~~	~~Not technically advisable/desirable~~

~~Oxygen concentration (excess)~~	~~Increase~~	~~Higher oxygen excess may allow wider range of waste to be incinerated without emission problems~~
	~~Decrease~~	~~Reduced flue-gas volumes mean lower FGC costs may restrict wastes that can be burned~~

~~In general the most significant cost issue is for existing plants where the rebuild/retrofit costs of upgrading an existing plant (that is already achieving effective emissions performance) to meet the traditional temperature and residence time requirements, will be very large.~~

~~Driving force for implementation~~
~~Reductions in NO_X production and, hence, a reduction in the measures required to treat flue-gases may be achieved. With very consistent wastes it may be possible to reach NO_X levels compliant with EC Directive requirements without, or with very minimal need for specific NO_X controls (e.g. SNCR or SCR).~~

~~Lower gas residence times, and flue-gas volumes (reduced by reducing the air supply) mean that smaller combustion chambers and flue-gas treatment plants can be used, resulting in cost reductions.~~

~~Example plants~~
~~VERA, Sewage sludge incinerator, Hamburg, Germany~~

~~Reference literature~~
~~[22, Mineur, 2002]. Information supplied by UBA during site visit to VERA. [64, TWGComments, 2003]~~

~~4.3.20 Use of automatically operated auxiliary burners~~

To the TWG: this is more for Chapter 2 and it is an IED requirement

~~Description~~
~~During start-up, auxiliary burners are used to create a zone above the required minimum temperature, through which the flue-gases are fed from the furnace zone to the secondary incineration. This is the predominant operational condition for the burner design.~~

~~In order to assure a sufficient temperature under extreme conditions, auxiliary burners are installed. These are used when the temperature falls under the required minimum temperature.~~
~~When the plant is shutdown, the auxiliary burners are used when the temperature has fallen below the design limit of the furnace and the temperature sinks below the required minimum temperature. They operate until there is no waste in the incineration chamber.~~

~~Achieved environmental benefits~~
~~Ensuring that incineration temperatures are adequate by the use of automatically operated burners ensures that the gases produced are properly combusted, reducing raw gas concentrations of PICs at the furnace outlet and hence emissions to all media.~~

~~Cross-media effects~~
~~Consumption of fuels (usually light oils or natural gas) by the burners.~~

~~Auxiliary burners must be optimized for low CO emissions, otherwise high emissions during start-up and shut-down are possible.~~

~~Operational data~~
~~Start-up without auxiliary burners is possible, but smoother starting with reduced soot and better control of temperature is attained by starting with the burners. Starting without auxiliary burners in normal MSWI plants can increase corrosion risks due to the chlorine content of the waste. [64, TWGComments, 2003]~~

~~Applicability~~

~~Applicable to all waste incinerators, particularly those receiving wastes of low LHV and/or wastes of inconsistent quality.~~

~~Economics~~

~~Retrofit costs may be significant owing to difficulties in positioning the burners.~~

~~Costs will be significantly higher at processes that operate on a batch basis, although this may be considered to be commensurate with the additional risk of releases that accompanies such operational modes.~~

~~Driving force for implementation~~

~~Ensuring emissions are reduced to all media and that start-up and shutdown operations are controlled and do not give rise to additional pollutant emissions other than those arising from the burning of gasoil and other fuels.~~

~~Legally required by Directive 2000/76/EC, although under certain circumstances this legislation allows for exemptions from the use of a start up burner (2000/76/EC article 6 paragraph 4).~~

~~Example plants~~

~~Widely used in modern plants throughout Europe.~~

~~Reference literature~~

~~[1, UBA, 2001] [64, TWGComments, 2003]~~

4.3.21 Reduction of grate riddlings ~~rate and/or return of cooled riddlings to the combustion chamber~~

Description

Grate riddlings are reduced by designing the grate in such a way as to reduce the space between grates as much as possible.

Technical description

In grate incinerators, some of the waste may fall through the grate and be partially combusted. These are called ‘riddlings’. Attention to grate design, particularly the reduction of spacing between grates, can reduce the effect. The quantity and quality of these riddlings depend on the design of the grate, on the interfaces between the moving pieces ~~together~~ and with the walls and on the mechanism for keeping them tight. [74, TWGComments, 2004]

~~In order to reduce the passage of riddlings through the grate, the following options are available:~~

- ~~design and maintain grates such that bar spacings and other factors that may increase riddling passage are reduced~~
- ~~where riddling rate and type is such that gives rise to ash quality concerns – re-burn in the combustion chamber.~~

Automatic conveyor systems are used to collect these riddlings. The collected material is usually stored for cooling before being reintroduced to the bunker (to avoid fire risk). ~~A proportion~~Some of the ~~re-introduced~~ riddlings can pass down the grate and accidentally mix ~~are discharged~~ with the bottom ash. ~~They will then have been subjected to the full incineration process and, therefore, be more sterile in nature.~~

This may be a particular issue where clinical or other wastes with infectivity risks, particularly those that are finely divided in nature, or which contain discrete objects that may fall through the grate (e.g. hypodermic needles) are co-combusted with other wastes.

Riddlings that arise earlier in the passage of the waste through the combustion chamber have a higher risk of retaining infectivity or having poor burnout and are ~~should~~ therefore ~~be~~ incinerated~~ most closely examined~~. Riddlings arising at later stages may be well treated and therefore less likely to require reburning.

Achieved environmental benefits

~~The main benefits are:~~

- Improved burnout of the waste.
- Improved ash quality.

Environmental performance and operational data

Storage of the riddlings prior to their reintroduction into the main waste feed is very important to prevent fire risks. Water may be added to ensure that cooling is thorough.

Regular observation is necessary to avoid clogging in the riddlings collection areas under the grates and to avoid safety risks for operators and personnel [74, TWGComments, 2004]

~~In France, the regulations set a burnout requirement for bottom ash in MSWIs that incinerate clinical waste of 3 % LOI, which is normally achieved without repeated incineration of riddlings. [74, TWGComments, 2004]~~

The riddlings of molten, burning drops of some common plastics (found in MSW) like PE and PET can contribute significantly to the total carbon content in ash, to increased COD in the bottom ash and to the significant leaching of copper. All of these parameters are improved by the use of this technique. [64, TWGComments, 2003]

Cross-media effects

Risk of fire when riddlings are in contact with waste.

Technical considerations relevant to applicability

Generally applicable.

~~Applicable, in principle, to all grate incinerators, but particularly applicable to those grate incinerators where:~~

- ~~particular concerns or requirements exist that require improved burnout~~
- ~~clinical or other infectious wastes are co-combusted that can go through the grate~~
- ~~grates with larger spacing between grate bars and high riddlings or in other systems where riddling levels may be relatively higher.~~

Economics

Improving ash burnout quality may reduce disposal costs where the current ash burnout does not meet reuse/disposal requirements without this technique. [74, TWGComments, 2004]

There can be significant investment costs for retrofitting existing plants and extra operational (handling) costs. [74, TWGComments, 2004]

Driving force for implementation

- Improved and thorough waste destruction..
- Improved bottom ash quality.

~~The technique is applied at grate incinerators in the Flanders Region of Belgium for the purpose of ensuring burnout and improved ash quality.~~

Example plants

Indaver GF, Beveren (BE).

Reference literature

[64, TWGComments, 2003]

~~4.3.22 Protection of furnace membrane walls and boiler first pass with refractory or other materials~~

To the TWG: already covered in Section 4.4.8

~~Description~~

~~[2, infomil, 2002] The furnace is formed by membrane walls (also called "water walls"), consisting of rows of vertical tubes, connected by strips, welded together in order to form a closed (membrane) wall, which are part of the boiler's evaporation section. In the lower section of the furnace especially, the membrane walls must be protected against the corrosive and abrasive effect of the flue-gases, which are not yet fully incinerated at that position. For this purpose, the furnace walls of the lower section are covered with a layer of ceramic refractory material or other protective materials. An additional advantage of this wall protection for lower calorific value wastes, is the reduction of the heat transfer to the boiler, which is beneficial where temperatures need to be maintained.~~

~~In most modern waste incineration plants, the whole boiler, except the economiser, is made of water tube walls. In steam boilers, these tubes are a part of the vaporiser.~~

~~When there are no water walls, cooling is sometimes made by air circulating behind the refractory plates, often the warmed air is then used for primary air heating.~~

~~The role of the refractory is to reduce the heat transfer and to protect the tubes from excessive heat and corrosion. It is installed inside the furnace/boiler; on the outside of the furnace/boiler there is thermal insulation material. [74, TWGComments, 2004]~~

~~With high LCV waste, combustion temperatures are normally reached without problems. The main purposes of the ceramic refractory layer are, therefore, the protection of the furnace walls against high temperature corrosion and to prevent the temperature from decreasing too quickly. With higher steam conditions and a higher LCV waste, a larger part of the furnace walls needs to be covered with ceramic refractory material. An alternative solution is the use of specific anti-corrosive alloy claddings, such as Nickel/Chromium, on boiler tubes for protecting the tubes from corrosion – it has a higher heat exchange coefficient (see Section 4.4.8) than the ceramic refractory alternatives.~~

~~Techniques have been developed to prevent the formation of solidified ash deposits in the furnace. These include:~~

- ~~cooling of the furnace side walls – which lowers the ash temperature, causing the ash to solidify before it reaches the furnace wall~~
- ~~designing the furnace with a lower specific heat load (larger dimensions for the same thermal capacity).~~

~~Achieved environmental benefits~~

~~The greater plant availability means that the additional risks of emissions associated with start up and shutdown are reduced.~~

~~Retaining heat generated during combustion in the furnace will reduce the need to add support fuels to lower LCV wastes.~~

~~The high heat capacity of the refractory lined furnace helps to reduce temperature fluctuations that may arise with wastes of variable LCV, thus promoting more stable incineration and reducing emissions from the combustion stage.~~

~~The use of water and air-cooled walls allows:~~

- ~~the heat to be recovered~~
- ~~gas temperature reduction, which reduces the stickiness of fly ashes and, hence, improves boiler availability and heat transfer efficiency~~

- ~~reductions to be made in secondary air addition (where this has been added for gas cooling) leading to lower flue-gas volumes, reduced flue-gas treatment equipment capacity requirements, and possibly lower NO_X in the raw gas.~~

~~Similar effects can be obtained with air-cooled refractory.~~

~~Cross-media effects~~
~~Where LCV of the waste is sufficient to maintain the combustion temperature, providing refractory lining over too wide an area can reduce heat transfer to the boiler and hence reduce energy recovery performance.~~

~~If support fuels are necessary because the water walls extract too much heat, and this results in combustion temperatures dropping below those required for effective combustion performance, then refractory walls should be used.~~

~~Operational data~~
~~Improved plant availability through reduced corrosion and bottom ash build-up.~~

~~With lower CV waste, increasing the refractory covering assists with maintaining combustion temperature.~~

~~Applicability~~
~~This technique is mainly applied to municipal grate incinerators [64, TWGComments, 2003]~~

~~Increasing protection of the boiler tubes by using refractory lining close to the primary combustion zone is mainly applicable where:~~

- ~~low calorific wastes require additional heat retention in the primary combustion zones~~
- ~~high chlorine loading give rise to additional corrosion concerns~~
- ~~high temperature combustion gives concerns regarding corrosion.~~

~~Economics~~
~~Improved plant availability results in reduced operational costs.~~

~~Changing the configuration of the furnace at existing plants may not be practicable due to high costs.~~

~~Driving force for implementation~~
~~Operational and environmental benefits. In particular, a better incineration process, less furnace corrosion, less maintenance, longer boiler lifetime.~~

~~Example plants~~
~~Widely used at MSWIs throughout Europe.~~

~~Reference literature~~
~~[2, infomil, 2002, 64, TWGComments, 2003] [28, FEAD, 2002]~~

4.3.23 Use of low gas velocities in the furnace and inclusion of empty passes before the boiler convection section

Description
Techniques to consider are:

- low gas velocity in the furnace; *To the TWG: are you able to quantify it?*
- empty pass between the furnace and the heat-exchange bundles.

Technical description

The furnaces of waste incinerators are normally designed large enough to provide low gas velocities and long gas residence times. This allows combustion gases to be fully burned out, and prevents boiler tube fouling by:

- reducing the fly ash content of the flue-gases;
- allowing the temperature of the flue-gases to be reduced before coming into contact with the heat-exchange bundles.

Heat-exchanger fouling may also be reduced by including empty passes (e.g. water walls without obstructions in the gas path) between the main furnace area and the heat-exchange bundles to allow the gas temperature, and hence fly ash stickiness, to be reduced. Temperatures of below 650 °C before the convective superheater are used to reduce the adhesion of ash to the boiler tubes and thus prevent corrosion. [2, infomil, 2002, 64, TWGComments, 2003]

Achieved environmental benefits

Benefits include reduced emissions of organic substances from the combustion stage.

Improved heat exchange in boilers owing to a reduction of deposits on boiler tubes can result in improved energy recovery.

Environmental performance and operational data

Reductions in boiler tube deposits results in improved process availability and better heat exchange.

Cross-media effects

No specific effects have been identified, but care may be required to ensure the secondary air supply or other mechanisms used to support gas mixing are adequate ~~with~~ for larger furnaces.

Technical considerations relevant to applicability

The technique is mainly applicable to ~~the design of~~ new plants and where substantial refits of existing furnaces and boilers are being carried out.

~~Applicable to nearly all kind of incinerators.~~

Economics

Larger furnaces are more expensive to construct. *To the TWG: can this be further explained/quantified?*

Driving force for implementation

~~Operational benefits from better incineration process,~~

- Reduced erosion of the furnace.
- Reduced fly ash production.
- Reduced maintenance.
- Longer boiler lifetime.

Example plants

Commonly applied to MSWIs in Europe.

Reference literature

[2, infomil, 2002], [64, TWGComments, 2003]

4.3.24 Determination of the calorific value of the waste and its use as a combustion control parameter

Description

The LHV of the waste is determined for the online optimisation of the incineration process. This can be done, for instance, by analysing the process parameters such as the steam production ratio, through a mass balance measuring the flue-gas concentration of CO_2, CO and H_2O.

Technical description

Fluctuations in the characteristics of the waste are more pronounced with some types of wastes (e.g. untreated MSW, some hazardous wastes) meaning that mass and volume are less reliable control parameters. The determination of LHV on-line ~~(e.g. as described in Section 3.5.2)~~ may then help to optimise process conditions and improve combustion with such heterogeneous inputs.

Techniques have been developed based upon:

- retrospective analysis of process performance parameters (not a predictive method);
- mass balance calculations based on CO_2, O_2 and H_2O concentrations in the flue-gas (i.e. not a predictive method as based on downstream measurement) and on waste input (averaged values, e.g. using a 'crane' scale) or on other smaller estimated heat flows; ~~estimated~~
- use of microwave equipment to assess the moisture content of the waste in the feed chute;
- waste colour and dimensions linked to plant output signals by fuzzy logic.

Achieved environmental benefits

Improved combustion control results in reduced emissions from the combustion stage.

Environmental performance and operational data

This technique may be used as a diagnostic tool or (with on-line methods) for process control ~~e.g. MSWI burning heterogeneous waste~~. Knowledge of the waste's calorific value ~~of the fuel input is useful in that it~~ allows optimisation of the air supply and other critical parameters that control combustion efficiency. With heterogeneous wastes ~~fuels~~, the mass and volume input rate of the ~~fuel~~ waste can be used as additional control parameters.

Control of ~~quality of~~ the waste features may be part of the delivery contract.

Cross-media effects

None reported ~~identified~~.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided ~~data supplied~~.

Driving force for implementation

The technique is implemented to improve the combustion and energy recovery performance of the plant ~~MSWI's~~.

Example plants

On-line techniques have been used in municipal plants in the Netherlands.

Reference literature

[23, VanKessel, 2002] [64, TWGComments, 2003]

~~4.3.25 Low-NOX burners for liquid wastes~~

To the TWG: Moved to Section 4.5.4.6

~~Low-NO_X burners provide a means of introducing and burning liquid wastes into the combustion chamber in such a way that nozzle head temperatures are reduced and therefore the production of thermal NO_X is reduced. Descriptions of low-NO_X burners used for conventional fuels are given in the LCP BREF (note: these may require specific modifications for use with wastes).~~

~~There are relatively few examples where low-NO_X burners are successfully used with wastes. Particular attention is required to ensure adequate combustion efficiency (with waste). The technique is only applicable to specific liquid waste streams. It may be suited to some liquid hazardous wastes.~~

~~The installation of Low-NO_X burners during plant construction helps reduce the production of NO_X while adding little to the capital cost. The cost of retrofitting such burners to existing plants, however, can be high.~~
~~[64, TWGComments, 2003]~~

~~4.3.26 Fluidised bed gasification~~

To the TWG: this is an applied process.

~~**Description**~~
~~This technique involves the use of a fluidised bed (see 0) under gasifying conditions (see 2.3.4).~~

~~In the fluidised bed, an inert material, like sand, is heated to reaction temperature and kept in a fluidised state by an up streaming gas, i.e. in general air or steam. In a circulating fluidised bed, the bed material is carried out of the reactor due to high gas velocity, collected in a cyclone and returned. In a bubbling fluidised bed the gas velocity is lower, so that the bed material moves only within the reactor. The basic operating principal of an internally circulating/bubbling fluidised bed is shown in Figure 2.25 and a more detailed description in section.~~

~~The gasification process may be carried out at high or low temperatures. In low temperature gasification, the waste is heated in the FB to a reaction temperature of usually between 500 and 600 ºC and in high temperature systems to 800 to 1 000 ºC. They are supplied with sub-stoichiometric oxygen levels, to be gasified. The synthesis gas produced in the gasification stage is usually then passed to a combustion stage, but in some circumstances may be purified for use as a chemical feedstock.~~

~~In some cases the syngas is cleaned before its combustion, in others not. This depends on the waste content and the combustion/generation options chosen. However most waste materials contain chlorine and other contaminants, which have to be removed from the gas prior to combustion. Syngas cleaning systems based on wet scrubbers and bag filters have been designed.~~

~~**Achieved environmental benefits**~~
~~Compared to incineration, gasification has the following features:~~

- ~~at the lower reaction temperature, metals (e.g. steel, copper, aluminium or brass) contained in the waste are not sintered, oxidised or molten, so when separated from the ash/bed material they may have higher value for recycling~~
- ~~a gas with heating value and chemical potential is generated, which may be used for various recycling or recovery options~~
- ~~the combustible gas may itself be combusted and the energy generated used for energy recovery~~
- ~~combination of the gas in special combustion conditions has been used to melt ashes (vitrification), generating a low leaching product (see 0)~~
- ~~the separation of the gasification and combustion stages may allow improved process control and result in a more stable overall combustion process~~
- ~~lower flue-gas volumes and hence improved FGC can result from the use of lower air ratios.~~

~~**Cross-media effects**~~

~~Compared with grate systems, waste particles are limited to 300 mm, which normally requires some energy for shredding and can affect the availability of the plant. While fluidised beds generate less bottom ash with less fine particle content, more fly ash is generated which requires special attention if not vitrified.~~

~~Tars and other pollutants removed at any syngas cleaning stages require management. Wet scrubbing systems result in an effluent which when treated yields a tarry residue that then requires disposal. Dry syngas treatment will also result in an accumulation of the removed impurities. In some cases the tarry residue, which has a calorific value, has been supplied to other industries as a waste derived fuel (information concerning the acceptance criteria/emission controls applied at these external industries was not supplied).~~

~~**Operational data**~~

~~Where shredders are required to prepare the waste these may experience some difficulties with blockages etc. See comments in Section 4.2.5.2.~~

~~Generally, fluidised beds achieve good mixing of the waste and a very homogeneous temperature distribution in the reactor. Due to the very turbulent reaction zone and the large heat content of the bed material, fluidised beds have low sensitivity to changes in the physical and thermal properties of the waste.~~

~~Bubbling fluidised beds offer the advantage of a large reaction volume without moving parts, so comparatively large waste pieces (up to 30 cm in diameter) can be gasified.~~

~~The following additional operational comments were made by the BREF TWG:~~

- ~~if metal pieces are in the waste they can throw it out of balance and can accumulate – resulting in operational difficulties~~
- ~~difficulties may be encountered finding a market for the syngas produced, limiting the options for chemical recovery~~
- ~~the market may not exist or be any better for the improved ash produced (ash quality improvements may arise from the homogenisation of the waste at the shredding stage and/or the coupling of the techniques with a high temperature post-gasification combustion stage).~~

~~**Applicability**~~

~~The main restriction on the use of FB Gasification arises from the need for the waste to be suitable for feeding to a fluidised bed, or readily treatable so that it may be fed to the FB. Wastes which have been fed to such systems include: pretreated (shredded) MSW, shredder residues, waste plastics and other industrial wastes of a suitable size or where they can be shredded to a suitable size. Oils and other liquids, bone meal, sludges and slags are suitable wastes in mixtures with others.~~

~~In Europe, although applied to some selected waste streams, in practice the technique has (at the time of writing) yet to be demonstrated on a full operational scale on many waste streams.~~

~~**Economics**~~

~~Investment costs are reported to be higher than for conventional grate incineration e.g. JPY 20 billion (ercury. EUR 160 million) in 2002 for a plant treating 120 000 t/yr of MSW. Cost includes construction and plant costs of an entire plant including: six waste shredder lines, fly ash melting (see 0), flue-gas treatment, and adjacent integrated offices, swimming pool and spa complex. Cost excludes land purchase.~~

~~Operated with air, at atmospheric pressure and moderate temperatures, fluidised bed gasifiers are more economic in construction and operation than other gasification technologies applied for waste.~~

~~Revenue incomes are to be expected for materials diverted for recycling. Metals recovered from the gasifier will be disinfected and not require cleaning (cf. removal from the shredder stage) and may be sold at higher value than that recovered from grate incineration ash owing to a reduced level of fusion and oxidation (where they are removed at a lower temperature). Markets for the use of vitrified ashes may be better than for grate bottom ashes due to the improved properties of the material produced – this is the case in Japan but is often not the case in Europe.~~

~~Electrical revenues may be reduced due to higher in-process consumption where oxygen generation is used i.e. where the technique is coupled with oxygen enrichment.~~

~~Difficulties have been encountered with the shredding stages required to prepare municipal wastes for fluidised beds. The provision of multiple shredding lines can help to reduce the risk of expensive loss of availability, but in turn the provision of such additional equipment adds significantly to costs.~~

~~Driving forces for implementation~~
~~The following factors promote the implementation of this technique:~~

- ~~waste within the size range required for the FB or waste which can relatively easily be treated to meet the specification required~~
- ~~waste has a high calorific value~~
- ~~requirements for very low leaching residues (such residues are produced where this technique is coupled with a secondary ash melting stage – see Section 0) either through availability of recycling markets or restrictions on disposal sites~~
- ~~the higher recycling value of the metals removed from the gasifier can be realised~~
- ~~a favourable market exists for the use of the syngas as a chemical feedstock.~~

~~Example plants~~
~~There are several examples in Japan for MSW, sewage sludge, shredder residues, plastic wastes and selected industrial wastes.~~

~~There is an operational example in Europe (Spain) treating selected commercial and industrial plastic wastes. This installation uses fluidised bed gasification coupled with syngas cleaning prior to its combustion of electricity generation in gas engines. Tars and other pollutants are removed to a cleaning stage by the syngas cleaning.~~
~~It is reported that some experiences in Germany (KWU- Schwelbrennverfahren, Thermoselect, Noell- Konversionsverfahren) of the use of pyrolysis/gasification have had difficulties in reaching their design throughput capacity, and that consequent real treatment costs have escalated. It is also reported that this has in some cases lead to the closure of installations.~~
~~[74, TWGComments, 2004]~~

~~A 50 – 60 MW circulating fluidised bed gasifier has been successfully operated since 1998 on waste derived fuels in Lahti, Finland. The gasification gas is co-combusted in a 350 MW hard coal combined heat and power plant replacing about 15% of the primary fossil fuel. A 50 MW bubbling fluidised bed gasifier for reject plastic material containing 10 – 15% aluminium foil has been operating at Varkaus cardboard mill in Finland since 2001. Part of the plastic waste is a reject from a pulping process recycling fibres of used liquid packaging. Metallic aluminium is recovered from the product gas for material recycling. The gas is fired in a gas fired boiler producing process heat and steam for energy production.~~

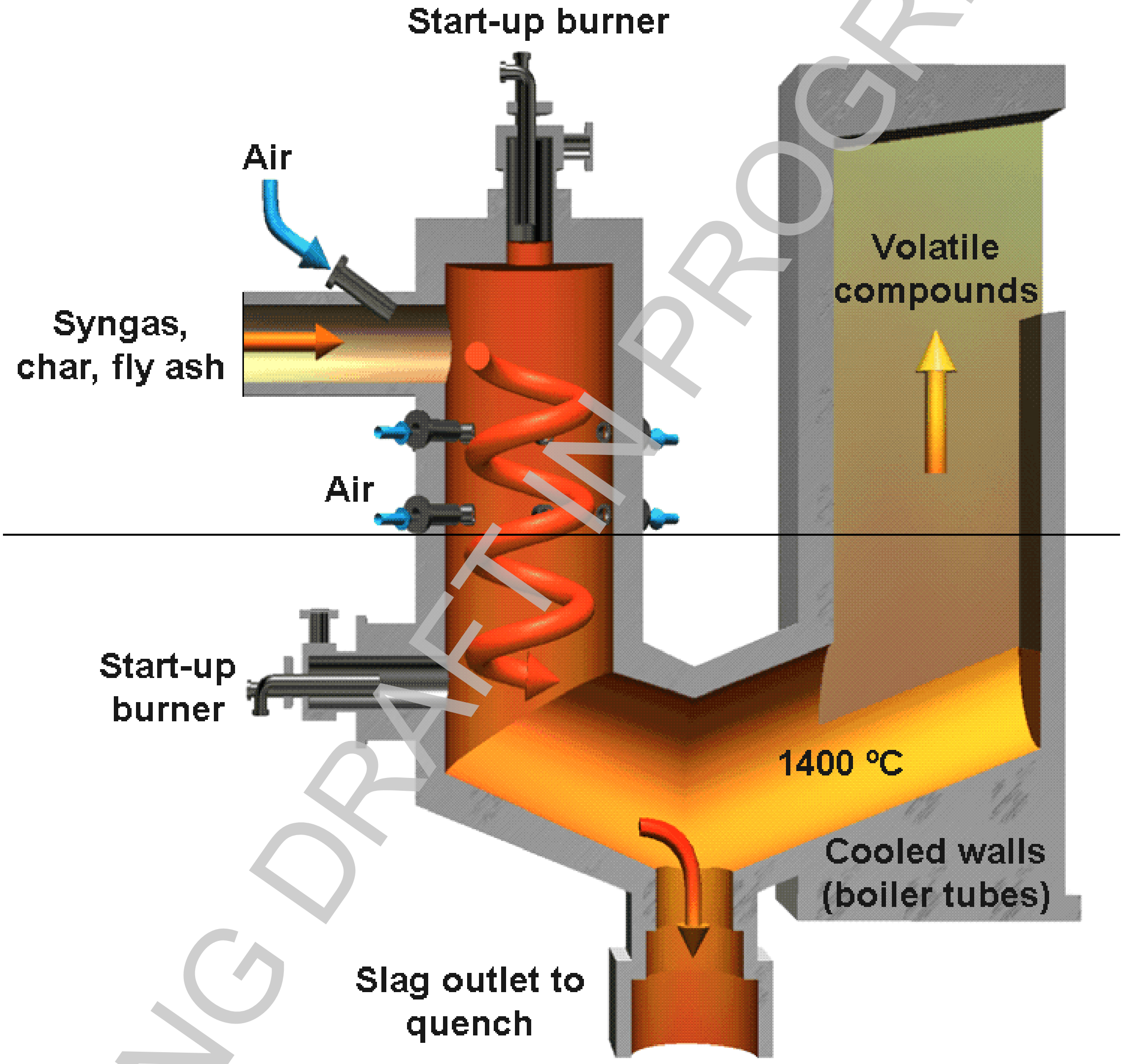
~~Reference literature~~
~~[64, TWGComments, 2003]~~

~~4.3.27 High temperature combustion of gasification syngas with ash melting~~

To the TWG: this is an applied process.

~~Description~~

~~This technique is an extension of fluidised bed gasification. Syngas from a gasification process and carbon-rich fly ash particles are combusted in a down flow melting chamber. Air and/or oxygen-enriched air is introduced such, that a cyclonic flow is induced, which drives ash particles to the wall.~~



~~*Source:* [68, Ebara, 2003]~~

Figure 4.3: Basic components of a cyclonic high temperature syngas ash melting furnace

~~The temperature is set to that at which the ash is vitrified (about 1400 °C) and will proceed towards the slag outlet. Due to the high temperature level, halogens and volatile metals, like lead and zinc, are evaporated.~~

~~The walls of the ash melting chamber are refractory lined and cooled by evaporator tubes of the boiler. In this way, the refractory is covered by a protective layer of slag, and the heat recovery is achieved.~~

~~Achieved environmental benefits~~

~~The following benefits are reported:~~

- ~~very efficient destruction of organic species at the high temperatures used~~

- ~~vitrification of the fly ash generates a stable low leaching granulate with additional (cf. grate ash) recycling possibilities~~
- ~~quantities of fly ash passed to the FGC residues are reduced and hence volumes of FGC residues themselves are reduced~~
- ~~lower contamination of FGC residues with fly ash may enhance FGC treatment options.~~

~~Compared with ash melting in a separate, off-line process, integrated ash melting is far more energy efficient, as it is an integrated part of the primary thermal process, where the high temperature required for vitrification is still available for steam production.~~

~~Cross-media effects~~

~~Vitrification requires high temperatures and, hence, sufficient energy to generate these temperatures. With lower calorific value fuels the temperature may be maintained by adding additional fuels (e.g. natural gas or fuel oils) and/or by increasing oxygen supply to the combustion chamber. The use of an oxygen generator adds an electrical requirement of approximately 0.5 – 1 MW depending on oxygen requirements.~~

~~Operational data~~

~~Plants using this technology have been in full commercial operation since 2000 in Japan.~~

~~Cooling of the refractory walls has proven to enable long refractory lifetimes. From the current level of experience, two annual inspections of the refractory are sufficient.~~
~~Some fly ash is re-evaporated and still needs special attention.~~

~~The flue-gas may be highly corrosive, and flue-gas treatment is required to remove those pollutants. Energy recovery may be complicated by this corrosivity. [74, TWGComments, 2004]~~

~~Applicability~~

~~The technique is applicable for gasification plants combined with syngas production when a vitrified fly ash is desired. The restrictions on the applicability of this technique to the various waste types are therefore the same as those to which this technique is connected i.e. where FBs are used many wastes require preparation before they can be treated.~~

~~Although applied in Japan, in practice the technique has yet to be demonstrated on a full operational scale in Europe.~~

~~Economics~~

~~Ash vitrification, even when process-integrated, increases waste treatment costs due to additional investment and operation effort. The resulting overall economics depends highly on the savings resulting from recycling of vitrified ash.~~

~~The product is used as a construction material and will most often not generate a higher revenue than mechanically treated bottom ash. [39, Vrancken, 2001]~~

~~Driving forces for implementation~~

~~The following factors promote the use of ash vitrification using this technique:~~

- ~~high costs for fly ash/FGC residue treatment/disposal~~
- ~~high costs for treatment/disposal of bottom ashes~~
- ~~requirements for very low leaching residues before re-use permitted.~~

~~Example plants~~

~~Examples operational in Japan.~~

~~It is reported that some experiences in Germany (KWU- Schwelbrennverfahren, Thermoselect, Noell Konversionsverfahren) of the use of pyrolysis/gasification have had difficulties in reaching their design throughput capacity, and that consequent real treatment costs have escalated. [74, TWGComments, 2004] It is also reported that this has in some cases lead to the closure of installations.~~

~~Reference literature~~
~~[64, TWGComments, 2003]~~

4.4 Techniques to increase energy recovery

4.4.1 Optimisation of overall energy efficiency and energy recovery

Description

- Optimisation of the installation’s energy efficiency and energy recovery.
- Securing of long-term base-load heat/steam supply contracts with large heat/steam users so that a more regular demand for the recovered energy exists and therefore a larger proportion of the energy value of the incinerated waste may be used.
- Location of new installations so that the use of the heat and/or steam generated in the boiler can be maximised through any combination of:
  a. electricity generation with heat or steam supply for use (i.e. use CHP);
  b. the supply of heat or steam for use in district heating distribution networks;
  c. the supply of process steam for various, mainly industrial, uses (see examples in Section 4.3.18).

Technical description

~~Incineration plants can liberate the energy value of waste and can supply electricity, steam and hot water. Where a plant is located so that the supply and use of these outputs can be maximised, this will allow better use of the energy value of the waste.~~

~~Energy inputs to incineration plants are mainly from the calorific content of the waste, but may also come from additional fuels added to support the combustion process, and also from imported power (electricity).~~

~~The plant itself can use some of the energy generated. The difference between the inputs and the (usable) outputs are the losses. A part of this (usable) recovered energy may be valorised (used). In general, the whole of the electricity generated is valorised but in respect of steam or hot water, it depends on the needs of the user; the most favourable situations being when the users needs are greater all year long than the incineration plant output (e.g. industrial steam use or large district heating network). [74, TWGComments, 2004]~~

Optimising the efficiency of the plant consists of ~~optimising the whole process. This includes~~ reducing losses and limiting the process consumption. Increasing the energy output does not, therefore, solely equate to the energy conversion efficiency; ~~as~~ it is also necessary to consider the energy required by the process itself and the possibilities for expoloitation.

The optimal energy efficiency technique depends, to a certain extent, on the particular location and on operational factors. Examples of factors that need to be taken into account when determining the optimal energy efficiency are as follows:

- Location. The presence of ~~Is there~~ a user/distribution network for the energy ~~or can one be~~ provided.~~?~~
- Demand for the energy recovered. ~~There is little point in recovering energy that will not be used.~~ This is a particular issue with heat but generally less of an issue with electricity.
- Variability of demand. Summer/winter heat requirements will vary for example. Plants that export steam as a base load can achieve a higher annual supply and hence export more of the recovered heat than those with variable output options, which will need to cool away some heat during low demand periods.
- Climate. In general, heat will be of greater value in colder climates (although the use of heat to drive chilling units can provide options where there is a demand for cooling/air conditioning).
- ~~reliability of fuel/power supply. Isolated plants may experience unreliable waste deliveries (related to storage times and capacities) or even electrical supply interruptions that can result in shut downs or greater dependence on the use of self generated power~~
- Local market price for the heat and power produced. A low heat price will result in a shift to electricity generation and vice versa.

- Waste composition. Higher concentrations of corrosive substances (e.g. chlorides) can result in an increased corrosion risk, thus limiting steam parameters (and hence possibilities for electricity generation) if process availability is to be maintained. The composition can also change depending on the season, including for example holiday seasons which cause population changes in some areas.
- Waste variability. Rapid and extensive fluctuations in composition can give rise to fouling and corrosion problems that limit steam pressures and hence electricity generation. Variation in waste composition ~~(itself influenced by many factors)~~ over the plant life favours the use of wide spectrum rather than finely optimised design.
- ~~high electrical efficiency conversion plants may be attractive when electrical power prices are high, however, frequently more sophisticated technology has to be used with a possible negative effect on availability.~~

  [74, TWGComments, 2004]

~~[28, FEAD, 2002] The optimisation of energy recovery techniques requires the incineration installation to be designed to meet the demand requirements of the energy user. Plants that can supply electricity only will be designed differently to plants than have the opportunity to supply heat or those plants that supply combined heat and power.~~

Recovery of only heat, as hot water or steam

The energy recovered can be supplied as hot water or steam (at various pressures). The possible consumers are:

- district heating (DH) and cooling (much less common) networks;
- industries, e.g. chemical plants, power plants, desalination plants.[2]

Most of these users require steam, except DH, which can use either steam or hot water. If no steam user is connected to the DH network, hot water can be used as the energy conveyor. ~~With water, the pipes have wider diameters and pumping requires more energy, but the DH operation and the safety measures are easier.~~

~~Most modern DH networks use hot water[3]. In this case, the incineration plant boiler can either produce steam or hot water. If the plant also generates electricity (CHP see below), it will be steam. If not, hot water is generally preferred.~~

Hot water will often be superheated[4] at a temperature of e.g. 200 °C and~~,~~ pressurised ~~and at higher temperature (e.g. 200 °C),~~ in order to facilitate the heat transfer in the exchangers~~ by increasing the heat differential between the heating and cooling mediums~~.

When the DH uses steam, the steam parameters (pressure and temperature) at the boiler outlet need to be above the highest level required for the DH. In the case of plants supplying heat only, the steam pressure is usually 2 or 3 bar above the DH pressure and the steam is superheated by 2 bar or 30 °C.

Electricity only

Two factors contribute to increasing the TG (turbo-generator) electricity output quantity:

- the high enthalpy of the steam, i.e. its high pressure and high temperature;
- the low enthalpy at the turbine outlet, which results from ~~a~~ the steam's low condensation temperature~~of condensation of the steam~~.

---

2) There is one example in Europe (AVR Rotterdam) of coupling between MSWI and desalination plants. This is interesting since thermal desalination plants need steam at low or medium pressure (3 bar in multi-flash, 20 bar in thermo-compression) and usually operate all year.

~~3) In some cases like in Basle (Switzerland) there are two networks, one DH network with hot water and another network supplying steam.~~

~~4) Superheated water is water at a temperature higher than 100 °C.~~

This latter temperature depends on the temperature of the cold source (air or water) and on the difference between this and the turbine outlet temperature.

In addition to electricity, hot water can be produced by the use of a heat exchanger after the turbine. [74, TWGComments, 2004]

CHP (Combined heat and power)
~~The~~ CHP generation ~~situation~~ reduces the loss of energy when the~~re is a low~~ heat demand is low, e.g. in summertime for DH. ~~The~~ Efficient electricity generation is enabled by appropriately locating ~~is generated in the best conditions if~~ the heat bleed ~~is well located~~ in the thermal cycle, i.e. low-pressure steam is used for the heat supply, leaving higher pressures for electricity generation.

With CHP, when the heat demand is high, the pressure at the outlet of the low-pressure part of the turbine is constant. The pressure depends only on the temperature of the cold DH water (or other return) and variation of the heat demand can be balanced by an accumulator tank or air cooler. [64, TWGComments, 2003]

When the heat demand is not high, the low-pressure section of the turbine must be very flexible because the steam flow inside will vary according to the heat demand. For example:

- from the maximum value: (100 % electricity production, no heat demand) when 100 % of the steam flow is passed to the low-pressure section of the turbine;
- to the minimum value: (maximum heat demand) when only a minimal steam flow is required for turbine protection.
  [74, TWGComments, 2004]

In the case of ~~a~~ CHP~~, the pressure and temperature of the steam sent to the heat consumer is determined by the location of~~ the bleed on the turbine[5]~~. The bleed~~ is located in such a way that the difference between the saturation temperature at this bleed and the temperature at the DH head will be around 10 °C. This bleed supplying the DH is usually controlled. This means that the pressure is ~~maintained as a~~ kept constant.

~~Priority is usually given to the heat supply but it can also be to the electricity supply. This often depends on the sale contracts.~~

Achieved environmental benefits
Increasing the recovery and effective supply/use of the energy value of the waste replaces the need for the external generation of this energy, resulting both in saved resources and in the avoidance of the emissions and consumption of the avoided external energy generation plant. ~~The amount of energy that is available to be recovered from the waste depends on the calorific value of the waste.~~
~~[74, TWGComments, 2004]~~

Maximisation of the benefit available from the energy value of the waste is often most likely to be achieved in situations where CHP is used, as this can allow *exergy* maximisation. This is because it allows the higher pressure steam to be used for electrical generation while the remaining steam energy (lower pressures) can still be supplied and used as heat. In individual circumstances where CHP is not possible, other options may give the optimal solution. [64, TWGComments, 2003]

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[5] In the case of back pressure turbines (without a low-pressure section), the steam pressure and temperature are those at the outlet of the turbine.

Environmental performance and operational data
~~[30, UBA, 2002]~~ [81, TWG 2016] In general, about 0.4 ~~0.3~~ MWh to 1.2 ~~0.7~~ MWh of electricity can be generated in a MSW incineration plant from one tonne of MSW, depending on the steam quantity as a function of the waste LCV, the plant size, steam parameters and the steam utilisation efficiency.

For the co-generation of electricity and heat, an additional 1.25 MWh to 1.8 ~~1.5~~ MWh (full-load hours) of heat per tonne of waste can be supplied, depending on the LCV of the waste, but the electricity generation may be reduced. Site-dependent heat supply opportunities are very significant in such cases. These include:

- geographical location;
- normal (district) heat utilisation periods (e.g. in Germany, this is only 1 300–1 500 h/yr of a possible 8 760 h/yr but in Denmark it is 4 000–8 760 h/yr of a possible 8 760 h/yr where the large size of the DH networks enables the year-round supply of the whole heat production).

Concerning heat, under favourable conditions, energy supplied after the boiler (as hot water or steam) can be increased to about 90 % of the total energy input to the boiler (not including internal consumption requirements) for an incineration plant operated at base load. Where a high conversion efficiency and base load demand are available (i.e. special arrangements made to create such circumstances), with specially prepared high calorific value wastes (in excess of 20 MJ/kg) it is possible to recover a total of 4–5.5 MWh of heat per tonne of waste [45, FEAD, 2002]. Such outputs are not available with lower calorific value wastes, e.g. untreated MSW – which generally has a LCV between 8 MJ/kg and 12 MJ/kg.

~~The following data summarise the results of surveys carried out by the TWG energy subgroup. The data~~ Table 4.15 shows the range and average values for heat and electricity production and demand per tonne of waste treated. ~~They are annual averages for installations in middle Europe during 2001.~~

Table 4.15: ~~TWG energy subgroup survey data for~~ Specific energy flows at some European MSWIs ~~per tonne of waste treated~~

Parameter		Values in MWh/t of MSW treated		Number of plants surveyed
		Range	Average	
Electricity	Production	0.415–0.644	0.546	8
	Exported	0.279–0.458	0.396	
Heat	Production	1.376–2.511	1.922	15
	Exported	0.952–2.339	1.786	
Installation energy demand	Total	0.155–1.116	0.575	50
	Electrical	0.062–0.257	0.142	

To the TWG: to be updated
1. All figures are absolute, i.e. no conversion/equivalence factors have been used.
2. Calculations carried out consistently according to methodologies used by the TWG subgroup.
Source: [64, TWGComments, 2003], [29, Energysubgroup, 2002]

Cross-media effects
The recovery of energy should not impede the safe and effective destruction of the waste. For example, high steam conditions may compromise plant availability ~~if all precautions are not taken~~. Higher energy efficiency leads to higher investment and maintenance costs and may also lead to lower availability. [74, TWGComments, 2004]

Particular attention must be paid to boiler design in the temperature range 450–200 °C to ensure dioxin reformation is minimised, e.g. prevention of dust retention in such zones (see Section 4.4.19).

Certain pollution control equipment and techniques have a high energy demand, ~~and whilst removing some FGT components may give rise to improved possibilities for energy recovery (through reductions in in-process energy consumption) this can also result in unacceptably high emissions – a balance is therefore required.~~ Some examples of significant energy demand techniques include:

- bag filter: it reduces dust (and other) emissions, multiple filters in series further increase the demand of energy
- SCR: it reduces NO_X and gaseous PCDD/F emissions but, as a tail-end FGC system, SCR requires energy for flue-gas heating;
- HCl or NaCl regeneration: external evaporation of effluent;
- ~~plume reheat - reduces plume visibility~~
- ash melting: improvement of ash quality.

In Austria, the energy demand of the waste incineration plant itself (also known as the ‘parasitic load’) is in the range of 2–3 % of the thermal output (for grate firing or rotary kilns) and 3–4 % in the case of ~~FBR~~ fluidised beds. [74, TWGComments, 2004]

Technical considerations relevant to applicability

The efficiency range that can be achieved depends significantly on the chemical and physical nature of the waste being burnt (i.e. MSW, HW, SS, etc.) as well as its calorific content. In general, higher electrical efficiencies can be achieved where the waste contains lower and/or less variable concentrations of substances that may enhance corrosion in boilers. As high-temperature corrosion becomes an increasing problem at higher steam parameters, the need for high plant availability can become a limiting factor.

[29, Energysubgroup, 2002] Quite often, when recovered energy is used as heat, a part of that heat supplied is not actually used. In some cases, the losses from the system which is supplied with the heat may be ~~very~~ significant because the demand is not constantly at full load. Typically the recovered heat may be maximised in situations when:

- the consumer is an industry with a demand for all the energy recovered;
- waste can be stored and then burned when heat is required (this avoids wasting fuel energy);
- the needs of the district heating network are greater than the energy supplied by the WI plant.

The last case is most commonly found in cities or other locations with extensive district heating networks.

Where a suitable heat distribution and use network is not available, this will limit the opportunities and rationale for achieving high levels of heat recovery and hence limit the ability of the process to export all of the available energy, thus making the highest levels of efficiency difficult to reach.

The choice of the site where the plant will be built and the European (climate) zone where it is located (e.g. colder climates are advantageous for heat export) are therefore critical in determining the available energy outlets, and hence the attainable efficiency.

~~Therefore, when comparing the achieved (and achievable) efficiencies of existing plants, it is important that the location of the installation is taken into account.~~

Opportunities for increasing the overall energy recovery from new WI plants can therefore be seen to be greatest at the time when the location of new plants is being selected. The decision to locate a plant so that it may be economically connected to a suitable energy distribution network will generally have a much greater influence on overall energy recovery than the technological choices made in the operating plant.

Decreasing the installation's energy demand may involve decisions regarding the type and extent of FGC system used. A balanced approach to such decisions is appropriate, i.e. one that takes account of the general desire to reduce the installation's energy requirements and the degree to which pollutants should be abated.

Economics

Higher relative treatment costs at smaller plants and the lack of economy of scale tend to lead to a lower availability of capital for investment in the most sophisticated energy recovery techniques. This, in turn, means that lower efficiencies can be expected at smaller installations, e.g. municipal waste incinerators with a throughput below 100 000 tonnes/yr.

The prices paid for supplied electricity and heat have a major influence on the economics of investments made to increase these outputs. In some cases, subsidies are paid that provide very attractive prices for electricity production. In other cases, a high demand for heat can result in favourable prices for heat. In such cases, the income to be derived from these sources can make capital investments to increase output more favourable.

For plants supplying electricity only, increasing electrical efficiencies induces higher revenues from the additional electricity generated/sold but also involves higher investment costs and often higher maintenance costs. Therefore the price of the (sold) kWh will play a key role in the choice of a solution. [74, TWGComments, 2004]

For CHP plants, the larger the quantity of energy exported as heat, the smaller the benefit from the improved efficiency of the electricity generation. [74, TWGComments, 2004]

Driving force for implementation

The main driving forces for increased energy efficiency are favourable economic conditions. These in turn are affected by factors such as:

- climate;
- location;
- prices for heat and power.

Higher income from energy sales can, in particular, allow the following:

- Increases to be made in electrical export efficiency to between 20 % and 30 % (e.g. 0.6–0.9 MWh/tonne for an untreated mixed MSW of 2.9 MWh/t). The higher levels are achieved through the use of waste pretreatment systems (note that pretreatment stages often require energy and can use all of that to be gained by increased efficiency at the incineration stage and more) including RDF production for fluidised bed combustion, and increased steam parameters beyond 40 bar and 400 °C.
- Investment in heat or steam supply networks to increase the ability to use the available energy, to give efficiencies in the order of 80 % to 90 % (e.g. > 2.3 MWh/tonne for an untreated mixed MSW of 2.9 MWh/t) where there is a year-round heat demand.
- Investment in techniques to capture the available heat from low temperature sources that might otherwise not be economic, e.g. condensing scrubbers and heat pumps (see Sections 4.4.16 and 4.4.17 ~~later sections~~).

In terms of optimising the energy recovery, reducing the technical risk and reducing costs, heat supply is favourable where this is possible. However, this still depends on the local conditions, and significantly on the sale prices of electricity and heat. If a (substantial) part of the heat cannot be used, then CHP may well be the right solution. If no heat can be sold, then good practice is generally to use the available energy to create electricity.

Heat

The client demand is the key driving force. Therefore location is of great importance.

An important factor is the duration of the contract to receive heat. Often industrial clients cannot commit themselves for more than one or two years. This does not fit well with incineration plants, where a project can require several years before the plant even starts; and incineration plants' financing and operation is usually long term (15–25 years).

The most favourable situation is when all the recovered heat can be sold for heat use. This may occur with industrial customers or with DH either in colder climates or for very large DH networks with a base load higher than the plant output[6].

Where all the recoverable heat cannot be sold, the aim is then to try to use the remaining energy for generating electricity. The decision depends on the remaining quantity of energy and on the capital investment and income costs to be derived from electricity sales.

CHP
Generally CHP provides a solution for increasing the overall energy output when only part of the heat can be sold. CHP is especially effective if the temperature of the required heat is low.

Electricity
If there is no customer for the heat, the only option is to generate electricity. Increasing electrical output can be achieved by using increased steam parameters (see Section 4.4.8). The choice of the steam parameters (high or low) is most commonly taken on an economics basis. The technological risk is also a factor as this increases where higher steam parameters are used (e.g. above 40 bar and 400 °C for mixed municipal waste), and, if not well managed and maintained, the plant may then experience losses of availability.

Example plants
Municipal incineration plants:

- Renova, Gothenburg and Dyvamuren (Umea) (SE) – high levels of internal energy integration with a view to maximising heat supply to local networks.
- Odense (DK) – use of special cladding in boilers to allow high steam parameters and electrical output.
- Indaver, Beveren (BE) – supply of process steam directly to neighbouring industry.

Examples of MSWI plants generating hot water for district heating:
Rungis (south of Paris, FR); Villejust (south of Paris, FR); Caen (FR); Thiverval-Grignon (west of Paris, FR); Nantes East (FR).

Examples of plants providing steam for district heating:
Three plants in France supply steam for DH for over 200 000 flats in Paris, FR: Issy-les-Moulineaux (south-west of Paris); Ivry (south-east of Paris); Saint-Ouen (north-west of Paris).

Examples of plants providing steam to industry:
Nantes (FR); Rambervilliers (FR).

Examples of plants generating electricity only:
Mataró (ES); Chineham (UK).

Examples of MSWI plants providing steam to electricity generation installations:
Brussels (BE); AZN Moerdijk (NL); Several examples in Germany; Vancouver (Canada).

Examples of hazardous waste incineration plants:
- Ekokem (FI) – electricity generation and heat supply;

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6) Some plants that report 100 % export of the heat that they recover actually supply steam to another company which then turns it into electricity, e.g. Brussels, Belgium; Metz, France; Vancouver, Canada. Among eight German plants selling heat only, all the plants which sell a high quantity of heat per tonne of waste supply their heat directly to a power station and, usually, exclusively as process steam.

- Indaver, Antwerp (BE) – on-site use of steam for other processes;
- HIM, Biebesheim (DE) – on-site use of steam for evaporation of oil/water wastes;
- German chemical industry (19 plants, capacity > 500 000 t/yr) with on-site use of steam for other processes, electricity (4 plants) and additional district heating.

[74, TWGComments, 2004]

Reference literature
[29, Energysubgroup, 2002], [28, FEAD, 2002], [30, UBA, 2002], [5, RVF, 2002], [64, TWGComments, 2003]

4.4.2 Reduction of ~~Energy loss reduction:~~ flue-gas volume ~~losses~~

Description
Reduction of the flue-gas flow.

Technical description
[28, FEAD, 2002]
Flue-gas losses correspond to the heat leaving the plant (usually considered at the boiler level) with the flue-gas. The actual loss depends on the flue-gas flow and on its temperature (enthalpy).

One of the ~~Some~~ possibilities for reducing these losses is ~~are:~~ thereduction of the flue-gas flow; to achieve this several options are possible:

- reduction of excess air, e.g. improve primary and/or secondary air distribution;
- ~~recycle~~ flue-gas recirculation, i.e. replace part of the secondary air with flue-gas;
- enriching of the combustion air in O_2, i.e. increase the proportion of O_2 and decrease that of N_2 by O_2 injection (this is only carried out in special cases – see Section 4.3.13);
- selection of FGC facilities with decreasing temperatures from the boiler to the stack as far as possible. [74, TWGComments, 2004]
- ~~reduce the flue-gas temperature, e.g. by using flue-gas condensation or by decreasing the temperature at the boiler exit – see techniques described later in this section.~~

Achieved environmental benefits
Reduction of the energy used by the flue-gas cleaning system.
~~By using techniques to reduce flue-gas losses the additional energy recovered can be supplied for use.~~

Environmental performance and operational data
For a municipal waste incineration plant, the energy lost via the flue-gases is typically in the range of 13–16 % (*To the TWG; this figure seems high, please check*) of the energy input from the waste.

Cross-media effects
Reducing the gas flow by reducing the excess air and FGR can increase corrosion risks ~~and therefore can require additional technical remedies~~. If levels are reduced too far, this may jeopardise the gas burnout and leave products of incomplete combustion ~~PICs~~ in the flue-gas.

Oxygen injection can increase combustion temperatures. If not carefully controlled, this may lead to clogging, and risk of destruction of refractory and ferrous materials.
[74, TWGComments, 2004]

The significant energy consumption for generating the required O_2 is higher than the achieved reduction of the energy loss, making the technique unviable if the only benefit considered is the energetic balance – other benefits of enriched oxygen (e.g. improved combustion)~~ may~~, however, provide an overall justification for this technique. [64, TWGComments, 2003]

~~Reducing gas temperatures at the boiler exit below the temperatures required to operate subsequent flue-gas treatment devices, will lead to additional energy requirements to reheat the flue-gases in order to operate those devices, as well as increased risk corrosion in economisers. This is a particular issue for bag filters and for SCR devices.~~

Lower flue-gas temperatures at the stack exit can result in:

- highly visible condensed plumes (less of a problem if condensing scrubbers are used as they reduce the water content of the flue-gases);
- reduced plume buoyancy and, hence, dispersion;
- corrosion in stacks (lining with fibreglass or similar required).

Technical considerations relevant to applicability
The technique is generally applicable~~ Optimisation of the boiler outlet temperature can be carried out at all plants~~. The extent to which energy losses through the flue-gas can be reduced ~~will need consideration of~~ is related to the energy requirements of downstream FGC equipment, and may be limited by the acid dew point of the flue-gas.

New installations have the most significant opportunity for ~~designing in~~including (in the design) techniques to reduce losses ~~from~~ through the flue-gases. Plants that have an outlet for the supply of relatively low temperature heat (most common in colder climates) are best placed to make use of the additional heat removed from the flue-gases. Where this heat cannot be supplied, or used within the plant, this low-grade heat may be better employed within the flue-gas to aid dispersion, etc.

Changes to the design exit temperature of the boiler must take account of the requirements of subsequent flue-gas cleaning operations. The removal of heat that must later be re-added from another source is likely to be counterproductive from an energy efficiency point of view, owing to additional losses from the heat exchange process.

Economics
No information provided~~ not supplied~~.

Driving force for implementation
Reduction of the overall process energy consumption and increase of energy exploitation ~~valorisation products~~.
[74, TWGComments, 2004]

Example plants
Many plants in Europe, e.g. Brescia (IT)~~Italy~~

Reference literature
[28, FEAD, 2002], [64, TWGComments, 2003]

~~4.4.3 Increasing burnout of the waste~~

~~**Description**~~
~~Good burnout results in a high conversion of fuel to energy. Therefore, techniques that ensure effective burnout and hence low TOC levels in ash may contribute, to some degree, to improved energy efficiency. Combustion techniques that agitate the waste well, and retain wastes within the combustion zone to allow unburned carbon in the bottom ash to enter the gas phase for combustion will assist.~~

~~Techniques to increase burnout are described in Section 4.3.17~~

~~**Achieved environmental benefits**~~
~~Extraction of energy value from the waste for possible recovery/use.~~

~~Improvement of residue quality by decreasing the proportion of unburned material left in it. See Section 4.3.17 for further information.~~
~~Diminishing energy returns are seen as waste is progressively burned out to a greater extent. This is because the amount of energy remaining in reasonably well burned out waste is low. The main benefit to be obtained from increased burnout is therefore less one of energy recovery and more one of improving residue quality.~~
Merged with Section 4.3.17

~~4.4.4 Reducing excess air volumes~~

~~See comments in Section 4.4.2 for further information.~~

~~4.4.5 Other energy loss reduction measures~~

To the TWG: description of the techniques is missing. In addition some of these techniques are already described in other Sections e.g. good waste burnout in Section 4.3.17
~~**Description**~~
~~In addition to other techniques described in this document (see Sections 4.4.2, 4.4.3, 4.4.12), the following losses and reduction techniques can be used:~~

~~**Table 4.16: Techniques for the reduction of various energy losses at WI plants**~~

~~**Description of energy loss**~~	~~**Techniques to reduce losses**~~	~~**Comments**~~
~~Heat radiation and convection – mainly from furnace and boiler~~	~~• lagging~~ ~~• build plant inside building~~	~~For a municipal plant losses can be limited to ercury. 1 % of energy input.~~
~~Losses with solid residues (bottom and fly ashes)~~	~~• good waste burnout~~ ~~• use heat from slag bath~~	~~For a municipal plant losses are in the order of 0.5 % - 1.0 % - most with bottom ash.~~
~~Boiler blowdowns and effluent~~	~~Re-use of the energy in the water for building heating at the plant.~~	~~Closed loop for cooling purposes~~
~~Fouling of boiler reduces heat transfer efficiency~~	~~• Design to lower the boiler fouling rate~~ ~~• Effective boiler cleaning – see Section 4.4.12~~	
~~Start-up and shutdown procedures~~	~~Avoid SU and SD by design and procedures for continuous operation and good maintenance~~	~~Example: design to reduce boiler fouling may reduce SU and SD frequency and improve availability.~~
~~Fast changes in waste characteristics or heat demand~~	~~• waste mixing and quality assurance/control~~ ~~• supply heat to buffer storage network~~	~~Techniques that increase stability of input and output will assist ability to optimise for the local circumstances.~~
~~Plant failures/outage~~	~~Maintenance procedures to prevent failures~~	~~Some outages may result in partial shut-down of energy recovery equipment (e.g. TG set). Others may require waste diversion from the plant and hence loss of throughput where storage is not an option.~~
~~Reductions/variations in external demand for energy~~	~~• secured contracts with user improve possibility of maximising supply of recovered energy~~ ~~• supply of heat to buffer storage network~~	~~External demand for the recovered energy has a major impact on ability of the plant to supply the energy. Generally more of an issue for heat than electricity.~~
~~Losses by measuring devices and instruments~~	~~• Use of measuring systems with low pressure drop and precise results~~	~~New instruments allow e.g. for steam measuring nearly zero losses with high accuracy.~~
~~Notes: SU = start-up, SD = shutdown~~ ~~*Source:* adapted from [28, FEAD, 2002], [74, TWGComments, 2004]~~		

~~Achieved environmental benefits~~
~~The additional energy recovered may be supplied for use.~~

~~Cross-media effects~~
~~Information not supplied.~~

~~Operational data~~
~~Furnaces, boilers and some ducting are commonly covered with rock wool lagging or other insulating material to limit heat losses and to limit external temperatures for operator safety. [74, TWGComments, 2004]~~

~~Applicability~~
~~The techniques described can help to reduce losses at all installations. However, Site-specific factors may mean that Some techniques are not locally available or not relevant (e.g. heat recovery from slag discharger, blowdown or heat buffer storage are considered only where heat at low characteristics can be sold all year around) [74, TWGComments, 2004]~~

~~Economics~~
~~Information not supplied.~~

~~Driving force for implementation~~
~~Information not supplied.~~

~~Example plants~~
~~Information not supplied.~~

~~Reference literature~~
~~[28, FEAD, 2002], [64, TWGComments, 2003]~~

4.4.6 Reduction of overall process energy consumption

Description

- Use of an integrated approach to target overall installation energy optimisation rather than optimising each separate process unit [74, TWGComments, 2004].
- Placement of high-temperature equipment upstream of lower temperature or high temperature drop equipment.
- Use of heat exchangers to reduce energy inputs.
- Use of energy generated by the WI plant that would otherwise not be used or supplied, to replace the import of external energy sources.
- Use of frequency-controlled rotating equipment.
- Use of regenerative network braking units.

Technical description
The incineration process itself requires energy for the operation of the plant. This energy can be recovered from the waste. The amount of energy required depends upon the type of waste being burned and the design of the plant.

The reduction of the installation's energy requirements needs to be balanced against the need to ensure effective incineration, to treat the waste and control emissions (particularly to air).

Common sources of significant process energy consumption are:

- waste pretreatment (shredders, etc.);
- waste transfer/loading equipment (e.g. pumps/cranes and grabs/screw feeders);
- fuels for combustion support and start-up/shutdown (most common for low CV wastes);
- induced and forced draught fan to overcome pressure drops and for combustion air;

- air-cooled condensers;
- flue-gas heating after wet flue-gas treatments (which cool flue-gases more than semi-wet and dry systems);
- flue-gas heating before ~~for~~ specific air pollution control devices (e.g. bag filters, SCR systems);
- flue-gas reheating before final discharge to reduce ~~for reduction in~~ plume visibility;
- electricity demand from other devices.

In many cases, particularly where a step change in FGC technology is required, the lower the emissions ~~ELVs~~ the more energy is consumed by the FGC system. It is therefore important that the cross-media impact of increased energy consumption is considered when seeking to reduce emission levels.

The following techniques ~~and measures can~~ reduce process demand:

- ~~avoiding the use of unnecessary equipment~~
- The use of an integrated approach to target overall installation energy optimisation rather than optimising each separate process unit [74, TWGComments, 2004].
- The placement of high-temperature equipment upstream of lower temperature or high temperature drop equipment.
- The use of heat exchangers to reduce energy inputs, e.g. for SCR systems.
- The use of energy generated by the WI plant that would otherwise not be used or supplied, to replace the import of energy from outside ~~external energy sources~~.
- The use of frequency-controlled rotating equipment for those equipment parts that operate at variable speeds, such as fans and pumps, where they are effectively often operated at reduced load. This will reduce their average energy consumption substantially, because pressure variations will be realised by varying speeds and not by valves.
- The use of a regenerative network braking system on the waste feed crane.

The regenerative network braking system feeds the energy generated during lowering and decelerating back to the supply network. This energy can also be used to power the other motions of the crane. Regenerative network braking eliminates the need for braking resistors [92, Denmark, 2015].

Achieved environmental benefits
Reducing the process demand reduces the need for external energy generation and/or allows the export of greater quantities of energy. The additional energy recovered may be supplied for use.

Environmental performance and operational data
[28, FEAD, 2002]
For a municipal incineration plant, the electricity consumption is typically between 60 kWh/t and 190 kWh/t of waste, depending on the LCV.

An average electricity self-consumption value of 75 kWh/t of waste is reported for: a MSWI incinerating waste with a LCV of 9 200 kJ/kg, generating electrical power only (not heat), ~~complying with EC/2000/76 ELVs~~ using a semi-wet cleaning system and SNCR deNO$_X$, and with no depluming device. In a MSWI such as this one, without pretreatment, flue-gas reheating, or plume visibility reduction reheating, the main electrical consumption levels are roughly:

- induced draught fan: 30 %;
- forced draught fan: 20 %;
- feed pumps and other water pumps: 20 %;
- air-cooled condenser: 10 %;
- others: 20 %.

[74, TWGComments, 2004]

Larger throughput plants have an economy of scale, which results in lower energy consumption per unit of waste treated. This is shown in Table 4.17 below.

Table 4.17: Plant throughput and total process energy demand for MSWI in Germany

MSWI plant size range (t/yr)	Process energy demand (kWh/t waste input)
Up to 150 000	300–700
150 000–250 000	150–500
More than 250 000	60–200

Source: [31, Energysub-group, 2003]

The size of such economies of scale may be less dramatic than the example data suggest above. The generally higher parasitic load values seen in the table above are most likely to be explained by the application of complex, retrofitted FGC systems that have often been applied in Germany in order to guarantee low emission levels~~ at values sometimes well below 2000/76/EC~~. [64, TWGComments, 2003]. To the TWG: to be updated

A regenerative network braking system can be used for waste handling and for the handling of residues. This type of system reduce the energy consumption by up to 30 %, and it eliminates the need for maintenance of the resistors. It stabilises the electricity supply to the crane against network disturbances and filters harmonic distortions from the crane to the supply network. It enables higher hoist, trolley traverse and brigde travel speeds, when the supply voltage is less than 500 V. For example, if the supply voltage is 380 V, this technique increases crane speeds by 30 % [92, Denmark, 2015].

Cross-media effects
Reducing energy consumption by FGC equipment design and operation can result in increased emissions to air.

Technical considerations relevant to applicability
Much of the additional energy consumed arises from the application of additional flue-gas treatment techniques that themselves consume energy. Reducing process energy consumption by eliminating these components is ~~less~~ not appropriate if it is not counterbalanced by the use of other techniques that ensure the same or a better environmental performance. ~~Where there are local environmental drivers that justify further reductions in emissions~~.

Options for optimisation are greatest at new installations. There, it will be possible to examine and select from a variety of overall designs in order to achieve a solution that balances emission reduction against energy consumption.

At existing installations, options may be more limited, owing to the expense (and additional technical risk) associated with a complete redesign. Plants that have been retrofitted to achieve a ~~particular~~ better environmental performance ~~emission limit values~~ generally have to fit tail-end gas cleaning equipment and will therefore have higher energy consumption figures.

Economics
Operational cost savings may be made by reducing the external process energy demand. Where the energy saved can be exported, this can result in additional income.

The capital costs of a significant redesign at existing plants may, in some cases, be large in relation to the benefits that can be achieved.

The cost for the installation of the regenerative network braking system depends on the crane size [92, Denmark, 2015].

Driving force for implementation

The driving force is the additional income from energy sales or reductions in operating costs due to the reduced energy use.

Example plants

No information provided~~ not supplied~~.

Reference literature

[28, FEAD, 2002], [31, Energysub-group, 2003], [64, TWGComments, 2003], [92, Denmark, 2015]

4.4.7 Selection of turbine

Description

Techniques to consider are~~ main types of turbine in common use in incineration plants are~~:

- back pressure turbines;
- condensing turbines;
- extraction condensing turbines;
- double stage condensing turbines.

Technical description

Back pressure turbines are used when a significant and possibly constant amount of heat can be supplied to customers. The back pressure level is dependent on the required temperature level of the supplied heat. The exhaust pressure of a back pressure turbine is above atmospheric (e.g. 4 bar absolute) [74, TWGComments, 2004]

Condensing turbines are used when there are few or no possibilities to supply heat to customers and the recovered energy is to be converted into electricity. The efficiency of the electricity production is influenced by the cooling system applied (see also Section 4.4.9). The exhaust pressure of a condensation turbine is under vacuum (e.g. 0.2 bar abs.) ~~and the low pressure part of a condensation turbine is much bigger~~. [74, TWGComments, 2004]

Extraction condensing turbines are condensing turbines with a significant extraction of steam at intermediate pressure for a particular purpose. There are nearly always some extraction(s) for process use ~~on~~ from a condensing turbine. Extraction condensing turbines are used when a significant and varying amount of heat or steam can be supplied to customers. The required amount of (low-pressure) steam is extracted from the turbine and the remaining steam is condensed.

Double stage condensing turbines heat up the steam between the two stages by using some of the input steam for superheating the steam in the second stage to reach higher energy production at low condensation temperatures, without damaging the turbine. [74, TWGComments, 2004]

Achieved environmental benefits

The type chosen has an influence on electricity production and energy output.

Steam tapping results in optimised energy use. Savings in fossil fuels lower pollutant and greenhouse gas emissions by reduced use of additional power from external generation stations.

Environmental performance and operational data

Turbines in MSWI plants are usually not very big, typically 10 $\mathrm{MW_e}$ (range from 1 $\mathrm{MW_e}$ to 74 ~~60~~ $\mathrm{MW_e}$). The number of bleeds is usually limited to three or four (which is different to power plants where a turbine can have many more bleeds).

The low-pressure section of the turbine needs a minimum steam flow for cooling the blades, avoiding vibrations and preventing condensation.
If the remaining steam flow is too small in some operating conditions, instead of one turbo-generator with a high-pressure section and a low-pressure section, it is also possible to have two turbines (one high-pressure, one low-pressure). The choice is made in function of the local conditions and the optimum choice may vary over time. [74, TWGComments, 2004]

In order to improve the electrical generation output with condensation turbines, the steam required by the incineration process (e.g. for the de-aerator, air heater, soot blowers) is normally taken from the turbine after its expansion in the high-pressure part of the turbine. This is made by bleed(s) (also called 'extraction' or 'tapping'). These bleed(s) are said to be 'uncontrolled' because the pressure depends on the turbine load (the pressure can be divided by two at a bleed when the steam flow is reduced by 50 %). The bleed(s) are located in such a manner that the pressure(s) are high enough for the process requirement whatever the load of the turbine

Cross-media effects
Low condensation temperatures at the end of the turbine may cause corrosion by high humidity in the steam. [74, TWGComments, 2004]

Technical considerations relevant to applicability
The turbine selection must be made at the same time as the rest of steam cycle characteristics and depends more on available infrastructures and/or on the energy market ~~external aspects~~ than the incineration process. [64, TWGComments, 2003]

Economics
No information provided~~not supplied~~.

Driving force for implementation
No information provided~~not supplied~~.

Example plants
1. ~~RMVA Köln (~~DE54~~)~~
By steam tapping from a condensation turbine, various uses are found for the energy and the overall energy use can be optimised. The steam is carried to the turbine at a temperature of 400 °C and at a pressure of 40 bars. ~~The~~ Tapping ~~of the~~ steam at approximately 300 °C and 16 bar for local and remote steam use and ~~tapping~~ at approximately 200 °C and 4.8 bar for purely local use results in optimal energy exploitation. ~~Means that the energy can be exploited to the best possible effect.~~

The steam is used locally for air and water preheating for local systems and buildings~~, here particularly as process heat for steam generation,~~ and also for flue-gas cleaning ~~exhaust air~~. The remote steam is primarily used to support production processes, but also as a remote source for heating. [64, TWGComments, 2003]

2. Rennes plant (FR) – Retrofit To the TWG: is this plant taking part to the data collection?
Two lines each of 5 t/h of waste producing steam at 26 bar abs and 228 °C (saturated) for DH. In 1995, a third line of 8 t/h of waste was added producing steam at the same pressure and 380 °C (150 °C of superheat).

A TG set of 9.5 MVA receives the mixed steam from the three lines with an intermediate superheat. However, the TG set can run with any of the three lines shut down. This means that it can run with the superheat of 150 °C when the two lines of 5 t/h are stopped but also with saturated steam when the 8 t/h line is offline. The turbine uses only saturated steam.

3. Three plants in Paris (FR) To the TWG: one of these should be FR96, do you know the other?
These plants incinerate a total of 1 800 000 t/yr and supply 4 000 000 t/yr of steam (2 900 000 MWh_{th}/yr) to the Paris District Heating network, which corresponds to 45 % of the

demand. They also generate 290 000 MWh/yr of electricity, of which 160 000 MWh/yr are supplied to the national grid.

Steam is delivered at a pressure adjusted by valve between 12 bar and 21 bar according to the DH requirements and is delivered directly to the DH network without heat exchangers. A varying part of the steam comes back as condensate. The demineralisation plants are able to produce two thirds of the steam flow rate.

The large size of the DH demand in comparison to the steam generated and the fact that the three plants supply the same DH network, belong to the same owner and are operated by the same company leads to these specific choices for the equipment.
[74, TWGComments, 2004]

Reference literature
[64, TWGComments, 2003]

4.4.8 Increased steam parameters and application of special materials to decrease corrosion in boilers

Description
Techniques to consider are:

- cladding;
- composite boiler tubes;
- ceramic refractory material.

Technical description
Higher steam parameters increase the turbine efficiency and result in higher electricity production per tonne of waste burned. However, because of the corrosive nature of the gases generated by the waste when it is burned, incinerators cannot use the same temperatures and pressures as some primary power generators, e.g. 100–300 bar and 620 °C. For example, a normal maximum temperature is 540 °C in coal power plants.

There is a distinction between:

- the steam pressure which gives the temperature (saturation pressure) in the water walls (which can be protected by cladding) and in the heat exchange bundles; and
- the steam temperature (superheated steam) which gives the temperature in the superheaters. [64, TWGComments, 2003]

In general, unless special measures are taken to avoid the effects of corrosion (which result in reduced installation availability and increased costs), MSWIs are generally limited to 40–45 bar and 380–400 °C. Above these values there is a trade-off between:

- costs of special measures, e.g. special materials to reduce corrosion;
- costs of lost availability where increased maintenance is required;
- value of any additional electricity produced.

To reduce the effects of corrosion, nickel/chromium (main components) alloy cladding or other special materials can be used for protecting exposed heat-exchange surfaces from the flue-gases. The cladding usually starts after the refractory and can cover the first pass and the beginning of the second pass of the boiler. The refractory wall can also be air-cooled (slight overpressure) to reduce corrosion of the tubes behind the refractory. Ceramic tiles are also used to protect boiler tubes.

High-temperature corrosion of membrane walls and superheaters can be reduced by lowering the flue-gas temperature to under 650 °C before the superheaters and/or protecting heat-exchange surfaces with ceramic tiles or special alloys.

The main advantage of special alloys over a ceramic cover on the furnace walls is the better transfer of heat to the boiler, resulting in a lower temperature of the flue-gases before the first convection bundles.

An alternative to cladding is to install composite boiler tubes. Composite tubes consist of two tubes, inner and outer, metallurgically bonded together. They come in different alloy combinations. Installation of composite boiler tubes in waste incineration boilers has taken place since the 1970s. [64, TWGComments, 2003]

Achieved environmental benefits

- The greater plant availability means that the higher emissions associated with start-up and shutdown are reduced. (*from Section 4.3.22*)
- The high heat capacity of the refractory-lined furnace helps to reduce temperature fluctuations that may arise with wastes of variable LHV, thus promoting more stable incineration and reducing emissions from the combustion stage. (*from Section 4.3.22*)
- A higher electrical output per tonne of waste burned can be achieved by the increase of steam pressure and/or temperature. This higher efficiency reduces external (e.g. in power plants) use of fossil fuel (resource saving) and the related CO_2 emissions (GHG). [74, TWGComments, 2004]

Environmental performance and operational data

The cladding ~~This technique~~ involves an increased technological risk and requires high skill levels for assessment and maintenance.

Cross-media effects

Increased steam parameters without the application of special anti-corrosion measures increase the risk of corrosion and the associated maintenance costs and availability loss.

Technical considerations relevant to applicability

The use of increased steam parameters is applicable to all incinerators recovering electricity only, or where the heat proportion of CHP is low, to increase electricity outputs.

The technique has limited applicability to processes that have reliable options for the supply of steam or heat, since in such cases there is no need to increase electrical output and bear ~~with~~ the associated additional technical risk and costs~~, and the steam/heat energy can be supplied~~.

The use of cladding and other special materials is applied to reduce corrosion when using increased steam parameters and/or highly corrosive waste content.

Existing plants that have experienced rising LCV in the waste supplied may benefit from the use of special materials and cladding because it can reduce the maintenance costs and allow improved electrical outputs.

Economics

The cost of cladding can be discounted against reduced maintenance costs and income from electricity sales and improved plant availability.

The cost of cladding has been reported to be approximately EUR 3000/m^2.

The range of increase in income depends on the energy price obtained.

[32, Denmark, 2003] The table below is based on ~~actual~~ electricity and heat prices in Denmark in 2003 and on real operational data for a ~~modern~~ CHP MSWI with a capacity of 34 t/h. The table shows the outputs and income at various steam pressures.

Table 4.18: Example energy outputs and income at various steam pressures for a CHP MSWI using elevated steam pressures

Steam value	bar	50	40	30
Generator output	MW	19.6	18.6	17.3
Heat production	MJ/s	71.2	72.2	73.5
Change in electricity output	MW	0	-1	-2.3
Change in heat output	MJ/s	0	1	2.3
Economy				
Availability	h/yr	8 000	8 000	8 000
Electricity price	EUR/MWh	47	47	47
Heat price	EUR/MWh	18	18	18
Annual income change	**million EUR/yr**	**0.0**	**-0.25**	**-0.54**

Source: [32, Denmark, 2003]

According to this example, taking into account energy prices in Denmark, increasing the steam pressure from 40 bar to 50 bar results in an additional annual income of approximately EUR 250 000. Calculated over an operational period of 15 years (at 2002 inflation rates), this gives an additional income of approximately EUR 2.5 million.

These figures do not include the additional capital cost required to increase pressures from 40 bar to 50 bar. In this case, these additional costs were not considered to be significant (over 15 years) compared to the additional income gained over the same period.

A change of the pressure might mean a complete change of the piping and the valves of the vessel and also a change of the steam drum, which would then lead to the need to apply for a new permit under the Pressure Equipment Directive 97/23/EC. [74, TWGComments, 2004]

Driving force for implementation
Higher electricity prices will encourage adoption of this technique, as it will allow faster payback of the investments required.

Example plants
High steam parameters:

- Odense (DK): 50 bar, 520 °C, with cladding.
- AVI Amsterdam, AVR Botlek, AVR AVIRA and AVI Wijster (all NL).
- AVE-RVL Lenzing (AT): circulating fluidised bed receiving various waste fractions including approximately 60 % plastics produces steam at 78 bar and 500 °C.
- Ivry (FR) : 75 bar, 475 °C.
- Mataró (ES) : 60 bar, 380 °C.
- Lasse Sivert Est Anjou (FR) : 60 bar, 400 °C.

Retrofit improvement :

- Rennes (FR): 26 bar, 228 °C (saturation state); ~~when~~ a third line was added ~~its~~ with a boiler rated at 26 bar, 380 °C; the ~~two mixed steams are~~ the combined steam from both lines is sent to the TG.

Application of special materials:

- Retrofit improvement : Toulon, Thiverval (FR), Mataró (ES), Stoke on Trent (UK).
- New plant: Lasse Est Anjou (FR).

[74, TWGComments, 2004]

Reference literature
[32, Denmark, 2003], [28, FEAD, 2002], [2, infomil, 2002], [3, Austria, 2002], [64, TWGComments, 2003]

4.4.9 Reduction of condenser pressure (i.e. improve vacuum)

Description
Techniques to consider are:

- air cooling;
- evaporation water cooling;
- water cooling by convection.

Technical description
After leaving the low-pressure section of the steam turbine, the steam is condensed in condensers and the heat is then passed into a cooling fluid. The condensed water from steam is ~~generally~~ recirculated and used as boiler feed water. [74, TWGComments, 2004]

~~The temperature of the cold source at the turbine outlet is important for the turbine production.~~ The colder the cold source the higher the enthalpy drop and, therefore, the higher the electrical energy generation. For reasons of climate conditions, ~~it is obvious that~~ it is easier to achieve this low pressure in cooler climates. This is one reason why northern installations can ercury better efficiency than they can in southern countries. [64, TWGComments, 2003]

The lowest temperatures are obtained by condensing the steam, using either air or water as cooling fluid. These temperatures correspond to pressures below the atmospheric pressure (i.e. vacuum).

Where a large DH network uses the full load production of the MSWI all year long, as occurs in Sweden or Denmark, the cold source is the cold water returned by the DH (see also Section 3.2.3.2 of the Reference Document on Best Available Techniques for Large Combustion Plants) which can sometimes be very low (e.g. 40 °C or 60 °C, seeTable 4.19 in Section 4.4.16).

~~Vacuum is not "unlimited".~~ As soon as the steam crosses the saturation line of the 'Mollier' diagram, it starts to be wet and the percentage of moisture increases with the expansion of the steam in the turbine. In order to avoid damage to the end stages of the turbine (erosion by water drops), the amount of moisture must be limited (often to around 10 %).
[74, TWGComments, 2004]

Achieved environmental benefits
Increased electrical energy generation is possible by improving the vacuum.

Environmental performance and operational data
The gains in electrical output are greater with the reduction of condenser pressure and the techniques are therefore of greater benefit for condensing turbines. [64, TWGComments, 2003]

Condenser pressure/condenser types

With an ACC (air-cooled condenser) and air at 10 °C, typically a pressure in the condenser of 100 mbar absolute to 85 mbar absolute can be obtained, depending on the condenser surface. When the ambient air temperature is 20 °C, the pressure in the same ACC will be respectively

200 mbar absolute to 120 mbar absolute. The design is a compromise between a reasonable heat-exchange surface and low condensation pressure. [74, TWGComments, 2004]

With a **hydro-condenser** (once-through cooling condenser, open loop) using river water at 10 °C, the pressure in the condenser will be around 40–80 mbar absolute, because the heat exchange is easier with water.

With an **atmospheric cooling tower**[7], the temperature of water is bound to the temperature of the air and to its hygrometry (temperature of the humid bulb). If the wet bulb temperature is 10 °C, the condenser pressure will be around 60 mbar absolute. The steam plume above the tower can be reduced (but not avoided) by the tower design and there will be a slight increase in the condenser pressure. This type of cooler may involve risk of legionella, due to water evaporation and direct contact. It is mainly applied for small cooling requirements (such as turbine auxiliaries). [74, TWGComments, 2004]

~~According to an overview calculation~~Theoretically, ~~an increase in~~ electrical energy generation increases from 24.1 % to 25.8 % (+ 7 %) if vacuum improves from 100 mbar to 40 mbar. [64, TWGComments, 2003]

Cross-media effects

In an open loop, i.e. a once-through cooling hydro-condenser, assuming a water temperature increase of 10 °C, the water flow needed will be around 180 m^3/MWh generated.

In a closed loop with a cooling tower, the water consumption (evaporated water) is approximately 2.5 m^3/MWh generated or 3 m^3/MWh generated.

Both open and closed loop systems may require the addition of chemicals, or other techniques, to reduce fouling in the heat-exchange system ~~as well as eventual~~ and possibly process water treatment. The impacts of discharge are much larger for open systems.

Low condenser pressure increases the humidity in the steam which can increase wear in the turbine [74, TWGComments, 2004]

Air condensers generate noise emissions. Detailed design (e.g. shielding, frequency converter noise level) is therefore important.

Cleaning of the surface of condensers is very important for their efficiency and should be carried out at low temperatures. [74, TWGComments, 2004]

Technical considerations relevant to applicability

Where electrical generation is of lower priority (e.g. where heat supply is possible), the turbine outlet pressure can be above atmospheric. In this case, the turbine is said to be operating with back pressure and the (remaining) steam is condensed in the condenser itself.

In arid areas, air-cooled condensers are often the only possible type applicable. [74, TWGComments, 2004]

Open loop hydro-condensers are only suited to locations where there is an abundant water supply that can tolerate the heating effect of the subsequent discharge.

Economics

The use of higher pressure reduction techniques will be most economical where electrical energy has a higher price.

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[7] Cooling tower or refrigeration tower. The steam condenser cooling fluid is water. This water is in a closed loop, and is cooled itself by contact with ambient air in a cooling tower. In this tower, part of the water is evaporated. This produces a water vapour plume above the tower.

For ACCs, higher pressure drops require equipment with a larger surface area and also better-performing fan motors, which increases costs.

Driving force for implementation

Electricity prices are a key driver.

Another driving force is easier synchronisation of the TG set when the ambient temperature is high. [74, TWGComments, 2004]

Example plants

Most European plants have an ACC installed, e.g. Issy and Ivry plant, near Paris, and Bellegarde (FR); Southampton (UK) (under construction). Both have open loop hydro-condensers.

Strasbourg and Rouen (FR) both have closed loop hydro-condensers with cooling towers.

Reference literature

[28, FEAD, 2002] [64, TWGComments, 2003]

4.4.10 Selection of cooling system

See the Reference Document on the Application of Best Available Techniques to Industrial Cooling Systems. [74, TWGComments, 2004]

~~**Description**~~

~~Choosing the cooling system that is best suited to the local environmental conditions helps to reduce overall environmental impacts.~~

~~There are three main cooling systems:~~

~~1. Water cooling by convection:~~

~~This system uses surface water which is discharged to surface again after being heated up several degrees. This cooling system requires much water and gives a large thermal load to local surface water. It is mainly used if large flow rivers are available or on the coast. Noise level is low. Cleaning facilities for water are normally necessary, which may lead to harm to fish and other biota in water source as the water is screened/filtered. Care should be taken to reduce this in design of water intake arrangements. [74, TWGComments, 2004]~~

~~2. Evaporation water cooling:~~

~~Water is used for condenser cooling. This is not discharged, but recycled after passing an evaporation cooling tower, where it is cooled by the evaporation of a small part of the water. A small water stream must be discharged to keep control of the water quality within the system.~~

~~There are three main technical variants of evaporation cooling:~~

- ~~forced draught cooling towers, where the air, required for evaporation of the water, is provided by means of a fan, with the subsequent electricity consumption~~
- ~~natural convection cooling towers, where the draught of the air is caused by the (small) temperature increase of the air temperature (the large concrete cooling towers of 100 metres high) and~~
- ~~hybrid cooling towers, where part of the heat in the water is transported to air by cooling bundles (“air cooling”), thus reducing the size of the water vapour plume.~~

~~Noise level of forced draught systems is high, and the level of convection draught systems is medium.~~

~~This type of cooler may involve a risk with respect to legionella, due to water evaporation and direct contact. [74, TWGComments, 2004]~~

~~3. Air cooling:~~
~~Here the steam is condensed in a heat exchanger of typical design (e.g. "camping tent model") with air. These condensers use larger amounts of electricity, as the required air movement is caused by large fans.~~

~~Noise levels are higher. The surface of the condenser needs regular cleaning. [74, TWGComments, 2004]~~

~~Influence on electricity efficiency is dependent on water temperatures, air temperatures and air humidity (wet bulb temperature), but generally water convection cooling scores best, followed by evaporation cooling and then followed by air cooling. Difference in efficiency between convection cooling and air cooling is normally in the range of 2 – 3 %.~~

~~See also the BREF "Reference Document on the Application of Best Available Techniques to Industrial Cooling Systems". [74, TWGComments, 2004]~~

~~Achieved environmental benefits~~
~~Depending on type chosen (see description above) it is possible to:~~

- ~~decrease installation parasitic electricity demand~~
- ~~decrease thermal impacts of discharged warm water~~
- ~~decrease noise impacts~~
- ~~decrease visual impacts.~~

~~Cross-media effects~~
~~Described in description above.~~

~~Operational data~~
~~Information not supplied~~

~~Applicability~~
~~Selection of cooling system dependent upon main local environmental and health issues and relative importance of cross-media effects associated with each system.~~

~~Water cooling by convection (type 1 above) is not applicable in dry inland situations.~~

~~Economics~~
~~Information not supplied~~

~~Driving force for implementation~~
~~Higher prices for electricity may encourage interest in convection cooling.~~

~~Example plants~~
~~Issy and Ivry plant, near Paris, France; Southampton, UK (under construction). Both have open loop hydro-condensers.~~

~~Strasbourg, and Rouen, France - both have closed loop hydro-condensers with cooling towers.~~

~~Reference literature~~
~~[64, TWGComments, 2003]~~

4.4.11 Optimisation of boiler design ~~architecture~~

Description

Optimisation of boiler design in order to:

- keep the flue-gas temperature as low as possible at the boiler exit;
- avoid fouling;
- guarantee low and homogeneous gas velocities across the whole boiler;
- achieve a good heat exchange.

Technical description

The recovered heat is the energy that is transferred from the flue-gases to the steam (or hot water). The remaining energy of the flue-gas at the boiler exit is most commonly lost (unless heat-exchange systems are used further downstream). So, in order to maximise energy recovery, it is usually favourable for the temperature of the flue-gases at the exit of the boiler to be reduced.

Boiler fouling has two effects on energy recovery. The first one is that it decreases the heat-exchange coefficients and, therefore, leads a reduction of the heat recovery. The second and most important one is that it leads to the blocking up of the heat-exchange bundles and, therefore, to the shutdown of the plant. Another unwanted effect of boiler fouling is that it increases the risk of corrosion under the deposited layer. In general, the boiler is designed to be manually cleaned once a year as a maximum to limit boiler fouling (see Section 4.4.19).

A good boiler must have a sufficient heat-exchange surface but also well-designed geometry in order to limit fouling. This can be achieved either in vertical, horizontal or combined vertical-horizontal boiler concepts (see Section 2.4.4.2) [74, TWGComments, 2004] Examples of good design practices are reported as follows:

- Gas velocities must be low (to avoid erosion) and homogeneous (to avoid high-velocity areas and to avoid stagnation, which can induce fouling) over the whole diameter (space) of the boiler.
- To maintain low gas velocities, the passes must have a wide cross-section and their geometry must be ~~‘~~aerodynamic~~’~~.
- The first pass(es) of the boiler should not contain heat exchangers and should have sufficient dimensions (especially height) in order to allow flue-gas temperatures below 650–700 °C. However, they can be cooled by water walls (working by convection). (These tube walls, in fact, envelop the whole boiler except the economiser. In steam boilers, they are generally a part of the vaporiser.) Radiating heat exchangers may also be placed in the open passes at higher temperatures.
- The first tube bundles must not be installed at locations where the fly ashes are still sticky, i.e. where temperatures are too high.
- The gaps between the tubes of the bundles must be wide enough to avoid ‘build-up ~~ing~~’ in between them (by fouling).
- Water-steam circulation in the membrane wall and convective exchangers should be optimal in order to prevent hot spots, inefficient flue-gas cooling, etc.
- Horizontal boilers should be designed in order to avoid a flue-gas preferential path, leading to temperature stratification and ineffective heat exchange.
- Suitable devices for cleaning the boiler of fouling *in situ* should be provided.
- Optimisation of the convective exchanger arrangement (counter-flow, co-current flow, etc.) in order to optimise the surface according to the tube wall temperature and prevent corrosion.

[28, FEAD, 2002], [74, TWGComments, 2004]

Achieved environmental benefits
Greater plant availability and better heat exchange allow increased overall energy recovery possibilities.

Design of the boiler to reduce ~~boiler~~ fouling also reduces the retention of dust within temperature zones where there may be ~~that may~~ increased risk of dioxin formation.

Environmental performance and operational data
No ~~additional~~ information provided ~~supplied~~.

Cross-media effects
None reported.

Technical considerations relevant to applicability
This technique is applicable at the design stage to all incineration plants with energy recovery boilers, particularly those looking ~~when concerns exist~~ to improve the operating life and efficiency. [74, TWGComments, 2004]

Economics
Operational savings through reduced maintenance and increased energy sales can lead to very short payback periods, and can then justify the adoption of these techniques at new installations.

Existing plants that are going to replace boilers or where lower boiler efficiencies are seen (generally less than 75 % heat transfer efficiency for municipal plants) may also take these factors into account in the design of the new system.

Driving force for implementation
Decreased maintenance, increased energy recovery and possible income from energy sales are all driving forces for implementation.

Example plants
Widely applied throughout Europe.

Reference literature
[28, FEAD, 2002], [2, infomil, 2002] [64, TWGComments, 2003]

4.4.12 Use of an integral furnace-boiler

To the TWG: Do we need this technique? As described it seems a standard engeeniering practice for grate incinerators

Description
The use of an integral furnace-boiler.

Technical description
Transporting very hot gases in ducts lined with refractory can be complex. It can result in sticky and sometimes molten deposits. In order to avoid this, the gas temperature is sometimes reduced by increasing the excess air volume, which can result in a loss of efficiency.

In an integral furnace-boiler, the boiler directly covers the furnace without intermediate piping. Therefore, the boiler tubes can cool the furnace sides. The tubes are protected by refractory and cool it (cross-benefit). A suitable design of the tubes and refractory allows fine control of the cooling of the furnace. Effective cooling of the furnace is essential to avoid clogging in the furnace, especially with a higher LHV.

Achieved environmental benefits
This technique improves heat recovery by reducing the heat losses by radiation at the furnace outlet (to complement the effect of the external lagging).

~~Allows the installation of SNCR de-NO$_X$ systems.~~

~~Reduction in the excess air requirement and hence flue-gas volumes.~~

Environmental performance and operational data
This technique avoids clogging in the furnace and, therefore, the need for shutdowns for manual cleaning ~~(e.g. with a pneumatic drill)~~.

Cross-media effects
None reported.

Technical considerations relevant to applicability
~~Suits all types of~~ Generally applicable to grate furnaces. Not applicable to rotary and oscillating kilns.
~~Indispensable for furnaces with a capacity above 10 t/h of waste.~~

~~No known lower capacity limit for integral boilers in "industrial" incinerators, i.e. capacity above 2.5 t/h.~~

Economics
Integral furnace-boilers are usually less expensive than a separate boiler for plants above very small-capacity furnaces (i.e. 1 t/h or 2 t/h).

Driving force for implementation
This technique is normal practice for designers today.

Example plants
Most ~~modern~~ plants have an integral boiler-furnace (except rotary and oscillating kilns).

Reference literature
[28, FEAD, 2002] [64, TWGComments, 2003]

~~4.4.13 Use of water walls in the first (empty) pass~~

~~This technique has been described in Section 4.3.22 in the context of its benefit as a combustion related technique.~~

4.4.14 Use of a platen-type superheater

Description
The use of a platen-type superheater.

Technical description
Platen-type superheaters are flat panels of folded tubes installed in parallel with wide gaps in between and parallel to the gas flow. The inlet is protected by shells made of stainless steel, held in place with special cement.

The heat exchange is ~~made~~ carried out by radiation instead of convection; because of this, these superheaters can be installed at hotter locations than the tube bundles (in flue-gases up to 800 °C ~~on~~ when incinerating municipal waste), with limited fouling and reduced erosion and corrosion.

On these platen superheaters, fouling can stabilise when its thickness is around 2 cm. There is no blocking, therefore,manual cleaning and associated shutdowns are greatly reduced.

Due to radiation exchange, the steam temperature can remain constant over a period of one year of operation. Erosion and corrosion are significantly delayed.

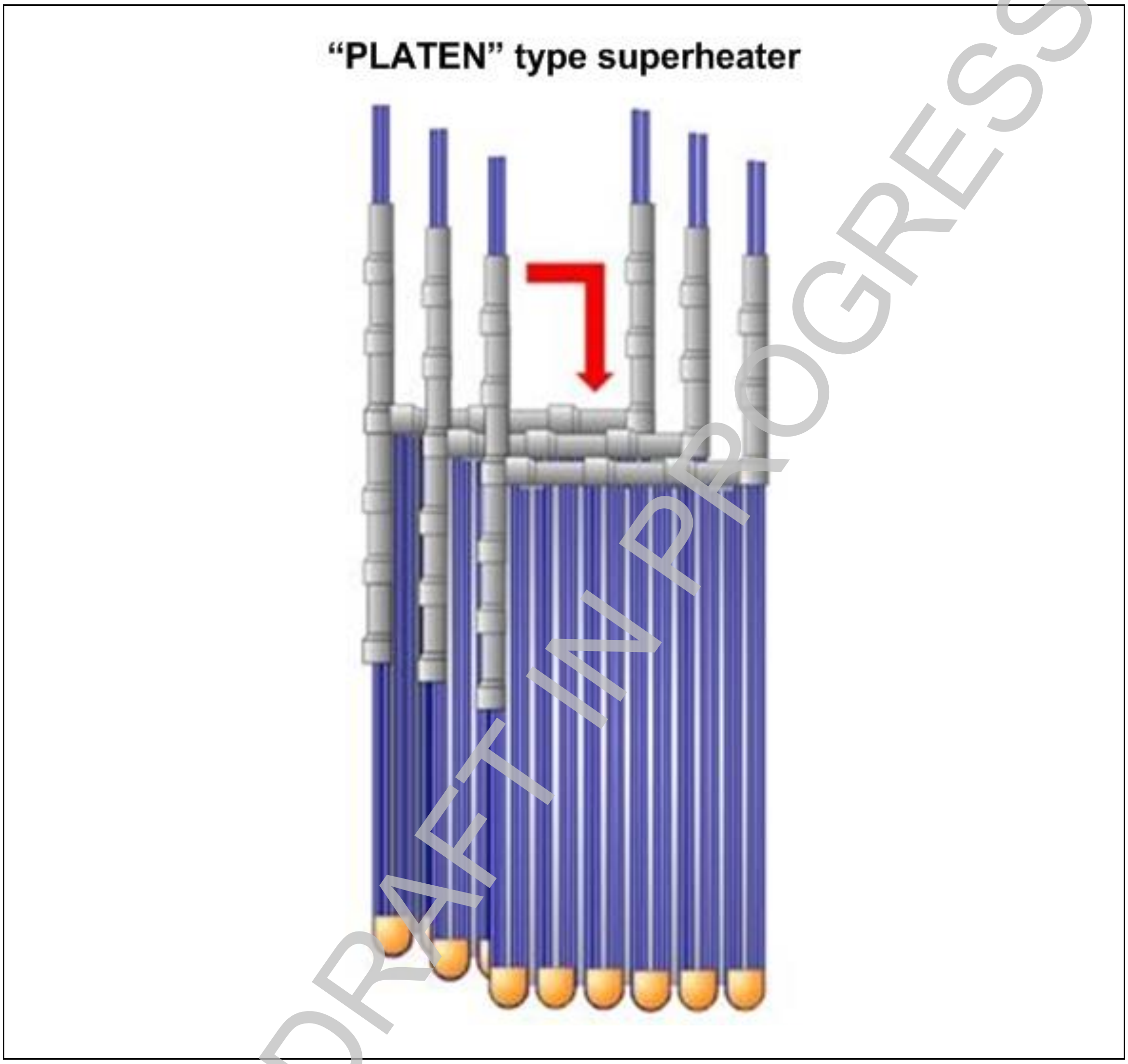


Figure 4.4: Schematic diagram of a platen-type superheater

Achieved environmental benefits

This technique increases energy recovery. ~~These~~ Platen-type superheaters allow a high superheated steam temperature with good availability and stability.

Environmental performance and operational data

No information provided ~~not supplied~~.

Cross-media effects

None reported.

Technical considerations relevant to applicability

It can be installed in ~~any~~ boilers with two or three open passes.

Economics

This technique is less expensive than bundles for last-stage superheaters (the hotter ones) when installed in areas with hotter flue-gas temperatures (second or third pass).

Use of this type of superheater may increase construction costs and this needs to be considered against the additional heat exchanger life that may be gained.

To the TWG: The overall economics is not very clear. Compared to what exactly would this technique be cheaper and more expensive?

Driving force for implementation

The driving force is the longer operation period with a high superheated steam temperature.

Example plants

- Toulon 3, Thiverval 3, Lons le Saunier, Cergy Saint-Ouen l'Aumône, Rennes 3, Monthyon, Chaumont, Nice 4, Belfort, Villefranche sur Saône, Toulouse-Mirail 1 and 2, Lasse (Saumur) (FR).
- Thumaide (BE).
- London SELCHP, Stoke-on-Trent, Dudley, Wolverhampton, Chineham, Marchwood (UK).
- Mataró (ES).
- Maia, Loures and Santa Cruz (Madeira) (PT).
- Piacenza (IT).
- Moscow (Russia).

Reference literature

[28, FEAD, 2002] [64, TWGComments, 2003]

4.4.15 Reduction of flue-gas temperatures after the boiler

Description

Techniques to consider are:

- the use of heat exchangers made of corrosion-resistant materials;
- design of the cycle to avoid conditions leading to corrosion.

Technical description

[2, infomil, 2002]

Additional heat-exchange capacity in the boiler can improve possibilities for use of that heat elsewhere and, hence, can contribute to improved energy efficiency. How much the flue-gas temperature at the end of the boiler can be reduced depends on:

- the fact that at temperature levels below 180 °C there is an increased risk of corrosion (as the dew point of the various acids is progressively approached);
- whether the heat in the flue-gases is required for the operation of subsequent flue-gas cleaning equipment;
- whether there is a beneficial use for the additional heat recovered at low temperature.

With MSW flue-gases (and other flue-gases containing these substances), the corrosion risks arise not only from HCl but from the SO_X, which are often the first to attack steel. The dew point depends on the concentrations of the acid gases in the flue-gases. In clean gas it can be around 100 °C, in raw gas 130 °C or more.

The key temperature to consider in terms of corrosion risk is not the temperature of the flue-gas but the (lower) surface temperature of the (cooled) metal tubes of the exchanger (which is necessarily colder than the flue-gas). [74, TWGComments, 2004]

Heat exchangers~~, which are~~ made of special materials (enamel~~, carbon~~) reduce low temperature corrosion problems. An example is found at AVI Amsterdam, where a heat exchanger is located after the spray absorber system and the related ESP. An additional advantage of this is the related reduction of scrubbing temperature, which improves the efficiency of the scrubbing system.

It is possible to design the cycle in such a manner as to avoid the corrosion conditions. In Sweden, for example, it is quite common to install a separate ~~'~~waste heat boiler~~'~~ after the main boiler or ESP. It is often cooled by a separate hot water circuit and by a heat exchanger to the district heating net. The outlet flue-gas temperature is normally about 130–140 °C and the water inlet temperature should not be under 115–120 °C to avoid corrosion. At these temperature levels, normal carbon steel tubes can be used without corrosion problems. [64, TWGComments, 2003]

Achieved environmental benefits

The recovered heat (temperature level 120 °C for example) can be used for heating purposes and/or internally for preheating of the boiler feed-water, etc.

Environmental performance and operational data

[28, FEAD, 2002]

Lowering the flue-gas temperature at the boiler outlet is limited by the acid dew point, which is a very important limitation in many FGC systems. In addition, the flue-gas cleaning system may require a working temperature or a temperature difference, for example:

- With semi-wet FGC processes, the minimum temperature at the inlet is determined by the fact that the water injection decreases the temperature of the gases. Typically, it will be 190 °C or 200 °C, and can be higher.
- A dry FGC process can generally accept 130–300 °C. With dry sodium bicarbonate, the minimum required temperature is 170 °C to obtain a fast ~~transformation~~ expansion of the sodium bicarbonate´s ~~into higher~~ surface area and, ~~hence~~ subsequently, more efficient sodium carbonate (the so-called popcorn or diatomite effect). The consumption of reagent is different according to the temperature.

Wet FGC systems do not have a theoretical minimum inlet temperature – the lower the gas temperature at the scrubber inlet, the lower the water consumption of the scrubber.

- Wet FGC systems do not have a theoretical minimum inlet temperature – the lower the gas temperature at the scrubber inlet, the lower the water consumption of the scrubber.

[74, TWGComments, 2004]

Cross-media effects

With flue-gas cleaning systems that require the flue-gases to be above a particular operational temperature (e.g. bag filters, SCR), any heat removed will need to be re-added~~ by some means~~ later in the process. Such reheating is likely to result in additional consumption of primary fuels or external power.

A low outlet gas temperature at the boiler outlet involves risks of corrosion (internal and external). Then specific material protection~~, etc. can~~ may be required.

Space requirement may limit the implementation in existing plants.

Technical considerations relevant to applicability

Reducing the flue-gas temperature after the boiler is only applicable where:

- the heat extracted can be supplied and put to some useful purpose;
- subsequent flue-gas cleaning systems are not adversely affected.

Careful consideration must be given to the compatibility of this technique with subsequent flue-gas cleaning systems. This is especially the case where bag filters, SCR or other systems that require particular operational temperatures or conditions are used.

Economics

The system is most likely to be economically viable where the value/price paid for the additional heat recovered heat is high.

Driving force for implementation

Supply of additional heat recovered.

Example plants

- AVI Amsterdam (NL).
- Brescia (IT).
- Many plants in Sweden and Denmark.
- Sheffield (UK).
- Rennes, Nice, Saint-Ouen (FR).
- Monaco.

Reference literature

[2, infomil, 2002] [64, TWGComments, 2003]

4.4.16 Use of flue-gas condensation scrubbers

Description

The use of a flue-gas condensation scrubber.

Technical description

The technique has already been described in Section 2.4.4.5.

In a flue-gas condensation scrubber, the flue-gas is cooled by direct contact with circulating cooling/process water. The cooling water, via an intermediate heat exchanger, is also typically in contact with a district heating network. Provided that the temperature of the district heating return flow is low enough, the water vapour in the flue-gas will reach its dew point. At the dew point, the vapour will condense and latent heat will be transferred to the intermediate cooling circuit. District heating water is thus heated by the energy recovered from the flue-gas condensation. Heat pumps can also be used to further increase energy recovery.

The flue-gas condensation scrubber also reduces the concentration of water-soluble pollutants such as HCl and, if NaOH is dosed into the scrubbing water, also of SO_2 and HF.

Removing water from the flue-gas reduces the gas volume. If the flue-gas fan is downstream of the flue-gas condesnser, the energy requirement for the fan is also reduced.

~~In summary, the technique involves the use of a cooled scrubber that condenses water vapour from the flue-gas of wet, semidry and dry systems normally as tail end solution. The cooling can be provided by heat exchange (using a heat pump system) with the returned district heating water.~~

Achieved environmental benefits

The use of condensing scrubbers allows the extraction of additional energy from the flue-gases for possible use or supply.

The amount of additional energy recovered is dependent upon the return water temperature in the district heating system.

Table 4.19: Relationship between the additional energy efficiency and the cooling medium (district heating) return temperature

District heating return temperature (°C)	Additional energy efficiency
40	14 %
50	7 %
60	0 %

Source: [5, RVF, 2002]

The drying effect on the flue-gases reduces the plume visibility. Where energy is used to reheat the plume, the amount of energy required to achieve a given reduction in plume visibility will be lower.

Emissions of ammonia to air (e.g. from SNCR) may be reduced. The ammonia is captured in the scrubber water. By using an ammonia stripper at the water treatment plant, it is possible to regenerate ammonia for use as a NO_X reduction reagent – thus replacing the need to purchase new ammonia~~, although stripping systems are reported to be complex and expensive~~.

The condensed water can be used to provide the majority of the scrubber feed water, therefore reducing water consumption.

Environmental performance and operational data

This technique is most applicable where:

- district heating gives a reliable low temperature return (this is essential and generally only available in colder climates);
- plume visibility is a concern;
- prices paid for the additional energy recovered justify the additional capital investment.

Because the technique is applied after the flue-gas cleaning stages, in principle the technique could be applied to any waste type.

The technique is applied at/near the end of the FGC system and could, therefore, be applied to new and existing plants ~~processes alike~~.

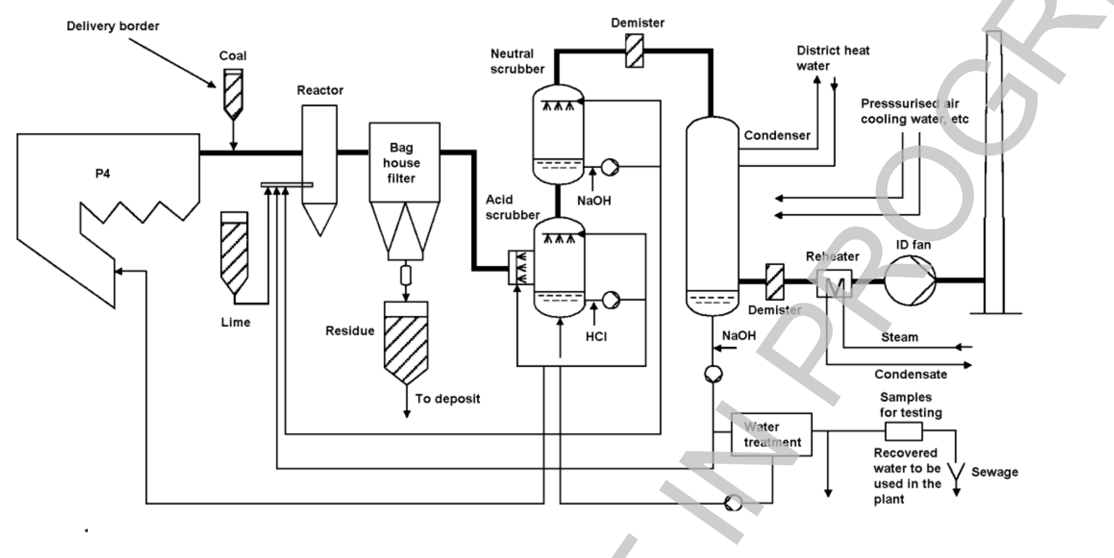
To the TWG: moved from Section 2.4.4.5 At the Hogdalen, Stockholm (SE) plant, this system is used with three conventional grate-fired steam boilers and one with a circulating fluidised bed. Flue-gases from the conventional grate-fired boilers are cooled in shot-cleaned waste heat boilers to about 140 °C. Return water from district heating is used as the cooling media.

FGC starts with a dry cleaning system for each boiler in which dry hydrated lime is injected and mixed with the flue-gas in a reactor. The acid impurities react with the lime and solid salts are formed which are removed in a fabric filter together with fly ash and the excess of lime. ~~The final reaction takes place in the dust cake on the bags.~~ The fluidised bed boiler has a slightly different reactor as recirculated dust from the fabric filter is slightly humidified before it is mixed with fresh lime and injected into the flue-gases.

The second cleaning stage includes wet scrubbers, which saturate the flue-gas and remove the rest of the acid gases, particularly hydrogen chloride (HCl) and sulphur dioxide (SO_2). The saturated gas leaving the wet scrubbers has a temperature of about 60 °C. It is sucked to a tube condenser, which is cooled by return water from the district heating network at a temperature of 40–50 °C. One wet system is used for all three grate boilers, although the CFB-boiler has its own.

If the return water temperature is 40 °C (the normal case for this plant but very low in comparison with the majority of European climates), 14 % additional energy is recovered in the condenser. On the other hand, if the return water temperature is 50 °C, only about 7 % additional energy is recovered. For extreme cases, when the return water temperature is as high as 60 °C, no extra heat is recovered.

In the Hogdalen, Stockholm case, the flue-gas is reheated before the induced draft fan and stack. Requiring the consumption of ~~and for this reheating~~ some MW *(to the TWG: could you please give a figure?)* of low-pressure steam ~~is consumed~~. It is also possible to operate without this reheat but with a wet fan and stack.



Source: [RVF, 2002 #5]

Figure 4.5: Pollution control and additional heat recovery by condensation of flue-gas water vapour at the Hogdalen waste-fired CHP plant

Cross-media effects

The low temperature of the flue-gases can result in condensation and, hence, corrosion in the chimney unless lined or double tube systems are used.

The condensed water will contain pollutants (removed from the flue-gas) that require treatment in a water treatment facility prior to discharge. Where an upstream wet scrubbing system is applied, the effluent from the condensing scrubber can be treated in the same facility.

The low temperature of the stack discharge will reduce the thermal buoyancy of the plume and, hence, reduce dispersion. This can be overcome by using a stack that is taller and/or has a reduced diameter.

Technical considerations relevant to applicability

The technique is ~~less~~ not applicable where:

- there is no user for the additional energy recovered;
- the cooling source (DH cold water return) is less reliable (i.e. warmer climates).

Plant size: The technique is known to have been applied at municipal plants of 37 000 t/yr throughput (DK), 175 000 t/yr throughput (SE) and 400 000 t/yr throughput (SE).

Economics

The total additional investment for the condensation stage is roughly estimated as EUR 3 million for four boilers serving a MSWI CHP plant with a capacity of 400 kt/yr.

Driving force for implementation

- Additional heat sales.
- Water conservation in dry regions.

[74, TWGComments, 2004]

Example plants

There are several examples in Sweden (see examples in Section 2.4.4.5). Possibilities are fewer in warmer climates owing to the reduced availability of cool DH water return.

Reference literature

[5, RVF, 2002], [64, TWGComments, 2003]

4.4.17 Use of heat pumps to increase heat recovery

Description

The use of a heat pump.

Technical description

The technique is ~~has already been~~ described in ~~some detail in~~ Section 2.4.4.6, where the three main types of heat pumps are also described ~~there~~.

In summary, heat pumps provide a means of uniting various relatively low temperature heat and cooling sources to upgrade the temperature of a strem ~~provide a stream at an upgraded temperature level~~. This allows, for example, the operation of condensing scrubbers (see Section 4.4.16) and the supply of the additional heat to users.

Achieved environmental benefits

This technique enables the recovery of additional energy by the use of condensing scrubbers.

An increase in the quantity of energy recovered of 23 % was reported when using absorption heat pumps in combination with condensing scrubbers. [35, Renova, 2002]

Based on the example of the Umea plant in northern Sweden (175 ktwaste/yr), the following estimated energy balance is seen:

The power balance including condensation and compressor heat pump:

Thermal power input	65 MW_{th} (approximately)
Electricity output from generator	15.1 MW_e
Internal electricity consumption	5.4 MW_e
Electricity output, net	9.7 MW_e
Hot water generation incl. cond.+ heat pump	54 MW_h
Own consumption for reheat	0.5 MW_h
Hot water to district heat	53.5 MW_h
Total power and heat for sale	**63 MW**

Without FG condensation and heat pumps, the power balance is estimated as:

Thermal power input	65 MW (approximately)
Electricity output, net	13 MW
Hot water to district heating, net	39 MW
Total power and heat for sale	**52 MW**

Environmental performance and operational data

See detailed information given in Section 2.4.4.6.

The technique is most applicable where:

- district heating gives a reliable low temperature return;
- district heating uses most of the available heat;
- prices paid for the additional energy recovered justify the additional capital investment;
- wet scrubbing is used;
- plume visibility is a concern.

[74, TWGComments, 2004]

Waste types: because the technique is applied after the flue-gas cleaning stages, in principle the technique could be applied to any waste type.

Plant size: the technique is known to have been applied at municipal plants of 175 000 t/yr throughput and 400 000 t/yr throughput.

New/existing: the technique is applied at/near the end of the FGC system and could therefore be applied to new and existing processes alike.

Cross-media effects
The heat pumps themselves require energy to function.

~~At wet ESP conditions,~~ For compressor-driven heat pumps, the ratio between output heat and compressor power (heat to power ratio) can be about five [5, RVF, 2002].

Technical considerations relevant to applicability
The technique is less applicable where there is no user for the additional energy recovered.

Economics
Heat pumps example for an MSWI in Sweden [35, Renova, 2002]:

- EUR 4.5 million installation in 1988;
- EUR 5.5 million installation in 2002 (12 MW capacity);
- income since 1998 = EUR 24.5 million.

The additional investment at the Umea plant for the condensation stage and electric motor-driven compressor heat pump and bigger water treatment plant is estimated to EUR 4 million. Using the proceeds for heat and power as given in Table 8.9, the simple payback time for this investment is therefore about 2.4 years (no allowance for increased maintenance and consumables).

Driving force for implementation
Additional heat sales and income are the drivers.

Example plants
Several examples in Sweden – see ~~also~~ Section 2.4.4.6.

Reference literature
[5, RVF, 2002] [64, TWGComments, 2003]

4.4.18 Special configurations of the water/steam cycle with external power plants

Description
The use of an external combustion plant to increase the steam parameters.

Technical description

[2, infomil, 2002] Due to the corrosive nature of the flue-gases, the efficiency of electricity production of municipal waste incineration is limited by the maximum acceptable temperature of the boiler tube materials and by the related maximum steam temperature (see Section 4.4.8).

~~Without the use of special materials to protect boiler tubes from corrosion, steam parameters in municipal waste incineration plants are generally less than or equal to 40 bar and 400 °C. In hazardous waste plants (where chloride etc. loading in the raw gas is higher) lower temperatures and pressures (e.g. 30 bar and 280 °C) are used to avoid excessive corrosion rates and consequent high maintenance costs. The adoption of higher steam parameters allows more heat to be transferred to the medium at higher temperature. The thermodynamic efficiency is, therefore, increased and hence the electrical output per tonne of waste. However, the costs of the materials required to protect the boiler tubes is generally significant in relation to the income to be received from the additional electricity sales (see Section 4.4.8).~~

An option that avoids higher temperatures of boiler tube materials is the superheating of the steam using cleaned flue-gases, which contain much less or no chlorine. This is possible if the ~~municipal~~ waste incineration plant can be combined with a combustion ~~power~~ plant of a sufficient capacity [94 Finland 2016].

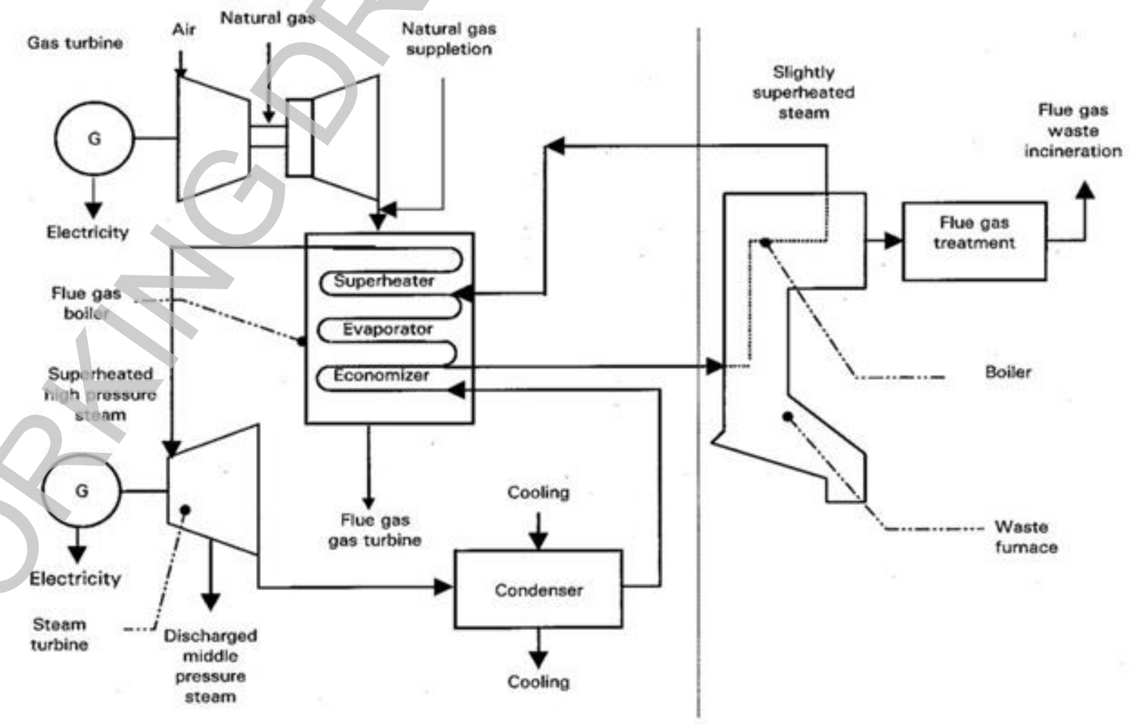
Achieved environmental benefits

Improved ~~overall~~ energy efficiency ~~by supply of heat to a synergistic user~~.

Environmental performance and operational data

With these types of configurations, the incineration process does not need to adopt high steam temperatures and therefore avoids corrosion and availability difficulties. However, sometimes the pressure may be increased in order to benefit further from the integration. In such cases, the higher steam temperature in the evaporator may lead to additional maintenance costs. For instance, at 40 bar the saturation temperature is 250 °C and at 100 bar 311 °C, a difference of 61 °C. Note that corrosion ~~mechanisms~~ increases exponentially with the external temperature on the boiler tube walls when coming into contact with flue-gases.

Example: Municipal waste incineration plant, AZN Moerdijk (NL)



Source: [2, infomil, 2002]

Figure 4.6: Combination of a waste incineration plant with a gas turbine power plant

This waste incineration plant is combined with an adjacent combined-cycle natural gas power plant, as indicated above. Steam at 100 bar, slightly superheated to 400 °C, is supplied to the waste heat boilers of the gas turbine plant, where it is superheated to approximately 545 °C.

Both the municipal waste incineration plant and the gas power plant have three separate lines. The design of both plants' combined process schemes enables all incineration and gas turbine lines to operate independently, although, under these circumstances, at a lower energy efficiency.

Example: Municipal waste incineration plant, Laanila, Oulun (FI)
The Laanila municipal waste incineration plant in Oulun (FI) is part of a system formed by the WI plant, one external superheater of 6 MW_{th} using lean gas coming from a nearby chemical plant to raise the steam temperature from 420 °C to 515 °C, and three other boilers combusting peat and oil. This plant system incorporates two steam turbine units with a total electrical output of 25 MW_e. The steam generated in the system is used to drive the turbines. For this purpose, the steam flow is conveyed with a pressure of 8.3 Mpa and temperature of 515 °C via a common steam pipe to the turbines. From this process, 100 MW_{th} are fed into the local district heating network.

The exhaust gases from the final superheater are introduced into the boiler's furnace area for further use of their heat content.

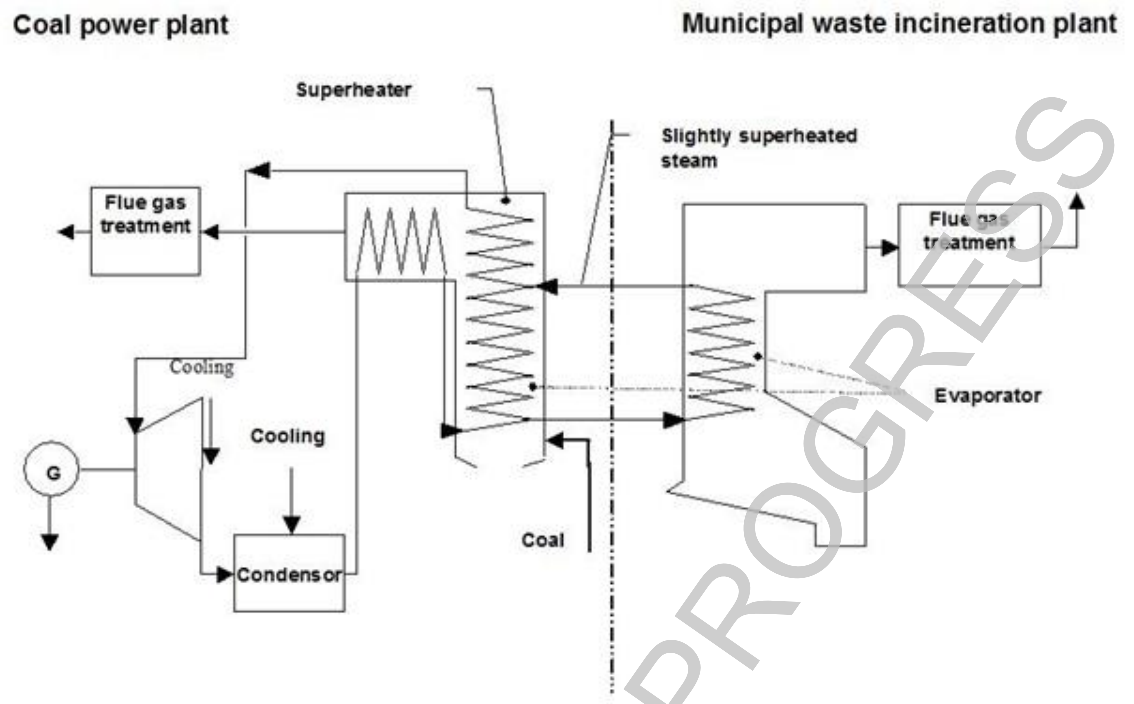
Table 4.20 provides a theoretical comparison between the achievable efficiency before and after the installation of the external superheater.

Table 4.20: Comparison of the achievable electrical energy efficiency with the external superheater at the Laanila plant

	Unit	**Without ESH**	**With ESH**
Steam pressure	Mpa	6.2 (1)	8.4
Seam temperature	°C	420	515
Thermal capacity DE	MW_{th}	48.0	48.0
Thermal capacity ESH	MW_{th}	0	4.7
Electrical output	MW_e	13.3	15.8
Efficiency range	%	27.2	29.3
Electrical efficiency range of the ESH	%	0.0	53.2

NB:
DE = direct exsport.
ESH = external superheater.
(1) The steam pressure is defined by the steam moisture in final turbine stage; with a temperature of 420 °C, a steam pressure of 8.4 Mpa cannot be achieved
Source: [94, Finland, 2016]

~~Example:~~
~~A similar configuration can be used in the combination of a waste incineration plant with a coal power plant. The coal power plant superheats the steam of the municipal incineration plant. In order to do this, the pressure of the steam produced by the municipal waste incineration plant has to be higher than usual.~~



For the TWG: Picture to be deleted
Source: [2, infomil, 2002]

~~**Figure 4.7: Municipal waste incineration plant in combination with a coal power plant**~~

~~This configuration was applied in the 1970s, by the combination of a municipal waste incineration plant in Munich with a large coal power plant. As the plant only functioned effectively when both the coal-fired boiler and the waste incineration plant were operational simultaneously, the combination was not considered cost-effective at the time.~~

This technique is mainly ~~applicable~~ suited where the focus of energy recovery is the production of electricity. It is less ~~applicable~~ suited to plants that can supply steam or heat directly to a user.

Cross-media effects
The external superheater increases the use of fossil fuels.
~~None reported.~~

Technical considerations relevant to applicability
Generally applicable to new plants.

~~Energy efficiency will only be increased where the user has a consistent demand and makes consistent use of the energy supplied.~~

Economics
The technique is only applicable where the location allows for a synergistic operation ~~is situated conveniently~~ and suitable commercial agreements are in place.

High electricity prices encourage the adoption of techniques that increase electrical ~~generation~~ efficiency. In this case, this has the impact of increasing the relative value of the steam/heat supplied by the incinerator to the adjacent power plant.

The external superheater is generally applicable to new plants. In existing plants, the retrofitting may not be economically sustainable [94 Finland, 2016].

Driving force for implementation
Integration of the energy supply with an external user increases the options for the use of energy derived from the waste.

Example plants

- ES08, FI04, NL06.
- ~~See text above. Also Bilbao Zabalgarbi (ES).~~
- Another waste incineration plant where steam is introduced in the water-steam cycle of an adjacent power plant is located in Austria. [74, TWGComments, 2004] To the TWG: is this plant taking part to the data collection?

Reference literature

[28, FEAD, 2002], [2, infomil, 2002] [64, TWGComments, 2003] [74, TWGComments, 2004] [94, Finland, 2016]

4.4.19 Effective ~~icient~~ cleaning of the convection bundles

Description

Techniques to consider include techniques for on-line cleaning, for off-line cleaning, and the prevention of higher temperature (above 650 °C) gases coming into contact with convective heat-exchange bundles.

Technical description

[2, infomil, 2002]
Clean boiler tubes and other heat-exchange surfaces result in better heat exchange. This may also reduce the risk of dioxin formation in the boiler.

Cleaning may be carried out on-line (during boiler operation) and off-line (during boiler shutdowns and maintenance periods). The dimensions of the boiler and heat exchanger design (e.g. tube spacings) influence the cleaning regime.

Techniques for on-line cleaning include the following:

- Mechanical rapping.
- Soot-blowing by steam injection.
- High- or low-pressure water spraying (mainly on the wall in the empty passes of the boiler).
- Ultrasonic/infrasonic cleaning.
- Shot cleaning or mechanical pellet scouring.
- Explosive cleaning. This technique uses the pressure waves generated by the explosion of an oxygen/ethane gas mixture and enables heat exchange values close to the plant´s nominal ones to be re-established after cleaning [95, ESWET 2015].
- High-pressure air injection (from 10 to 12 bar) with movable lances.

[74, TWGComments, 2004]

Off-line techniques include:

- periodic manual cleaning (in general once a year in MSWI);
- chemical cleaning.

[74, TWGComments, 2004]

In addition to these techniques, it can also be beneficial to prevent higher temperature (above 650 °C) gases (when fly ashes are more sticky and hence more likely to adhere to surfaces they come into contact with) coming into contact with convective heat-exchange bundles by:

- including empty passes with water walls only;
- using large furnace dimensions and hence lower gas velocities before the bundles.

The explosive cleaning is used before the scheduled shutdown for maintenance. By drastically diminishing the deposits to extract before performing the work, the shutdown duration can be reduced and thus the annual availability of the whole installation increased [95, ESWET, 2015].

Achieved environmental benefits
Improved heat-exchange increases energy recovery.

~~Although FGT systems can be used to absorb or destroy~~ The PCDD/F~~, the~~ reformation risk may be reduced by effective cleaning. This is because it reduces the amount of time that dusts (and other materials that can promote their formation) are present at temperatures of between 450 °C and 250 °C – where reaction rates are at their highest.

By soot-blowing with self-produced steam injection, most of the energy will be recovered by the boiler itself (80–90 %). [74, TWGComments, 2004]

Environmental performance and operational data
Those techniques that allow continuous on-line tube cleaning (normally operated once per 8-hour shift) normally have reduced downtime for boiler maintenance cleaning operations.
[74, TWGComments, 2004]

Usually, manual cleaning is done when fouling has induced a flue-gas temperature increase of 20 °C to 50 °C, i.e. a 1.5 % to 3 % decrease in energy efficiency.

Potential mechanical damage of the boiler structure/tubes can occur, particularly with explosive cleaning and mechanical rapping. It depends on the initial state, but, in general with explosive cleaning, more than 80% of the cumulated deposits are removed and the plant recovers its operating conditions close to the nominal values [95, ESWET, 2015].

Tube erosion caused by clogging can lead to decreasing energy efficiency and eventually tubes will require replacement.

Cross-media effects
Consumption of the soot-blowing agent, e.g. high-pressure water, low-pressure water, steam (only partially).

Noise may be an issue with some of the techniques, e.g. explosive cleaning, mechanical rapping.

Technical considerations relevant to applicability
Generally applicable. ~~All waste incinerators with boilers.~~

Economics
No information provided.

Driving force for implementation
The driving forces are improved availability and heat recovery, and reduced corrosion, emissions and energy consumption. [74, TWGComments, 2004]

Example plants
All waste to energy plants. [74, TWGComments, 2004]

Specific cleaning systems exist in several plants in the Netherlands and Denmark, e.g. AVI ARN Beuningen (explosive cleaning with gas), AVI Amsterdam and AVI Wijster (explosive cleaning with dynamite). [74, TWGComments, 2004]

Reference literature
[2, infomil, 2002] p 51 – 52, [1, UBA, 2001] p 119, [64, TWGComments, 2003], [95, ESWET, 2015]

4.5 Flue-gas cleaning ~~treatment~~

4.5.1 Factors to consider when selecting flue-gas cleaning ~~treatment~~ systems

4.5.1.1 General factors

[54, dechefdebien, 2003]
The following (non-exhaustive) list of general factors requires consideration when selecting flue-gas cleaning (FGC) systems:

- type of waste, its composition and variation;
- type of combustion process, and its size;
- flue-gas flow and temperature;
- flue-gas content, size and rate of fluctuations in composition;
- target emission limit values;
- restrictions on discharge of aqueous effluents;
- plume visibility requirements;
- land and space availability;
- availability and cost of outlets for residues accumulated/recovered;
- compatibility with any existing process components (existing plants);
- availability and cost of water and other reagents;
- energy supply possibilities (e.g. supply of heat from condensing scrubbers);
- availability of subsidies for exported energy;
- tolerable disposal charge for the incoming waste (both market and political factors exist);
- reduction of emissions by primary methods;
- release of noise;
- arrangement of different flue-gas cleaning devices if possible with decreasing flue-gas temperatures from boiler to stack.

[74, TWGComments, 2004]

4.5.1.2 Energy optimisation

Some flue-gas treatment techniques can add significantly to the overall energy requirements of the incineration process. It is necessary to consider the additional energy requirements imposed by applying lower ELVs. The following key observations can be made:

- Reducing dust emissions including boiler ash (and metals filtered with dust) generally requires additional filtration and increases energy consumption.
- Reducing NO_X emissions to below 100 mg/Nm^3 is most often achieved using SCR – which, because it is typically only used as a low-dust system in waste incineration, is situated at the clean gas end of the FGC system. It therefore usually requires some additional energy for flue-gas reheating. Very low SO_X levels in the raw flue-gas may allow SCR to be used without reheating (see Section 2.5.5.2.2). The energy required for the operation of additional flue-gas cleaning (to meet very low ELVs), if supplied from that generated by the incinerator, will result in a reduction of the energy available for export.
- The boiler exit temperature has a key influence on FGC energy requirements – if it is below the acid dew point, additional energy input will be required to heat the flue-gas.
- In general, placing the FGC components so that those requiring the highest operational temperatures precede those that operate at lower temperatures results in lower overall FGC energy demand (but this cannot be achieved in all cases, e.g. SCR generally requires clean gas and must therefore be placed after the lower temperature gas cleaning stages).
  [64, TWGComments, 2003] [74, TWGComments, 2004]

4.5.1.3 Overall optimisation and the 'whole system' approach

As well as considering the energy aspects (see sections on energy above), there is a benefit to considering the FGC system as a whole unit. This is particularly relevant to the removal of pollutants because the units often interact, providing primary abatement for some pollutants, and an additional effect on others. Depending on the position in the cleaning sequence, different cleaning efficiency values are obtained. [74, TWGComments, 2004] Multifunctional devices are common, for example:

- If a bag filter (BF) is used downstream of reagent injection, in addition to its dedusting effect, it acts as a complementary reactor. The pressure drop through the fabric material distributes the flue-gas on the adhered cake which contains some deposited reagent and, due to the low velocity of the gases, the residence time is long. A BF can, therefore, contribute to the treatment of acid gases, gaseous metals such as mercury and cadmium, and POPs (persistent organic pollutants) such as PAHs, PCBs, dioxins and furans.
- In addition to acid gas treatment, wet scrubbers can help with the capture of some particulate and, if the pH is low enough or with the use of scrubber reagents, of mercury.
- SCR deNO$_X$ has an additional destruction effect on dioxins if designed (sized) accordingly.
- Adsorption by activated carbon and lignite coke has an effect on dioxins as well as on mercury and other substances.

[64, TWGComments, 2003] [54, dechefdebien, 2003]

4.5.1.4 Technique selection for new or existing installations

Overall optimisation and the interface between FGC system components (as well as the rest of the incineration process) is important for both new and existing installations. With existing installations, the number of options may be more severely restricted than with new installations. Information ~~Comments~~ regarding inter-process compatibility may be found in the sections that deal with individual FGC techniques.

4.5.2 Techniques to reduce ~~Reduction of~~ dust emissions

The application of a system to remove dust from the flue-gas is generally considered essential for all waste incineration installations. This section considers the locating of a dust removal stage before other subsequent FGC stages (i.e. *pre-dedusting*) or after other FGC systems as a final flue-gas polishing system. In some cases, double filtration is applied; this is also considered in this section.

4.5.2.1 ~~Application of a p~~Pre-dedusting stage before other flue-gas treatments

Description
This section considers the locating of a dust removal stage, generally after pre-dedusting in the boiler stage, [74, TWGComments, 2004] but before other subsequent FGC stages.

Technical description
The following pre-dedusting systems are used for waste incineration:

- cyclones and multi-cyclones;
- electrostatic precipitators (ESPs);
- bag filters (BFs).

The individual techniques ~~themselves~~ are ~~have already been~~ described in Section 2.5.3.

~~ESPs can be divided into multiple compartments (usually 1 – 4 successive fields), each with their own electrical system. This gives the advantage that, even during a breakdown of one of the electrical systems (e.g. short circuit by dust clogging or broken high voltage wires), [74, TWGComments, 2004] a relatively large part of the dust removal capacity is still available.~~

~~A specific version of the ESP is the~~ ~~**wet ESP**~~~~. This is~~ Wet ESPs are not generally applied to pre-dedusting on account of the flue-gas temperatures in ~~that~~ the pre-dedusting area.~~,~~ [64, TWGComments, 2003] In general, ~~it is~~ they are ~~more~~ used for polishing after scrubbing. [74, TWGComments, 2004]

~~Bag filters are often divided in compartments that may be isolated for maintenance purposes; an even flue-gas distribution is important for optimal performance.~~

Achieved environmental benefits

Benefits include the reduction of emissions to the flue-gas stream by reducing the particulate load on later FGC processes.

Separation of the fly ash from the FGC residues allows:

- reductions in the quantity of FGC residues produced;
- separate treatment of fly ashes for possible recycling uses.

Pre-dedusting reduces dust loads on subsequent FGC systems. These may then be reduced in capacity and will experience reduced clogging risks, and hence downstream units may be designed smaller and with some degree of reduced costs.

Separate collection of the flue-gas components will not be of any environmental benefit if the separated residues are then remixed afterwards. Consideration of downstream aspects is therefore required to evaluate the possibility of real benefits. [64, TWGComments, 2003]

ESPs and cyclones alone may have problems reaching the ~~lower of the generally applied~~ required dust emission levels ~~standards on their own~~. However, they are useful as pre-dedusters and contribute to meeting the lowest ~~of~~ emission levels when applied in combination with other techniques.

Environmental performance and operational data

[2, infomil, 2002] Cyclone collection efficiency increases directly as a function of the dust load, flue-gas flow rate, particle size and density. As the fly ash particles are fine, the density is low and the dust load and flue-gas flow rate change, so the dust removal efficiency of cyclones is limited. Normally, dust concentration values no lower than 200–300 mg/Nm^3 can be reached. Multi-cyclones, which are based on the same removal principle, can reach somewhat lower values, but values below 100–150 mg/Nm^3 are very difficult to achieve.

[2, infomil, 2002] An ESP can reach substantially lower dust concentration values than (multi-) cyclones. Depending on the design and the siting in the flue-gas treatment system (pre- or end-dedusting), and the number of fields, dust emission concentration values of 15–25 mg/Nm^3 can normally be achieved. Achieving values below 5 mg/Nm^3 is possible with more fields (two or three) and an increased ESP surface (and hence increased cost and space requirements).

Bag filters are generally very efficient dust removers. Where bag filters are used, most commonly reagents are also injected (although this is not always the case) to build a pre-coat layer over the bags to protect from corrosion and help filtration (especially for in-depth filtration). [74, TWGComments, 2004] The reagents used are commonly lime and activated carbon. ~~The presence of the a~~Activated carbon reduces the dioxin loads passing on to the subsequent flue-gas cleaning stages. For wet systems, this helps to reduce memory-effect dioxin build-up in the scrubber materials.

Care should be taken concerning the level of ash in the hopper as well as cinder (especially if bag filters are ~~implemented~~ installed directly after the boiler) to prevent risk of fire.

[2, infomil, 2002] Cyclones are a relatively simple design without moving parts (except for the transport systems used for the removal of the fly ash from the bottom) and, therefore, can have high availability at relatively low costs. However, the pressure drop of the flue-gas stream is relatively high, resulting in an increased power requirement for the flue-gas fan and therefore in additional energy consumption.

[2, infomil, 2002] For the proper functioning of an ESP, it is important that the flue-gas stream is evenly distributed over its total surface. The pressure drop of the flue-gas over an ESP is low, reducing energy consumption. However, some pre-dedusting equipment (e.g. ESPs, filters) require electricity for their operation. [74, TWGComments, 2004] ~~Further information on ESP systems can be found in Chapter 2.5.3~~.

Table 4.21: Operational data associated with the use of pre-dedusting systems

Criteria	Description of factors affecting criteria	Evaluation (high/medium/low) ~~or data~~	Comments
Complexity	• Additional process units required • Critical operational aspects	M	The extra process unit adds complexity, but can simplify later operations
Flexibility	• Ability of technique to operate under a range of input conditions	H	Each of the systems can be applied to variable flue-gas flows and compositions
Skill requirements	• Notable extra training or manning requirements	H/M	Bag filters require the most attention, and cyclones the least; ESPs are in between
Other requirements	• Bag filters may require addition of reagents for corrosion and fire protection		

The table below provides a comparison of ~~the various~~ dust removal techniques ~~systems~~ (used at the pre- and post-dedusting stages):

Table 4.22: A comparison of dust removal systems

Dust removal technique ~~systems~~	Typical dust emission concentrations	Advantages	Disadvantages
Cyclone and multi-cyclone	Cyclones: 200–300 mg/m^3 Multi-cyclones: 100–150 mg/m^3	- Robust, relatively simple and reliable - Applied in waste incineration	- Only for pre-dedusting - Relatively high energy consumption (compared to ESP)
Dry ESP	< 5–25 mg/m^3	- Relatively low power requirements - Can use gas temperatures in the range of 150–350 °C - Widely applied in waste incineration	- Risk of formation of PCDD/F if used in 450–200 °C range
Wet ESP	< 5–20 mg/m^3	- Able to reach low emission concentrations - Sometimes applied in	- Little experience in waste incineration

Dust removal technique ~~systems~~	Typical dust emission concentrations	Advantages	Disadvantages
		waste incineration	- Mainly applied post-dedusting - Generation of process waste water - Increase of plume visibility
Bag filter	< 5 mg/m^3	- Widely applied in waste incineration - The layer of residue acts as an additional filter and as an adsorption reactor	- Relatively high energy consumption (compared to ESP) - Sensitive to condensation of water and to corrosion
Source: [2, infomil, 2002]			

Cross-media effects

~~Cross-media effects are identified~~ Energy requirements of different pre-dedusting tehcniques are evaluated in the table below ~~with available data~~.

Table 4.23: ~~Cross-media effects~~ Energy requirements associated with the use of various pre-dedusters

~~Criteria~~ Energy requirements	Units	Value	Comments
~~Energy requirements:~~	kWh/t waste input		
Cyclone		Low	Lower efficiency for removal of particles < 5 µm
Multi-cyclone		Low	
Dry ESP		Higher (electrostatic loading)	Common technology
~~**Wet ESP**~~		~~Higher (pressure drop)~~	
Bag filter		Highest by pressure drop and high-pressure pulse-jet cleaning	Common technology
~~**Residue – type**~~		~~Fly ash~~	~~Separate collection of fly ash from main chemical pollutants possible if not operated with reagents~~
Residue – amount	kg/t waste input	12–20 (< 50)	Without reagents (with reagents)
~~**Water consumption**~~	~~l/t waste input~~		~~• for wet ESP~~ ~~• for gas cooling prior to bag filters~~
~~**Effluent production**~~	~~l/t waste input~~		~~• wet ESP effluent~~
~~**Plume visibility**~~	~~yes/no~~	~~yes~~	~~wet ESP highest visible plume~~
Source: [74, TWGComments, 2004]			

The most significant cross-media effects associated with this technique are:

- energy consumption due to pressure loss, which is higher with bag filters than for other systems;
- electricity consumption for ESP operation;
- ~~generation of fly ash from the gas cleaning~~
- flue-gas PCDD/F concentrations may increase during their residence time in the ESP, particularly when operated at temperatures above 200 °C to 450 °C.
- ~~the FGC residues and fly ash can be separated using pre-dedusting.~~

Technical considerations relevant to applicability
Pre-dedusting requires space for the additional process unit, which may be a limiting factor for existing plants.

Greater temperature control may be required in the case of using a bag filter at the pre-dedusting stage.

~~The applicability of the pre-dedusting technique is assessed in the following table:~~

~~Table 4.24: Assessment of the applicability of pre-dedusting~~

~~Criteria~~	~~Evaluation/Comment~~
~~Waste type~~	~~• applicable to all waste types~~ ~~• may not be required for low raw gas dust concentrations~~
~~Plant size range~~	~~• no restriction~~
~~New/existing~~	~~• space may be a factor for existing plants~~
~~Inter-process compatibility~~	~~• greater temperature control required for bag filter~~
~~Key location factors~~	~~• space required for additional process unit~~

Economics
The key aspects of this technique are:

- increased capital and investment costs – for additional process units;
- increased energy costs, particularly for bag filtration;
- possible cost reductions for disposal where outlets are available for segregated fly ash;
- possible increased cost of handling additional residue streams (either for recovery or disposal).

Investment costs for a two-line MSWI with a total capacity of 200 000 t/yr are estimated as [12, Achternbosch, 2002]:

• ESP (3 field)	EUR 2.2 million
• ESP (2 field)	EUR 1.6 million
• Bag filter	EUR 2.2 million (not clear if this includes an upstream flue-gas cooler).

The unit operational costs of a bag filter for pre-dedusting may be higher due to the higher energy use associated with the pressure drop and the reagent injection. However, the bag filters' greater removal capacity for dust and for other pollutants (particularly when used with reagent injection) can result in reduced costs for subsequent components of the FGC system.

Driving force for implementation
~~This technique has been implemented where:~~

- ~~the fly ash removed can be treated and recycled~~
- The FGC residues and fly ash can be separated and treated/recycled separately.
- Smaller capacity downstream FGC equipment is required (~~requirement for~~ dust loads are reduced).
- Improvements in the operation of downstream FGC systems.
- ~~there is a~~ Preference for the removal of PCDD/F before wet scrubbing to reduce memory effects.

Example plants
Widely applied in many incineration plants.

Reference literature
[2, infomil, 2002], [55, EIPPCBsitevisits, 2002] [64, TWGComments, 2003]

4.5.2.2 ~~Application of an a~~Additional flue-gas polishing system

Description

This technique relates to the application of flue-gas polishing systems for the final reduction of dust emissions after other FGC has been applied, but before the final release of stack gases to the atmosphere.

Technical description

The main systems used for flue-gas polishing ~~applied~~ are:

- bag filters;
- wet ESPs;
- electrodynamic ~~venture~~ Venturi scrubbers;
- agglo-filtering modules;
- ionising wet scrubbers.

[74, TWGComments, 2004] *To the TWG: is this list of techniques up to date?*

The ~~main technical components~~ individual techniques are ~~have already been~~ described in Section 2.5.3.

~~Also, it is possible to consider that~~ The addition of a final wet flue-gas treatment system ~~is~~ can also be considered a polishing treatment after other systems that deal with acid gases, etc. This addition is generally made to specifically control HCl emissions where they are highly variable. This additional treatment is considered in Section 4.5.3.6. [64, TWGComments, 2003]

Polishing devices are also implemented to remove droplets (especially fine ones). They are generally implemented to prevent fouling in downstream devices such as an SCR system. [74, TWGComments, 2004]

Achieved environmental benefits

In addition to the reduction of dust, emissions to air of the following substances can also be reduced:

- heavy metals – as their emission concentrations are usually associated with dust removal efficiency;
- mercury and PCDD/F – where carbon (usually with alkaline reagent) is added as an absorbent on bag filters;
- acid gases – where alkaline reagents are added to protect bag filters.

The benefits of these additional reductions may be small where upstream techniques are already being applied to reduce the concentrations in the flue-gas to a low level.

Environmental performance and operational data

Further reduction of emissions to air beyond that already achieved by other FGC components are as shown in the table below.

Table 4.25: Emission levels associated with the use of BF flue-gas polishing systems

Substance	~~Reduction efficiency range (%)~~	Achievable emission ranges				Comments
		Half-hourly average (mg/Nm^3)	Daily average (mg/Nm^3)	Annual average (mg/Nm^3)	Specific emission (g/t waste input)	
Dust		~~<30~~ < 15	~~0.04~~ < 1–5	~~<0.5~~ < 0.4	To be updated	

NB: The precise final emission level achieved will depend on the level at the inlet to the final dust removal stage (itself depending on the performance of the earlier stages applied) and the efficiency of the final dust removal stage used. The figures given here provide a guide to the sort of emission levels that are generally seen where a polishing stage is added.

Source: ~~[2, infomil, 2002], [1, UBA, 2001]~~, [81, TWG 2016]

Effective maintenance of bag filters is very important to ensure their effective operation and hence low emissions. The pressure drop across the bags is monitored in order to maintain a cake on the filter. It can also be used as a means to detect bag damage (such as irreversible fouling). Dust emissions can usually be controlled to a very low level, simply by more closely observing the pressure drop and adopting stricter criteria (i.e. less latitude allowed before maintenance action is taken) for bag replacement. Analysis of the filter media may also be used to assess the reagent dose rate required and to assess its condition and its remaining lifetime.

~~Multiple chamber systems which are independently monitored for pressure drop, and bag houses with sufficient over capacity to allow damaged areas to be shut off for bag replacement, improve the capability to meet the lowest of emission limit values.~~

~~Bag filters are often divided into compartments that may be isolated for maintenance purposes An even flue-gas distribution is important for optimal performance.~~

Table 4.26: Operational data associated with the use of flue-gas polishing

Criteria	Description of factors affecting criteria	Evaluation (high/medium/low) or data	Comments
Complexity	• Additional process units required • Critical operational aspects	H	Additional process units add complexity
Flexibility	• Ability of technique to operate under a range of input conditions	M	As a tail-end technique, the process will be less subject to such variations
Skill requirements	• Significant extra training or manning requirements	H	Bag filters require ~~close~~ careful maintenance

Cross-media effects

Cross-media effects are identified in the following table.

Table 4.27: Cross-media effects associated with the use of additional flue-gas polishing

Criteria	~~Units~~	~~Range of achieved values~~	Comments
Energy requirements	~~kWh/t waste input~~		Increased due to pressure drop across process unit
Reagent consumption	~~kg/t waste input~~		More reagent used
Water consumption			Wet ESP leads to water discharge, which may be recycled in the process
Residue – type			Fly ashes and/or other substances removed in the polishing filter generally become an additional solid waste stream
Residue – amount	~~kg/t waste input~~		Varies according to input loads and applied upstream FGC techniques but will generally be low
Plume visibility	~~+/0/-~~	~~+/0~~	Non-dry systems can increase plume visibility
Source: [74, TWGComments, 2004]			

For this technique, the most significant cross-media effect~~s are:~~ is the consumption of energy due to the pressure drop across the bag filters.

- ~~production of solid residues (negligible in case of polishing purpose).~~

Technical considerations relevant to applicability

Flue-gas polishing requires space for the additional process unit, which may be a limiting factor for existing plants.

The temperature and the acid dew point need consideration.

~~The applicability of this technique is assessed in the table below:~~

~~**Table 4.28: Assessment of the applicability of flue-gas polishing**~~

~~**Criteria**~~	~~**Evaluation/Comment**~~
~~**Waste type**~~	~~• the additional abatement of heavy metals (with flue-gas) using these techniques increases suitability where these require further reduction~~
~~**Plant size range**~~	~~• larger plants with higher gas flows can achieve greater reductions in local contributions to emissions by applying such techniques~~
~~**New/existing**~~	~~• applicable to new and existing plants~~ ~~• as and end-of-pipe technique – well suited to retrofits where dust requires reduction~~ ~~• existing plants already achieving low emission levels (<10 mg/Nm³ daily average) through other means may not benefit greatly from the addition of this technique~~
~~**Inter-process compatibility**~~	~~• temperature and acid dew point needs consideration~~ ~~• provides effective gas cleaning step prior to SCR~~
~~**Key location factors**~~	~~• space available can be a restriction (additional process unit)~~

Economics

Cost information for this technique is given in Section 8.2.4.

The key cost aspects of this technique are:

- increased capital investment costs of the additional process unit;
- increased operational costs – mainly due to energy requirements for the pressure drop, provision of compressed air for back pulsing of the BF (if used), and additional maintenance costs.

Driving force for implementation

~~This technique has been implemented where:~~

- ~~legislation has required low permit emission limit values for dust, (dust related) heavy metals, or where additional dioxin and acid gas reduction potential is required~~
- ~~local air quality concerns exist that may be affected by the process~~
- Compliance with legislation/local permit conditions that require additional reductions of dust, metals, dioxin and/or acid gas emissions.
- ~~it acts as a~~ Need for effective dedusting~~er~~ for a subsequent SCR process.

Example plants

Examples in Germany, Austria, France and the Netherlands.

~~Other examples in France:~~

~~Toulouse: agglo-filtering modules after wet FGC~~

~~Tronville (FR003): tail end bag filter with lime + activated carbon injection (downstream wet FGC)~~

~~Oceal (FR059): tail end bag filter with activated carbon injection for PCDD/F treatment~~

~~[74, TWGComments, 2004]~~

Reference literature
[3, Austria, 2002], [2, infomil, 2002], [64, TWGComments, 2003]

4.5.2.3 ~~Application of d~~Double bag filtration

Description
This technique considers the application of two bag filters in series in the FGC system. The two bag filters may not be immediately adjacent to one another (i.e. other FGC components may be used in between them). This technique does not refer to situations where a bag filter is combined with another technique different from a ~~non-~~bag filter, e.g. with an ESP, cyclone or wet scrubber, etc.

Technical description
Bag filtration is described in Section 2.5.3.

Achieved environmental benefits
Benefits include an additional reduction in dust emissions to air. Daily average levels of below 1 mg/Nm^3 can be achieved in nearly all situations.

Separation of FGC residues is possible, i.e. separation of fly ash from the FG neutralisation residues. This may then allow the recovery of one or other fraction where suitable outlets exist.

Environmental performance and operational data

Table 4.29: Operational data associated with the use of double filtration

Criteria	Description of factors affecting criteria	Evaluation (high/medium/low) or data	Comments
Complexity	• Additional process units required • Critical operational aspects	H	Additional process units add complexity
Flexibility	• Ability of technique to operate under a range of input conditions	H	Input to first stage can vary greatly without large variation in output emissions from second stage
Skill requirements	• Notable extra training or manning requirements	H	Bag filters require ~~close~~ careful maintenance, which increases ~~This is increased~~ because of the extra unit.

~~Bag filters are often divided into compartments that may be isolated for maintenance purposes. An even flue-gas distribution is important for optimal performance.~~

Cross-media effects
~~Cross-media effects are identified in the table below:~~

~~**Table 4.30: Cross-media effects associated with the use of double filtration**~~

~~**Criteria**~~	~~**Units**~~	~~**Range of achieved values**~~	~~**Comments**~~
~~**Energy requirements**~~	~~kWh/t waste input~~	~~High~~	~~Increased due to pressure drop across process units~~
~~**Reagent consumption**~~	~~kg/t waste input~~	~~3 – 15~~	~~Depending on the kind of reagent~~
~~**Residue – type**~~		~~dry~~	~~Fly ashes and salts residue~~
~~**Residue – amount**~~	~~kg/t waste input~~	~~15 – 25~~	~~Varies according to input loads and applied upstream FGC techniques~~
~~**Plume visibility**~~	~~+/0/-~~	~~+/0~~	~~Spray dry systems can increase plume visibility~~
~~*Source:* [74, TWGComments, 2004]~~			

For this technique, the most significant cross-media effect~~s are:~~ is the consumption of energy due to pressure drop across the FGC system as a whole~~, will be significantly higher~~.

- ~~production of solid residues (usually separated from other flue-gas residues).~~

It is reported that the ~~additional energy consumption from the~~ use of two bag filters in series (even if separated), although it may provide ~~some~~ potential benefits in terms of ~~additional~~ improved pollutant control, requires significantly higher power fans to overcome the additional pressure drop and therefore higher electricity consumption.

Technical considerations relevant to applicability

Double bag filtration requires space for the additional process unit, which may be a limiting factor for existing plants.

The temperature and the acid dew point need consideration.

~~This can be applied to any incineration process, but most applicable where very low dust ELVs are applied, or separation of FGC residue components is desired.~~

~~The applicability of this technique is assessed in the table below:~~

~~Table 4.31: Assessment of the applicability of double filtration~~

~~Criteria~~	~~Evaluation/Comment~~
~~Waste type~~	~~• any~~
~~Plant size range~~	~~• larger plants with higher gas flows can achieve greater reductions in local contributions to emissions by applying such techniques~~
~~New/existing~~	~~• applicable to new and existing plants~~ ~~• where the additional filtration is added as an end-of-pipe technique it is well suited to retrofits at an existing installation~~ ~~• existing plants already achieving low emission levels (<10 mg/Nm³ daily average) through other means may not benefit greatly from the addition of this technique~~
~~Inter-process compatibility~~	~~• temperature and acid dew point needs consideration~~ ~~• provides effective gas cleaning step prior to SCR~~
~~Key location factors~~	~~• this requires larger space to implement~~ ~~• location of the industrial plant that can recycle the salts~~
~~*Source:* [74, TWGComments, 2004]~~	

Economics

Additional costs are associated with the investment in the of an extra process unit, as well as with additional energy use ~~costs~~ and maintenance.

Driving force for implementation

- ~~Most often applied where low emissions for dust are required~~ Compliance with legislation/local permit conditions that require additional reductions of dust to very low emission levels (e.g. values below 2 mg/Nm^3).
- Possibility to recycle the salts arising from the removal of acid gases.

Example plants

Several examples in Belgium, Germany, France and others.

Reference literature

[64, TWGComments, 2003]

Information from the following section has been moved to Chapter 2.5.3.5

~~4.5.2.4 Selection of bag filter materials~~

~~Description~~
~~The filter material selected must be suited to the physical and chemical conditions under which it will operate.~~

~~Technical description~~
~~The key characteristics of fabrics for use in gas filtration include maximum operational temperature and resistance to acids, alkalis and flexing (due to bag cleaning). Also gas humidity can affect the strength and dimensional stability of the fabrics, due to hydrolysis. Several basic fibre properties are summarised below, some may be coated or impregnated with special chemicals (e.g. sulphur). [74, TWGComments, 2004]~~
~~Special filter bags including catalytic elements for the reduction of NO$_X$ and/or for the destructions of PCDD/F are described separately, in Sections 4.5.4.2 and 4.5.5.4 respectively.~~

~~Table 4.32: Operational information for different bag filter materials~~

~~**Fabric**~~	~~**Maximum temperature (°C)**~~	~~**Resistance**~~		
		~~Acid~~	~~Alkali~~	~~Physical flexibility~~
~~Cotton~~	~~80~~	~~Poor~~	~~Good~~	~~Very good~~
~~Polypropylene~~	~~95~~	~~Excellent~~	~~Excellent~~	~~Very good~~
~~Wool~~	~~100~~	~~Fair~~	~~Poor~~	~~Very good~~
~~Polyester~~	~~135~~	~~Good~~	~~Good~~	~~Very good~~
~~Nylon~~	~~205~~	~~Poor to fair~~	~~Excellent~~	~~Excellent~~
~~PTFE~~	~~235~~	~~Excellent~~	~~Excellent~~	~~Fair~~
~~Polyimide~~	~~260~~	~~Good~~	~~Good~~	~~Very good~~
~~Fibreglass~~	~~260~~	~~Fair to good~~	~~Fair to good~~	~~Fair~~

~~Notes:~~
3. ~~not all of these materials are commonly used in incineration – see operational data below~~
4. ~~Some operational experiences suggest a common maximum operational temperature to be 200°C.~~

~~Source: [2, infomil, 2002] [67, Inspec, 2004]~~

~~Achieved environmental benefits~~
~~A reliable filter material, suited to it's the specific application provides for reliable emissions abatement.~~

~~Environmental performance and operational data~~
~~See information provided in Technical description above.~~

~~Increasing temperature may lead to melting of any plastic components in the fabric material, and the potential for fires. High humidity in the flue-gas may cause the filter materials to stick together and lead to shut downs. [74, TWGComments, 2004]PTFE covering of sheets/foils can be used to improve the removal of such sticky salts and solid particles from the bags. Operational improvements in semi-wet systems (see also Section 4.5.3.2) are reported to have been obtained by using PTFE in an MSWI facility in Prague (CZ) and in Schwandorf (Germany).~~

~~Regular bag analysis may help to assess the bag's its remaining lifetime [74, TWGComments, 2004]~~

~~Several filtration media are reported to not be commonly used in MSWI e.g. cotton, wool, propylene. In MSWI, the main media are: polyimide (known as P84), PPS (rarely), PTFE, fibreglass (with or without PTFE coating). Some fibres may be combined (e.g. P84+PTFE for higher resistance at high temperature)~~
~~Chemical reactions in the absorbent media may effect operational temperature. Quality of the scrim is also of importance, as well as fibre quality.~~
~~Cross-media effects~~

~~If the media is not appropriate, pressure drop may increase and limit waste throughput.~~
~~If high pressure air is required for cleaning the bag it can reduce the bag lifetime.~~

~~Technical considerations relevant to applicability~~
~~Correct bag material selection is relevant to all waste incineration installations using bag filters.~~

~~Economics~~
~~Cost of the different bag filters varies.~~

~~Driving force for implementation~~
~~Main driving forces are abatement performance and engineering suitability.~~

~~Example plants~~
~~Wherever bag filters are applied i.e. very widely.~~

~~Reference literature~~
~~[2, infomil, 2002], [64, TWGComments, 2003]~~

4.5.3 Techniques to reduce~~tion of~~ acid gas emissions

The sections that follow ~~within this section deal with the following~~ address:

- description and assessment of the performance generally achieved by the main techniques applied for acid gas reduction – including consideration of applicability to various situations;
- description and assessment of some other technological and procedural options relevant to acid gas removal.

4.5.3.1 Wet scrubbing systems

Description
This technique is ~~has already been~~ described in Section 2.5.4.

Technical description
Wet scrubbers generally have at least two effective stages, the first at low pH removes mainly HCl and HF, the second stage is dosed with lime or sodium hydroxide and operated at a pH of 6–8 primarily for the removal of SO_2. Scrubbers may sometimes be described as three or more stages – the additional stages generally being subdivisions of the first low pH stage for specific purposes.

Achieved environmental benefits
Wet FGC systems provide the highest removal efficiencies (for soluble acid gases) of all FGC systems with the lowest excess stoichiometric factors. [74, TWGComments, 2004]

Whilst single stage filtration-based FGC systems (e.g. semi-wet, dry) combine and collect residues together, this is not generally the case with wet systems. The wet systems can treat HCl, HF and SO_2 separately from particulate, etc. which is often removed before. Having noted this, wet systems do provide some additional reductions of the following substances:

- Dust - where scrubber capacity is large enough to prevent clogging (most usually a pre-dedusting stage is used before the wet scrubber to reduce dust loads and prevent operational problems up to 50 % of the dust input). [74, TWGComments, 2004]
- PCDD/F - if carbon-impregnated packing materials are used it is possible for reductions of 70 % to be seen across the scrubber, otherwise removal rates are negligible.

Activated carbon or coke may be added to the scrubber for a similar purpose, with reported higher removal efficiencies. [74, TWGComments, 2004]

- Hg^{2+} - if a low pH (~1) first stage scrubber is used, and HCl concentrations in the waste provide for acidification of this stage, then $HgCl_2$ removal can take place, but metallic Hg is not generally affected. [64, TWGComments, 2003]
- Other pollutants – when water-soluble pollutants like bromine and iodine are present in the raw gas, they may be condensed at the low temperatures in the scrubber and in this way enter the scrubber waste water.

Environmental performance and operational data

~~Reduction of e~~ The air emission levels generally achieved by plants fitted with wet scrubbers are ~~as follows~~ shown in Table 4.33.

Table 4.33: Emission levels associated with the use of wet scrubbers

Substance(s)	~~Reduction efficiency range (%)~~	Achieved emissions				Comments
		Half-hourly average (mg/Nm^3)	Daily average (mg/Nm^3)	Annual average (mg/Nm^3)	Specific emission (g/t waste input)	
HCl		~~0.1 – 10~~ 2 – 10	~~<5~~ < 2 – 4	~~0.1 – 1~~ < 2	~~1 – 10~~ To be updated	Very stable outlet concentrations
HF		< 1	~~<0.5~~ < 1	~~<0.1~~ 0.5	~~< 0.05 – 2~~ To be updated	Very stable outlet concentrations
SO_2		~~< 50~~ 10-50	~~< 20~~ 5 – 30	< 10	~~< 5 – 50~~ To be updated	Requires reaction stage and absorbent (lime or NaOH) ~~SO_2 half-hourly averages may fluctuate more~~

Source: ~~[1, UBA, 2001, 2, Infomil, 2002, 12, Achternbosch, 2002],~~ [81, TWG 2016]

Table 4.34: Operational data associated with the use of wet FGC

Criteria	Description of factors affecting criteria	Evaluation (high/medium/ low)	Comments
Complexity	• Additional process units required • Critical operational aspects	H	The number of process units is greater than other systems
Flexibility	• Ability of technique to operate under a range of input conditions	H	Very robust – highest ability of all systems to achieve emission reduction of HCl/HF under fluctuating inlet concentrations
Skill requirements	• Notable extra training or manning requirements	H	The associated effluent treatment plant requires a high skill input

The main operational issues are as follows.

PCDD/F build-up in wet scrubbers can be a problem, in particular from maintenance and start-up periods, and may require specific measures to be taken.

Effluent treatment requires highly skilled operation to achieve low emission levels.

For effective operation, wet scrubbers require flue-gases that have already been dedusted using for example an ESP or BF. [64, TWGComments, 2003]

~~The flexibility of w~~Wet scrubbing enables flexibility in terms of the variation in the inlet concentrations, ~~applies~~ mainly ~~to~~ of HCl and HF. Sometimes additional treatment is required for ~~to meet~~ mercury ~~ELVs~~, for example: the injection of a complex builder in the basic scrubber; injection of activated carbon in the acidic scrubber; injection of oxidising agent or abatement in the gas phase with adsorbent. [64, TWGComments, 2003]

Cross-media effects

Cross-media effects are identified in
Table 4.35 below.

Table 4.35: Cross-media effects associated with the use of wet scrubber FGC

Criteria	Units	Range of values	Comments
Energy requirements	kWh/t waste input	19	Pumps add demand
Reagent consumption	kg/t waste input	~~2–3 (NaOH) or ~10 (CaO) or 5–10 (lime/limestone)~~ 3–5 NaOH 2–4 CaO 1–2 $Ca(OH)_2$ 6–9 $CaCO_3$	Lowest of all systems
Reagent stoichiometry	Ratio	1.0–1.2	Lowest of all systems
Residue – type			Effluent treatment sludge; in some cases HCl or gypsum may be recovered
Residue – amount	kg (wet)/t waste input kg (dry)/t waste input	10–15 3–5	Lowest of all systems. This figure does not include separately removed fly ash ercury. 16 kg/t input.
Water consumption	l/t waste input	100–500	Highest of all systems but can be reduced by treatment and recirculation /condensation and by low temperatures before scrubber inlet.
Effluent production	l/t waste input	~~25~~0–500	Treatment required before discharge or reuse
Plume visibility	+/o/-	+	High gas moisture content, but can be reduced by reheat/condensation

NB: The data in this table aim to provide the typical operational range. The precise amounts of residues and effluents produced will depend on many factors including raw gas concentrations (waste-related), flow rates, reagent concentrations, etc.
Source: [1, UBA, 2001, 2, infomil, 2002, 12, Achternbosch, 2002], [81, TWG 2016]

For this technique, the most significant cross-media effects compared to other options are:

- lowest reagent consumption rates;
- lowest solid residue production rates;
- higher water consumption;
- production of an effluent that requires management;
- increased plume visibility;
- PCDD/F build-up (memory effect) on scrubber plastic components requires addressing;
- if the input temperature is too high the material used in the wet scrubber may be destroyed. [74, TWGComments, 2004]

~~Effluent production is usually considered as 300 kg/t MSW input, assuming a consumption of water of 1000 kg/t MSW input. These figures are higher than those quoted in the table above. [64, TWGComments, 2003]~~

Technical considerations relevant to applicability

The technique is generally applicable.

Due to the low outlet temperature (approximately 70 °C), the flue-gas may need to be reheated for subsequent FGC systems, e.g. bag filters and SCR.

~~The applicability of this technique is assessed in the table below:~~

~~Table 4.36: Assessment of the applicability of wet FGC~~

~~Criteria~~	~~Evaluation/comment~~
~~Waste type~~	- ~~can be applied in principle to any waste type~~ - ~~particularly suited to highly variable inlet gas compositions (e.g. hazardous wastes)~~
~~Plant size range~~	- ~~not restricted but generally applied at medium to larger plants where economies of scale exist~~
~~New/existing~~	- ~~widely applied at many existing plants~~
~~Inter-process compatibility~~	- ~~low flue-gas outlet temperature (ercury. 70 °C) requires reheat for subsequent FGC systems e.g. bag filters and SCR~~ - ~~separate (pre-) collection of fly ash possible~~
~~Key location factors~~	- ~~increased plume visibility (unless counter measures taken)~~ - ~~salt water effluent (post treatment) requires discharge (or evaporation which requires energy)~~ - ~~can permit recovery of HCl, salt, gypsum~~

Economics

Estimated capital costs ~~information~~ for the technique are as ~~is shown~~ in the table below.

Table 4.37: Estimated investment costs of selected components of wet FGC systems

FGC component	Estimated investment cost (million EUR)	Comments
Two-stage wet scrubber	5	Including waste water treatment
Three-stage wet scrubber	7	Including waste water treatment
External scrubber effluent evaporation plant	1.5–2	
Spray absorber for internal effluent evaporation	1.5	~~Cost estimate believed to be on the low side~~
NB: Costs estimated relate to a two-line MSWI with a total capacity of 200 kt/yr. *Source:* [12, Achternbosch, 2002] [74, TWGComments, 2004]		

The key cost aspects of this technique compared to the alternatives are:

- higher capital investment costs than other systems, mainly due to the effluent treatment plant and the higher number of process units required, which may be a limiting factor in particular at smaller non-hazardous waste incineration sites;
- operational costs associated with disposal of residues may be lower, due to the lower specific residue production~~, which are normally wet.~~ [74, TWGComments, 2004];
- labour costs are higher due to the increased complexity of the system.

Driving force for implementation

~~This technique has been implemented where:~~

- ~~emission limit values have been set at or below those detailed in Directive 2000/76/EC~~

- Reduction of disposal costs for flue-gas treatment residues.
- Possibility to recover HCl, salt, gypsum.
- ~~input waste composition is~~ Particularly difficult to predict/control input waste composition.
- Input waste may contain high and variable loads of acid gas~~es~~ precursors or metals (e.g. ionic mercury) [74, TWGComments, 2004].
- ~~salt-containing effluent may be discharged (e.g. to the sea).~~

Example plants

Wet flue-gas scrubbing is widely used throughout Europe for the full range of waste types.

Reference literature

[1, UBA, 2001, 2, infomil, 2002, 3, Austria, 2002, 12, Achternbosch, 2002] [64, TWGComments, 2003]

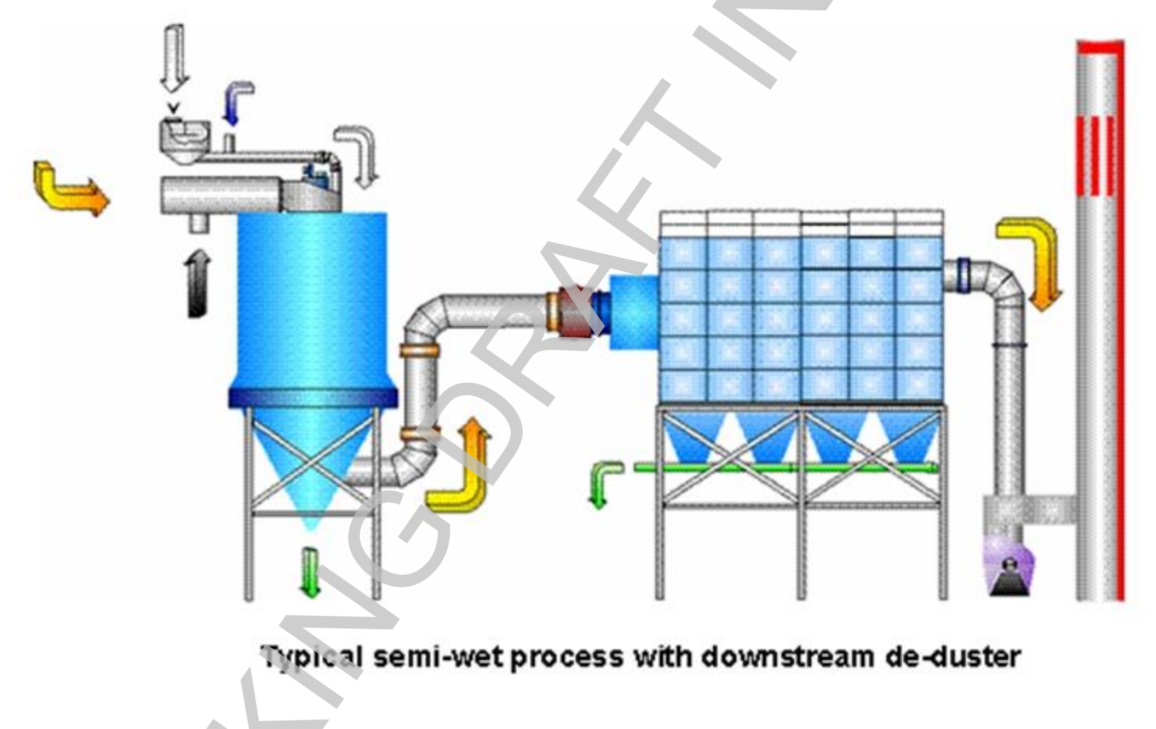
4.5.3.2 Semi-wet scrubbing systems

Description

This technique~~s has already been~~ is described in Section 2.5.4.

Technical description

The diagram below shows a typical semi-wet FGC system, with a contact tower on the left and downstream deduster.



~~Figure 4.8:~~ **~~Diagram showing~~ Typical design ~~diagram~~ of a semi-wet FGC system**

Achieved environmental benefits

There is no effluent discharge from semi-wet scrubbers as the amount of water used is generally lower than with wet scrubbers and ~~that used~~ it is evaporated with the flue-gases. If of suitable quality, other site waste water (e.g. rainwater) may be sent to the FGC system. [74, TWGComments, 2004]

Semi-wet FGC systems provide high removal efficiencies (for soluble acid gases). ~~Low ELVs can be met~~ Emission levels can be decreased by adjusting the reagent dosing rate and design point of the system, but generally at the cost of increased reagent consumption and residue production rates.

Semi-wet systems are used with fabric filters to remove the reagents added and their reaction products. Reagents, other than alkaline reagents, can also be added to adsorb other flue-gas components (e.g. activated carbon for mercury and PCDD/F).

They are most commonly used as a single stage reactor/filter for the combined ~~emission~~ reduction of:

- acid gases - removed by the alkaline reagent;
- dust - filtered by the fabric filter;
- PCDD/F - adsorbed if activated carbon is injected as well as alkaline reagent;
- Hg - adsorbed if activated carbon is injected as well as alkaline reagent.

Environmental performance and operational data

The air emission levels generally achieved by plants fitted with semi-wet scrubbers are as follows.

Table 4.38: Emission levels associated with the use of semi-wet scrubbers

Substance (s)	**~~Reduction efficiency range (%)~~**	**Achieved emissions**				**Comments**
		Half-hourly average (mg/Nm^3)	**Daily average (mg/Nm^3)**	**Annual average (mg/Nm^3)**	**Specific emission (g/t waste input)**	
HCl		~~< 50~~ 12 – 25	~~3 – 10~~ 2 – 8	~~2~~ < 6	~~4 – 10~~ To be updated	~~Lowest values achieved with higher reagent dosing and regulation control~~. Peaks can be dealt with by upstream HCl analyser. The semi-wet process can capture SO_2 at the same time as HCl and HF in the same scrubber.
HF		< 2	< 1	<0.5	~~< 2~~ To be updated	
SO_2		~~<50~~ 30 – 70	~~<20~~ < 40	~~<10~~ < 25	~~5 – 50~~ To be updated	

Source: ~~[1, UBA, 2001, 2, infomil, 2002, 12, Achternbosch, 2002], [64, TWGComments, 2003] [74, TWGComments, 2004]~~, [81, TWG 2016]

Table 4.39: Operational data associated with the use of semi-wet FGC

Criteria	Description of factors affecting criteria	Evaluation (high/medium/low) or data	Comments
Complexity	• Additional process units required • Critical operational aspects	M	• The number of process units is lower than wet systems, but greater than dry and flash dry. • Inlet temperature requires control • Pre-dust removal may ease semi-dry operation
Flexibility	• Ability of technique to operate under a range of input conditions	M	• Can achieve low emission levels under most conditions • Rapid inlet load changes can be problematic
Skill requirements	• Significant extra training or manning requirements	M	• No effluent treatment requirements • Care required to optimise reagent dosing

Most systems consist of only a reagent mixing unit (reagent plus water) and a spray tower, and then a bag filter – complexity is therefore lower than with wet FGC systems.

The reagent handling and dosing require good management to ensure effective and optimised operation, particularly where heterogeneous waste types are treated, e.g. merchant HWIs. Upstream HCl monitoring (see Section 4.5.3.11) improves optimisation of reagent dosing in these systems and allows management of peak loads of HCl, HF, SO_2 without high reagent dosing rates.

Some installations produce the $Ca(OH)_2$ for the FGC system on site by slaking of CaO. Effective lime preparation can be critical to good operation, as can be controlling the risk of fouling in the injection device. The injectors have to be located and designed such that they can be easily maintained and/or replaced for cleaning. [74, TWGComments, 2004]

Bag filters require close monitoring and management to address bag damage and consequent releases. Differential pressure monitors are commonly used to indicate bag damage and monitor operation in general.

Temperature requirements are critical. Care is required to ensure dew point corrosion in the bag filter is avoided – inlet gas temperatures of above 130–140 °C are usually used. At temperatures below 130 °C there may be problems due to the hygroscopic nature of the $CaCl_2$ formed. Reagents usually require a specific temperature for optimal reaction conditions.

It is reported that there may be operational problems when semi-wet FGC systems are used with very highly acidic polluted raw gases as this can lead to an increased risk of filter clogging.

The operational complexity of reactors and bag filters used in semi-dry systems can ~~themselves~~ itself be decreased further by the use of a degree of pre-dedusting, e.g. use of a single stage ESP, or by using non-sticky bag materials (see also Section 4.5.2.4). This ~~helps because it~~ avoids the problems of:

- sticking of some zinc (and similar salts with low melting temperatures); and
- hygroscopic salts forming sticky~~ing~~ layers on the surface of the reactor.

[64, TWGComments, 2003]

Cross-media effects

Cross-media effects are identified in the following table.

Table 4.40: Cross-media effects associated with the use of semi-wet acid gas treatment

Criteria	Units	Range of achieved values	Comments
Energy requirements	kWh/t waste input	6–13	Pressure drop across bag filter creates energy demand
Reagent consumption	kg/t waste input	~~12 – 20~~ 7–10 (lime)	Mid range of system options applied
Reagent stoichiometry	Ratio	1.4–2.5	Lowest values achieved with recirculation/with low pollution load wastes
~~**Residue – type**~~	~~kg~~	~~Not supplied~~	~~Combined FGC and fly ash~~
Residue – amount	kg/t waste input	25–50	Combined FGC and fly ash
Water consumption	l/t waste input	~~Not supplied~~ NA	Lowest where FGC inlet temperature is low; otherwise water for cooling also necessary
~~**Effluent production**~~	~~l/t waste input~~	~~Not supplied~~	
Plume visibility	+/o/-	0	Mid range of applied systems

NB: The data in this table aim to provide the typical operational range. The precise amounts of residues and effluents produced will depend on many factors including raw gas concentrations (waste-related), flow rates, reagent concentrations, etc.
Source: [3, Austria, 2002, 12, Achternbosch, 2002], [64, TWGComments, 2003] [74, TWGComments, 2004], [81, TWG 2016]

For this technique, the most significant cross-media effect is higher residue production rates than for wet systems.
Separate collection of fly ash is possible if this system is preceded by an ESP. This then increases separation of fly ash and FGC residues, which can be beneficial if separate treatment/recycling options exist for these residues.

The semi-wet FGC system is often applied as a single stage multi-reactor. Such systems usually have lower energy requirements than more complex multistage FGC systems.

Technical considerations relevant to applicability

The technique is generally applicable.

Due to the outlet temperature (120–170 °C), the flue-gas may need to be reheated for some subsequent FGC systems, e.g. SCR.

~~The applicability of this technique is assessed in the table below:~~

~~**Table 4.41: Assessment of the applicability of semi-wet FGC**~~

~~Criteria~~	~~Evaluation/comment~~
~~**Waste type**~~	• ~~suited to most waste types~~ • ~~generally less capable of dealing with very highly variable inlet concentrations than wet scrubbers~~
~~**Plant size range**~~	• ~~applied at all size ranges~~
~~**New/existing**~~	• ~~applied at new plants and as a retrofit~~

~~**Inter-process compatibility**~~	~~flue-gas outlet temperature (120 – 170 °C) requires reheat for subsequent FGC systems e.g. SCR~~ ~~separate (pre-) collection of fly ash possible~~ ~~bag filter provides effective gas cleaning step for subsequent SCR or wet system (if used as pre-deduster).~~
~~**Key location factors**~~	~~no effluent is produced and no discharge required~~ ~~availability/cost of solid residue outlets~~

Economics

Capital cost information for the technique is shown in the table below.

Table 4.42: Estimated investment costs of selected components of typical semi-wet FGC systems

FGC component(s)	Estimated investment cost (million EUR)	Comments
Fabric filter	2	
Spray dryer	1–1.5	
NB: Costs estimated relate to a two-line MSWI with a total capacity of 200 kt/yr. *Source:* Source [12, Achternbosch, 2002]		

Key operational factors of this technique are:

- investment costs are lower than for wet FGC systems, especially for relatively small capacities [2, infomil, 2002]; ~~p 119~~
- possible higher cost of disposal of the higher quantity of residues produced (than wet systems);
- reduced labour cost (compared to wet systems) due to the lower complexity, particularly because it avoids the costs of ~~the~~ operating~~on of~~ an effluent treatment plant;
- increased alkaline reagent cost due to higher stoichiometric ratios.

Driving force for implementation

~~This technique has been implemented where:~~

- ~~emission limit values have been set at those detailed in Directive 2000/76/EC~~
- ~~wastes treated do not result in~~ Capability to deal with moderate~~very high~~ and moderately variable inlet flue-gas loads.
- ~~outlets exist for solid residues produced~~
- No production of effluent. ~~Production is not desirable~~
- Lower investment cost than for a wet scrubber.
- ~~water supplies are limited because the lower~~ Water consumption lower than for a wet scrubber.
- ~~the infrastructure for waste water handling is not available, or limited, e.g. remote rural areas in dry climates due to the lack of need for effluent treatment~~
- Lower plume visibility than with ~~non-~~wet systems~~ may also be a particular advantage in areas where there is high sensitivity to visual impacts~~. [64, TWGComments, 2003]

Example plants

Widely used in Europe, e.g. the UK, Germany, France and Denmark.

Reference literature

[1, UBA, 2001, 2, infomil, 2002, 3, Austria, 2002, 12, Achternbosch, 2002, 26, RSP, 1999, 54, dechefdebien, 2003], [64, TWGComments, 2003]

4.5.3.3 Intermediate systems with some water addition and residue recirculation (flash dry systems)

Description
This technique is ~~has already been~~ described in Section 2.5.4.

Technical description
The technique has elements of both semi-dry and dry systems, and is mainly characterised by low water addition and high residue recirculation rates.

This technique is reported to only be applied with ~~when~~ lime as ~~is the~~ reagent. [74, TWGComments, 2004]

Achieved environmental benefits
The process, in combination with a bag filter and reagent addition, also provides for the emission reduction of:

- dust and associated heavy metals (to 0.4–2 mg/Nm^3 dust);
- Hg (with carbon injection to 0.002–0.015 mg/Nm^3);
- PCDD/F (with carbon injection to 0.005–0.1 ng TEQ/Nm^3).

The recirculation of reagents generally used with this system has the following advantages compared with other FGC systems:

- reduced reagent consumption (compared to dry and semi-wet systems);
- reduced solid residue production (contains less unreacted reagent);
- reduced water consumption and no effluent production (compared to wet systems).

Environmental performance and operational data
The technique is reported to be able to cope with the inlet concentrations associated with most waste types, with the exception of the highly variable inlet concentrations that may arise for instance when incinerating merchant hazardous wastes.

The reduction of emissions to air and achieved emission levels are as follows.

Table 4.43: Emission levels associated with the use of flash dry FGC

Substance(s)	Reduction efficiency range (%)	Achieved emission ranges				Comments
		Half-hourly average (mg/Nm^3)	Daily average (mg/Nm^3)	Annual average (mg/Nm^3)	Specific emission (g/t waste input)	
HCl	> 99	< 10	< 6	2.9	10–30	Stable due to high circulation rate
HF	> 99.5	< 2	< 1	< 0.5	1–5	Stable due to high circulation rate
SO_2	> 99	< 50	< 5	< 1	5–50	Stable due to high circulation rate

Source: [57, Alstom, 2003] [64, TWGComments, 2003] [74, TWGComments, 2004]

Table 4.44: Operational data associated with the use of flash dry FGC

Criteria	Description of factors affecting criteria	Evaluation (high/medium/ low) or data	Comments
Complexity	• Additional process units required • Critical operational aspects	M	• Very few process components • Care required to ensure effective circulation of reagent and humidity control
Flexibility	• Ability of technique to operate under a range of input conditions	H/M	• Large buffer volume of circulating reagent increases flexibility • Not as flexible as wet systems
Skill requirements	• Notable extra training or manning requirements	M	• Simple system
Source: [57, Alstom, 2003] [74, TWGComments, 2004]			

Reagent injection and residue bleed rates require optimisation to prevent absorbent loading and eventual substance breakthrough (e.g. mercury and PCDD/F absorbed on carbon).

Moisture levels require monitoring and control to maintain the acid gas absorption efficiency.

Upstream HCl monitoring is used to optimise alkaline reagent/water dose rates.

Cross-media effects

Cross-media effects are identified in the table below.

Table 4.45: Cross-media effects associated with the use of flash dry systems

Criteria	Units	Range of achieved values	Comments
Energy requirements	kWh/t waste input		• Pressure drop of bag filter is main consumer • Circulation system consumes energy
Reagent consumption	kg/t waste input	7–15 (lime)	
Reagent stoichiometry	ratio	1.2–1.8	
~~**Residue – type**~~			~~• combined FGC and fly ashes (if no pre-collector)~~ ~~• lower levels of unreacted reagents~~
Residue ~~– amount~~	kg/t waste input	12–25	• Lower levels of unreacted reagents
Water consumption	l/t waste input		Dependent on inlet flue-gas temperature, cooling may be required to ~~achieve~~ reach the operating temperature
~~**Effluent production**~~	~~l/t waste input~~	~~0~~	
Plume visibility	+/o/-	0	• Minimal water addition for conditioning
NB: The data in this table aim to provide the typical operational range. The precise amounts of residues and effluents produced will depend on many factors including raw gas concentrations (waste-related), flow rates, reagent concentrations, etc. *Source:* [3, Austria, 2002, 12, Achternbosch, 2002, 57, Alstom, 2003] [74, TWGComments, 2004]			

For this technique, the most significant cross-media effects are:

- production of solid residues;
- energy consumption from the pressure drop associated with the use of a bag filter.

Technical considerations relevant to applicability
The technique is generally applicable.

The bag filter needs to be larger than other systems to cope with the recirculated FGC residue.

~~The applicability of this technique is assessed in the table below:~~

~~**Table 4.46: Assessment of the applicability of flash dry FGC**~~

~~**Criteria**~~	~~**Evaluation/comment**~~
~~**Waste type**~~	• ~~all waste types except where inlet concentrations are highly variable e.g. merchant hazardous wastes~~ • ~~currently applied to: MSW, RDF, wood wastes~~
~~**Plant size range**~~	• ~~mainly applied at small to medium scale plants owing to increased scale of filter required (to accommodate re-circulated residues)~~
~~**New/existing**~~	• ~~no specific restrictions~~ • ~~filters need to be larger than other systems to accommodate re-circulated~~
~~**Inter-process compatibility**~~	• ~~can provide pre-dusting for SCR system~~ • ~~can be operated with SNCR~~
~~**Key location factors**~~	• ~~small footprint~~ • ~~less suitable where outlets already exist for treatment/recovery of segregated fly ash~~
~~*Source:* [57, Alstom, 2003]~~	

Economics
Capital costs are reported to be somewhat lower than for wet and semi-wet systems due to the reduced number of process components and consequently the smaller footprint~~.~~, but ~~S~~slightly ~~greater~~ higher ~~capital cost~~ than for dry gas cleaning. However, the bag filter size increase, the larger capacity required, and other specific recirculation equipment are also reported to increase costs when residues are recirculated. [74, TWGComments, 2004]

Operating~~onal~~ costs associated with reagent consumption and residue production will be between those of semi-wet and dry systems using similar degrees of recirculation. Running costs are reported to be reduced when using recirculation (a common feature with this system) because of the lower reagent consumption (improved stoichiometric ratio compared to dry and semi-wet systems and no requirement for water treatment ~~cf.~~ like there is in the wet system) and the reduced residue disposal costs.

Driving force for implementation
~~This technique has been implemented where:~~

- Lower reagent consumption compared to dry systems. ~~Requires specific reduction~~
- Lower residue production compared to dry systems. ~~Requires reduction~~
- Limited space requirement.~~d is restricted~~
- Limited process complexity~~ is a concern~~.

Example plants
Some existing processes/plants, mainly small- to medium-scale, incinerating MSW, RDF and waste wood in Sweden, Norway, Germany and Denmark. *To the TWG: please identify specific plants using this technique.*

Reference literature
[57, Alstom, 2003] [64, TWGComments, 2003]

4.5.3.4 Dry FGC systems

Description

This techniques is ~~has already been~~ described in Section 2.5.4.

Technical description

Lime (e.g. hydrated lime, high specific surface area lime) and sodium bicarbonate are commonly used as the alkaline reagents. The addition of activated carbon provides for the reduction by adsorption of mercury and PCDD/F emissions.

~~When~~ Finely ground sodium bicarbonate, when ~~is~~ injected into hot gases (above 140 °C), ~~it~~ is converted~~s it~~ to sodium carbonate of high porosity and hence is effective for acid gas absorption. [59, CEFIC, 2002]

Achieved environmental benefits

~~Although compliance with EC/2000/76 is achieved using~~ With this technique, it is generally~~, for a given situation,~~ not possible to reach the same very low emission levels ~~limits~~ as with other FGC systems without increasing reagent dosing rates and consequent residue generation ~~production~~. Reagent recycling can reduce these cross-media effects to some degree, but can lead to operational difficulties related to ~~in respect of~~ reagent dosing systems.

Environmental performance and operational data

The air emission levels generally achieved by plants fitted with dry FGC are as follows.

Table 4.47: Emission levels associated with the use of dry lime FGC

Substance(s)	~~Reduction efficiency range (%)~~	Achieved emission ranges				Comments
		Half-hourly average (mg/Nm^3)	Daily average (mg/Nm^3)	Annual average (mg/Nm^3)	Specific emission (g/t waste input)	
HCl		~~<60~~ 10 – 30	~~<10~~ 5 – 8	< 6	To be updated	~~Information supplied states compliance with air ELVs in EC/2000/76.~~
HF		~~<4~~ < 0.6	~~<1~~ < 0.3	< 0.2	To be updated	
SO_2		~~<200~~ 20 – 70	~~<50~~ 10 -40	< 15	To be updated	

Source: [81, TWG 2016]

Table 4.48: Emission levels associated with the use of dry sodium bicarbonate FGC

Substance(s)	~~Reduction efficiency range (%)~~	Achieved emission ranges				Comments
		Half-hourly average (mg/Nm^3)	Daily average (mg/Nm^3)	Annual average (mg/Nm^3)	Specific emission (g/t waste input)	
HCl		~~<20~~ 6 – 30	~~<5~~ < 2 – 8	< 6	To be updated	
HF		< 1.2	<1	< 0.5	To be updated	
SO_2		~~<30~~ 30-50	~~<20~~ 5 – 25	< 15	To be updated	

Source: ~~[59, CEFIC, 2002] [74, TWGComments, 2004]~~, [81, TWG 2016]

Table 4.49: Operational data associated with the use of dry FGC

Criteria	Description of factors affecting criteria	Evaluation (high/medium/low) or data	Comments
Complexity	• Additional process units required • Critical operational aspects	L	• Simple process of few components
Flexibility	• Ability of technique to operate under a range of input conditions	M/L	• Can cope with high acid loads • Wide operational temperature range (with sodium bicarbonate (140–300 °C))
Skill requirements	• Notable extra training or manning requirements	M/L	• Simple system • Bag filter requires effective management

Source: [59, CEFIC, 2002]

Dry reagents need to be handled in such a manner as to prevent dust emissions, e.g. emissions from loading silo breather vents.

It is reported that the use of operational temperatures above approximately 180 °C may give rise to a deterioration in the PCDD/F and mercury adsorption performance of injected carbon reagents.

Cross-media effects

Cross-media effects are identified in the table below.

Table 4.50: Cross-media effects associated with the use of dry FGC

Criteria	Units	Range of achieved values	Comments
Energy requirements	kWh/t waste input		Mainly from pressure drop across bag filter. Higher operational temperature can lead to savings for FG reheat
Reagent consumption	kg/t waste input	10–20 (CaO) 10–15 ($NaHCO_3$)	~~Figure relates to sodium bicarbonate consumption in MSWI~~ Mid range of system options applied
Reagent stoichiometry	Ratio	1.25 ($NaHCO_3$) 1.5–2.5 (CaOH)	Typical excess of 25 % with sodium bicarbonate Lower values with lime achieved with recirculation
~~**Residue – type**~~			~~FGC residues with fly ash or separated if pre-dedusting~~
Residue~~**– amount**~~	kg/t waste input	7–25	From 1 tonne MSW
~~**Water consumption**~~	~~l/t waste input~~	~~0~~	~~Not required~~
~~**Effluent production**~~	~~l/t waste input~~	~~0~~	~~None~~
Plume visibility	+/o/-	-	Lowest of all systems

NB: *In situ* operational values will vary depending upon local variations in waste type, etc.
Source: [64, TWGComments, 2003]

The most significant cross-media effect of this technique is the production of solid residues, which, other parameters being equal, is generally greater than with other systems. ~~Although~~ The excess may be reduced somewhat by residue recirculation ~~(note: operational specifics)~~.

With sodium bicarbonate, the solid residues are more soluble than with lime, but significantly lower in quantity~~ than with dry lime system~~. Residues from bicarbonate systems have in some cases been treated and recycled in the chemical industry. [74, TWGComments, 2004]

Technical considerations relevant to applicability

The technique is generally applicable.

~~The applicability of this technique is assessed in the table below:~~

~~**Table 4.51: Assessment of the applicability of dry FGC**~~

~~**Criteria**~~	~~**Evaluation/comment**~~
~~**Waste type**~~	~~• Applied to a full range.~~
~~**Plant size range**~~	~~• Modern dry systems applied to wide size range~~
~~**New/existing**~~	~~• no restriction~~
~~**Inter-process compatibility**~~	~~• higher operational temperatures makes the process well suited to combination with downstream SCR~~
~~**Key location factors**~~	~~• low plume visibility~~ ~~• no effluent produced~~ ~~• residue treatment/disposal needs consideration~~
~~*Source:* [59, CEFIC, 2002], [64, TWGComments, 2003]~~	

Economics

Process unit costs are similar to semi-wet systems except:

- a relatively bigger bag ~~house~~ filter is generally used with dry systems;
- higher possible operational temperatures can lead to savings for flue-gas reheating, e.g. for SCR;
- reagent slurry handling/mixing unit not required with dry systems.

Operational cost considerations relative to other techniques include:

- increased reagent consumption rates, compared to wet FGC;
- increased disposal costs for residues, compared to other FGC systems;
- savings for treatment/disposal because of lack of effluent.

Driving force for implementation

The simplicity of such systems is the main reason for their use.

~~This technique has been implemented where ELV have been set at those detailed in Directive 2000/76/EC.~~

Restrictions on water supply and outlets make the use of dry FGC systems favourable. ~~In some cases permitting authorities have placed specific conditions forbidding~~ When water discharges are forbidden, dry (and semi-dry) systems are ~~then~~ favoured.

Example plants

The technique is widely used throughout Europe. Over ~~110~~ 240 plants are operating in more than 10 European countries, and Japan and the US.

There are examples of merchant HWIs using dry systems in France and Germany.

The technique has a growth rate of approximately 10 to 15 plants per year.

Reference literature

[59, CEFIC, 2002] [2, infomil, 2002] [64, TWGComments, 2003]

Information from the following section has been moved to Section 2.5.4

~~4.5.3.5 Selection of alkaline reagent~~

~~Description~~

~~Various alkaline reagents (and combinations) are used in FGC systems of waste incineration plants.~~

~~Technical description~~

~~Lime is used in all types of FGC systems, although most often with wet and semi-wet systems. It is used as hydrated lime in dry systems, as slaked lime in semi-wet systems, and also as high specific surface (HSS) lime [74, TWGComments, 2004] Sodium bicarbonate is applied to a range of mainly dry systems. Sodium hydroxide and limestone are generally only applied to wet FGC systems.~~

~~Achieved environmental benefits~~

~~The different options have various advantages and disadvantages and are usually strongly influenced by the overall technology selection.~~

~~Environmental performance and operational data~~

~~The advantages and disadvantages of the use of each reagent are highlighted in the table below:~~

~~Table 4.52: Comparison of features of various alkaline reagents~~

~~Reagent~~	~~Advantages~~	~~Disadvantages~~	~~Comments/other data~~
~~Sodium Hydroxide~~	• ~~highly reactive with acid gases~~ • ~~low consumption rates~~ • ~~low solid waste production~~	• ~~higher cost/kg reagent~~ • ~~variable cost (quarterly)~~ • ~~soluble salts formed~~ • ~~highly corrosive material~~ • ~~odour if in contact with humidity~~	• ~~only used in wet systems~~ • ~~well suited to variable inlet concentrations e.g. HWI.~~
~~Lime~~	• ~~medium reactivity (higher reactivity with HSS lime)~~ • ~~possibility to operate at higher temperature with HSS lime~~ • ~~lower cost/kg reagent~~ • ~~low solubility residues~~ • ~~can allow gypsum recovery from wet scrubbers~~	• ~~handling can be problematic and recycling difficult~~	• ~~residues from lime-based dry, intermediate and semi-dry systems are highly alkaline~~
~~Lime stone~~	• ~~medium reactivity~~ • ~~lower cost/kg reagent~~ • ~~low solubility residues~~ • ~~can allow gypsum recovery from wet scrubbers~~	• ~~releases CO_2, which must be stripped off by bleeding from an HCl scrubber~~	• ~~Not widely applied in MSWI~~ • ~~mainly used in wet systems~~ • ~~sometimes used in fluid bed systems~~
~~Sodium Bicarbonate~~	• ~~highly reactive both on SO_2 and HCl~~ • ~~low consumption rates (stoichiometric ratio ~1.25)~~ • ~~low residue production depending on the stoichiometric~~ • ~~purification and re-use of residue possible and applied~~ • ~~effective over wide FGC operational temperature range (140 – 300 °C, see comments in “operational data below)~~ • ~~high operational temperature range and high efficiency on SO_2 may increase compatibility with~~	• ~~higher soluble part in residue~~ • ~~soluble solid residues formed can be problematic for disposal (but use in chemicals industry possible)~~ • ~~higher cost than lime/kg reagent~~ • ~~size reduction device is required and may cause problems of availability due to fouling~~	• ~~10 – 15 kg/t MSW incinerated without fly and boiler ash~~

	~~SCR~~ - ~~no water injection/humidity control required~~		
~~Source:~~ ~~[64, TWGComments, 2003] [74, TWGComments, 2004]~~			

~~See comments given in Table 4.52 above. The temperature range which is adequate for the dry sodium bicarbonate process is linked to the phenomenon of the transformation of sodium bicarbonate to sodium carbonate; this phenomenon increases the surface area and porosity of the reagent and hence its reactivity. The phenomenon is observable from temperatures around 100 ºC, but higher temperatures are required to ensure reaction kinetics are acceptable. From 140 ºC the kinetics are generally fast enough, with experience of further increases in reactivity at temperatures of 160 – 180 ºC.~~

~~In some cases mixed FGC systems are implemented: they can operate either with HSS lime or sodium bicarbonate. Although less operationally optimised, reagent costs may thus be better controlled. [74, TWGComments, 2004] The co-injection of hydrated lime with sodium bicarbonate is also possible, as recently applied in plants in DE and NL to make up for the lower reactivity of sodium bicarbonate with HF and thus improve the continuous control of HF emissions. The co-injection of hydrated lime has been reported to also potentially reduce the overall use of reagents and associated operating costs [VDI 2012].~~

~~Cross-media effects~~

~~The most significant cross-media factors to take account of in reagent selection are:~~

- ~~quantity of residue production~~
- ~~possibilities for re-cycle of residue produced (off site)~~
- ~~nature/composition of residue and its impact on subsequent disposal/re-cycling etc~~
- ~~production and management of effluents containing soluble salts.~~

~~Chloride residues from removing hydrogen chloride in the flue-gas are highly soluble.~~

~~Technical considerations relevant to a~~pplicability

~~See applicability of different reagents in Table 4.52.~~

~~The applicability of this technique is assessed in the table below:~~

~~Table 4.53: Assessment of the applicability of various alkaline reagents~~

~~Criteria~~	~~Evaluation/comment~~
~~Waste type~~	- ~~NaOH is well suited to variable inlet concentrations e.g. HWI.~~
~~Plant size range~~	- ~~For cost reasons NaOH is less attractive in larger plants than $CaCO_3$~~
~~New/existing~~	- ~~can be applicable to both~~
~~Inter-process compatibility~~	- ~~NaOH used only in wet systems~~
~~Key location factors~~	- ~~disposal/recycling options for residues produced may be influential~~ - ~~local cost/availability of reagents may be a factor~~
~~Source:~~ ~~[64, TWGComments, 2003] [74, TWGComments, 2004]~~	

~~Source~~

~~Economics~~

~~Reagent associated costs are one component in the overall FGC selection and may not be critical on their own.~~

~~Overall reagent cost is a factor of both the unit cost per kilogram of reagent and the amount required (stoichiometric ratio) as well the availability and cost of residue treatment/disposal options. For example, for dry FGC systems, lime has the lowest reagent cost per kilogram of reagent, but the lower dose rates (kg reagent per tonne waste treated) encountered required with sodium bicarbonate mean that effective reagent cost per unit of waste treated will be similar. The relative prices and availability of residue treatment/disposal options may then become a determining factor.~~

~~Some additional cost information and estimates are given in the annex to this document (see Section 8.2.4).~~

~~NaOH prices are reported to vary.~~

~~**Driving force for implementation**~~
~~Key driving forces for the selection of reagents are:~~

- ~~ability to treat flue-gases of the waste in question~~
- ~~compatibility with the rest of the installation/FGC system~~
- ~~reagent cost per tonne of waste treated~~
- ~~availability and cost of residue disposal/treatment outlets.~~

~~**Example plants**~~
~~Lime, sodium hydroxide and lime stone are all used in a wide variety of incineration plants throughout Europe and elsewhere. The total number of WI plants in Europe alone using these reagents is estimated to exceed 100.~~
~~The dry sodium bicarbonate FGC is used in more than 130 plants in more than 10 European countries, as well as in Japan. (It is also recognised as a reference process in the United States). [64, TWGComments, 2003]~~

~~Of In these 130 plants, there are about 75 are incineration plants:~~

- ~~36 municipal waste incineration plants (ercury. 2 Mt/yr municipal waste)~~
- ~~special waste incineration plants (more than 500 kt/yr special waste).~~

~~Other incineration plants use dry sodium bicarbonate for used tyres, sewage sludge, and hospital waste:~~

- ~~ercury. 35 in France~~
- ~~44 in Italy~~
- ~~others in Germany, Belgium, Portugal and United Kingdom.~~

~~The growth in use of dry sodium bicarbonate is of about 10 to 15 new plants each year.~~

~~**Reference literature**~~
~~[59, CEFIC, 2002, 64, TWGComments, 2003]~~

4.5.3.6 Addition of wet scrubbing as a flue-gas polishing system after other FGC techniques ~~processes~~

Description
It is possible to consider that the addition of a final wet flue-gas treatment system is a polishing treatment after other systems that deal with acid gases, etc. This addition is generally made to control HCl and SO_2 emissions where they are high or variable. [74, TWGComments, 2004]

Technical description
Flue-gas polishing is typically performed in packed bed wet scrubbers. A usual feature of wet scrubbing in the polishing position is that HCl, SO_2, HF and possibly mercury can be removed in one common stage rather than in two separate stages. NaOH can be added to improve the removal of SO_2 and HF. The process water may be injected into the furnace or into the upstream dry flue-gas cleaning system for waste-water-free operation. Energy recovery by condensation can be integrated in the system, and the occurrence of wet plume can be avoided by reheating the flue-gas by the addition of a steam heater or by a gas-gas heat exchanger without the need for an additional energy supply.

Achieved environmental benefits

~~Further~~ Increased reliability in ~~reduction of~~ acid gases (HCl, HF, SO_2) emission~~s~~ reductions ~~to air~~ down to levels at the lower end of the ranges achievable with wet scrubbing ~~are shown in~~ (see Section 4.5.3.1).

The consumption of sorbent and the related production of residues in the upstream dry system may be decreased due to the high efficiency and low stoichiometric factor of the polishing scrubber.

Environmental performance and operational data

See Section 4.5.3.1.

Cross-media effects

See Section 4.5.3.1.

Technical considerations relevant to applicability

See Section 4.5.3.1.

Economics

~~See Section 4.5.3.1. Because in this case the consideration is of the addition of a further polishing stage, the additional costs incurred will be significant.~~ The typical investment cost reported for a scrubber sized for treating a 100 000 Nm^3/h gas flow is EUR 2 million including circulation pumps. An additional cost of around EUR 100 000 may be also required for a reheater or fiberglass-reinforced plastic stack pipe.

Operating costs have been reported as EUR 10–15/h for electricity (additional fan pressure drop of typically 1 200 Pa) and circulation pump operation. The NaOH cost depends on the design.

See also Section 4.5.3.1.

Driving force for implementation

See Section 4.5.3.1 for the driving forces for ~~respects~~ the use of wet FGC in general.

Where emissions of acid gases are high or variable, the addition of a polishing stage may be driven by legislation requiring improved flue-gas cleaning related to peak concentrations of pollutants. The technique is thus most suited to wastes that have high and variable concentrations of chlorine or other acid-forming components (e.g. hazardous wastes or MW that includes industrial wastes).

The addition of a polishing stage may also be driven by savings in reagent costs in the upstream dry flue-gas cleaning system.

Example plants

Many plants in Scandinavia and WTE ACCAM Busto Arsizio (IT) (IT01); Usine de Fort-De-France (FR) (FR46); Halluin (FR) (FR92). ~~Information not supplied.~~

Reference literature

[64, TWGComments, 2003], [97, Denmark et al. 2015]

4.5.3.7 Recirculation of FGC residues in the FGC system

Description

Residues collected in the bag filters used for dry, semi-wet and similar (but not wet) FGC (see also Sections 4.5.3.2, 4.5.3.3, 4.5.3.4) systems usually contain a significant proportion of unreacted flue-gas treatment reagents, as well as the fly ash and other pollutants removed from the gas stream. A proportion of the accumulated residues can be recirculated within the FGC system.

Technical description

Because of the recirculation, the size of the FGC is generally increased to accommodate the additional volume of recirculating material.

An alternative to this technique, which also reduces reagent use and residue production, is the use of efficient once-through systems. That is, those where the installation design and operation are such that the reagents used are already largely reacted (i.e. little unreacted reagent remains) without recirculation. Analyses of the FGC residues may be carried out to determine the proportions of reacted and unreacted reagent.

Achieved environmental benefits

The recirculation of reagents within the system has the following advantages:

- reduced reagent consumption (compared to dry and semi-wet systems);
- reduced solid residue production (contains less unreacted reagent).

Reductions of emissions to air are similar to those ~~already~~ shown in Section 4.5.3.3.

Environmental performance and operational data

Table 4.54: Operational data associated with the use of residue recirculation

Criteria	Description of factors affecting criteria	Evaluation (high/ medium/low)	Comments
Complexity	• Additional process units required • Critical operational aspects	H/M	• Care required to ensure effective circulation of reagent and humidity control
Flexibility	• Ability of technique to operate under a range of input conditions	H/M	• Large buffer volume of circulating reagent increases flexibility • Not as flexible in respect of inlet variations as wet systems
Skills required	• Notable extra training or manning requirements	M/L	

Source: [57, Alstom, 2003] [64, TWGComments, 2003]

Reagent injection and residue bleed rates require optimisation to prevent adsorbent loading and eventual substance breakthrough (e.g. mercury and PCDD/F adsorbed on carbon).

Moisture levels require monitoring and control to maintain the acid gas adsorption efficiency.

Upstream HCl monitoring may be used to optimise alkaline reagent/water dose rates.

Some parts of the FGC system volume must be larger to incorporate the additionally recirculated material.

Cross-media effects

For this technique, the most significant cross-media effects are:

- production of solid residues (although less than without recirculation);
- energy consumption from the use of a bag filter.

In some cases, increases in ercury releases have been reported. Consideration of the mercury input rates and the provision of sufficient mecury removal may therefore be required to control this.

Technical considerations relevant to applicability

The technique is generally applicable in combination with FGC systems other than wet systems.

The recirculation of FGC residues requires a larger bag filter and additional space to accommodate a larger reactor.

~~The applicability of this technique is assessed in the table below:~~

~~**Table 4.55: Assessment of the applicability of residue re-circulation**~~

~~**Criteria**~~	~~**Evaluation/comment**~~
~~**Waste type**~~	~~• all waste types except where inlet concentrations are highly variable e.g. merchant hazardous wastes, unless in combination with another system for these pollutants~~ ~~• currently applied to: MSW, RDF, wood wastes~~
~~**Plant size range**~~	~~• no restriction~~
~~**New/existing**~~	~~• no specific restrictions~~ ~~• filter need to be larger than other systems to accommodate re-circulated~~
~~**Inter-process compatibility**~~	~~• compatible with FGC systems other than wet systems~~
~~**Key location factors**~~	~~• space required for larger reactor~~
~~***Source:*** [57, Alstom, 2003], [64, TWGComments, 2003]~~	

Economics

The bag filter size and cost are increased owing to the larger capacity required for the recirculation of residues.

~~Revenue~~ Operating costs are reduced by the lower reagent consumption (improved stoichiometric ratio compared with dry systems) and the reduced residue disposal costs.

Driving force for implementation

- Reduction of reagent consumption ~~requires specific reduction~~.
- Reduction of residue production ~~requires reduction~~.

Example plants

Existing ~~processes~~ plants incinerating MSW, RDF and wood wastes in Sweden, Norway, Germany, Denmark and Spain.

Reference literature

[57, Alstom, 2003], [64, TWGComments, 2003]

4.5.3.8 Direct addition of alkaline reagents to the waste (direct desulphurisation)

Description

This techniques~~ has already been~~ is described in Section 2.5.4.2. It is generally only applied to fluidised bed furnaces.

The alkaline reagent reacts in the furnace with acid gases to reduce the acid loads in the raw flue-gas passing to subsequent flue-gas cleaning stages.

Technical description

Adsorption within the furnace at high temperatures is much more effective for SO_2 than for HCl; the main applications are therefore processes with a relatively high SO_2 content, e.g. sludge incineration.
[74, TWGComments, 2004]

Achieved environmental benefits

Benefits include some reduction of raw gas loads and the reduction of emissions and reagent consumption associated with the downstream FGC system~~ later in the process~~.

Environmental performance and operational data

The main advantage of this technique is that it may reduce corrosion problems in the boiler. As the stoichiometric ratio is quite high it does not improve the overall FGC performance [64, TWGComments, 2003]

Cross-media effects

For this technique, the most significant cross-media effects are:

- consumption of reagents in the furnace (but reduced consumption downstream);
- effects on the bottom ash quality since salts and the excess reagent are mixed with it;
- changing the composition of the flue-gas (SO_2 to HCl ratio) can effect the performance of downstream FGC systems, can alter the PCDD/F profile and can cause corrosion problems in the FGC.

The addition of lime will not only affect the bottom ash quality, but also the composition and resistivity of the fly ash (i.e. there will be more Ca and more sulphurous compounds and higher dilution of pollutants with an increasing amount of FGC residues) [64, TWGComments, 2003]

Technical considerations relevant to applicability

~~Only~~ The technique is generally applicable to fluidised bed systems.

Economics

The reduced flue-gas treatment costs need to be considered against the costs of adding the reagent at the earlier stage.

There are additional capital costs for the provision of reagent injection into the furnace/waste.

Driving force for implementation

The technique is implemented as a retrofit at existing plants where there is only a limited possibility to increase the acid gas cleaning capacity of the FGC systems.

Example plants

~~No information available.~~ SOGAMA, Cerceda (ES) (ES07.1/ES07.2); Area Impianti Bergamo (IT) (IT07); SNB, Moerdijk (NL) (NL06).

Reference literature

[1, UBA, 2001] [64, TWGComments, 2003]

4.5.3.9 Boiler injection of alkaline reagents (high-temperature injection)

Description

Direct injection of dedicated reagents into the boiler at high temperature, in the boiler post-combustion area, to achieve partial abatement of the acid gases. Hydrated lime and magnesium lime have been used as reagents.

Technical description

In this technique, the hydrated lime reagent is injected and reacts with the acid gases directly in the furnace, at optimal temperatures of 800–1 200 ºC, to reduce the raw gas acid loads passing to subsequent flue-gas cleaning stages. Since adsorption at high temperatures is highly efficient for SO_X and HF removal, this reaction consumes significantly less reagent compared to achieving an equal removal rate at a lower temperature at the stage of the bag filter. The technique also flattens pollutant peaks, allowing the further reduction of reagent use in the downstream flue-gas cleaning unit.

Achieved environmental benefits

Benefits are reduction of raw gas loads and reduction of acid gas peaks, and reduction of emissions and reagent consumption in the downstream flue-gas cleaning unit.

Environmental performance and operational data

The reduction of SO_2, SO_3 and HF by 80–96 % and of HCl by 25–30 % (at the exit of the boiler) is reported with an injection rate of 3–8 kg hydrated lime per tonne of waste.

Cross-media effects

Since an overall reduction in the use of reagents in the combined in-boiler and downstream flue-gas cleaning systems is reported, no cross-media effects are expected.

Technical considerations relevant to applicability

The technique is generally applicable to grate and rotary kiln plants.

Economics

Investment costs are reported to be in the range of EUR 100 000–300 000.

Operating costs, including maintenance and energy costs for the conveying system and reagent costs for for boiler injection, are EUR 0.4–2.20 per tonne of waste.

Avoided operating costs in the case of downstream $NaHCO_3$ sorbent injection are EUR 0.72–2.04 per tonne of waste.

Driving force for implementation

- Allowance of increased input loads of acidic pollutants in the waste.
- Reduction of boiler maintenance downtime.
- Reduction of the occurrence of acid gas emission peaks.
- Increase of the reliability of the FGC system by adding an additional step.
- As a retrofit, the technique can provide a simple upgrade of the existing FGC unit to increase the removal rate of acidic pollutants while keeping the reagent dosage rate moderate.

Example plants

ACSM S.p.A., Como (IT) (IT02); AMSA S.p.A. Milano (IT); REA Dalmine (IT) (IT10.1/IT10.2); Silea S.p.A, Valmadrera (IT) (IT11); Tecnoborgo S.p.A., Piacenza (IT) (IT12); Ambiente 2000 Trezzo Adda (IT); Brianza Energia Ambiente-Desio (IT) (IT03); AEM Gestioni Cremona (IT); ACCAM S.p.A., Busto Arsizio (IT) (IT01); Ecolombardia 4 Filago (IT); Schwandorf MWI (DE); Heringen RDF plant (DE) (DE50).

Reference literature

[99, EuLA 2015]

4.5.3.10 Combination of semi-wet absorber and dry injection system

Description

Combination of a semi-wet process (SDA) and of dry sorbent injection (DSI). The technique is also known as the three-quarters dry system.

Technical description

The technique consists of the injection of a dry reagent (DSI) upstream or downstream of the semi-wet reactor (SDA).

The reagent of the DSI can be hydrated lime, high surface hydrated lime, high porosity hydrated lime or a blend of hydrated lime and carboneous or mineral materials.

The basic principle of operation is to keep the injection of lime milk in the reactor constant at the optimal design rate to capture most of the pollutant load, while the DSI is used to remove the residual acidic gas load including peaks by means of a direct regulation control.

Achieved environmental benefits

- Reduction of the overall pollutant load released into air compared to a typical semi-wet process.
- Reduction of the quantity of residues generated thanks to improved stoichiometry compared to reaching the same removal rate with a semi-wet process alone.

Environmental performance and operational data

Reported removal efficiencies are > 98 % for SO_2 and > 99 % for HCl.

Reported advantages are:

- constant operation of the lime milk preparation;
- fast and accurate response of the DSI to peak pollutant loads;
- redundancy of equipment for maintenance purposes;
- reduction of total reagent consumption for similar acid removal compared to the semi-wet process alone.

Cross-media effects

Since an overall reduction in the use of reagents compared to the use of SDA alone is reported at an equal pollutant removal rate, no cross-media effects are expected.

Technical considerations relevant to applicability

The technique is applicable to new plants and to existing plants using SDA as the FGC process.

Economics

Investment costs are: EUR 100 000–200 000 for a DSI system.

Operating costs, including maintenance and energy costs for the conveying system and reagent costs (1 kg hydrated lime per tonne of waste) for DSI are EUR 0.17–0.29 per tonne of waste.

Avoided operating costs by reducing reagent consumption in the SDA unit are EUR 0.33–0.38 per tonne of waste, based on reducing lime consumption from 10 kg to 7.5 kg per tonne of waste.

Driving force for implementation

- As a retrofit, to enable a plant fitted with SDA to further reduce emission levels.

- Allowance of increased input loads of acidic pollutants in the waste.
- Savings in operating costs.

Example plants

Intradel Uvelia-Herstal (BE) (BE04); SNVE, Rouen (FR); BSR, Berlin (DE); IPALLE, Thumaide (BE); Vattenfall IKW, Ruedersdorf (DE) (DE84); SWB MHKW, Bremen (DE) (DE39); SERTRID Usine de Bourgogne (FR); IBW, Virginal (BE); Amagerforbraending, Copenhagen (DK); Slagelse Forbrændings Anlæg, Slagelse (DK) (DK03).

Reference literature

[100, EuLA 2015]

4.5.3.11 Use of acid gas monitoring for FGC process optimisation

Description

By using fast-response ~~gas~~ HCl monitoring upstream and/or downstream of dry and semi-wet FGC systems, it is possible to adjust the operation of the FGC system so that the quantity of alkaline reagent used is optimised for the emission set point of the operation.

Technical description

The technique is generally applied as an additional method to control peak concentrations, with the build-up of a layer of reagent on the bag filters also providing an important buffering effect for reagent fluctuations.

This technique is not relevant to wet scrubbers as the scrubbing medium is water and the supply of water to a wet scrubber is controlled by the evaporation and bleed rates, not by the raw HCl concentration. [64, TWGComments, 2003]

SO_2 measurement is sometimes also carried out [64, TWGComments, 2003]. However, just preventing HCl breakthrough may assist in ensuring that sufficient reagent is available to also provide for SO_2 control and, therefore, reduce such peak emissions.

Achieved environmental benefits

Benefits of the technique are that:

- peak raw gas loads are anticipated and therefore do not result in elevated emissions to air;
- neutralisation reagent consumption can be reduced by matching the demand;
- the amount of unused reagent in residues is reduced.

These environmental benefits are highest where waste quality control at the input to the furnace is limited, and lower where wastes are homogenised and subjected to good quality control by means of selection, mixing or pretreatment operations.

Smaller plants may benefit the most as rogue waste inputs can exert a larger influence on smaller throughput systems.

Environmental performance and operational data

The response time of the monitor needs to be fast to pass the control signal to the reagent dosing equipment in time to provide an effective response.

Corrosion resistance of the monitors is essential as they are located in an extremely aggressive environment. Fouling can also be a problem.

The variation in the ~~dosing of~~ absorption capacity in the FGC system ~~device~~ can be ~~made~~ achieved by:

- changing the flow rate using variable speed pumps or variable speed dosing screws;
- changing the concentration of reagent in semi-wet systems – when smaller mixing tank volumes improve the rate of change of concentration.

Cross-media effects
None reported~~ significant effects~~.

Technical considerations relevant to applicability
The technique is generally applicable.
~~The applicability of this technique is assessed in the table below:~~

~~**Table 4.56: Assessment of the applicability of raw gas monitoring for optimisation of FGC**~~

~~**Criteria**~~	~~**Evaluation/comment**~~
~~**Waste type**~~	~~Particularly suited to dry, semi-wet and intermediate FGC processes with high variability inlet concentrations of acid gases~~
~~**Plant size range**~~	~~Smaller plants may benefit the most as rogue waste inputs can exert larger influence on smaller throughput systems.~~
~~**New/existing**~~	~~Suited to new and existing processes but particularly suited to retrofits where acid gas control could be further optimised.~~
~~**Inter-process compatibility**~~	~~Mainly applicable to dry and semi-wet systems.~~
~~**Key location factors**~~	~~No significant issues~~

~~This technique is not generally necessary for processes with wet scrubbers owing to their greater flexibility with respect to inlet concentrations of HCl.~~

~~Less applicable where wastes are homogenised and well quality controlled by means of selection, mixing or pretreatment operations. Most applicable where waste quality control at the input to the furnace is limited.~~

Economics
No information provided.~~ Not supplied.~~

Driving force for implementation

- ~~The technique has been applied a~~As a retrofit at existing plants, to avoid exceeding ~~where excesses of~~ short-term emission limits~~ have occurred~~.
- ~~The technique has also been included~~ In the design of new plants~~processes~~, to optimise reagent consumption while ensuring compliance with short-term emission requirements.

Example plants
Applied ~~at some~~ incinerators across the EU~~ in the UK and France~~, e.g.Vitre (FR) (FR002); Cergy, Saint-Quen L'Aumône (FR) (FR075); MHKW Bremerhaven, Breme (DE) (DE39); UTE-TEM, Mataró ES) (ES04); Allington Incinerator (UK) (UK07); Lincoln (UK) (UK12).

Reference literature
[17, ONYX, 2000] [64, TWGComments, 2003]

4.5.4 Techniques to reduce~~tion of in the emissions~~ nitrogen oxides emissions

Primary measures are generally of great importance for reducing the formation of NO_X at the combustion stage. These have been described earlier in this document (see Sections 4.1 and 4.3). They mainly relate to the management and preparation of wastes, and particularly to the thermal treatment techniques applied. This section of the BREF deals with the techniques that are applied for the reduction of NO_X emissions by the application of secondary (abatement) techniques. In general, combinations of primary and secondary techniques are applied.

4.5.4.1 Selective catalytic reduction (SCR)

Description

This technique~~ has already been~~ is described in Section 2.5.5.

Technical description

The most common SCR reactions, which are catalysed, are:

$$\begin{array}{llll} 4\,NO & +\ 4\,NH_3\ +\ O_2 & \rightarrow & 4\,N_2\ +\ 6\,H_2O \\ NO & +\ NO_2\ +\ 2\,NH_3 & \rightarrow & 2\,N_2\ +\ 3\,H_2O \\ 2\,NO_2 & +\ 4\,NH_3\ +\ O_2 & \rightarrow & 3\,N_2\ +\ 6\,H_2O \\ 6\,NO_2 & +\ 8\,NH_3 & \rightarrow & 7\,N_2\ +\ 12\,H_2O \end{array}$$

In waste incineration, SCR is generally applied after dedusting and acid gas cleaning (examples of the high dust/dirty gas use of this technique are rare). This being the case, flue-gases usually require reheating after the earlier FGC stages (usually the FGC exit temperature is 70 °C for wet systems and 120–180 °C for most bag filters) to reach the operational temperature for the SCR system (see below). The location of the SCR directly after a hot dedusting system is not common but is used at some plants across Europe and can avoid the disadvantages of any reheating of the flue-gases along the whole FGC line. [74, TWGComments, 2004]

Operational temperature ranges for SCR systems are reported [64, TWGComments, 2003] to range from 180 °C to 450 °C. However, it is most common for systems to operate in the range 230–320 °C. The lowest operational temperatures generally require cleaner flue-gases at the SCR inlet. The SO_2 concentration in the flue-gases may be critical and ~~they~~ can result in poisoning ~~of~~ the catalyst. The catalyst material generally consists of the carrier (TiO_2) with added active substances (V_2O_5 and WO_3).

Achieved environmental benefits

The application of SCR generally results in lower NO_X emissions than other techniques. The main disadvantages are its higher capital cost, and the consumption of energy (usually natural gas, light oil or high-pressure steam) that is required to support the reheating of flue-gases to the catalyst reaction temperature. The selection of systems that operate effectively at the lower end of this temperature range and the use of heat exchange reduces the additional energy requirement.

Environmental performance and operational data

Emission reductions and the levels of emissions to air ~~are generally as shown in the table below~~ generally achieved by plants fitted with SCR are as follows.

Table 4.57: Emission levels associated with the use of SCR

Substance(s)	~~Reduction efficiency range (%)~~	Achieved emission ranges				Comments
		Half-hourly average (mg/Nm^3)	Daily average (mg/Nm^3)	Annual average (mg/Nm^3)	Specific emission (kg/t waste input)	
NO_X	~~> 80 %~~	~~15 – 220~~ 50–200	~~15 – 100~~ 40–150	~~15 – 100~~ 40–120	0.15–0.60 To be updated	
NH_3	~~n/a~~	3–30	~~<10~~ 3–10	< 3	To be updated	
~~N_2O~~	~~n/a~~					~~Not supplied~~

Source: ~~[1, UBA, 2001, 2, infomil, 2002, 13, JRC(IoE), 2001, 60, Reimann, 2002]~~, [81, TWG 2016]

In addition, if specifically designed (extra catalyst layer, higher operational temperature), SCR can also catalytically destroy PCDD/F (see Section 4.5.5.3). Destruction efficiencies of 98–99.9 % are seen, giving PCDD/F emissions in the range of 0.05–0.002 ng/Nm^3 TEQ.

Table 4.58: Operational data associated with the use of SCR

Criteria	Description of factors affecting criteria	Evaluation (high/medium/low) or data	Comments
Complexity	• Additional process units required • Critical operational aspects	H	~~Additional process units required~~
Flexibility	• Ability of technique to operate under a range of input conditions	H	High reduction rates generally achieved. Sensitive to SO_2, SO_3 and P inlet concentrations. Multifunctional NO_X and PCDD/F reduction
Skill requirements	• Notable extra training or manning requirements	H/M	

The temperature of the catalyst has an important effect on the (relative speed of) reactions. The optimum temperature range for catalytic reduction depends upon the type of catalyst used, but is commonly between 200 °C and 350 °C. Other types of catalysts have lower optimal temperatures. [2, infomil, 2002] [64, TWGComments, 2003]

Generally, a lower operational catalyst temperature results in a slower reaction rate (NO reduction rates are slowed relatively more by lower temperatures than NO_2 rates) and possible ammonia slippage. A higher temperature results in a shortened catalyst lifetime and can lead to the oxidation of NH_3 and the production of additional NO_X [2, infomil, 2002].

Lower temperature SCR systems are generally less effective for PCDD/F destruction and additional catalyst layers may be required. Lower temperature systems generally require cleaner inlet flue-gases – with low SO_2 values ~~of~~in particular ~~interest~~. [64, TWGComments, 2003]

~~The l~~Low operating temperature SCR requires an automatic cleaning device (e.g. air soot blower).

Regular regeneration is required to remove ensure ammonia salts. The frequency of regeneration with lower temperature systems may be as high as every 1000 hours. At such a

frequency this may become operationally critical as it could~~an~~ lead to ~~elevated pollutant~~ NH_3 and SO_2 emission peaks if the flue-gas is not recirculated (see Section 2.5.5.2.2). ~~levels in the final flue-gas for HCl and SO_2.~~
[74, TWGComments, 2004]

The achieved environmental benefits may depend on the positioning ~~g~~in the overall FGC system. Where the SCR is before the scrubber, the NO_X reduction efficiency may be reduced, leading to emission values for NO_X above those presented in Table 4.48.
[74, TWGComments, 2004]

Catalysts:
[2, infomil, 2002] Criteria for determining the type of catalyst to be used are:

- flue-gas temperature;
- NO_X reduction required;
- permissible ammonia slip;
- permissible oxidation of sulphur dioxide;
- concentration of pollutants;
- lifetime of the catalyst;
- requirement for additional gaseous PCCD/F destruction;
- dust concentration in the flue-gas.

[74, TWGComments, 2004]

The following types of degradation limit the lifetime of catalysts:

- poisoning: where the active site of the catalyst is blocked by a strongly bound compound;
- deposition: where pores are blocked by small particles or condensed salts, such as ammonium bisulphate (NH_4HSO_4) – this can be reduced by SO_X reduction at the inlet and may be partially reversible by reheating the catalyst;
- sintering: where at too high temperatures the microstructure of the catalyst is destroyed;
- erosion: due to physical damage caused by solids and particles.

Lifetimes of 3 to 5 years are reported for catalysts.

Droplets at the outlet of scrubber system which cause salt deposition are considered a critical factor that increases the catalyst degradation rate.

Note: The *catalyst lifetime* is the number of hours until the catalyst can no longer provide the required NO_X reduction without exceeding an agreed maximum NH_3 slip. ~~Consequently, when deciding to apply the SCR technique, both a NO_X and an NH_3 emission limit value must be guaranteed.~~

Cross-media effects
For this technique, the most significant cross-media effect is the energy requirement for flue-gas heating. ~~However, the magnitude of~~ This can be minimised ~~reduced if the~~ with a low operating temperature of the catalyst. However, in such cases, catalyst regeneration (this is usually off site) then requires additional energy to regenerate the catalyst by sublimation of the salts deposited ~~generated~~. [74, TWGComments, 2004]

~~Reheat~~ The energy demand (and cost) for reheating is generally greatly reduced by the use of a heat exchanger that uses the heat from the SCR exhaust to heat the SCR inlet. Energy losses, and hence additional demand, are then reduced to heat exchange and radiant losses. In cases where a demand exists for medium hot water, further economies may be made by installing an additional heat exchanger for the recovery of the SCR outlet energy for supply. Such a system has been used at SYSAV, Malmö, Sweden. [64, TWGComments, 2003]

The two diagrams below show the application of SCR downstream of non-wet (i.e. dry or semi-dry) FGC and wet FGC systems. The temperature profiles are given. It can be seen that the second system (with the wet FGC) in this case includes an additional heat exchange step. Such a set-up reduces the requirement for additional energy input, but results in a colder final flue-gas discharge. Colder final stack discharge may require special measures to prevent stack corrosion and is likely to increase plume visibility.

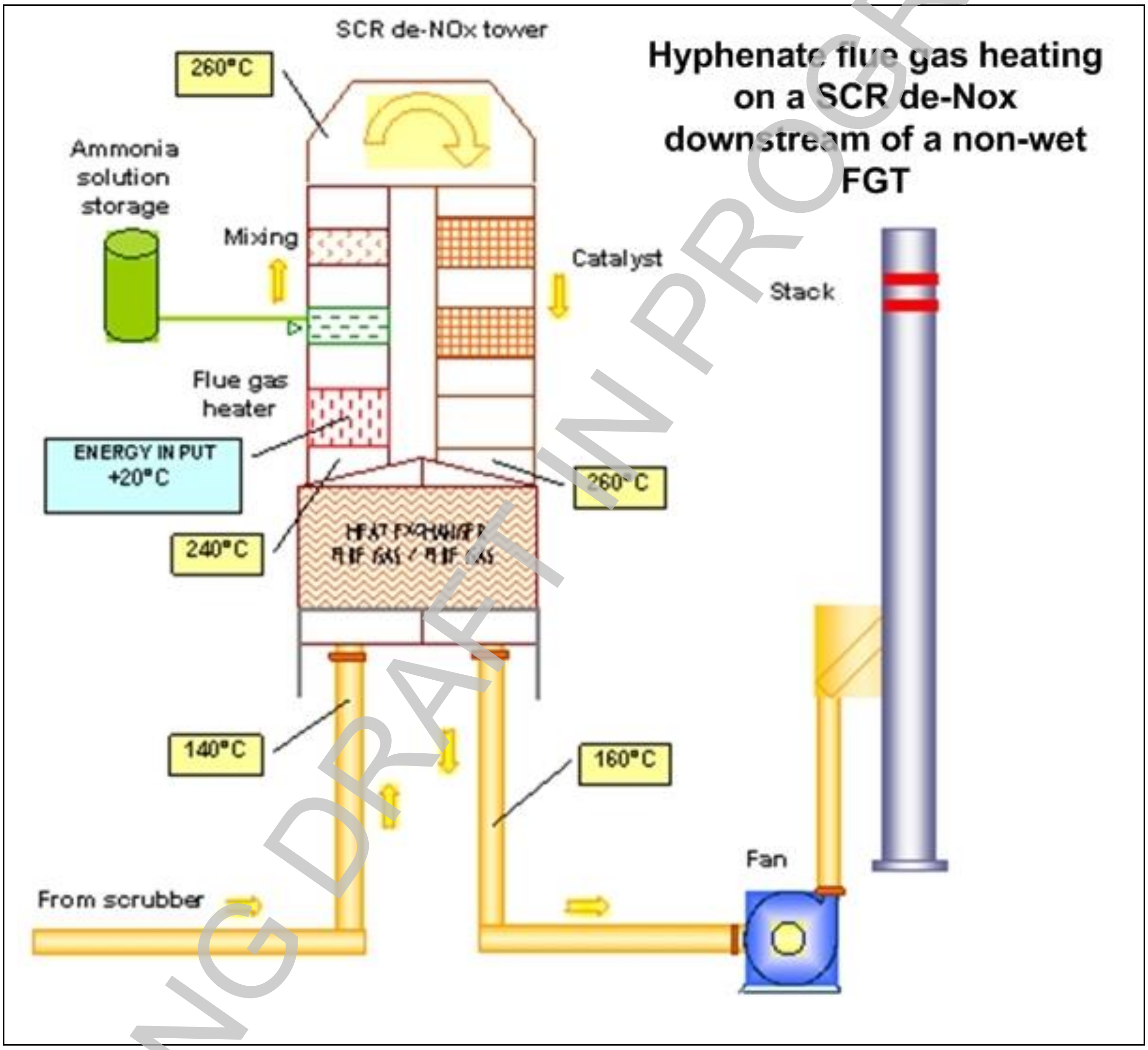


Figure 4.9: Diagram of a SCR system downstream of non-wet FGC showing typical heat exchange and temperature profiles

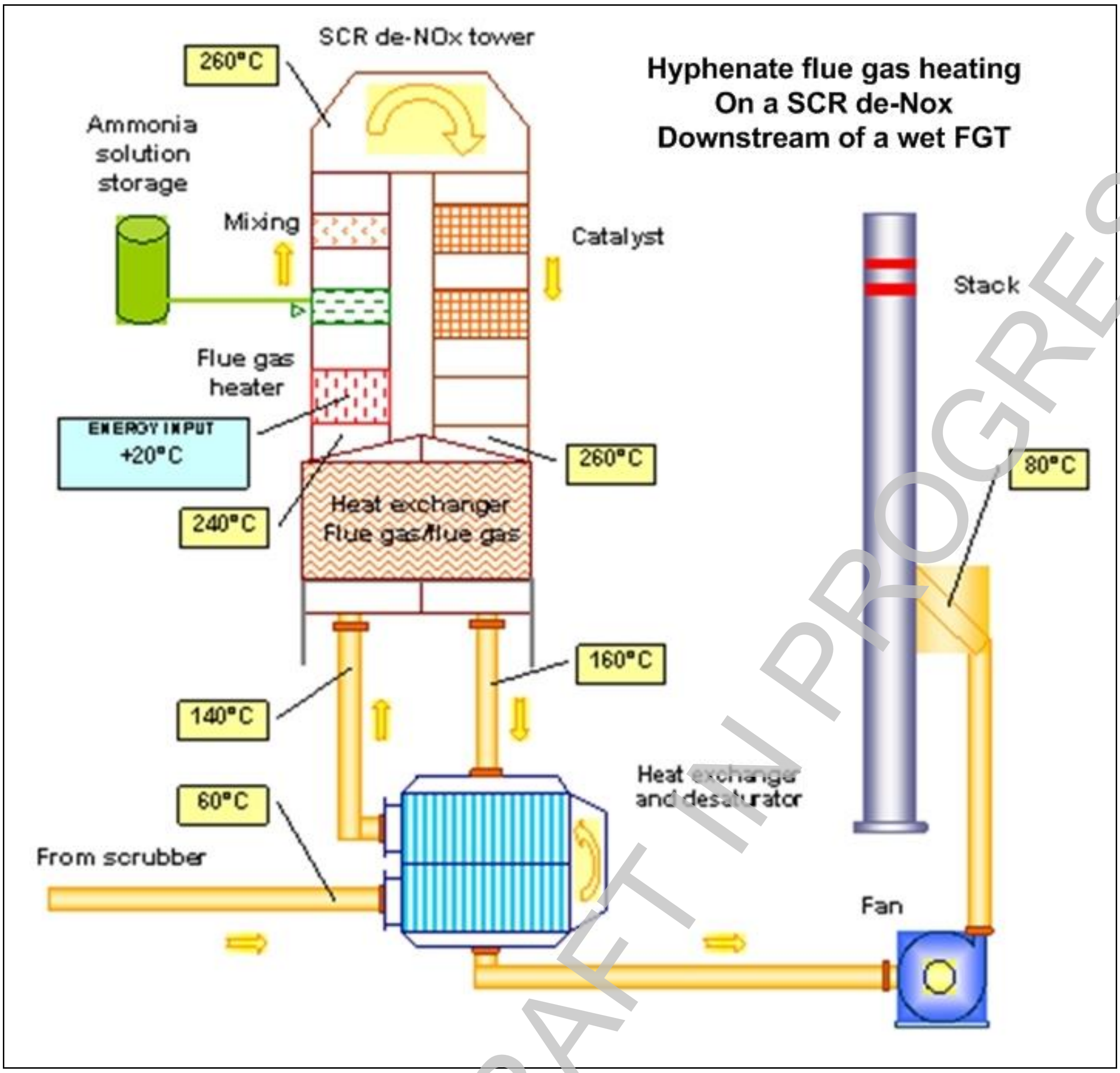


Figure 4.10: Diagram of a SCR system downstream of a wet FGC system showing additional heat exchange and temperature profiles

At equal NO_X reduction levels, reagent (usually ammonia solution) consumption rates are lower with SCR ~~this technique~~ than with SNCR because of the lower level of unreacted ammonia (ammonia slip).

Cross-media effects are identified in the table below.

Table 4.59: Cross-media effects associated with the use of SCR

Criteria	Units	Range of values	Comments
Energy requirements	kWh/t waste input	65–100 thermal 10–15 electrical	Thermal relates to reheating, electrical to the additional pressure drop across the catalyst
Reagent consumption	kg/t waste input	~~3.2 (3.6l)~~ 1–3	25 % ammonia solution
Reagent stoichiometry	ratio	1–1.1	Figure relates to input pollutant concentration
Residue – type			Spent catalyst when changed
Residue – amount	kg/t waste input	0.01	
Water	l/t waste		Not significant

consumption	input		
~~**Effluent production**~~	~~l/t waste input~~		~~none~~
Plume visibility impact	+/o/-	-	Reduced due to reheating applied with SCR
NB: The data in this table ~~aims to~~ provide the typical operational range. The precise amounts of residues and effluents produced will depend on many factors including raw gas concentrations (waste-related), flow rates, reagent concentrations, etc. *Source:* [1, UBA, 2001, 2, infomil, 2002, 13, JRC(IoE), 2001, 60, Reimann, 2002] [74, TWGComments, 2004], [81, TWG 2016]			

Technical considerations relevant to applicability

The technique is generally applicable.

The SCR process unit is usually installed at the tail-end position because the flue-gas usually needs to be pre-dedusted and may also require the removal of SO_2/SO_3, and sometimes of HCl. Meeting the minimum inlet temperature needed for SCR may thus require reheating of the flue-gas.

~~The applicability of this technique is assessed in the table below:~~

~~**Table 4.60: Assessment of the applicability of SCR**~~

~~**Criteria**~~	~~**Evaluation/comment**~~
~~**Waste type**~~	• ~~can be applied to any waste type~~
~~**Plant size range**~~	• ~~can be applied to any size plant but most often to medium to larger plants for economic reasons~~
~~**New/existing**~~	• ~~often a tail-end process that can be applied to new or existing processes~~
~~**Inter-process compatibility**~~	• ~~mostly requires pre-dedusting of the flue-gas and may also require SO_2/SO_3 removal. HCl removal may also be required.~~ • ~~minimum inlet temperature required for operation~~ • ~~use of SCR can allow lowering of NO_X emissions without additional techniques if lower ELVs applied~~
~~**Key location factors**~~	• ~~locations with high NO_X sensitivity may benefit from additional NO_X reductions achievable with this technique~~ • ~~space is required on site for the additional process unit~~

Economics

~~Capital cost information for the technique is shown in the table below:~~

~~**Table 4.61: Estimated investment costs of selected components of typical semi-wet FGC systems using SCR and SNCR**~~

~~**FGC component(s)**~~	~~**Estimated investment cost (EUR million)**~~	~~**Comments**~~
~~**Fabric filter**~~	~~2~~	
~~**Spray dryer**~~	~~1 – 1.5~~	
~~**SNCR/evaporation cooler/reagent injection/fabric filter**~~	~~7~~	~~Example of typical combination~~
~~**Evap. Cooler/reagent injection/fabric filter/SCR**~~	~~10~~	~~Example of typical combination~~
~~Costs estimated related to a 2 line MSWI of total capacity 200K t/yr.~~ ~~*Source:* [12, Achternbosch, 2002]~~		

~~Table 4.61 above shows, for the plant described (both using semi-wet technology), an increased investment cost when using SCR instead of SNCR in the order of EUR 3 million.~~

Investment costs for SCR for a two-line 200 000 t/yr MSWI ~~are~~ were estimated at EUR 4 million. This compares with around EUR 1 million for SNCR. [12, Achternbosch, 2002].

A recent DeNO$_X$ study shows that the capital cost for a SCR unit for a ~~plant of 15 t/h (i.e.~~ 100 000 t/y~~)~~ plant is in the range of EUR 7.5 million to EUR 9.5 million. [74, TWGComments, 2004]

[2, Infomil, 2002] The operating costs~~ of removing one~~ per tonne of NO$_X$ removed ranges between EUR 1 000 and EUR 4 500, with a ~~trend for costs~~ decreasing trend. ~~If this cost is allocated to the processing costs per tonne of waste, t~~This corresponds to EUR 5 to EUR 7.7 per tonne of waste processed. ~~SNCR~~ Operating~~onal~~ costs are in general 25–40 % lower for SNCR than for SCR (depending on reagent for SNCR, temperature for SCR, preheating, etc.). [13, JRC(IoE), 2001] [74, TWGComments, 2004]

Large plants with higher gas flow rates and economies of scale are more able to support the additional cost burden of SCR~~, as the cost will be distributed over a greater quantity of waste~~.

High-pressure steam can be used for the SCR reheating~~.~~, which entails an economic impact proportional to the price that can be charged for exported energy (either as heat or when converted into electricity). ~~At installations where low incomes are received for this energy (either as heat or when converted into electricity) its use for reheat involves a lower income loss (i.e. cost) than where higher revenues are received. It follows then that SCR operational costs can, therefore, be effectively lower at those plants that receive lower fees for the mid and high pressure fraction of the energy.~~

~~Example: New MSWI line in Southern Sweden 2002/3:~~
~~The capital cost of SCR for a new MSWI line (2002 price) of 25 t/hr (gas flow 586pprox.. 150000 m^3/h) was estimated at EUR 5 – 7 million. There is some uncertainty in this cost because the SCR was purchased as part of an overall FGT package.~~

~~For this example, the cost structure for deciding to use SCR was derived from the following calculations:~~

~~Avoided expenditure:~~
~~NO$_X$ tax avoided through reduced emissions (such taxes are applied in Sweden at a rate of approximately 4500 EUR/t NO$_X$).~~

~~The destruction of gaseous PCDD/F may mean that there are economies on other measures techniques for PCDD/F control (see Section 4.5.5.3) [74, TWGComments, 2004]~~

~~Costs incurred:~~
~~Financing of higher SCR capital investment + lost income from heat/steam used for SCR that would otherwise be sold + any additional reagent consumption or catalyst replacement costs.~~

Driving force for implementation

~~This technique has been implemented where:~~

- ~~permit values for~~ Reaching NO$_X$ levels ~~are set~~ below 100 mg/Nm^3.
- ~~large plants have been identified as significant local NO$_X$ contributors~~
- NO$_X$ taxes ~~are~~ set at a level that makes the technique economically favourable.
- Availability of high-pressure steam ~~is available~~ for the flue-gas reheating (this reduces operational costs when low ~~incomes~~ revenues are received for the energy produced).

Example plants

SCR is widely used in the incineration industry. There are examples in Germany, Austria, the Netherlands, Belgium, Japan and elsewhere.

~~Data provided by FEAD shows that at least 43~~ Around 150 of approximately 350 incineration lines operating in the installations that participated in the 2015 data collection ~~European MSWI plants surveyed~~ use SCR. They include non-hazardous incineration palnts as well as ~~SCR is also applied in~~ merchant and industrial HWIs~~, particularly in Germany~~.

Reference literature
[1, UBA, 2001, 2, infomil, 2002, 3, Austria, 2002, 13, JRC(IoE), 2001, 60, Reimann, 2002, 61, SYSAV, 2002] [64, TWGComments, 2003]

4.5.4.2 SCR by catalytic filter bags

Description
This technique is described in Section 2.5.8.3. $DeNO_X$ catalytic filters are filter bags which are installed in a bag filter for the reduction of dust, but also have a catalyst layer that performs the SCR function.

Technical description
The technique can be implemented as slip catalyst in combination with SNCR, with an additional NH_3 injection step immediately before the bag filter.

Achieved environmental benefits
For WI plants equipped with a bag filter but not with SCR, the replacement of filter bags with $DeNO_X$ catalytic bags can reduce NO_X emissions to those characteristic of SCR at a low investment cost, and with minimal change to the existing plant configuration. NO_X emission levels in the 50–75 mg/Nm^3 range are reported.

Environmental performance and operational data
The following levels have been reported for plants retrofitted with this technique.

Table 4.62: Emission levels associated with the use of SCR by catalytic filter bags

	Prior to retrofit	With catalytic filter bags
NO_X (daily average, 11% O_2)	135–200 mg/Nm^3	50–75 mg/Nm^3
NH_3 (daily average, 11% O_2)	1–10 mg/Nm^3	1–5 mg/Nm^3

The operating temperature is between 190 °C and 210 °C with PTFE-based filter bags, and may be extended to up to 260 °C with fibreglass-based filter bags.

Compared with a SNCR system, operational consequences associated with this technique may include:

- some increase of ammonia water or urea solution consumption for the further reduction of NO_X emissions;
- potential increase in alkaline reagent consumption to ensure SO_2 levels below 5 mg/Nm^3 as required by the technique (similar to other tail-end SCR systems).

Cross-media effects
No major cross-media effects are reported.

NH_3 slip is reduced compared to the SNCR technique.

The energy consumption from the pressure drop across the filter is similar to conventional bag filters.

Technical considerations relevant to applicability

The technique is applicable to new plants and to existing plants fitted with bag filter, with or without pre-existing SNCR.

Economics

The total investment cost to install the technique on an existing line was reported as EUR 273 000 for plant modification and EUR 416 000 for the special filter bags.

Driving force for implementation

- Reaching NO_X emissions below 100 mg/Nm^3 while keeping low levels of NH_3 slip.
- Lack of space for SCR.
- Reduced investment costs compared with a conventional SCR unit.

Example plants

Acegas in Padova (IT) (IT18), since September 2011; CEDLM Limoges (FR) (FR052), since January 2014; Villefranche (FR), since September 2013.

Reference literature

[102, CEFIC 2015]

4.5.4.3 Selective non-catalytic reduction (SNCR)

Description

This technique ~~has already been~~ is described in Section 2.5.5.2.1.

Technical description

[2, infomil, 2002] In the SNCR process, ammonia (NH_3) or urea ($CO(NH_2)_2$) is injected into the furnace to reduce NO_X emissions. The NH_3 reacts most effectively with NO_X between 850 °C and 950 °C, although temperatures of up to 1050 °C are effective when urea is used. If the temperature is too high, a competing oxidation reaction generates unwanted NO_X. If the temperature is too low, or the residence time for the reaction between NH_3 and NO_X is insufficient, the efficiency of NO_X reduction decreases, and the emission of residual ammonia can increase. ~~This is known as ammonia slip.~~ Some ammonia slip will always occur because of reaction chemistry. Additional ammonia slip can be caused by excess or poorly optimised reagent injection. [74, TWGComments, 2004]

Advanced SNCR designs have recently been introduced, in which the reaction temperature is optimised by a computer-controlled injection system with multiple lances distributed at different levels in the boiler. The temperature profile is measured by an acoustic or IR pyrometer and divided into sections that can be assigned to individual lances or groups of lances depending on the gas temperature measured. This ensures that the reagent is always injected at the most effective position in the boiler even with rapidly varying and asymmetric temperature profile, resulting in lower NO_X levels with optimised reagent consumption and minimised ammonia slip [106, HWE 2015], [108, Sweden 2016].

Achieved environmental benefits

Benefits include the reduction of NO_X emissions at a substantially lower cost than SCR.
~~It has been reported that application of SNCR may also reduce PCDD/F formation (although quantitative evidence of this has not been provided) [64, TWGComments, 2003]~~

Environmental performance and operational data

Emission reductions and the levels of emissions to air ~~are generally as shown in the table below~~ generally achieved by plants fitted with SNCR are as follows.

Table 4.63: Emission levels associated with the use of SNCR

Substance (s)	~~Reduction efficiency range (%)~~	Achieved emission ranges				Comments
		Half-hourly average (mg/Nm^3)	Daily average (mg/Nm^3)	Annual average (mg/Nm^3)	Specific emission (g/t waste input)	
NO_X	~~30–75~~	~~150–400~~ 155–300	80–180	70–180	~~0.4–1.2~~ To be updated	Varies with dosing rate, waste and combustor type
NH_3	~~n/a~~	5–60	~~5–30~~ 3–15	1–6	To be updated	Lowest where wet scrubbers are used. See notes ~~in this table~~ below~~.~~
~~N_2O~~	~~n/a~~		~~10–30~~			~~See notes below in this table~~

~~NB:~~
~~N_2O emissions increase rapidly with higher reagent dose rates required to achieve NO_X below 120 mg/Nm^3.~~
~~The N_2O emissions depend on the reaction (furnace) temperature and on the reagent. Generally, higher N_2O emissions are attained with urea than with ammonia. With urea the N_2O emissions can be higher.~~
~~To achieve higher NO_X reduction efficiencies (%), higher reagent dose rates are required which may lead to higher NH_3 slip – with downstream wet FGC the NH_3 may be absorbed but measures are then required to deal with its presence in the waste water, e.g. NH_3 stripping.~~
Source: [1, UBA, 2001, 2, infomil, 2002, 3, Austria, 2002, 12, Achternbosch, 2002, 60, Reimann, 2002], [81, TWG 2016]

The main source of N_2O emissions in SNCR is the use ~~utilisation~~ of urea instead of ammonia (leading to 2–2.5 times higher N_2O emissions than in the case of reduction by ammonia). To reduce N_2O formation, it is therefore important to optimise the reactant choice (ammonia or urea) and to control the process conditions (especially gas mixing, temperature and ammonia slip) [64, TWGComments, 2003].

Table 4.64: Operational data associated with the use of SNCR

Criteria	Description of factors affecting criteria	Evaluation (high/medium /low) or data	Comments
Complexity	• Additional process units required • Critical operational aspects	M	• Reagent injection equipment required but not separate reactors (compared to SCR) • Temperature and reagent injection optimisation important
Flexibility	• Ability of technique to operate under a range of input conditions	M	• Good NO_X reduction across a range of inlet concentrations • Temperature critical
Skill requirements	• Notable extra training or manning requirements	M	• Care required to control and optimise injection rates
Source: [64, TWGComments, 2003]			

The main factors influencing performance are:

- the mixing of the reactants with the exhaust gases;
- the temperature; and
- the residence time in the appropriate temperature window.

Increasing the reagent dose rates generally results in decreased NO_X emissions. However, this can increase ammonia slip and N_2O emissions (particularly with urea).

The ammonia slip is absorbed if wet scrubbers are used. It can also be removed from the effluent stream using an ammonia stripper – although this adds complexity to the operation, and increases capital and operating costs [74, TWGComments, 2004]. The regenerated ammonia can then be used as feedstock for the SNCR process (see also comment under Cross-media effects regarding effluent discharges if made).

Generally, N_2O concentrations increase as NO_X concentrations decrease. Under unfavourable conditions, levels of over 50 mg/m^3 can be reached, whereas, under favourable conditions, emission concentration levels are below 10 mg/m^3. To reduce N_2O formation, it is therefore important to optimise and control process conditions.

The amount of injected NH_3 depends on the raw gas NO_X concentration, as well as on the required NO_X reduction. The NH_3 is introduced into the flue-gas by injection of an aqueous ~~ammonia~~ solution. The most commonly used solutions are (concentrated or diluted) caustic ammonia (NH_4OH) or urea ($CO(NH_2)_2$). The use of urea is effective for relatively small units, as urea can be stored as a solid (in bags) and the operational and safety requirments related to the storage of ammonia are avoided ~~(including the related safety provisions) is not then required~~. For larger units, the use of ammonia is generally more effective.

Effective mixing of reagents and ~~the~~ NO_X in the flue-gas at the optimum temperature is essential to reach a high NO_X removal efficiency. In order to achieve the optimum temperature and to compensate for fluctuations in temperature, several sets of injector nozzles can be installed at different levels in the furnace, commonly in the first pass.

In principle, SNCR can be applied where a temperature window is available in the range of 850–1050 °C. In most waste incineration plants, this window occurs in the upper part of the furnace.

SNCR systems perform best under steady operating conditions (equal ammonia distribution and NO_X concentration). When operating conditions are not steady, ammonia slip (excessive ammonia emission), inadequate NO_X treatment, or N_2O formation can occur.

Cross-media effects

Cross-media effects are identified in the table below.

Table 4.65: Cross-media effects associated with the use of SNCR

Criteria	Units	Range of achieved values	Comments
Energy requirements	kWh/t waste input	45–50 thermal	Cooling effect of in-furnace injection
Reagent consumption	kg/t waste input	~~8.5 (9.5 1)~~ 1–4	~~25 % ammonia solution~~ ammonia, urea or ammonia water
Reagent stoichiometry	Ratio	2–3	
~~**Residue - type**~~			~~None~~
~~**Residue - amount**~~	~~kg/t waste input~~		~~None~~
~~**Water consumption**~~	~~l/t waste input~~		~~Not significant~~
~~**Effluent production**~~	~~l/t waste input~~		~~None~~
~~**Plume visibility**~~	~~+/o/-~~	~~0~~	~~No significant effect~~

Source: **[60, Reimann, 2002]** *to the TWG: the stoichiometry ratio seems excessive; please check availability of updated information*

For this technique, the most significant cross-media aspects are:

- energy consumption (lower than with SCR);
- possible production of N_2O (high global warming potential) and ammonia slip if the SNCR process is not well controlled;
- consumption of reagent (higher than with SCR);
- ammonia slip can contaminate residues and waste water; recovery of ammonia is possible.

In lime-based semi-dry, intermediate and dry FGC systems, the NH_3 slip is absorbed by the $CaCl_2$ formed from the removal of HCl. If this residue is subsequently exposed to water, the NH_3 will be liberated. This can have consequences for ~~in respect of~~ downstream residue treatment or cement stabilisation.

An ammonia stripper may be needed with wet systems to comply with local effluent discharge standards or in order to ensure adequate precipitation, e.g. of cadmium and nickel, from the process waste water. The addition of such a process adds operational complexity and cost.

Technical considerations relevant to applicability
The technique is generally applicable.

Higher dose rates may be used (hence resulting in lower NO_X emissions) while keeping ammonia slip levels low with downstream wet scrubbing. In such cases, an ammonia stripper may be required to reduce NH_3 levels in the effluent and reutilise the stripped NH_3 in the SNCR.

~~The applicability of this technique is assessed in the table below:~~

~~Table 4.66: Assessment of the applicability of SNCR~~

~~**Criteria**~~	~~**Evaluation/comment**~~
~~**Waste type**~~	~~Any~~
~~**Plant size range**~~	~~Any~~
~~**New/existing**~~	~~Locating injection points may be problematic in some existing plants~~
~~**Inter-process compatibility**~~	~~Higher dose rates (and hence lower NO_X emissions) may be used without ammonia slip when used with downstream wet scrubbing (which absorbs the excess ammonia). In such cases an ammonia stripper may be required to reduce NH_3 levels in effluent – stripped NH_3 can be re-fed to the SNCR injection.~~

The normal maximum reduction efficiency of the technique is approximately 75 %. It is therefore not common for SNCR to be used where higher percentage reductions are required, typically this may align with NO_X emission levels below 100 mg/Nm^3 (daily average). The higher reagent dose rates required to achieve reduction rates above 75 % means that achieving ammonia slip of < 10 mg/Nm^3 may require the use of additional measures such as downstream wet scrubbing, and then techniques to control ammonia levels in the effluent may also be required, e.g. stripping. [74, TWGComments, 2004]

Economics
The key aspects of this technique are:

- capital costs are significantly lower than with SCR (see Table 4.61);
- if an ammonia stripper is added the capital costs are still 10–30 % lower than SCR;
- reagent consumption costs are higher than with SCR;
- operating costs are lower than with SCR, mainly due to the reduced energy requirements for flue-gas reheating.

Investment costs for SNCR for a two-line 200 000 t/yr MSWI are estimated as EUR 1 million. This compares with around EUR 4 million for SCR. [12, Achternbosch, 2002]

Driving force for implementation

~~This technique has been implemented where:~~

- ~~permit ELVs are set between 100 and 200 mg/Nm³ daily average~~
- Compliance with legislative NO_X emission requirements.
- Cost advantage compared with SCR.
- Lack of space ~~is not available~~ for SCR.
- ~~suitable locations are available for reagent injection (including temperature requirements).~~

If a discharge of ammonia-rich effluent is permissible, the use of this technique with a wet FGC system will be more economical as there will be no requirement for an ammonia stripper. This does not apply to other FGC systems that do not produce effluents.

Example plants

Widely applied throughout Europe.

Laanila WtE Plant-Oulu (FI) (FI4-1), Westenergy Oy Ab-Mustasaari (FI) (FI6-1), and Gärstadverket-Linköping (SE) (SE3) are example plants using advanced SNCR with acoustic or IR temperature profile measurement systems.

Reference literature

[1, UBA, 2001, 2, infomil, 2002, 3, Austria, 2002, 12, Achternbosch, 2002, 60, Reimann, 2002] [64, TWGComments, 2003]

Information from the following section has been moved to Section 2.5.5.2.1

~~4.5.4.4 Optimisation of reagent selection for SNCR NO_X reduction~~

~~**Description**~~

~~The reagents used for SNCR are ammonia and urea.~~

~~**Technical description**~~

~~Obtaining a good understanding of temperature profiles in the combustion chamber is fundamental to the selection of reagent.~~

~~New processes can be specifically designed to achieve the stable and predictable combustion conditions, and select the allowing for optimal injection locations for the reagent, that then allow thus making it possible to use ammonia with the most the benefits of ammonia (i.e. highest peak NO_X reduction at lowest N_2O emissions) to be secured. Those This also applies to existing processes that have stable and well controlled combustion and temperature profiles in the furnace will also be able to maximise this benefit.~~

~~Existing processes that experience difficulties in stabilising combustion conditions (e.g. for design, control or waste type reasons) are less likely to be in a position to optimise the reagent injection (location, temperature, mixing) and may therefore benefit from the use of urea. However, if temperatures above 1 000 °C are anticipated, the N_2O production rate with urea becomes more significant.~~

~~In cases where the advantages and disadvantages are finely balanced, storage and handling hazards may have a greater impact on final reagent selection.~~

~~**Achieved environmental benefits**~~

~~Both reagents result in reductions in NO_X emissions. Selection of the reagent that is best suited to the combustion characteristics of the furnace will result in the most effective emissions reduction, i.e. effective NO_X reduction with minimal ammonia slip and N_2O production.~~

~~Environmental performance and operational data~~

~~The relative advantages and disadvantages of their selection ammonia and urea are outlined in the table below. The reagent selection needs to take account of a variety of process operational, cost and performance factors to ensure that the optimal one is selected for the installation concerned.~~

~~Table 4.67: Advantages and disadvantages of urea and ammonia use for SNCR~~

~~Reagent~~	~~Advantages~~	~~Disadvantages~~
~~Ammonia~~	• ~~higher peak NO_X reduction potential (if well optimised)~~ • ~~lower N_2O emissions (10 – 15 mg/Nm³)~~	• ~~narrower effective temperature range (850 – 950 °C) therefore greater optimisation is required~~ • ~~handling and storage hazards higher~~ • ~~higher cost per tonne waste~~ • ~~ammonia slip approx. 10 mg/Nm³~~ • ~~odour of residues if in contact with humidity~~
~~Urea~~	• ~~wider effective temperature range wider (540 – 1 000 °C) makes therefore temperature control less critical~~ • ~~lower hazard storage and handling~~ • ~~lower cost per tonne waste~~ • ~~lower ammonia slip (approx. 1 mg/Nm³)~~	• ~~lower peak NO_X reduction potential (cf. ammonia when optimised)~~ • ~~higher N_20 emissions (25 – 35 mg/Nm³) and hence GWP~~ • ~~ammonia slip approx. 1 mg/Nm³~~

~~Note: The lower cost of associated to urea is most significant at relatively small plants. For larger plants the higher storage cost of ammonia may be fully compensated by the lower chemical cost.~~
~~*Source:* [62, Tyseley, 2001] [64, TWGComments, 2003]~~

~~The urea/N_2O reaction is very dependent on temperature, with as much as 18 % of the NO_X removed appearing as N_2O at 1 000 °C, while it is (although negligible at 780 °C).~~

~~Cross-media effects~~

~~Optimising the selection of reagent should result in the optimisation of NO_X reduction with minimal ammonia slip and N_2O releases.~~

~~Technical considerations relevant to applicability~~

~~Generally applicable to SNCR~~

~~Consideration of the reagent to be used is applicable to all situations where SNCR NO_X reduction is to be employed.~~

~~Economics~~

~~Ammonia is reported to be marginally more expensive to use than urea. Handling and storage requirements for ammonia liquid, gas and solutions are generally more stringent and, hence, more expensive than for urea, which can be stored as a solid - this contributes to the cost differential between the two reagents.~~

~~Storage of more than 50 tonnes of gaseous or liquefied ammonia is subject to stringent safety requirements, which regulated under COMAH Directive. This may cause extra costs due to requirements of local authorities and permit application procedures. In most cases ammonia is used as a solution., as in this case the There are still some safety requirements are less onerous. but less stringent than with gaseous or liquefied ammonia.~~

~~The lower cost use of urea is only valid cheaper for relatively small plants. For larger plants the higher storage cost of ammonia may be fully compensated by the lower chemical cost.~~

~~Driving force for implementation~~

~~Requirements to reduce NO_X effectively, without excessive release of N_2O, which has a high greenhouse gas potential (310 times higher than CO_2).~~

~~**Example plants**~~
~~SNCR is widely applied in Europe.~~

~~**Reference literature**~~
~~[62, Tyseley, 2001] [64, TWGComments, 2003]~~

4.5.4.5 Replacement of secondary air with recirculated flue-gas

See Section 4.3.12.

4.5.4.6 Low-NO_X burners for liquid wastes

Description
The technique is based on the principles of reducing peak flame temperatures. These burners are designed to delay but improve the combustion and increase the heat transfer (increased emissivity of the flame). The air/fuel mixing, reduces the availability of oxygen and reduces the peak flame temperature, thus retarding the conversion of fuel-bound nitrogen to NO_X and the formation of thermal NO_X, while maintaining a high combustion efficiency.
[110, COM 2016].

Technical description
~~Low-NO_X burners provide a means of introducing and burning liquid wastes into the combustion chamber in such a way that nozzle head temperatures are reduced and therefore the production of thermal NO_X is reduced.~~ Descriptions of low-NO_X burners used for conventional fuels are given in the LCP BREF (note: these may require specific modifications for use with wastes).

Achieved environmental benefits
Reduced NO_X emissions to air.

Environmental performance and operational data
There are relatively few examples where low-NO_X burners are successfully used with wastes. Particular attention is required to ensure an adequate combustion efficiency (with waste). The technique is only applicable to specific liquid waste streams. It may be suited to some liquid hazardous wastes.

Cross-media effects
None reported.

Technical considerations relevant to applicability
Only applicable to the incineration of liquid waste.

Economics
The installation of low-NO_X burners during plant construction helps reduce the production of NO_X while adding little to the capital cost. The cost of retrofitting such burners to existing plants, however, can be higher. [64, TWGComments, 2003]

Driving force for implementation
Reduction of NO_X emissions.

Example plants

Drehrohrofenanlage Schkopau (DE) (DE22); Reststoffverwertungsanlage, Stade (DE) (DE23); Sonderabfallverbrennungsanlage, Brunsbüttel (DE) (DE28); Vantaan Jätevoimala, Vantaa (FI) (FI05); CIE, Creteil (FR) (FR087.3); Four d'incinération John Zink, Chalampé (FR) (FR106); WIP Sarpi Dabrowa Gornicza, Dąbrowa Górnicza (PL) (PL03); Veolia High Temperature Incineration Plant, Ellesmere Port (UK) (UK01).

Reference literature
[110, COM 2016]

4.5.5 Techniques to reduce~~tion of Reduction of~~ organic compounds including PCDD/F and PCB emissions

~~For the majority of wastes, it is not possible for waste incinerations to meet the air emission limit values of EC 2000/76 (0.1 ng/Nm^3) only through the use of primary (i.e. combustion related) measures. Secondary (i.e. abatement) measures are, therefore, necessary. In general achieving such emission levels involves using a combination of: primary techniques, to reduce PCDD/F production with; secondary measures to further reduce the air emission level. [64, TWGComments, 2003]~~

4.5.5.1 Primary techniques for prevention or reduction of organic compounds including PCDD/F and PCBs

~~Primary techniques are not dealt with in this section (which concerns FGC aspects) but elsewhere as described below.~~

A well-controlled combustion process, preventing the formation of precursors, is key for the prevention of PCDD/F formation in waste incinerators. The techniques that are applicable for improving the combustion-related aspects that will lead to generally improved incineration performance, including a reduction in the risk of PCDD/F production, are addressed ~~dealt with in earlier sections of this chapter. In particular~~ in the following sections of this BREF:

4.2 General practices applied before the thermal treatment stage
~~This section has relevance in that it deals with~~ Techniques for the control and preparation of the waste before it is incinerated~~.~~ result in ~~The~~ improved combustion characteristics and knowledge of the waste, ~~that results from the application of these techniques contributes to improving subsequent~~ allowing for better combustion control and, hence, a reduced~~s~~ risk of PCDD/F formation.

4.3 Thermal processing
~~As already noted in the paragraph above,~~ Well-controlled combustion aids the destruction of PCDD/F and its precursors which may already be in the waste and prevents the formation of precursors. ~~The techniques listed in this section, as applicable to the waste/installation concerned, are of key importance for the primary reduction of PCDD/F releases to all media.~~

4.4 Techniques to increase energy recovery
In the energy recovery zones of the incineration installation, the most important concern from a PCDD/F perspective is the prevention of reformation. ~~In particular,~~ The presence of precursor substances and detailed design in the temperature zones that may increase the risk of PCDD/F formation~~,~~ are of particular importance. The descriptions of techniques to increase ~~included in the~~ energy recovery ~~section of this chapter~~ include consideration of the PCDD/F aspects.

~~Therefore, the sections that follow (i.e. those here in 4.5.5) deal only with PCDD/F aspects that are relevant to the FGT system, with primary measures being considered elsewhere as described above.~~
~~[64, TWGComments, 2003]~~

4.5.5.2 Prevention of reformation of PCDD/F in the FGC system

Description

Reducing the residence time of dust-laden gas in the 450 °C to 200 °C temperature zone reduces the risk of formation of PCDD/F and similar compounds.

Technical description

If dust removal stages are used in this temperature range the residence time of the fly ash in this range is prolonged, increasing the risk of PCDD/F formation. Dust removal devices in the high dust zones (commonly electrostatic precipitators and some bag filters) operated at temperatures above 200 °C increase the risk of PCDD/F formation. Temperatures at the inlet to the dust removal stage should, therefore, be controlled to below 200 °C. This can be achieved by:

- additional cooling in the boiler (the boiler design in the 450–200 °C range should itself limit dust residence to avoid simply transferring the problem upstream);
- addition of a spray tower to reduce the temperature ~~from~~ at the boiler exit to below 200 °C for the subsequent dust cleaning stages;
- full quench from combustion temperatures to approximately 70 °C - this is carried out at plants where there is no boiler cooling and usually only where there is an increased dioxin risk owing to the nature of the waste incinerated (e.g. high PCB inputs); quenching down to 70 °C is common in HWIs operated by the chemical industry;
- gas-gas heat exchange may also be implemented (gas from inlet scrubber - gas from outlet scrubber).

[74, TWGComments, 2004]

Achieved environmental benefits

The risk of PCDD/F production in the process and, hence, subsequent emissions are reduced.

Where solid wastes and flue-gas already go for subsequent treatment that effectively destroy the dioxins produced (e.g. SCR for gas, plus heat treatment for fly ash), the benefit achievable by adopting the technique is reduced.

Environmental performance and operational data

Quench systems employed at some HWIs are reported to effectively eliminate PCDD/F formation. [46, Cleanaway, 2002]

Where heat recovery boilers are used, but dust removal is avoided in the 450–200 °C range, raw gas concentrations in the range of 1–30 ng TEQ/Nm^3 are seen before dioxin removal/destruction. Where dust removal is carried out in the 450–200 °C range, downstream gas can contain from 10 ng TEQ/Nm^3 to >100 ng TEQ/Nm^3 PCDD/F.

Cross-media effects

Existing plants with high-temperature dust removal stages may utilise such systems in order to retain heat in the flue-gases so that this heat can subsequently be used for some other purpose, e.g. transfer by heat exchange to later flue-gas treatment systems. If the gases are cooled to below 200 °C, this may lead to a need for additional heat input to the flue-gas to maintain the required temperature profile for those downstream systems. It may be possible for losses to be reduced by, instead, using the heat removed prior to the dust removal stage for reheating using heat exchange systems.

Full quench systems generally result in limited opportunities for energy recovery (boilers are not ~~generally~~ usually found where full quench is employed). They also create a very high moisture content plume that increases visibility and condensation, and require large water injection rates to provide sufficient cooling of the hot flue-gases. The waste water produced may be recirculated to some degree, but discharge and water treatment are usually required. Recirculated water may require cooling to prevent losses to the stack and to maintain FGC operation.

Technical considerations relevant to applicability
~~The applicability of this technique is assessed in the table below:~~

~~Table 4.68: Assessment of the applicability of PCDD/F reformation prevention techniques~~

~~Criteria~~	~~Evaluation/comment~~
~~Waste type~~	~~Particularly an issue where PCBs or other waste where risks of PCDD/F formation is believed to be higher.~~
~~Plant size range~~	~~The technique is suitable to all size ranges~~
~~New/existing~~	~~More difficult to re-design existing processes~~
~~Inter-process compatibility~~	~~Significant issue concerning temperature~~
~~Key location factors~~	

The technique is generally applicable to new plants.

Retrofitting ~~At~~ existing plants ~~such changes~~ will require a detailed reappraisal of the flue-gas treatment process, with particular attention paid to heat distribution and use.

Economics
There are no significant cost implications for new processes.

Very significant capital investments may be required at some existing processes for the replacement of boiler and flue-gas treatment systems. Investments in the order of EUR 10–20 million may be required for such changes.

Operational cost reductions may be seen from:

- sales of additional energy (heat) recovered in boilers;
- where adsorption is used, reduced cost of disposal of solid residues due to their lower PCDD/F contamination ;
- reduced dioxin content may have a positive impact on FGC downstream: lower activated carbon rate and/or lower catalyst volume.
  [74, TWGComments, 2004]

Driving force for implementation
~~This technique has been implemented where:~~

- Concerns ~~exists~~ regarding the possible production of PCDD/F by the process.
- Concerns ~~exist~~ regarding the PCDD/F concentrations in FGC absorbents requiring disposal.
- Waste types with a ~~combusted are~~ high risk ~~for~~ of PCDD/F formation ~~production~~.

Example plants
~~Quench systems are used for two hazardous waste incineration plants in the UK.~~
Quench systems are used widely used in Europe, e.g. Belgium, Germany, France, the Netherlands, Norway, Sweden and the UK.

Low boiler exit temperatures and post-boiler gas cooling is widely used in Europe.

Reference literature
[46, Cleanaway, 2002], [64, TWGComments, 2003], [74, TWGComments, 2004]

4.5.5.3 Destruction of PCDD/F using SCR

Description
PCCD/F destruction by catalytic oxidation over the SCR catalyst.

Technical description
While SCR systems are primarily used for NO_X reduction (see description in Sections 2.5.5.2.2 and 4.5.4.1)~~.~~, if large enough they can also destroy gas phase PCDD/F through catalytic oxidation. Typically two to three SCR catalyst layers are required to provide combined NO_X and PCDD/F reduction.

It is important to note that in waste incineration the majority of airborne PCDD/F is adhered to dust, with the ~~balance~~ rest being the gas phase PCDD/F. Techniques that remove dust will, therefore, remove the dustborne ~~carried~~ PCDD/F, whereas SCR (and other catalytic methods) only destroy the smaller proportion in the gas phase. A combination of dust removal plus destruction generally gives the lowest overall emissions of PCDD/F to air.

Achieved environmental benefits
Where these FG polishing residues would normally be sent off site, this results in an overall reduction in the dioxin outputs to all media from the installation. Where the dioxin residues are collected separately (e.g. using carbon) from other FGC residues and reburned, if allowed, in the installation then the reduction in overall outputs that may be gained by using SCR as an additional destruction method is less significant.

NO_X is treated by SCR at the same time as PCDD/F to give very low NO_X releases (see Section 4.5.4.1).

In the few cases where SCR is applied before other FGC components, it must be noted that the non-gas phase (dust-bound~~-adhered~~) PCDD/F may not be treated in the SCR unit and may therefore require subsequent dust removal to reduce it.

Environmental performance and operational data
Operational data are given in Section 4.5.4.1.

Destruction efficiencies for gas phase PCDD/F of 98 % to 99.9 % are seen, giving PCDD/F emissions (in combination with other FGC techniques) ~~below the 0.1 ng/Nm^3 TEQ set in 2000/76/EC, and more~~ often in the range of ~~0.05 – 0.002~~ 0.005–0.05 ng/Nm^3 TEQ.

In general, SCR is applied after initial dedusting. The dust that is removed at the pre-dedusting stage will carry with it the adsorbed PCDD/F (this may be the majority). The residues from the pre-dedusting stage will, therefore, be contaminated with PCDD/F to the same degree whether SCR is applied or not. ~~The destruction benefit of SCR, in respect of the reduction in~~ SCR, therefore, reduces PCDD/F contamination of FGC residues ~~it provides, is, therefore, limited to cases~~ only where further downstream dust polishing is also applied.

Because it is normal for the majority of PCDD/F to be associated with dust ~~solid particulate matter~~, for overall PCDD/F reduction, it is usually important that dust removal techniques are applied as well as SCR. This is to ensure that dust-bound PCDD/F, which would not be destroyed in the SCR unit, is removed from the flue-gases.

While a single catalyst layer may have a dramatic impact on NO_X, a greater size is required to ensure effective PCDD/F destruction as well. The higher the number of layers of catalyst, the greater the impact will be on PCDD/F reduction.

Cross-media effects
Cross-media effects are detailed in Section 4.5.4.1.

The most significant cross-media aspects are:

- consumption of energy for flue-gas reheating to reach the SCR system reaction temperature;
- as a destruction technique, the PCDD/F are not transferred to solid residues (as with some adsorption processes).

In general, destruction is ~~favourable~~ preferable to transfer to another media. However, the magnitude of the ~~cross-media~~ benefit associated with the destruction rather than adsorption of PCDD/F will depend on the avoided risk that is associated with the subsequent downstream management of the PCDD/F-laden residues.

Technical considerations relevant to applicability
The applicability of this technique is assessed in Section 4.5.4.1.~~Table 4.68 below:~~

~~**Table 4.69: Assessment of the applicability of SCR for PCDD/F removal**~~

~~**Criteria**~~	~~**Evaluation/comment**~~
~~**Waste type**~~	• ~~can be applied to any waste type~~
~~**Plant size range**~~	• ~~can be applied to any plant size, but most economical for medium to large size installations due to capital costs~~
~~**New/existing**~~	• ~~when applied as a tail end technique (most common), the system can be added to any process~~ • ~~more complex to retrofit as non-tail end~~
~~**Inter-process compatibility**~~	• ~~particularly beneficial where substantial reductions in NO_X are also required~~ • ~~reheat of flue gases usually required to reach SCR operational range~~
~~**Key location factors**~~	• ~~space is required for the SCR reactor~~

Economics
The costs of the technique are shown in Section 4.5.4.1.

Driving force for implementation
The implementation of this technique is favoured where the combination of high NO_X reduction and the additional PCDD/F reduction given by SCR is required.

Example plants
SCR is widely used in the incineration industry. There are examples in Austria, Belgium, Germany, France, the Netherlands, Japan and elsewhere.

~~Data provided to EIPPCB by FEAD show that at least 43 of approx. 200 European MSWI plants surveyed use SCR, although it is not clear which of these use the technique for PCDD/F destruction as well as NO_X reduction.~~

SCR is also applied to merchant HWIs, particularly in Germany, and at ES11, PL03.

Reference literature
[1, UBA, 2001, 2, infomil, 2002, 3, Austria, 2002, 13, JRC(IoE), 2001, 27, Belgium, 2002, 61, SYSAV, 2002] [64, TWGComments, 2003]

4.5.5.4 Destruction of PCDD/F using catalytic filter bags

Description
This techniques is ~~has already been~~ described in Section 2.5.8.3.

Technical description

See Section 2.5.8.3.

Achieved environmental benefits

Destruction efficiencies of PCDD/F entering the catalytic filter bags of above 99 % are reported at a MSWI. Emission concentrations of PCDD/F of below 0.02 ng/Nm^3 TEQ resulted from inlet concentrations of 1.9 ng/Nm^3. [27, Belgium, 2002]

The filters also provide for dust removal. In the example given here, the MSWI used an ESP for pre-dedusting and with the addition of the filters gave dust emission levels in the range of 0.2–0.6 mg/Nm^3. NO_X reduction is also reported using these filters [64, TWGComments, 2003]

The total release of dioxins from the installation (to all media) is also reported to be reduced by destruction, rather than adsorption (with activated carbon). At the same time as reducing emissions to air as described above, samples of bag filter hopper dust showed average concentrations dropped from 3 659 ng I-TEQ/kg dust (when using activated carbon) to 283 ng I-TEQ/kg dust (using catalytic filter bags).

Environmental performance and operational data

Operational matters are similar to those of other bag filters.

The temperature range ~~in order~~ necessary for the catalytic reaction to occur ranges between ~~varies from~~ 180 °C ~~to~~ and 260 °C. [27, Belgium, 2002], [74, TWGComments, 2004]

Tests carried out over 21 months on inlet and outlet PCDD/F concentrations at a MSWI (without upstream acid gas removal, but with a pre-dedusting ESP) showed the following results.

Table 4.70: Destruction efficiency data for catalytic filter bags over 21 months of operation

Number of months of operation	0.25	1.5	3	4.8	8	13	18	21
Inlet PCDD/F (ng TEQ/Nm^3)	3.4	7	11	10.5	11.9	11.8	8.1	5.9
Outlet PCDD/F (ng TEQ/Nm^3)	0.01	0.0035	0.005	0.004	0.01	0.011	0.002	0.023
Calculated efficiency	99.7 %	99.9 %	99.9 %	99.9 %	99.9 %	99.9 %	99.9 %	99.6 %

Source: [27, Belgium, 2002]

The catalytic media do not treat mercury so an additional technique ~~device~~ is required such as injection of active carbon or similar.

Cross-media effects

~~For this technique t~~The most significant cross-media effect associated with catalytic filter bags is the energy consumption from the pressure drop, but ~~drop across bag filter (~~this is similar to any bag filter~~)~~.

Catalytic filter bags are generally used as a replacement for other filter bags. These may already adsorb dioxins by the injection of activated carbon. Where, in the replaced system, it is the injection of activated carbon that also provides for the main absorption of metallic mercury, the removal of the activated carbon may then result in an increase in mercury emissions to air unless alternative techniques for mercury are used.

Tchnical considerations relevant to applicability

Generally applicable to new plants and to existing plants fitted with bag filter.

~~The applicability of this technique is assessed in the table below:~~

~~Table 4.71: Assessment of the applicability of catalytic bag filters~~

~~Criteria~~	~~Evaluation/comment~~
~~Waste type~~	~~Any~~
~~Plant size range~~	~~Any~~
~~New/existing~~	~~Applicable to both new and existing processes~~
~~Inter-process compatibility~~	~~Need to consider Hg abatement in addition~~
~~Key location factors~~	~~None~~

Economics

For a MSWI of two lines with a capacity of 27 500 t/yr each, the additional cost of the use of catalytic bag filters was reported as between EUR 2 and 3 per tonne of waste treated. [27, Belgium, 2002]

The key cost aspects of this technique are:

- increased investment cost of the bags compared with non-catalytic bags; the cost of the media is EUR ~ 300/m^2, compared to EUR ~ 60/m^2 for other non-catalytic media, e.g. 100 % PTFE;
- lower investment costs than SCR but with similar destruction efficiencies;
- the need to make additional provision for mercury removal.

[74, TWGComments, 2004]

Driving force for implementation

~~This technique has been implemented where:~~

- Reduction of PCDD/F emissions to well below 0.1 ng/Nm^3 TEQ.~~ are to be achieved~~
- Lack of space for SCR. ~~is not available and alternative means of NO$_X$ reduction is already installed~~
- ~~alternative means of Hg control is already installed (the catalytic bags do not control Hg).~~

Example plants

Several installations in Belgium and France.

Reference literature

[27, Belgium, 2002] [64, TWGComments, 2003]

~~4.5.5.5 Destruction of PCDD/F by re-burn~~ing ~~of adsorbents~~

~~Description~~

~~This technique has already been described in Section 2.5.8.4~~

~~The basic principle is that the PCDD/F residues collected in the FGT system, may in certain circumstances (see notes regarding Hg below), be destroyed by burning them in the incinerator itself, thereby reducing the overall installation output of PCDD/F.~~

~~Achieved environmental benefits~~

~~PCDD/F in solid residues are destroyed in the process rather than being transferred from the installation in the residues.~~

~~Cross-media effects~~

~~There is a risk of metallic mercury re-circulation (and hence emissions) unless the process also contains a means for mercury removal at an adequate rate.~~

~~Operational data~~

~~Care required when handling the contaminated reagents to ensure spillage is avoided and loading to the furnace is at an even rate to ensure the residues are destroyed effectively in the combustion process.~~

~~Applicability~~
~~The applicability of this technique is assessed in the table below:~~

~~Table 4.72: Assessment of the applicability of re-burn of absorbers~~

~~Criteria~~	~~Evaluation/comment~~
~~Waste type~~	~~Any~~
~~Plant size range~~	~~Any~~
~~New/existing~~	~~Can be applied to new and existing plants~~
~~Inter-process compatibility~~	~~Mainly only suited to residues from specific PCDD/F dioxin absorption stages (e.g. static coke fixed beds and wet scrubber dioxin absorber inserts) where there are other provisions to avoid mercury build up and potential release.~~
~~Key location factors~~	~~None~~

~~Economics~~
~~Investment costs are not generally required unless additional systems for mercury removal are required, when these additions can be significant.~~

~~Operational cost savings can be made by reducing the disposal costs of the PCDD/F contaminated residues.~~

~~Driving force for implementation~~
~~Requirement to reduce the PCDD/F concentrations in solid FGT residues.~~

~~In some countries the residues from the incinerator may not be re-burned in the installation for legal reasons. In such cases it is considered that the residues are classified as a waste type that is prohibited from treatment within the incineration installation. [64, TWGComments, 2003]~~

~~Example plants~~
~~This technique is used in Belgium and Germany.~~

~~Reference literature~~
~~[55, EIPPCBsitevisits, 2002] [64, TWGComments, 2003]~~

4.5.5.6 Adsorption of PCDD/F by activated carbon injection or other reagents

Description
This technique is ~~has already been~~ described in Section 2.5.8.1.

Technical description
In summary, activated carbon is injected into the gas stream where it mixes with flue-gases. Activated carbon is injected on its own or is combined with an alkaline reagent such as (usually) lime or sodium bicarbonate~~ alkaline reagent~~. The injected alkaline reagent, their reaction products and the carbon adsorbent are then collected in a deduster, usually a bag filter. The adsorption of the PCCD/F occurs in the gas stream and on the reagent layer formed when barrier filters are used (e.g. filter bags).

The adsorbed PCDD/F is discharged with other solid wastes from the bag filter, ESP or other dust collection apparatus used downstream.

It is reported that mineral adsorbents (e.g. mordenite, zeolite, mixtures of clay minerals, phyllosilicate and dolomite) may also be used for PCDD/F adsorption, at temperatures of up to

260 ºC without risk of fire in the baghouse. Lignite coke is also reported to be used [64, TWGComments, 2003]. [74, TWGComments, 2004]

The effect of catalytic destruction of PCDD/F on the surface of the activated coke has been reported [74, TWGComments, 2004].

Achieved environmental benefits
The benefit is the reduction of PCDD/F emissions. ~~is adsorbed on the activated carbon to result in emissions of below 0.1 ng/Nm³ TEQ.~~

Metallic mercury is also adsorbed (see Section 4.5.6.2).

Environmental performance and operational data
Carbon consumption rates of ~~0.35~~ 0.5–3 kg/t of waste are reported as typical for MSWI. Higher injection rates may provide additional reductions in PCDD/F. [64, TWGComments, 2003]

Usually the dose rate of activated carbon is between 0.5 kg/t and ~~1~~ 2 kg/t to achieve an emission level below ~~0.1~~ 0.06 ng I-TEQ/Nm^3.
~~French examples:~~
~~(1) MSWI 12 t/h - semi-wet FGC: 0.35 kg/t,~~
~~(2) MSWI 2.5 t/h - dry FGC: 1.2 kg/t~~
~~[64, TWGComments, 2003]~~

Different types of carbon have different adsorption efficiencies.

Cross-media effects
Cross-media effects of the use of bag filters or other dust abatement systems associated with the use of this technique are described in Section 4.5.2.

Solid residue containing the adsorbed pollutants is produced. It should be noted that the amount removed with the reagent, and accumulated with it, will be lower than that which is removed with the dust by effective dust control. It is reported that 80 % of the PCDD/F is discharged with the dust already removed. [64, TWGComments, 2003]

Polluted reaction material from the FGC system may, in some cases, be used as a neutralisation agent in scrubber water effluent treatment and in this way reduce amount of fresh material that needs to be added at the waste water treatment stage. There, the activated carbon or coke also captures heavy metals, e.g. mercury, from waste water. It is reported that no extra residues, except the non-water-soluble carbon, are produced by using these reagents in scrubber water. There is a higher risk of ignition/fire and therefore increased safety measures must be in place for storage and handling of activated carbon and coke. [74, TWGComments, 2004]

Technical considerations relevant to applicability
The technique is generally applicable and is most often used in combination with a bag filter.
~~The applicability of this technique is assessed in the table below:~~

~~Table 4.73: Assessment of the applicability of carbon injection for PCDD/F removal~~

~~Criteria~~	~~Evaluation/comment~~
~~Waste type~~	• ~~any~~
~~Plant size range~~	• ~~any~~
~~New/existing~~	• ~~applicable to both – easily retrofitted in most cases~~
~~Inter-process compatibility~~	• ~~may be easily employed where there is an existing bag filter system~~
~~Key location factors~~	• ~~none~~

Economics

Lignite coke is reported to be more economical than activated carbon. [64, TWGComments, 2003] It is also reported that, in general, the consumption of lignite coke is higher than that of activated carbon (up to ~~twice~~ double the ratio). [74, TWGComments, 2004]

Driving force for implementation
The driving force is compliance with legislative requirements for PCDD/F emission levels. ~~The technique has been introduced to many plants in order to achieve an emission level <0.1 ng/Nm³. [74, TWGComments, 2004]~~

Example plants
Widely applied technique in many countries.

Reference literature
[64, TWGComments, 2003]

4.5.5.7 Fixed-bed adsorption of PCDD/F ~~in static beds~~

Description
This technique ~~has already been~~ is described in Section 2.5.8.6.

Technical description
Wet and dry ~~static~~ fixed coke/coal beds are used. Wet systems include countercurrent washing with water.

Achieved environmental benefits
Reduction of emissions to air of PCDD/F and of mercury.

- ~~PCDD/F adsorbed to give clean gas emissions below 0.1ng/Nm³ TEQ~~
- ~~Hg is adsorbed to give emissions below 50 µg/Nm³, typically below 30 µg/Nm³~~
- ~~dust is collected by the filter.~~

Environmental performance and operational data
PCDD/F are adsorbed to give clean gas emissions below ~~0.1~~ 0.03 ng/Nm^3 TEQ.

The temperature at the inlet to a dry fixed coke bed is typically 80–150 °C, and 60–70 °C in the case of wet fixed beds. If followed by a SCR system, the reheat required would therefore be greater for a wet system.

With dry systems, particular care is required to ensure that the flue-gas is evenly distributed as this reduces the risk of fire. The temperature across the bed requires close monitoring and control to reduce the fire risk, e.g. several CO measurements over the whole filter body to measure hot spots. [74, TWGComments, 2004] The use of inert gases may be required.

Wet fixed beds ~~coke filters~~ have a significantly lower fire risk. Neither firefighting or inert blanketing are required. The addition of a partially recirculated water feed also provides a means for removal of the accumulated dust, which can lead to bed clogging.

The bed saturation rate is assessed to determine the required reagent replenishment rate. [74, TWGComments, 2004]

The lack of moving parts ~~means that~~ ensures high reliability ~~is high~~.

A summary evaluation of the operational implications associated with the use of fixed-bed adsorption is presented in Table 4.74.

Table 4.74: Operational data associated with implications of the use of the fixed-bed adsorption static coke filters

Criterion	Description of factors affecting the criterion	Evaluation (high/medium/ low) or data	Comments
Complexity	• Additional process units required • Critical operational aspects	M	~~• Additional process units required~~ • Fire risks require careful control (dry systems)
Flexibility	• Ability of technique to operate under a range of input conditions	H	• Very high adsorption capacity
Skill requirements	• Significant extra training or manning requirements	H/M	• Robust, but care required regarding fire risk (dry systems) and if reburning carried out

Cross-media effects

Cross-media effects are identified in the table below.

Table 4.75: Cross-media effects associated with the use of the fixed-bed adsorption static filters

Criteria	Units	Value	Comments
Energy requirements	kWh/t waste input	30–35	Pressure drop across filter
Reagent consumption	kg/t waste input	1	Coke
~~**Residue - type**~~			~~Used coke~~
Residue ~~– amount~~	kg/t waste input	0–1	Zero if coke can be burned in the incinerator
~~**Water consumption**~~	~~l/t waste input~~		~~*No information*~~
~~**Effluent production**~~	~~l/t waste input~~		~~*No information*~~
Plume visibility	+/0/-	+/0	Wet system will add to plume visibility
Source: [12, Achternbosch, 2002] *For the TWG: please check the consumption information as it may be on the high side*			

For this technique, the most significant cross-media effect is the energy required to overcome the filter pressure drop.

The fire risk might be increased with dry ~~static coke~~ fixed beds depending on the design of the whole FGC line [74, TWGComments, 2004].

For one rotary kiln HWI line treating 50 000 t/yr, a new 550 kW ID fan was installed~~. The new ID fan has 550 kW where the old one had only~~ to replace a 355 kW fan (ΔP of the filter of between 25–40 mbar) [64, TWGComments, 2003].

When saturated, the used activated carbon is often landfilled as a toxic residue. If permitted, it can be reburnt in the incinerator to destroy the adsorbed PCDD/F. As the carbon adsorber will adsorb mercury as well as PCDD/F, if reburning of the spent coke is to be carried out mercury circulation requires careful consideration. The practice of reburning will result in an accumulation of mercury in the process unless there are additional techniques that provide a mercury outlet, e.g. low pH wet acid scrubbing.
[74, TWGComments, 2004]

The following ~~operational data about~~ cross-media effects data were reported for ~~in respect of~~ the use of a wet ~~static~~ fixed coke bed at a HWI treating around 11 000 t/yr waste [64, TWGComments, 2003]:

- use of lignite coke~~s~~: 0.5 kg/t waste input;
- exhausted lignite is burned into the installation – in this case, ~~due to~~ the accumulation of mercury is prevented by a low pH wet acid scrubbing system;~~, the re-burn of the spent coke will not result in an accumulation of Hg~~
- water is used for periodically flushing the lignite bed; this generates acid waste water which is sent to an on-site physico-chemical treatment process;
- the wet system adds to flue-gas humidity and plume visibility.

Technical considerations relevant to applicability

The technique is generally applicable to new plants.

The availability of space for the additional process unit is required for the retrofit of existing plants.

Especially at plants already fitted with a bag filter, the cumulated pressure drop caused by the flue-gas cleaning system may be a constraining factor.

~~The applicability of this technique is assessed in the table below:~~

~~Table 4.76: Assessment of the applicability of the fixed-bed adsorption static coke filters~~

~~Criteria~~	~~Evaluation/comment~~
~~Waste type~~	- ~~any in principle~~ - ~~particularly suited to highly heterogeneous and hazardous wastes where PCDD/F may be high due to difficult combustion conditions~~
~~Plant size range~~	- ~~size does not matter~~
~~New/existing~~	- ~~applied at existing and new processes~~
~~Inter-process compatibility~~	- ~~generally applied as a tail-end polishing stage~~ - ~~most suited down stream of a wet scrubber~~ - ~~can be used up stream of SCR with reheat (more for wet system)~~
~~Key location factors~~	- ~~space required for the additional process unit~~

Economics

The investment cost of a fixed-bed coke filter for a 100 000 t/yr MSWI was estimated as EUR 1.2 million in 2002 [12, Achternbosch, 2002].

The investments cost for one ~~static~~ fixed-bed wet filter (empty) (incineration line of 50 000 t/yr) is approximately EUR 1 million (equipment and civil work).

The cost of lignite coke~~s~~ is a factor three to four times lower than activated coal.

The consumption of lignite cokes is low enough that refilling can be carried out during planned shutdown.

Driving force for implementation

The driving force for implementation is compliance with legislation in relation to emission limits for PCDD/F and mercury, especially in the case of highly heterogeneous and hazardous wastes where PCDD/F may be high due to difficult combustion conditions.

~~This technique has been implemented to reduce PCDD/F emissions to below 0.1ng/Nm³ TEQ~~

Example plants

Hazardous waste incinerators in Austria, Belgium, Germany and the Netherlands.

Municipal waste incinerators in Austria and Germany.

Reference literature

[1, UBA, 2001, 3, Austria, 2002, 12, Achternbosch, 2002] [64, TWGComments, 2003]

4.5.5.8 Use of carbon-impregnated materials for PCDD/F adsorption in wet scrubbers

Description

The addition in the scrubber of tower packing containing plastics embedded with carbon sorbent.

Technical description

This technique is described in Section 2.5.8.5.

Achieved environmental benefits

PCDD/F are strongly adsorbed on the carbon particles in the material. Therefore the emissions are reduced and the memory-effect release of PCDD/F is prevented. [74, TWGComments, 2004] Start-up releases may be reduced. The benefits can be summarised as:

~~Whilst the achieved outlet concentration (2 – 3 ng TEQ/Nm³) do not, on their own, comply with the 0.1 ng/Nm³ requirement of Directive 2000/76/EC, the technique can be used in combination with subsequent downstream FGT to provide overall compliance. The benefits are therefore:~~

- prevention of memory-effect uptake in wet scrubbers and the associated risk of breakthrough and desorption releases;
- reduction of PCDD/F loads on subsequent FGC operations (especially during start-up);
- if the used reagent is reburned in the furnace, there will be an overall reduction in the dioxin mass balance due to the destruction of the PCDD/F in the furnace (which is facilitated by the separation of the mercury absorption step) rather than ~~its~~ their transfer to solid residues.

Environmental performance and operational data

With inlet concentrations of ~~6 – 10~~ 1–5 ng TEQ/Nm^3, gas phase removal efficiencies in the range of ~~60 – 75~~ 99–99.8 % are reported across a wet scrubber. ~~This compares with 0 – 4 % without the impregnated packing material. The adsorption efficiency is reported not to have declined over the test period. [58, Andersson, 2002].~~ Additional operational aspects are summarised in Table 4.77.

Table 4.77: Operational aspects data associated with the use of carbon-impregnated materials in wet scrubbers

Criteria	Description of factors affecting criteria	Evaluation (high/medium/ low) or data	Comments
Complexity	• Additional process units required • Critical operational aspects	L/M	Adjustment to existing technique (wet scrubbing)
Flexibility	• Ability of technique to operate under a range of input conditions	M	
Skill requirements	• Notable extra training or manning requirements	L	No significant additional requirements

When used as the main technique to reduce PCDD/F in combination with an electrostatic precipitator, the technique requires a more extensive tower packing installation. [74, TWGComments, 2004]

Cross-media effects

The used packing is in some cases landfilled as a toxic residue. In some cases, it is reburned in the incinerator (although local regulations sometimes do not permit reburning). [74, TWGComments, 2004]

Technical considerations relevant to applicability

The technique is generally applicable to new plants and to existing plants fitted with a wet scrubber. Implementation is easier in packed tower scrubbers using caustic soda.

The technique has also been demonstrated in dry and semi-wet systems.
[109, Sweden 2016.]

~~Applicable to processes that have already selected wet scrubbing systems, particularly during start-up, and where there is evidence of dioxin build up in the wet scrubber and where there is no subsequent FGC stage to control PCDD/F desorbed from the wet scrubber.~~

~~Also applicable as a pre-dioxin filter before an additional dioxin filter system – in this way it can be used to reduce the PCDD/F load on the *main* dioxin filter without additional space requirements.~~
~~Also used as main dioxin filter in combination with electrostatic precipitator (then requires a more extensive tower packing installation) [74, TWGComments, 2004]~~

~~The applicability of this technique is assessed in the table below:~~

~~**Table 4.78: Assessment of the applicability of the use of carbon impregnated materials in wet scrubbers.**~~

~~**Criteria**~~	~~**Evaluation/comment**~~
~~**Waste type**~~	~~Any~~
~~**Plant size range**~~	~~Any where wet scrubbers are used~~
~~**New/existing**~~	~~Applicable to new and existing installations~~
~~**Inter-process compatibility**~~	~~Only applicable to wet scrubbers~~
~~**Key location factors**~~	~~It is easier to implement in packing tower, using caustic soda~~
~~*Source:* [74, TWGComments, 2004]~~	

Economics

The approximate investment cost for the initial installation of tower packing in two wet scrubber stages is between EUR 30 000 and EUR 150 000 in total for incineration plants ~~in the size~~ of 5–20 t/h.

The cost for replacement material is estimated as EUR 0.1–0.2 per tonne of incinerated waste. No additional energy consumption is anticipated, except the additional pressure drop. [74, TWGComments, 2004]

Driving force for implementation

- Reduction of dioxin build-up in the wet scrubber and of PCDD/F emissions at start-up especially where there is no subsequent FGC stage to control PCDD/F desorbed from the wet scrubber.
- As a pre-dioxin filter before a subsequent dioxin reduction system, to reduce the PCDD/F load on the main dioxin reduction system.

~~This technique has been implemented where there are concerns regarding the PCDD/F concentration in and possible release from wet scrubbers.~~

~~The technique has also been installed where a cost-effective dioxin removal of 50 – 70 % reduction degree is required.~~

Example plants

The technique has (October 2003) been implemented at 10 municipal and hazardous waste incineration plants in Sweden, Denmark, France and Germany. *To the TWG: please provide updated information.*

Reference literature

[58, Andersson, 2002] [64, TWGComments, 2003]

4.5.5.9 Use of carbon slurries in wet scrubbers

Description
The use of a slurry of activated carbon in a wet scrubber can both reduce the level of dioxin emissions to the flue-gas stream and prevent the accumulation of dioxins in the scrubber material ('memory effect').

Technical description
At a pH near neutral, activated carbon at a concentration varying between a few g/l to 50 g/l, is added into the system, using a decanter to bleed the liquids, while retaining the carbon.

Because the activated carbon has active sites, the PCDD/F molecules are transferred to the liquids sprayed in the scrubber and the dioxins are subsequently adsorbed on the carbon, where a catalytic reaction takes place.

Achieved environmental benefits
In addition to the reduction of PCDD/F, the activated carbon ~~has~~ also adsorbs~~ption capacity for~~ mercury.

The activated carbon that is purged from the system is not contaminated by PCDD/F.

As activated carbon converts SO_2 to sulphuric acid, this process is also a polishing step for SO_2 removal.

The reported PCDD/F concentration in the waste water evacuated is ~~reported to comply with the PCDD/F ELV in water set by the Waste Incineration Directive 2000 (i.e.~~ below 0.~~3~~1 ng TEQ/l~~)~~.
[74, TWGComments, 2004]

Environmental performance and operational data
Emissions of PCDD/F at the stack are ~~reduced~~ below ~~to 0.01–0.1~~ 0.06 ng TEQ/Nm^3.

~~Used under the above conditions,~~ Emissions of mercury ~~outlet~~ are usually well below 50 µg/Nm^3 for municipal waste incineration.

NaOH must be used to control the pH in the unit where the activated carbon slurry is used.
~~Information not supplied.~~

Cross-media effects
Use of carbon.

~~Increased risk of fouling by the use of carbon may cause problems to maintain the site in tidy and clean state. [74, TWGComments, 2004]~~

Technical considerations relevant to applicability
~~Only~~ Applicable ~~where~~ to wet scrubbers ~~are used~~ operated with caustic soda to control the pH at near neutral level.

~~Not applicable to dry, intermediate or semi-wet scrubbing systems.~~

Economics
Costs are limited to the reagent costs if used for polishing or to treat memory effect. Only minor modifications to the scrubber system are required to allow the use of the technique.

For efficient PCDD/F removal this technique may require a specific packing tower scrubber, to ensure effective contact between the flue-gas and the washing water. [74, TWGComments, 2004]

Driving force for implementation

The driving force for implementation is compliance with legislation in relation to emission limits for PCDD/F.

~~The technique has been used in order to achieve emission level below 0.1 ng TEQ/Nm^3.~~

Example plants

Around 100 waste incineration plants are reported to be fitted with the technique.

- ~~Brussels (BE) – stack: 0.02–0.03 ng TEQ/Nm^3. (dry, @11 %O$_2$)~~
- ~~Mulhouse (FR) – stack: 0.01–0.03 ng TEQ/Nm^3. (dry, @11 %O$_2$)...~~
- ~~Toulouse (FR) – stack: 0.04–0.1 ng TEQ /Nm^3. (dry, @11 %O$_2$)~~
- ~~Svendborg (SE) – stack: 0.01–0.02 ng TEQ/Nm^3. (dry, @11 % O$_2$)~~

Reference literature

[64, TWGComments, 2003]

4.5.6 Techniques to reduce~~tion of~~ mercury emissions

4.5.6.1 Low pH wet scrubbing and additives injection ~~addition~~

Description

The wet scrubbing technique is described in Section 2.5.4.

Technical description

[63, Langenkamp, 1999] The use of wet scrubbers for acid gas removal causes the pH of the scrubber to reduce. Most wet scrubbers have at least two stages. The first removes mainly HCl, HF and some SO$_2$. A second stage, maintained at a pH of 6–8, serves to remove SO$_2$.

The mercury reduction capacity can be increased with the use of additives in the scrubbing liquor, to bind mercury into the stable and insoluble species HgS. The injection of additives may be automatically controlled by the signal of the mercury emission monitor, thereby providing effective peak control capability.

Achieved environmental benefits

The environmental benefit is the reduction of mercury emissions to air by transfer to the aqueous phase and subsequent capture at the waste water treatment stage.

~~Percentage reduction efficiencies are given in the description above.~~

~~The impact of the concentration of Hg in the incinerated waste and the content of Cl are decisive in the determination of the final emission levels achieved.~~

Environmental performance and operational data

If the first stage of the wet scrubber is kept at a pH of below 1, the removal efficiency of ionic mercury as HgCl$_2$, which is generally the main compound of mercury after waste combustion, is over 95 %. However, the removal rates of metallic mercury are only in the order of 0–10 %, mainly as a result of condensation at the scrubber operational temperature of around 60–70 °C.

Metallic mercury adsorption can be improved up to a maximum of 20–30 % by the following:

- Addition of sulphur compounds to the scrubber liquor.
- Addition of activated carbon to the scrubber liquor.
- Addition of oxidants, e.g. hydrogen peroxide, to the scrubber liquor. This technique converts metallic mercury to the ionic form as HgCl$_2$ to facilitate its precipitation, and has the most significant effect. See also Section 4.5.6.6.

The overall mercury removal (both metallic and ionic) efficiency is around 85 %.

It is reported that a removal efficiency higher than 90 % can also be achieved ~~with a technique~~ by adding bromine-containing wastes or by injection of bromine-containing chemicals into the combustion chamber. [74, TWGComments, 2004]

The concentration of mercury in the incinerated waste and the content of chloride are decisive in the determination of the final emission levels achieved. ~~For MSW with an average mercury concentration of 3–4 mg/kg of MSW, emission concentrations to air of 50–80 µg/Nm^3 are achieved. [63, Langenkamp, 1999]~~

~~At the inlet concentrations usually found with many waste types, and with the additional uncertainty over the composition of most wastes, the removal efficiency of this type of scrubbing is not generally sufficient. to reach an emission level below 50 µg/Nm^3. In one Member State an ELV of 30µg/Nm³ has been set.~~

In any ~~either~~ case, the addition of further mercury abatement capacity may be required, depending on the inlet concentration, such as:

- carbon injection before a bag filter system;
- static coke bed filter.

(See Sections 4.5.6.2 and 0.) [74, TWGComments, 2004]

The variation of mercury input to MSW can be very large and, therefore, can result in significant variations in emission levels. Values measured at an Austrian MWI gave values between 0.6 mg/kg and 4 mg/kg. This variation can be much greater in other waste types, e.g. some hazardous wastes.

~~Levels achieved just with a wet scrubbing system are approximately 36 µg/Nm^3, with a wet scrubber and an activated coke filter < 2 µg/Nm^3, and with a combination of the flow injection process and a wet scrubber 4 µg/Nm^3. [74, TWGComments, 2004]~~

The use of acid wet scrubbers for mercury emission reduction ~~can only meet the emission limits set in Directive EC/2000/76~~ may be sufficient to achieve the required emission levels where:

- the pH is well controlled below 1;
- chloride concentrations are high enough for the crude flue-gas mercury content to be almost entirely ionic (and hence removable as ~~the~~ chloride).

Where additives are added to the low pH scrubber, in the case of typical constant mercury input, e.g. in municipal waste incinerations, the additive dosage is kept low (e.g. 0.5–2 l/h), and raised in the case of mercury breakthrough (e.g. up to 10–20 l/h). Typical mercury emission reduction efficiencies between 90 % and more than 99 % are reported when using additives, allowing for outlet mercury concentrations below 30 µg/Nm^{3}as a short-term average. ~~in some cases.~~
[111, Germany 2016]

Cross-media effects
Cross-media effects of the use of wet scrubbing are given in Section 4.5.3.1.

Consumption of any reagents added also has to be taken into consideration.

Technical considerations relevant to applicability

~~The applicability of this technique is assessed in the table below:~~

~~**Table 4.79: Assessment of the applicability of wet scrubbing for Hg control**~~

~~**Criteria**~~	~~**Evaluation/comment**~~
~~**Waste type**~~	
~~**Plant size range**~~	~~• any~~
~~**New/existing**~~	~~• not generally applied on its own at new installations~~
~~**Inter-process compatibility**~~	~~• see comments for wet scrubbers~~ ~~• additional Hg removal may be required to comply with EC/2000/76 (depending on the Hg inlet content)~~
~~**Key location factors**~~	~~• none~~

The technique is ~~only~~ generally applicable as a pretreatment step to control mercury emissions to air in combination with other techniques, ~~as an Hg pretreatment step,~~ or applicable alone where input mercury ~~waste~~ concentrations in the waste are low enough (e.g. below 4 mg/kg). ~~Otherwise emissions to air of above 50 µg/Nm³ may result.~~

Economics
No information provided~~not supplied~~.

Driving force for implementation
~~This technique has been implemented as an adaptation to wet scrubbing for acid gas removal in order to reduce Hg emissions.~~
Reduction of mercury emissions.

Example plants
Wet scrubbing is widely used in Europe.

Several plants use wet scrubbing enhanced with additives, e.g. DE29 for the NET floc technique.

Reference literature
[1, UBA, 2001, 2, infomil, 2002, 3, Austria, 2002, 12, Achternbosch, 2002, 55, EIPPCBsitevisits, 2002, 63, Langenkamp, 1999] [64, TWGComments, 2003] [111, Germany 2016]

4.5.6.2 Activated carbon injection for mercury adsorption

Description
This technique involves the injection of activated carbon upstream of a bag filter (see also Section 4.5.5.6, bag filters are described in Section 2.5.3.5) or another dedusting device. Metallic mercury ~~metal~~ is adsorbed in the stream and where barrier filters such as bag filters are used, and also on the reagent that is retained on the bag surface.

Technical description
Metallic mercury is adsorbed on activated carbon. Ionic mercury is also removed by chemical adsorption arising from the sulphur content in the flue-gases or from sulphur impregnated in some types of activated carbon. [74, TWGComments, 2004]

A further development of this technique involves the separate injection of highly effective activated carbon (e.g. carbon impregnated with 25 % sulphur) when mercury peaks occur, controlled by continuous mercury monitoring in the raw flue-gas. This system has been reported to be very effective as it combines effective mercury abatement with decreased operating costs due to reduced use of sorbents.

Achieved environmental benefits
Benefits include the reduction of mercury emissions to air by adsorption on activated carbon.

The carbon also adsorbs dioxins (see Section 4.5.5.6). Bag filters provide a means of particulate and heavy metal removal too. Bag filters are described in Section 2.5.3.5. It is normal for alkaline reagents to be added with the carbon; this then also allows the reduction of acid gases in the same process step as a multifunctional device. [74, TWGComments, 2004]

Environmental performance and operational data
Operational aspects are similar to other situations where bag filters are used (see Section 4.5.2.2).

Effective bag filter and reagent injection system maintenance is particularly critical for achieving low emission levels.

Metallic mercury is adsorbed (usually at about 95 % removal efficiency) to result in emissions to air of below 30 µg/Nm^3. Ionic mercury is also removed by chemical adsorption arising from the sulphur content in the flue-gases or from sulphur impregnated in some types of activated carbon. [74, TWGComments, 2004]

Mercury emissions in the range between 3 µg/m^3 and 5 µg/m^3 (yearly average) are reported for the use of separately injected sulphur-impreganted activated carbon controlled by upstream continuous mercury measurement in the raw flue-gas.
[112, Germany 2016]

In some systems where removal of mercury is carried out in wet acid scrubbers (pH < 1) to reduce the inlet concentration, final emission levels below 1 µg/Nm^3 are seen.

Different types of activated carbon have different adsorption capacities. Another possibility to improve mercury removal is sulphur impregnation of the adsorbent. [74, TWGComments, 2004]

In experiments carried out at a HWI, various types of activated carbon were used, and the consumption rate per hour required to obtain a particular mercury emission level was as follows:

- coke from coconut shells:	8–9 kg/h;
- coke from peat:	5.5–6 kg/h;
- brown coal:	8–8.5 kg/h;
- peat coal:	4–4.5 kg/h.

[64, TWGComments, 2003]

The carbon consumption rate is similar to that mentioned for PCDD/F, as the adsorbent is generally used for both mercury and PCDD/F removal. Carbon consumption rates of 3 kg/t of waste are typical for MSWI. Levels from 0.3 kg/t to 20 kg/t of hazardous waste have been reported [41, EURITS, 2002]. The adsorption capacity of the reagent, the mercury inlet concentrations and the required emission level determine the required reagent dosing rate.

The fire risk is significant with activated carbon. The adsorbent may be mixed with other reagents to reduce the fire risk; 90 % lime and 10 % carbon is used in some cases. The proportion of carbon is generally higher where there are additional process stages that perform acid gas removal (e.g. wet scrubbers).

Cross-media effects
The cross-media effects are similar to those for other situations where bag filters are used (see Section 4.5.2.2). The energy consumption of bag filters is a significant aspect.

In addition, for this technique the most significant cross-media effect is the production of residues contaminated with the removed pollutant (mercury).

In cases where the solid reagent is reburned (for PCDD/F destruction) in the incinerator, it is important that:

- the installation has an outlet for mercury that prevents internal pollutant build-up (and eventual breakthrough release);
- the alternative outlet removes the pollutant at a sufficient rate;
- where wet scrubbers are used, the mercury can pass into the effluent stream, from where ~~(although~~ it can then be precipitated to the solid residue using treatment techniques~~)~~.

Technical considerations relevant to applicability

The applicability of ~~the use of~~ bag filters is assessed in Section 4.5.2.2.

Activated carbon injection is generally applicable to new and existing plants.
~~The table below details specific aspects relating to the use of activated carbon injection:~~

~~**Table 4.80: Assessment of the applicability of carbon injection for Hg removal**~~

~~**Criteria**~~	~~**Evaluation/comment**~~
~~**Waste type**~~	~~• provides effective emission reductions across a range of waste types~~
~~**Plant size range**~~	~~• any~~
~~**New/existing**~~	~~• applicable to new installations and as a retrofit~~
~~**Inter-process compatibility**~~	~~• no specific issues~~
~~**Key location factors**~~	~~• none~~

Economics

The additional capital costs of the technique in processes that already ~~have, or intend to~~ use~~,~~ reagent injection and bag filters are minimal. See also Section 4.5.5.6.

Additional operating~~onal~~ costs are from:

- reagent consumption;
- disposal of residues.

The cost of operations (carbon cost) is approximately EUR 125 000/yr for a facility treating 65 000 tonnes of hazardous waste per year.

The separate injection of sulphur-impregnated carbon controlled by continuous mercury monitoring in the raw flue-gas is reported to allow for operating cost savings due to the reduced overall sorbent consumption.

Driving force for implementation

~~The technique has been applied to both new and existing systems as a means of reducing~~ Cost-effective reduction of mercury emissions to air.

Example plants

Widely used throughout Europe.

The separate injection of sulphur-impregnated carbon controlled by continuous mercury mornitoring has been in use at the Hahn MWI since 2012.

Reference literature

[1, UBA, 2001, 2, infomil, 2002, 3, Austria, 2002, 12, Achternbosch, 2002, 55, EIPPCBsitevisits, 2002, 63, Langenkamp, 1999] [41, EURITS, 2002] [64, TWGComments, 2003] [112, EEB 2015]

4.5.6.3 Use of flue-gas condenser ~~ing scrubbers~~ for flue-gas polishing

Description
This technique is ~~has already been~~ described in Sections 2.4.4.5 and 4.4.16~~, where they are presented~~ primarily from the energy recovery point of view.

Technical description
In addition to the potential benefits of the use of such systems for energy recovery, the condensing effect of the use of a cold scrubber can condense some pollutants. This may reduce releases of pollutants to air, but only to a significant degree where the scrubber is operated at a particularly low temperature, e.g. 40 ºC.

Achieved environmental benefits
The condensation of pollutants from the flue-gas provides an additional reduction of emissions to air.

The condensation of the water from the flue-gas can, when used with downstream flue-gas heating, greatly reduce plume visibility and reduce scrubber water consumption.

Environmental performance and operational data
For mercury, this technique alone cannot guarantee ~~generally be relied upon, on its own, to achieve~~ emission levels below 50 µg/Nm^3. It is therefore only ~~be~~ considered as an additional polishing stage.

The temperature of the scrubber effluent is critical for some pollutants, e.g. to ensure mercury is condensed and does not pass through the scrubber to be released to air. The supply of a sufficiently cold cooling medium is, therefore, critical. To be effective for metallic mercury removal, scrubber outlet temperatures of below 40 °C may be required (even lower temperatures still are reported in some cases - see below).

Cooling the gas using a gas cooler (i.e. no liquid injection) ~~until the~~ down to a temperature ~~is~~ as low as 5 °C has been reported not to give sufficiently good results for mercury abatement (~~ref. Bayer AG Dormagen,~~ DE17~~ – HWI~~).

The low temperature of the flue-gases can result in condensation and, hence, corrosion in the chimney unless it is lined.

Cross-media effects
The condensed water will contain pollutants that require treatment in a water treatment facility prior to discharge. Where an upstream wet scrubbing system is applied, the effluent from the condensing scrubber can be treated in the same facility.

The technique is generally only applied where there is a readily available cooling source, for example a particularly cold (40 ºC) district heating water return, which is generally only encountered in colder climates. The application of this technique in other circumstances (which is not reported~~ in other circumstances~~) would lead to high energy costs for the cooling required.
The low temperature of the stack discharge will reduce the thermal buoyancy of the plume and hence reduce dispersion. This can be overcome by using a taller stack or one with a reduced diameter.

Technical considerations relevant to applicability
The technique is applied primarily as an energy recovery technique and where additional pollutant removal steps have already been incorporated in the installation (e.g. carbon absorption, low pH wet scrubbing).

The technique is not generally applied on its own as a means for pollution control but can be effective as a polishing stage in combination with other systems.

The table below details specific aspects relating to the use of condensing scrubbers.

Table 4.81: Assessment of the applicability of condensing scrubbers for mercury removal

Criteria	Evaluation/comments
Waste type	Because the technique is applied after the flue-gas cleaning stages, in principle the technique could be applied to any waste type
Plant size range	The technique has been applied at MSWI plants with capacities between 175 000 t and 400 000 t per year
New/existing	The technique is applied at/near the end of the FGC system and could therefore be applied to both new and existing processes
Inter-process compatibility	No specific issues
Key location factors	Only likely to be applicable where energy is not required for additional scrubber cooling, i.e. in colder northern climates, where colder district heating returns provide the energetic driving force

Economics

The total additional investment for a condensation scrubber is roughly estimated as EUR 3 million. [5, RVF, 2002]

Driving force for implementation

Additional heat sales are the main driver for using the technique. The additional pollutant removal is a secondary benefit.

Example plants

Several examples of MWI in Sweden, and a SSI in the Netherlands (NL06).

Reference literature

[5, RVF, 2002], [64, TWGComments, 2003]

The following technique was moved to Section 4.6 because it is for WWT, not for FGC

~~4.5.6.4 Separation of mercury using a resin filter~~

4.5.6.5 Chlorite injection for elemental mercury control

Description

Addition of chlorite as an oxidising agent to convert elemental mercury to water-soluble oxidised mercury at the inlet of a wet scrubber.

~~While oxidised mercury is readily soluble in water and can be removed using a wet scrubber, elemental mercury is not. Therefore, it is difficult to achieve a significant abatement of the elemental mercury in a wet scrubber unless activated carbon is also used.~~

Technical description

The injection of a strong oxidising agent will convert the elemental mercury into oxidised mercury and make its scrubbing possible in the wet scrubber. To avoid that~~,~~ this agent is used up by reaction with other compounds (e.g. sulphur dioxide), ~~and~~ it is introduced just before the spray nozzles of the first acidic scrubber. The pH of the scrubber is kept between 0.5 and 2.

When the sprayed liquid comes into contact with the acidic fumes containing hydrogen chloride, chlorite is transformed into chlorine dioxide, which is the actual active species. It should be noted that, unlike other oxidants such as hypochlorite (bleach), the chlorite or chlorine dioxide lacks the ability to introduce a chlorine atom into an aromatic ring, and therefore cannot alter the dioxin balance.

Achieved environmental benefits
The technique's benefits include reduced mercury emissions.

As a side benefit, the use of oxidants favours the removal of NO in the scrubber by oxidising it to the more soluble NO_2. This results in a reduction of NO_X emissions to air.

Environmental performance and operational data
No information provided.

Cross-media effects
Since the use of oxidants favours the oxidation of NO ~~in the wet scrubber (by changing it into~~ to a more soluble species (NO_2) in the wet scrubber, this can lead to problems related to a high nitrogen content in the waste water. ~~There is no ELV for NH_3 in the WI Directive, but local regulation often sets a limit, as it is a great concern for the aquatic environment.~~ [74, TWGComments, 2004]

Technical considerations relevant to applicability
~~Incineration of waste;~~ The technique is only applicable where the hydrogen chloride concentration in the raw ~~mercury abatement of~~ flue-gas is ~~containing~~ at least 400 mg/Nm^3 ~~of hydrogen chloride~~.

The technique is only compatible with wet scrubbing systems.

Economics
The cost of the reagent is the limiting factor.

Driving force for implementation
No information provided.

Example plants
Bottrop and Ludwigshafen waste incineration plants (DE).
To the TWG, exspecially Germany: the plant in Bottrop did not take part to the data collection exercise, while in Ludwigshafen there are three plants but from the data gathered it is not clear which of those is using this technique. Could you please clarify?

Reference literature
[64, TWGComments, 2003]

4.5.6.6 Addition of hydrogen peroxide to wet scrubbers

Description
The main purpose of the wet scrubbing system is to separate Hg, HCl and SO_2 from the flue-gas. In the process, by adding hydrogen peroxide as an oxidising agent, SO_2 is oxidised to H_2SO_4 and absorbed by the scrubber, and all elemental mercury is oxidised to water-soluble Hg^{2+}.

Technical description
The first step is a quench situated downstream of a bag filter (with carbon injection – which will absorb much of the mercury). In the quench, the flue-gas is cooled so that it is saturated. After the quench, the flue-gas comes into contact with the scrubber fluid which contains hydrogen peroxide and an additive. The scrubber fluid reacts with the flue-gas and an acidic waste water is transferred for neutralisation and precipitation of mercury.

Achieved environmental benefits
Benefits include the additional reduction of the concentration of all types of mercury in the flue-gas.

The wet scrubber also reduces ~~as well as reduction of~~ HCl, HF and SO_2.

Environmental performance and operational data

Operational issues are similar to those described for other wet scrubbers (see Table 4.34).

The peak removal efficiency for mercury is typically around 99.9 %. During extended periods of high inlet concentrations, the mercury concentration in the scrubber liquid and clean gas will gradually increase. The mean removal efficiency depends on the number of stages and on the liquid discharge rate. In an installation with a low discharge rate, the mean removal efficiency will be typically in the range of 90–95 %.

Mercury emission levels below 10 µg/Nm^3 can be consistently achieved, in principle regardless of the inlet concentration thanks to the very high buffer capacity.

~~, together~~ In series with an upstream activated carbon process, the mercury removal efficiency is usually about 99.5 %.~~ removal efficiency)~~

The technique is also very efficient as a polishing stage for SO_2, HCl and HF.

Waste-water free operation is possible by recycling the waste water into the FGC system.

Cross-media effects

The consumption of reagent~~ added~~ H_2O_2 (35 wt-%) is 4–5 kg/t hazardous waste. The consumption can increase as H_2O_2 reacts not only with mercury but also with all other oxidisable compounds like iron or heavy metals. [74, TWGComments, 2004]

Mercury absorbed in the scrubbing liquid is precipitated in the waste water treatment stage, producing small amounts of stabilised mercury-containing sludge that requires disposal.

Energy consumption will vary depending on design parameters. A pressure drop between 1 200 Pa and 2 400 Pa can be expected for the wet scrubber, depending on the design and independent of the addition of H_2O_2.

Technical considerations relevant to applicability

This method is applicable to all types of waste incinerators using wet scrubbing. The best effect is achieved if the scrubber is situated downstream of a bag filter with carbon injection.

Economics

~~The cost of an installation is approx EUR 4 million for a capacity of 200000 tonnes of waste. This is the cost for the wet scrubber including the specific technique mentioned here, but not the additional cost of applying this technique.~~

Investment costs can vary over a broad range, from very low costs if a suitable scrubber stage already forms part of the design, up to around EUR 3 million if an entirely new scrubber system is required (based on a 100 000 Nm^3/h gas flow).

Operating costs include the cost of chemicals and, if an additional scrubber stage is required, electricity consumption to compensate for the extra pressure drop. These have been estimated to be in the range of EUR 20–35/h at a 130 000 Nm^3/h plant.

~~H_2O_2 is reported to be costly and its consumption may prove difficult to control. [74, TWGComments, 2004]~~

Driving force for implementation

The technique can be used at both new and existing facilities that need to:

- achieve low emission levels ~~cope with new and lower emission limits~~ for Hg, HCl and SO_2;
- reduce high mercury peaks.

Example plants

~~Sydkraft~~ The Sakab Ekokem plant in Kumla (SE) (SE21) implements a MERCOX system as a polishing scrubber.

Reference literature

[64, TWGComments, 2003], [113, Sweden 2015]

4.5.6.7 Boiler bromine addition

Description

Injection of bromide into the furnace or addition to the waste to enhance the oxidisation of mercury during the passage of the flue-gas through the boiler, thereby promoting the transformation of the insoluble elemental gaseous mercury into water-soluble and adsorbable $HgBr_2$. Mercury removal is thus enhanced in downstream control devices such as wet scrubbers or dry activated carbon injection systems.

Technical description

An aqueous solution of bromides such as $CaBr_2$ is added to the waste prior to or during combustion. At high temperatures, the bromide dissociates into dimolecular bromine (Br_2) or atomic bromine radicals and hydrolysed bromine (HBr), which oxidise the mercury in the flue-gas. It has been shown that bromide salts are far more effective at mercury oxidation than chloride salts, because, while chlorine is scavenged by the conversion of SO_2 to SO_3, the same reaction is not enthalpically favourable with bromine. This results in a much smaller amount of bromine being sufficient for the complete oxidation of mercury than when using chlorine.

Achieved environmental benefits

The benefits are the reduction of mercury emissions to air and the efficient control of mercury emission peaks associated with occasionally high input levels in the waste.

Environmental performance and operational data

The technique improves the mercury removal efficiency of the techniques that are implemented downstream, allowing for an overall abatement efficiency of > 90 % and up to 99.8 % in combination with multistage wet scrubbers; an abatement efficiency of > 99.5 % is reported to be achievable with dry activated carbon injection systems too.

A bromine-to-mercury mass ratio of > 300 is required for the complete oxidation of the mercury contained in the flue-gas.

For the control of occasional mercury input peaks, the volume flow rate of bromide as $CaBr_2$ (52 wt-%) for example can be set at between 15 l and 75 l $CaBr_2$ (52 %) per hour depending on plant size and the magnitude of the mercury peaks. The bromide injection rate can be automatically dosed in response to the mercury levels measured in the flue-gas.

Cross-media effects

Consumption of acqueous bromide solution is a cross-media effect.

The use of bromine in the process may lead to the formation of polybrominated dioxins and/or polyhalogenated dioxins and furans.

Technical considerations relevant to applicability

The technique is not applicable to plants operating with an oxygen level near zero, such as pyrolysis plants or low-pressure gasification plants, but is possibly applicable in downstream plant sections (e.g. at afterburning chambers where the O_2 content is sufficient).

The technique is not relevant for plants burning waste with a high chlorine content.

Economics

Investment costs are reported to be low, ranging from EUR 10 000 to around EUR 250 000 depending on local standards for the installation, and covering an adequate storage tank for the bromide solution, dosing pumps and injection lances.

Operating costs are essentially related to the consumption of bromide as an oxidiser and depend on the overall mercury content in the waste and are therefore variable. They are reported as ranging between less than EUR 20 000/yr and EUR 120 000/yr.

For a site operating two hazardous waste incinerators and one multiple-hearth kiln for sewage sludge combustion, the reported consumption over a period of 13 years is between 25 m^3 and 125 m^3 bromide solution per year.

Driving force for implementation

- Compliance with emission legislation.
- Suppression of mercury peaks.
- Potential cost savings compared with the use of other oxidisers.

Example plants

The technique has been demonstrated in Germany since 2002 at four rotary kiln incinerators for the combustion of hazardous wastes at Currenta GmbH&Co OHG; since 2004 at two stationary fluidised bed incinerators for communal sewage sludge at Emschergenossenschaft--Lippeverband in Bottrop; and since 2008 at another two stationary fluidised bed incinerators for communal sewage sludge at WWTP Karlsruhe-Neureuth in Karlsruhe.

It has recently also been demonstrated at three rotary kiln incinerators for the combustion of hazardous wastes of SARPI-VEOLIA in France, which are fitted with three different flue-gas cleaning systems: a dry FGC system based on activated carbon and hydrated lime, a similar semi-dry FGC system as the first stage having an additional tail-end scrubber, and a multistage wet FGC system.

Reference literature

[115, Vosteen et al. 2015]

4.5.6.8 ~~Use of~~ Fixed-bed adsorption of mercury ~~static activated carbon or coke filters~~

The use of this technique, and its benefits for mercury reduction, cross-media effects and other issues ~~has already been~~ are described in Section 4.5.5.7.

Mercury is adsorbed to give emissions to air typically below ~~30~~ 20 µg/Nm^3.

4.5.6.9 Fixed Sorbent Polymer Catalyst (SPC) systems

Description

Fixed sorbent system utilising a Sorbent Polymer Catalyst (SPC) that captures both elemental and oxidised mercury and removes SO_2. Can be used in a wet scrubber, or as a standalone unit.

Technical description

Open-channel modules with low associated pressure drop are installed downstream of a dust collector, where they continuously remove mercury from the flue-gas. The mercury is chemisorbed into the structure, forming a stable species which will not desorb or leach.

The modules are replaced after several years of use once they are loaded with chemisorbed mercury. No sorbents or chemicals are injected into the gas stream, resulting in very little solid waste compared with a typical carbon injection system. SO_2 is also removed as a co-benefit by oxidation to sulphuric acid, which is typically processed in the wet scrubber.

The modules may be installed inside an existing wet scrubber above the mist eliminators at the outlet of the scrubber. As a self-standing tailpipe solution, they can be typically installed immediately before the stack, either in the outlet of a wet scrubber or immediately following a wet scrubber or a wet ESP.

Achieved environmental benefits

- Reduction of mercury emissions to air, thus avoiding contamination of process dust or process waste water.
- Minimal solid waste generation (modules replaced every several years of operation).
- Low energy penalty since the low pressure drop obviates the need for an additional ID fan.
- SO_2 emissions to air are also reduced as a co-benefit.

Environmental performance and operational data

The technique is implemented as a modular design, with each module removing approximately the same percentage of mercury in the flue-gas, which depends on the flue-gas velocity. The overall removal percentage is determined by the number of modules stacked in series. For a flue-gas velocity of 4 m/s, a 60 cm high stack is reported to remove 40–50 % of the mercury in the flue-gas, meaning that 80–90 % mercury is removed by a 180 cm high stack.

The technique thus provides for a fixed percentage removal of inlet mercury in the flue-gas, but no significant operational flexibility or buffer capacity. As such, it may be sufficient as a sole mercury control technique in plants where the mercury load and its variability are relatively low, e.g. in sewage sludge incinerators, but not for example in the case of merchant hazardous waste incinerators.

A maximum operating temperature of 80 °C is reported. If necessary, a cooling device such as an evaporative cooler may be used upstream. Pre-dedusting is required, although the technique is tolerant to moderate particulate loadings such as after an ESP. The open-channel modules can be washed in use, and process dust is rinsed off of the surfaces with water.

The technique does not involve any moving parts or require the injection of chemicals or sorbents. Minimal washing with process water is required.

At six sewage sludge incineration lines in the US operated by the Northeast Ohio Regional Sewer District and by the Metropolitan Sewer District of Greater Cincinnati, mercury emission reductions ranging between 60 % and 97 %, resulting in emission concentrations between < 1 µg/Nm^3 and 9 µg/Nm^3 (converted to 11 % O_2). SO_2 reductions ranging between 78 % and 98 % were also reported at the same sites.

A pressure drop of 0.25–0.5 kPa is reported.

Cross-media effects
The main cross-media effect is the generation, after a few years of use, of mercury-laden spent polymer catalyst. Considering that a 20 kg module may capture around 1 kg mercury before replacement is needed, the amount of waste generated is much lower than with activated carbon injection systems.

Technical considerations relevant to applicability
The technique is generally applicable to new plants.

Adaptability to existing plants may be constrained by the space requirement for an additional process unit and, in plants fitted only with dry FGC techniques, by additional flue-gas cooling requirements.

Economics
Investment costs are reported to be highly site-specific, but in general substantially lower than for fixed-bed adsorption. In the cases of two sewage sludge incinerators already fitted with wet scrubber in the US, investment costs between USD 225 000 and USD 450 000 were reported, which included the costs for a separate vessel constructed to hold the modules, placed after the scrubber (either on top, or down-stream).

Operating costs are reported to be typically low.

Driving force for implementation
Reducing mercury emissions while limiting cross-media effects.

Example plants
In the US, 16 sewage sludge incinerator sites use the technique Gore Mercury Control System.

Reference literature
[119, EEB 2015] [120, Smith et al. 2017]

4.5.7 Techniques to reduce~~tion~~ emissions of other ~~techniques and~~ substances

4.5.7.1 Use of specific reagents for iodine and bromine reduction

Description
This technique ~~has already been~~ is briefly described in Section 2.5.4.1.

Special reagents, e.g. sodium thiosulphate or sodium bisulphite, can either be added as required to an existing wet scrubbing system for the treatment of particular batches of waste (when knowledge of the waste content is critical) or added routinely to an additional stage of the wet scrubbing system (when consumption of reagent may be higher).

Technical description

In the halogen scrubber, any free halogens are reduced to halogen hydrides by reaction with an alkaline $Na_2S_2O_3$ solution. Together with the remaining SO_2, the halogen hydrides are then removed from the flue-gas by dissolution.

The halogens in question are bromine and iodine, mainly ~~deriving~~ originating from flame-retardants and medical waste. As fluorine and chlorine are stronger oxidising agents, both are totally reduced to hydrides.

It is also possible to reduce iodine and bromine emissions to air by injecting sulphur-containing wastes or SO_2 in the furnace. [64, TWGComments, 2003]

Achieved environmental benefits

A yellow/brown or purple coloured flue-gas can be seen in some cases when appreciable concentrations of bromine or iodine (respectively) pass through the FGC system. This is prevented by ~~The use of~~ targeted or regular $Na_2S_2O_3$ addition ~~prevents this effect~~.

Environmental performance and operational data

It has not been possible to control the process by on-line redox measurement, due to a mixture of several interfering redox processes in the scrubber water. The addition is, therefore, controlled by the SO_2 concentration in the raw gas. If the waste contains enough sulphur, no additional reduction of halogens is required – this reflects the alternative option of metered burning of higher sulphur waste or SO_2 injection mentioned above.

Cross-media effects

The consumption of $Na_2S_2O_3$ depends on the sulphur content of the waste, with its addition being controlled according to the SO_2 concentration in the raw gas. If the waste contains enough sulphur, no additional reduction of halogens is required.

The removed pollutants are transferred to the effluent; subsequent treatment may therefore be required.

Where SO_2 or higher sulphur wastes are added, this will require a change in the operational set-up of subsequent FGC stages to allow for the altered standard waste chemistry. Changes in the sulphur/chlorine balance can also effect PCDD/F reformation rates.

Technical considerations relevant to applicability

The technique is generally applicable to any plant fitted with a wet scrubber.

It is mainly relevant for ~~applicable to~~ HWIs or other installations where concentrations of iodine and bromine in the waste incinerated are highly variable and/or difficult to predict/control, e.g. wastes from laboratories or chemical/pharmaceutical wastes. In general, these are ~~it is only~~ HW installations ~~that may have iodine or bromine concentrations in the waste that merit the use of such special measures for their control~~.

~~The applicability of this technique is assessed in the table below:~~

~~**Table 4.82: Assessment of the applicability of $Na_2S_2O_3$ for halogen removal**~~

~~**Criteria**~~	~~**Evaluation/comment**~~
~~**Waste type**~~	• ~~mainly applied to HWIs where I and Br loads in the waste can be high e.g. wastes from laboratories or chemical/pharmaceutical wastes~~
~~**Plant size range**~~	• ~~any~~
~~**New/existing**~~	• ~~targeted reagent addition may be used at any existing plant with a wet scrubber system~~ • ~~addition of a permanent dosing system is more~~

	~~complex/expensive to add to existing processes, but can be incorporated in new plant designs~~
~~**Inter-process compatibility**~~	~~• applied with wet scrubber systems~~
~~**Key location factors**~~	~~• sensitivity to visible (coloured) plume releases~~

~~Difficulties in control and steering is reported. [74, TWGComments, 2004]~~

Economics

The yearly consumption of $Na_2S_2O_3$ for each of the three incineration lines, as an average, is approximately 50 tonnes. At a price of EUR 0.5/tonne, the total costs for running this third step (excluding power) for the scrubber pumps etc. are EUR 25 000/yr per line.

Costs for targeted addition of reagent are likely to be lower, but additional resources may be required for control and management of incoming wastes.

Costs for addition of reagent to an existing wet scrubber system are limited mainly to the reagent costs and are, therefore, significantly less than the cost of adding a separate scrubbing stage.

Costs of SO_2 injection are the gas costs. The addition of higher sulphur waste will depend on the availability of such waste.

~~The construction costs for a third scrubber step at an existing~~ At a HWI ~~(~~in Denmark~~)~~, a third scrubber stage was added at a cost of ~~are~~ approximately EUR 600 000 (in the year 2000).

Driving force for implementation

~~This technique has been implemented where:~~

- Control of iodine and bromine emissions. ~~is required~~
- Cases where the concentrations of iodine and bromine in the waste incinerated are highly variable and/or difficult to predict/control.

Example plants

~~The additional stage scrubber has been applied at a HWI in DK.~~ Targeted dosing is used at many ~~other~~ European HWIs. An additional scrubber stage was installed at a HWI in Denmark.

Reference literature

[25, Kommunikemi, 2002] [64, TWGComments, 2003]

4.6 Waste water treatment and control

~~4.6.1 General~~

The general principles to be applied in respect of the selection and operation of waste water treatment systems have already been outlined in the BREF on ~~common waste water and flue-gas management~~ Common Waste Water and Waste Gas Treatment/Management Systems in the chemical sector (CWW). This section of this BREF therefore only deals with some specific issues that have been identified as important for, or specific to, the WI sector.

~~4.6.2 Application of optimal incineration technology~~

An optimal incineration process is an important condition for the effective control of emissions to water. Incomplete incineration has a negative effect on flue-gas and fly ash composition, by the increased presence of organic compounds with a polluting and/or toxic character. These in turn can impact on the content of the scrubber effluent.

The techniques to be considered in respect of reducing the pollutant content of the flue-gases (and hence reducing the potential for risk of transfer to scrubber effluents) have already been outlined in Sections 4.1 and 4.3.

4.6.3 Application of waste water free gas cleaning technology

Description
Techniques to consider are:

- use of a dry sorbent injection or semi-wet absorber;
- use of a wet scrubber followed by evaporation of the produced effluent;
- recycling of waste water from the wet flue-gas cleaning system.

Technical description
Waste-water-free technologies for gas cleaning can be achieved by:

- use of dry and semi-wet processes: these do not give rise to waste water;
- wet processes that use evaporation: wet FGC gives rise to a waste water; however, under certain conditions this waste water can be recirculated into the process and evaporated.

Some features of these processes are given in Section 4.5.3.

It is also possible to feed ~~for~~ low- ~~to~~ or medium-volume waste water effluents (*to the TWG: could you please provide a figure?*) to ~~be fed into~~ the incineration process at appropriate points, as follows:

- ~~the use of~~ send the leachate from open-air bottom ash or other storage areas ~~for the supply of water~~ to the wet bottom ash discharger; ~~de-slaggers~~
- use of collected rainwater as a ~~for~~ scrubbing medium; ~~or feed~~
- recirculation of condensates;
- reuse of cooling water from electricity production;
- use of the permeated water from boiler water preparation.

~~This can be done in such a way that it does~~ The correct implemention of these techniques does not prejudice the operation of the incineration plant or its environmental performance.

Achieved environmental benefits

- Reduction of ~~no discharge of waste~~ emissions to water.
- Reduction of ~~in consumptions associated with waste~~ water consumption with the use of dry or semi-wet scrubbers. ~~treatment~~
- Recovery of salts by ~~in~~ evaporation. *To the TWG: please provide more information on the recovery of salts*

Environmental performance and operational data

~~See information included in the description above.~~

Dry and semi-dry FGC systems do not generate waste water. Other waste water from other on-site processes or rainwater may be recycled in semi-wet or wet systems. Wet processes generate waste water that can be ~~discharged~~ recycled after treatment or evaporated either on-line or in a specific evaporation unit. The amount of waste water from a wet process is typically 0.2 m^3/t of waste. Wet scrubber effluent is neutralised (e.g. with lime). Complex builders are also injected to treat heavy metal compounds. Then the treated waste water ~~final effluent~~ is sprayed into an evaporative cooling tower and vaporises using the energy of the flue-gas at the boiler outlet. (*from Section 4.6.15*)

Evaporation of effluent may cause risk of fouling in the evaporative cooling tower. [74, TWGComments, 2004]

Cross-media effects

- ~~salts and other substances that would have been discharged to water accumulate in scrubber residues or WWTP residues~~
- Increase in energy consumption. The energy consumption of the evaporation unit~~, if applicable – this~~ may not be ~~as~~ significant if supplied from otherwise wasted heat.
- Increase in residues production.

Technical considerations relevant to applicability

Generally applicable. ~~Technologies that give rise to waste water free incineration (as described here) can in principle be applied to all waste incinerators.~~

Economics

~~The relatively larger amounts of solid wastes produced with dry and semi-dry systems may make these systems less favourable where availability of waste treatment/disposal outlets is reduced, or the costs of such are higher.~~

Where a discharge of effluent is acceptable, there is reduced incentive to adopt systems that eliminate this discharge. Possible examples include marine environments that can absorb post-treatment salty waste waters ~~without environmental impacts~~.

Energy costs for a separate evaporation plant may be high.

Where solid waste disposal costs are high, there may be benefits in adopting wet flue-gas treatment with (or without where a discharge is possible) evaporation owing to the reduced solid waste arising.

An outlet for recovered salt arising in separate evaporation systems will avoid the need to pay disposal charges for this fraction. Impurities have proven to complicate this in some cases. [74, TWGComments, 2004] (from Section 4.6.16) *To the TWG: is there an example?*

Driving force for implementation

The lack of availability of a water discharge outlet is a key driver.

Example plants
Evaporation is carried out at a number of installations in Germany and gives rise to wet FGC installations that do not discharge an effluent.

Zero-effluent production FGC (i.e. non-wet FGC) systems are widely used throughout Europe.

~~In France: Azalys~~ FR56 (wet process + evapocondensation of the waste water), FR33 ~~Arcante, Ouarville~~ (semi-wet + wet processes). [74, TWGComments, 2004]

Reference literature
[2, infomil, 2002], [64, TWGComments, 2003], [72, El-Halwagi, 1997], [74, TWGComments, 2004]

~~4.6.4 Recirculation of polluted waste water in wet gas cleaning systems~~

To the TWG: recirculation of the scrubbing liquor is common to all wet scrubbers. The quantity of waste water produced usually depends on the liquor's salt content and on the required environmental performance. Do you have more information and data on the use of scrubbing effluent to dilute the organic flocculants for sewage sludge dewatering?

~~**Description**~~
~~Polluted waste water from wet scrubbers is recirculated as much as possible before any treatment, so that it may be reused as a feed for the scrubbers or as dilution water for organic flocculants for sewage sludge dewatering.~~

~~**Achieved environmental benefits**~~
~~Reduction in water consumption by wet scrubbers.~~

~~**Cross-media effects**~~
~~Consumptions associated with the treatment of waste water.~~

~~**Operational data**~~
~~Organic flocculants can be diluted from 3 % concentration to 0.1 – 0.2 % with the salt containing waste water without any problems. Reusing the waste water in scrubbers depends on the concentration of salt.~~

~~**Applicability**~~
~~Only of use in wet scrubbing systems or for sewage sludge dewatering.~~

~~**Economics**~~
~~No fresh water for dilution of organic flocculants is necessary, reduced effluent to the sewer plant, reduced demand of fresh water. [74, TWGComments, 2004]~~

~~**Driving force for implementation**~~
~~Reduction of waste water effluent/legal demand.~~

~~**Example plants**~~
~~MHKW Bamberg in Germany and some HWI.~~

~~**Reference literature**~~
~~[64, TWGComments, 2003] [74, TWGComments, 2004]~~

4.6.5 Additional cooling of feed water of wet gas cleaning systems

To the TWG: can it be improved?

~~**Description**~~
~~The technique involves the cooling of scrubber inlet water, using:~~

- ~~a cooling system (air or cooling tower)~~
- ~~an available cold water supply e.g. sea or river water, or a cold (typically below 40 – 50 °C) district heating supply~~

~~**Achieved environmental benefits**~~
~~The main benefit in relation to process water control is the possibility of reducing wet scrubber water consumption.~~

~~For other aspects see the general section on cooling system selection in~~ 4.4.10

4.6.6 Use of boiler drain water ~~as a water supply for scrubbers~~

Description
Techniques to consider are:

- feeding of the boiler water drainage into a semi-wet or wet scrubber, or a quench system;
- treating the boiler water drainage to recycle it in the incineration process itself.

Technical description
Boiler water requires regular draining in order to reduce the levels of the dissolved solids ~~levels and to maintain the system~~. This waste water stream can be fed directly to the scrubbers (semi-dry and wet) or to a quench, instead of separate treatment/discharge.

Another option is to treat it and send it back to the boiler. The water coming from the boiler is cooled down in a heat exchanger where the heat is exchanged with cold demineralised water going to the deaereator (in this way the waste heat is also recovered) to a level which allows further treatment. The cooled water goes to a buffer tank for a temporary storage. The water, at temperatures below 40°C, is sent from the tank to an activated carbon filter (to remove the ammina content), than sent to an ion exchange column (with anionic and cationic resins) to reach a targeted silicon content. Then the water is ready to be sent to the deaereator and recycled. [96, Italy 2016]

Achieved environmental benefits
Reduction in water consumption by replacement of scrubber feed water.

Environmental performance and operational data
No information provided on the feeding of boiler waste water to scrubbers ~~not supplied~~.
To the TWG: without operational data it is not possible to check the amount of saved water. Do you have any figure? Is it possible to improve the text?

It is important to check if the quality of the effluent is suitable for the process, in particular to prevent the risk of fouling due to salt precipitation (e.g. calcium phosphate). [74, TWGComments, 2004]

At IT10, the plant for the reuse of the boiler waste water works at full capacity (100 %). A water tank receives the water from the boilers. When the tank is full, the treatment starts. The maximum flow is 2 m^3/h and the minimum flow is 0.7 m^3/h.

There is a circulating pump of 1.1 kW; 20 l/min of compressed air is needed to control valves. The consumption of HCl for regeneration of resins in the ion exchange bed is 30 l/month and the consumption of NaOH for regeneration of resins is also 30 l/month.

The residues produced are:

- activated carbon filter: 50 kg (substitution every 8 years);
- quartz: 50 kg every 8 years;

- anionic and cationic resins: 100 kg every 8 years;
- waste water produced during regeneration (every 2 weeks): 4 m^3/month.

All the water from continuous blowdown of boilers is recovered.

The limit of the application is the temperature of the water at the inlet of the activated carbon filter (which has to be lower then 40°C).

The equipment used for this technique has a very long lifetime (substitution of filters and resins every 8 years).

The water conductibility and silicum concentration is checked after the ion exchange bed.

The energy that the treatment requires is compensated by the reduced energy needed for the supplied fresh water. [96, Italy 2016]

Cross-media effects
Slight increase in energy use and in raw materials consumption.

Technical considerations relevant to applicability
The feeding of boiler waste water to the scrubbers is only applicable to gas cleaning systems that require a water feed (i.e. not dry systems unless conditioning feed water is added).

The treatment of boiler waste water is generally applicable.

Economics
No information provided on the feeding of boiler waste water to scrubbers. ~~not supplied~~.

The investment cost of the treatment of boiler waste water is around EUR 40 000 (2006), while the operating cost, including the maintenance, is EUR 1 600/year.

The savings are:

- approximately EUR 294 000/year due to the avoided cost for waste water disposal;
- approximately EUR 650/year for the energy saved for the groundwater suction;
- benefits from heat recovered for heating of deminiseralised water going to the deaereator.

[96, Italy 2016]

Driving force for implementation
Cost savings ~~Information not supplied~~.

Example plants
MHKW Bamberg (DE), Rea Dalmine (IT) and many other MWIs in Europe.

Reference literature
[2, Infomil, 2002], [96, Italy 2016]

4.6.7 Treatment of laboratory waste water in the scrubber

To the TWG: no example plant. How many WI plants implement this and what is the real contribution?

~~**Description**~~
~~Some laboratory waste water streams contain low levels of contamination and can be used as make up water for scrubber feeds.~~

~~By segregating unsuitable materials, those that might lead to increased emissions or process problems in the laboratory, the relatively low flow of these wastes can be incorporated into the plant treatment facility.~~

~~Achieved environmental benefits~~

- ~~reduction in water consumption at scrubbers (only a small reduction)~~
- ~~reduction of potential emissions by treating in process the laboratory waste water.~~

~~Cross-media effects~~
~~Some substances may not be effectively treated in the scrubber if added at the wrong part of the system, or they may adversely impact upon the scrubber performance.~~

~~Operational data~~
~~Ensuring inappropriate substances are not discharged to the scrubbers with the laboratory waste water, relies on the assessment, and efficient segregation, of waste in the laboratory.~~
~~Applicability~~
~~Only applicable where wet scrubbers are used.~~

~~Applicable to sites that have on-site laboratory facilities, particularly HWIs.~~

~~Economics~~
~~The waste is dealt with in the process and therefore saves external disposal costs.~~

~~Driving force for implementation~~

~~Example plants~~

~~Reference literature~~
~~[2, infomil, 2002] [64, TWGComments, 2003]~~

~~4.6.8 Recirculation of effluents to the process in place of their discharge~~

To the TWG: merged with Section 4.6.3

~~Description~~
~~Because the incineration process itself provides a means of concentration and removal of pollutants from waste streams, it is possible for low to medium volume waste water effluents to be fed into the incineration process at appropriate points. This can be done in such a way that it does not prejudice the operation of the incineration plant, nor its environmental performance.~~

~~Examples of such practices are given in Sections 4.6.4, 4.6.5, 4.6.6, 4.6.7 above. Other possibilities include:~~

- ~~the use of leachate from open-air bottom ash or other storage areas for the supply of water to the de-slaggers~~
- ~~use of collected rainwater for scrubber feed~~
- ~~recirculation of condensates~~
- ~~cooling water from electricity production~~
- ~~permeated water from boiler water preparation.~~
  ~~[74, TWGComments, 2004]~~

~~Achieved environmental benefits~~
~~If well designed and operated, such a system can allow the waste incinerator to:~~

- ~~concentrate inorganic pollutants into solid wastes (e.g. with FGC residues or WWT residues)~~
- ~~reduce water consumption~~

- ~~eliminate, or limit, the need for effluent discharges.~~

~~Cross-media effects~~
~~Where effluent stream treatment is required to improve its quality in order to allow re-circulation, this will result in additional energy and materials consumptions (and costs) that could be sufficiently large to negate the benefits of the eventual recirculation. Such an assessment will depend greatly upon local detailed circumstances.~~

~~It is essential that the re-circulation of materials within the installation is accompanied by outlets for those materials that may accumulate. Accumulation of some substances (notably Hg) can lead to build up and eventual breakthrough and release. To avoid such possibilities a correct assessment and provision of *sinks* for such substances is required.~~

~~In particular these techniques tend to cause a concentration of pollutants into the solid waste stream.~~

~~Operational data~~
~~It is possible to identify opportunities for re-circulating partially contaminated waste streams for other uses within the installation by assessing overall flows and exchanges of mass. Such assessments are sometimes called *Pinch Assessments* or *Materials Exchange Networks*. Such tools, when applied to effluent systems, provide a means for assessing the possibility of effluent re-circulation, taking into account the quality requirements of the inputs to the process units themselves and the overall objective of the system to reduce emissions.~~

~~Applicability~~
~~The re-circulation of effluents may be applied at all WI installations, although will have particular benefits where:~~

- ~~the re-circulation can be made without interim pretreatment of the effluent~~
- ~~there is a particular need to reduce installation water consumption~~
- ~~availability of discharge outlets is restricted.~~

~~Economics~~
~~Costs will increase if interim effluent treatment is required.~~

~~Savings may be made by reducing water consumption and discharge costs.~~

~~Driving force for implementation~~
~~Particular drivers include:~~

- ~~lack of availability of effluent discharge outlets – e.g. restricted by legislation or local circumstances~~
- ~~dry climates where water supply may be limited.~~

~~Example plants~~
~~MSWI with zero discharge: Azalys, Ouarville [74, TWGComments, 2004]~~

~~Reference literature~~
~~[72, El-Halwagi, 1997], [64, TWGComments, 2003] [74, TWGComments, 2004]~~

4.6.9 Segregation of waste water streams and separate treatment, depending on the pollutant content ~~Separate discharge of rainwater from roofs and other clean surfaces~~

Description

Waste water streams (e.g. surface run-off water, cooling water, waste water from flue-gas treatment and from IBA treatment) are segregated to be treated separately based on their pollutant content and on the combination of treatment techniques required. Uncontaminated waste water streams are segregated from waste water streams that require treatment.

Technical description

This techniques involves the separation of the drainage of clean rainwater so that it does not mix with streams that are potentially or actually contaminated.

Achieved environmental benefits

- Reduction in the volume of waste water requiring treatment.
- The remaining polluted fraction has a higher concentration and can therefore be treated more effectively.

Envirnmental performance and operational data

If the incinerator is located in a community with only one sewer for both polluted waste water and rainwater the separate collection of unpolluted streams is of limited benefit, unless it can be suitably treated for direct discharge to the environment. [74, TWGComments, 2004]

~~Separate discharge is recommended to avoid a dilution effect of the treated waste water. The more concentrated effluent that results from separation, can be more effectively treated.~~

~~Prevention of sudden large volume additions to ETPs or storage areas.~~

Cross-media effects

None reported.

Technical considerations relevant to applicability

The technique is generally applicable to new plants.

It is applicable to existing plants within the constraints associated with the configuration of the water collection systems. ~~Applicable to all WI.~~

Economics

Retrofit costs can be significant at existing sites, but the technique can be installed efficiently at new sites.

Savings may be made from the reduction in the water-holding capacity needed on the site.

Driving force for implementation

In some countries, the mixing of uncontaminated rainwater with other effluents is not permitted.

Example plants

Applied throughout Europe.

Reference literature

[64, TWGComments, 2003] [74, TWGComments, 2004]

~~4.6.10 Provision of storage/buffering capacity for waste water~~

To the TWG: already described in CWW BREF Section 3.3.2.1 Equalisation

~~**Description**~~

~~The larger the volume of storage that is provided the greater the homogeneity of the waste water composition. This, in turn, allows improved optimisation and process control at the treatment stage.~~

~~**Achieved environmental benefits**~~

- ~~lower emission to water~~
- ~~improved stability and confidence in treatment processes~~
- ~~optimisation of treatment can lead to reduced consumptions for effluent treatment.~~

~~**Cross-media effects**~~

~~Information not supplied.~~

~~**Operational data**~~

~~Information not supplied.~~

~~**Applicability**~~

~~This system is of greater importance where wastes are highly heterogeneous, or of uncertain composition, as this leads to greater variation in the effluent content.~~

~~**Economics**~~

~~It is necessary to provide for higher volume for buffering and throughput capacity of waste water treatment. Often costs for effluent treatment are different for waste water and rainwater as described under 4.6.9. [74, TWGComments, 2004]~~

~~**Driving force for implementation**~~

~~Information not supplied.~~

~~**Example plants**~~

~~Amagerforbrænding, DK~~

~~**Reference literature**~~

~~[64, TWGComments, 2003] [74, TWGComments, 2004]~~

4.6.11 Application of physico-chemical treatment to the waste water from the wet flue-gas cleaning system ~~scrubber effluents and other contaminated waste water from the plant~~

Description

The conversion of dissolved pollutants into insoluble compounds by adding chemical precipitants. The precipitates are subsequently separated by sedimentation, flotation or filtration. If necessary, this may be followed by microfiltration or ultrafiltration. Typical chemicals used for metal precipitation are lime, dolomite, sodium hydroxide, sodium carbonate, sodium sulphide and organosulphides. Calcium salts (other than lime) are used to precipitate sulphate or fluoride.

Technical description

A description of the technique is provided in Section 2.6.4.1 (physico-chemical treatment in general) and Section 2.6.4.2 (use of sulphides).

In general, the provision of a waste water treatment system for wet scrubber effluents, as well as for waste water collected in the plant ~~(see 4.6.10),~~ is considered essential. [64, TWGComments, 2003]. [74, TWGComments, 2004]

Achieved environmental benefits
Reduction of water emissions.

Environmental performance and operational data
~~Emission levels achieved using these techniques are provided in Sections 3.3.4 and 3.3.5.~~

With the application of sulphides to increase heavy metal precipitation from wet scrubbing effluents, a 99.9 % reduction of mercury levels in effluents treated can be achieved. Emissions to water of mercury below 0.003 mg/l can be achieved. Other substances are also reduced ~~(see Table 3.30)~~.

~~Operation of WWTP ETP is generally considered to be a critical process step, requiring close supervision and operation to ensure the final effluent quality remains good.~~

Problems with encrustation and clogging of pipes by sedimentation may occur. [74, TWGComments, 2004]

Cross-media effects
Consumption of energy and raw materials in the WWTP ~~ETP~~.

Technical considerations relevant to applicability
This technique is applicable to all incineration installations with wet scrubbing. It may also be applicable to other waste water streams that require such treatment prior to their discharge. [74, TWGComments, 2004]

Economics
Additives and reagents can be costly. [74, TWGComments, 2004]

Driving force for implementation
Environmental legislation requirements. ~~A legal requirement in many countries. Minimum standards for the quality of discharged effluents are included in the WID (EC/2000/76).~~

Example plants
Widely applied throughout Europe in installations with wet scrubbing.

Reference literature
[2, infomil, 2002], [1, UBA, 2001], [64, TWGComments, 2003] [74, TWGComments, 2004], [101, Sweden 2016]

4.6.12 Stripping of wet scrubber waste water containing ammonia ~~removal from effluents~~

Description
Techniques to consider are as follows:

- Stripping: The removal of ammonia from waste water by contact with a flow of a steam current in order to transfer it to the gas phase. The ammonia is removed from the stripping gas in a downstream treatment and may potentially be reused.
- Reverse osmosis: A membrane process in which a pressure difference applied between the compartments separated by the membrane causes water to flow from the more concentrated solution to the less concentrated one.

Technical description
The technique is described in Section 2.6.4.4.

Ammonia slip can result from the use of ammoniacal reagents for NO_X reduction. Slip is higher when reagent dosing is high or poorly optimised, and is generally higher with SNCR than SCR systems. The ammonia is highly soluble in water and will accumulate in the effluent from downstream wet scrubbers. Using ~~special apparatus, such as~~ stripping or~~,~~ reverse osmosis~~, or others,~~ it is possible to remove ammonia from wet scrubber effluents. It is possible for the ammonia collected in this way to be returned for use as a NO_X reduction reagent.
[74, TWGComments, 2004]

Achieved environmental benefits
~~The main achieved environmental benefits are:~~

- Reduction of ammonia in the discharged scrubber effluent.
- Reduction in ammonia consumption where recirculated to be reused as the NO_X reduction reagent.

Environmental performance and operational data
The technique is ~~can be~~ applied at ~~to all~~ WI installations with wet scrubbers downstream of the ammonia/urea reagent injection for NO_X reduction. The abatement efficiency of the stripping under normal operating conditions is about 99 %. [101, Sweden 2016]

The technique is of particular benefit where ammonia slip levels downstream of the boiler are higher. This tends to occur where:

- it is difficult to optimise the SNCR reagent injection (e.g. injection/mixing/temperature are poorly optimised);
- reagent injection levels are relatively high (e.g. where high NO_X abatement is required).

[74, TWGComments, 2004]

Higher SNCR reagent injection rates (larger over-stoichiometric rates) are particularly common when the required NO_X reduction rate is high. ~~This is generally the case when NO_X ELVs are set at lower levels and SCR is not used. For most waste incinerators using SNCR, guaranteeing emission levels (daily average) below 150 mg/Nm^3 (below 120 mg/Nm^3 for some wastes prepared in fluidised beds) requires these higher reagent injections —~~ the associated increased risk of ammonia slip, therefore, enhances the applicability of using wet scrubbers with ammonia stripping.

Handling of ammonia solutions requires care to reduce risk of exposure.

Cross-media effects
If the gases are not returned to the combustion unit, then ammonia is transferred from water to air.

Ammonia removal techniques require significant additional energy consumption for their operation and there is a risk of fouling. [74, TWGComments, 2004] [101, Sweden 2016]

Technical considerations relevant to applicability
Generally applicable.

Economics
Operational and capital costs for the ammonia stripper may be partially offset by the reduction in reagent costs when the recovered ammonia is recirculated to the SNCR reagent injection.

Driving force for implementation
The main driving force for the technique is the restriction of ammonia levels in the effluent discharged from the site.

Example plants
Umea (SE) and SE03.

Reference literature

[55, EIPPCBsitevisits, 2002], [64, TWGComments, 2003] [74, TWGComments, 2004], [101, Sweden 2016]

The following technique was moved from Section 4.5 because it is for WWT, not for FGC

4.6.13 Separation of mercury using ion exchange ~~a resin filter~~

To the TWG: is it possible to improve this Section?

Description

The removal of ionic pollutants from waste water and their replacement by non-polluting ions by transferring them to an ion exchange resin. The pollutants are temporarily retained and afterwards released into a regeneration or backwashing liquid.

Technical description

~~After dust separation and the first acidic wet rinse, the raw acids in the ionically bound heavy metal~~ The raw acids and the ionically bound metals in the waste water from the first acidic stage of the wet scrubber are carried off through a mercury ion exchanger. Mercury is separated off in a resin filter. Then the acid is neutralised using lime milk.

~~If, after washing, there is still residual mercury in the exhaust air, it is retained by a downstream oven coke filter.~~

Achieved environmental benefits

Highly reliable abatement of mercury.

Environmental performance and operational data

In Table 4.83, the environmental performace of plants incinerating non-hazardous waste and using ion exchange for the reduction of mercury emissions is shown.

Table 4.83: Water emissions from plants using ion exchange

Plant	Techniques	Emissions				
		Max. (mg/l)	Avg. (mg/l)	Min. (mg/l)	Flow (kg/yr)	Direct/indirect
AT04	A, CPs, IE Se,Fi, Fl	NA	0.001	NA	0.044	Direct
AT05	A, CPh, CPs, IE, C, Se,Fi Fl	0.004	0.00175	0.001	0.318	Direct
AT09	A, CPs, IE, Se, Fi, Fl	NA	0.0006	NA	0.003	Indirect
DE44	IE	NE	NE	NE	NE	No emission
DE54	IE	NE	NE	NE	NE	No emission
DE58	A, CPh, CPs, IE, Se, Fi	NE	NE	NE	NE	No emission
DE80	CPh, IE, Fi	0.001	0.0002	0.0001	0.009	Direct
DK01	A, CPs, IE, Fi, Fl	NA	0.00082	NA	0.04	Direct
NO01	A, CPh, CPs, IE	0.0002	0.0001	0.00001	0.001	Direct
SE20	IE, RO, Fi	0.01	0.01	0.01	0.00063	Direct

NB:
NA = Not available.
NE = No emission to water.
A = Adsorption on activated carbon.
C = Coagulation.
CPh = Chemical precipitation with hydroxide.
CPs = Chemical precipitetion with sulphides.
Fi = Filtration.
Fl = Floculation.
IE = Ion exchange.
RO = Reverse osmosis.
Se = Sedimentation.
Source: [81, TWG 2016]

Cross-media effects
The resin filter will require regeneration which results in the transfer of the abated mercury.

Technical considerations relevant to applicability
Generally applicable.
~~The technique is reported to not be widely applied in the sector.~~

Economics
The technique is reported ~~indicated by the TWG~~ to be expensive in relation to alternatives.

Driving force for implementation
No information provided.

Example plants
~~RMVA Köln, Germany~~ AT04, AT05, AT09, DE44, DE 54; DE58, DE80, DK01, NO01, SE20.

Reference literature
[64, TWGComments, 2003], [81, TWG 2016]

4.6.14 Separate treatment of effluents arising from different wet scrubbing stages

To the TWG: Sections 4.6.17 and 4.6.18 can be merged with this.

Description
The technique involves the separation and separate treatment of the acid and alkaline wet scrubber streams in order to allow improved optimisation of the effluent and increased options for the recovery of components of the effluent streams.

Technical description
The technique is described ~~in more detail~~ in Section 2.6.4.5.

Achieved environmental benefits
- Emissions to water can be reduced further than with combined treatment.
- Optimisation of separate streams reduces reagent consumption and allows targeted treatment.
- Gypsum can be recovered from sulphur scrubbers (see Section 4.6.18); this reduces sulphur discharges with the waste water and the sulphur content of solid residues from the WWTP ~~ETP~~.
- HCl may be regenerated from first-stage acid scrubbers (see Section 4.6.17).

Environmental performance and operational data
There is additional complexity due to the operation of two WWTP ~~ETP~~ lines. More complexity means higher investment and operational costs and that more space is required.

An outlet for the recovered ~~y of the~~ materials is required. This may be complicated due to impurities. [74, TWGComments, 2004]. For instance, there may be problems recovering HCl as HF may give rise to impurities.

Cross-media effects
~~Additional~~ Energy ~~and materials~~ consumption.

Technical considerations relevant to applicability
~~Only applicable to WI installations with wet scrubbers – can be applied, in principle, to all such installations.~~ The technique is generally applicable to new plants. It is applicable to existing plants within the constraints associated with the configuration of the drainage systems.

~~Most applicable where there is a need for final effluent of the highest quality and/or where there are outlets for the beneficial use of the recovered HCl/gypsum.~~

Economics
The cost of replacing existing combined treatment systems is likely to be very high. ~~– the technique may therefore in general only be suited to new installations where there are special driving forces for effluent purity etc.~~

Operational and capital costs for the second WWTP ~~ETP~~ may be partially offset by reduced disposal costs when gypsum and salts like NaCl or CaCl are recovered. [74, TWGComments, 2004]

Driving force for implementation
The existence of markets for the recovered materials may drive the adoption of this system. The main reason is generally the application of particularly low effluent discharge emission limits, possibly to protect a sensitive water body.

Example plants
AT03, AT04, AT08, AT09, DE30, DE40, DE43, DE51, DE58, DE62, DE74, DE78, DK01, DK02. ~~Reported to be employed in the Netherlands, Germany and Austria.~~
~~Seen in use at the Umea Plant in N Sweden for discharge to a fresh water river.~~
~~Vestforbrænding and Odense, DK~~

Reference literature
[64, TWGComments, 2003]

~~4.6.15 Evaporation of wet scrubber effluent in the incineration process~~

To the TWG: already in Section 4.6.3

~~**Description**~~
~~Described in Section 2.6.4.7.1~~

~~Pollutants (acid gas, heavy metals, etc.) are removed from the cleaning process during exhaust air cleaning and transferred to wet scrubber effluent. This effluent is neutralised (e.g. with lime milk). Complex builders are also injected to treat heavy metal compounds. Then the final effluent is sprayed into an evaporative cooling tower and vaporises using the energy of the flue-gas at the boiler outlet.~~

~~Other aspects of this technique have already been described in Section 4.6.3 on the application of waste water free FGC.~~
~~[74, TWGComments, 2004]~~

~~4.6.16 Separate evaporation of wet scrubber effluent~~

To the TWG: already in Section 4.6.3

~~**Description**~~
~~Described in Section 2.6.4.7.2.~~

~~Other aspects of this technique have already been described in Section 4.6.3 on the application of waste water free FGC.~~

~~An outlet for recovered solid residues (e.g. Salt) arising from effluent evaporation is required. Impurities have proven to complicate this in some cases. [74, TWGComments, 2004]~~

4.6.17 Recovery of hydrochloric acid from wet scrubber effluents

Description

Hydrochloric acid is recovered from the waste water coming from the first-stage scrubber by stripping.

Technical description

See Section 2.6.4.8 for a description of this process.

Achieved environmental benefits

- Recovery of HCl.
- Reduction of solid residues.

~~If the HCl was not recovered, it would require neutralisation, giving a salt laden effluent requiring either discharge or evaporation. Recovering HCl therefore results in a reduction in the salt content of the effluent produced.~~

Environmental performance and operational data

This technique is ,most suited to those plants which ~~treat~~ incinerate high amounts of chlorinated waste ~~i.e. where there are large amounts of HCl to be recovered.~~ [74, TWGComments, 2004]

In the recovery of HCl, a product with a concentration of about 30 % hydrochloric acid is produced from untreated acid of about 10 %.

Data from two plants in Germany are shown in the table below.

Table 4.84: Quantity of HCl (30 %) recovered per tonne of waste

Year	**kg of HCl recovered per tonne of waste**	
	Plant at Borsigstrasse	**Plant at Rugenberger Damm**
2000	10	10
2001	-	12.5
2002	10.6	13

Source: [64, TWGComments, 2003] [74, TWGComments, 2004]

It is vital that systems and materials are suitable ~~required~~ to avoid/limit corrosion in the recovery system.

~~If evaporation (not discharge) of the salt laden effluent is the option chosen,~~ Recovering HCl ~~effectively~~ reduces the amount of solid salt residues arising from the installation by approximately 50 % [73, Rijpkema, 2000].

The use of one plant was reported to have been discontinued following difficulties with HF contamination of the recovered HCl.

The recovered hydrochloric acid may be used, e.g. for pH control.

Cross-media effects

- Energy requirements.
- Use of chemicals in the recovery process.

Technical considerations relevant to applicability

Generally applicable. ~~Only applicable where wet scrubbing is used.~~

Economics
Significant investment is necessary, therefore these procedures are only applicable where sufficient flue-gas loading with chlorine is available. Maintenance and operating costs can also be high owing largely to the highly corrosive nature of the material being recovered. [74, TWGComments, 2004]

The benefits of the products may not be that significant (there are market fluctuations) but waste disposal costs are reduced. Eco-efficiency analyses have shown that this technique is economical in some circumstances (*to the TWG: is it possible to be more precise?*) compared to other procedures.

Driving force for implementation

- Raw material recovery.
- Savings of neutralisation cost.

Example plants
Rotary kilns (HWI) DE22, DE23, and a MWI DE30.

~~In Germany there are six plants with HCl procedure.~~

Reference literature
[64, TWGComments, 2003], US patent Number 5174865 from December 29, 1992

4.6.18 Recovery of gypsum from wet scrubber effluent

Description
Quality optimisation of the calcium-based reaction residues generated by the wet scrubber so that they can be used as a substitute for mined gypsum.

Technical description
This technique involves the separate treatment of the effluent from the high pH (6–8), sulphur dioxide removal stage in wet scrubbers; this can allow the production of saleable gypsum.

In a multistage wet scrubber, at the earlier stages the dust and the HCl are removed from the flue-gas. Then the flue-gas is passed to the SO_2 cleaner, where the SO_2 is absorbed by oxidation to sulphate by the addition of lime.

The gypsum suspension formed is removed and thickened in a hydrocyclone and passed to a container. The gypsum suspension is then dehydrated in a centrifuge. The gypsum is then cleaned with condensate to remove the remaining soluble contaminants. Further centrifuging is carried out to a remaining humidity of less than 10 wt-% and, if required, until the whiteness for marketing of this gypsum is reported to be possible. [74, TWGComments, 2004]

Achieved environmental benefits

- Recovery of gypsum.
- Reduction of sulphate content of discharged effluent by it removal from the waste water.
- Where reuse outlets can be found this reduces gypsum disposal, either on its own or with other residues.
- Reduction of solid residues.
- When mixing together with hydroxide and ~~with~~ sludge from the first waste water cleaning stage, which is very difficult to dewater, the dewatering effect of this mixture is greatly improved up to 70 % dry matter.
  [74, TWGComments, 2004]

Environmental performance and operational data
Data from two plants in Germany are shown in the table below.

Table 4.85: Quantities of gypsum recovered per tonne of waste treated

	kg of gypsum recovered per tonne of waste	
Year	**Plant at Borsigstrasse**	**Plant at Rugenberger Damm**
2000	3.5	1.7
2001		3.9
2002	3.5	3.3

Source: [64, TWGComments, 2003]

Cross-media effects
Consumption of energy and materials in treatment/recovery plant.

Technical considerations relevant to applicability
Generally applicable within the constraints associated with the required gypsum quality. ~~Only applicable where wet scrubbing is used.~~

Economics
Significant investment is necessary, therefore these procedures are only applicable where sufficient flue-gas loading with sulphur is available.

The economic income benefits of the products may be limited (due to market fluctuations) but waste disposal costs are reduced. Eco-efficiency analyses have shown that these plants are economical compared to other procedures. [64, TWGComments, 2003]

Driving force for implementation
Availability of outlets for the recovered material.

Example plants
AT03, AT04, AT08, AT09, DE30, DE40, DE43, DE51, DE58, DE62, DE74, DE78, DK01, DK02. ~~Seen at incineration plants in Germany.~~

Reference literature
[1, UBA, 2001], [64, TWGComments, 2003]

4.6.19 Crystallisation

Description
The removal of ionic pollutants from waste water by crystallising them on a seed material such as sand or minerals, working in a fluidised bed process.

Technical description
The crystallisation device consists mainly of:

- the cylindrical reactor with bottom influent and top effluent;
- seed material, i.e. pellets of filter sand or minerals, kept in a fluidised bed condition;
- the circulation system with a recirculation pump.

The principle of the circulation system is to mix the influent waste water with the circulation stream with the lower anion or metal concentration. Because of the circulation system, the reactor can work more flexibly, e.g.:

- fluctuations in the influent flow and composition are easily eliminated;
- all kinds of waste water with concentrations in the range of 10–100 000 ppm can be treated by simply adapting the circulation ratio (more highly concentrated waste water requires a larger circulation ratio);
- fluidisation of pellets is also maintained if no waste water is fed into the reactor.

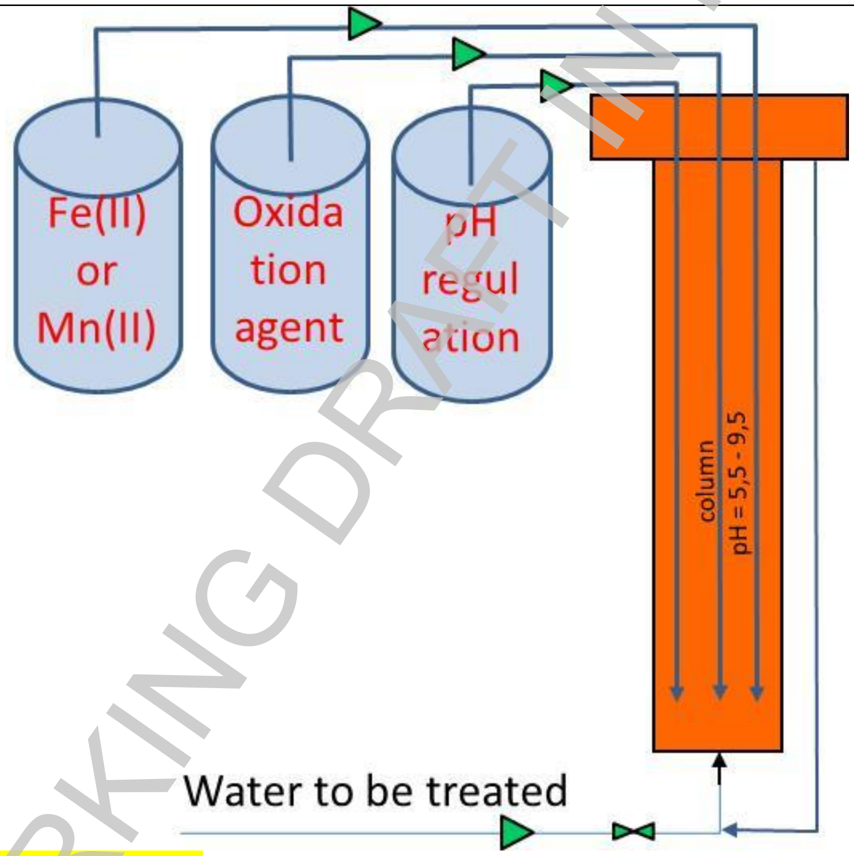
Achieved environmental benefits

Reduction of metals and metalloids, sulphate (SO_4^{2-}) and fluoride (F^-) in the waste water discharge.

Environmental performance and operational data

Crystallisation has been tested by three incineration plants in Denmark (Karanoveren, full-scale plant, 2006 (full-scale temporary plant, 2004) Esbjerg, full-scale, 2010; RenoNord, full-scale pilot test, 2008) to further reduce the concentration of metals after the chemical precipitation stage. [103 Denmark, 2016]

The water to be treated is introduced into the reactor through a nozzle at the bottom. The chemicals are also injected at the bottom of the reactor. Inside the reactor, the granulated product is kept fluidised by the upflow stream of water to be treated and the recirculated water (see Figure 4.11). Iron or manganese is adsorbed on the granulate surface and, with the oxidation agents, transformed into the granulate building material FeOOH or MnO_2. At the same time, soluble metals are removed from the water and incorporated into the surface layer of FeOOH or MnO_2. The process described has been tested for the removal of the cations Al, Ba, Cd, Co, Cr(III), Cu, Hg, Ni, Pb, Ra and Zn, as well as the anion-forming metalloids As, Cr(VI), Mo, Sb, Se(IV), U and V. Especially, the anion-forming metalloids are often difficult to remove by conventional precipitation without producing a huge amount of sludge. [103 Denmark, 2016]



Source: [103 Denmark, 2016]

Figure 4.11: Flowsheet of crystallisation applied at three waste incineration plants in Denmark

Table 4 below shows the results of a testing period (April to August 2013) at the Esbjerg waste incineration plant in Denmark (L90 union of municipalities in Jutland), to remove antimony and molybdenum that could not be removed in the chemical precipitation stage.

Table 4.86: Results of a testing period carried out to remove Mo and Sb at the Esbjerg incineration plant in Denmark

Sample date	Flow (m^3/h)	Untreated water		Reagents used		Treated waste water			Capture rate	
		Mo	Sb	$FeSO_4$	H_2O_2	pH	Mo	Sb	Mo	Sb
		(mg/l)	(mg/l)	(?)	(?)		(mg/l)	(mg/l)	%	%
24/04/13	2.38	230.00	170.00	4.38	2.25	6.29	7.40	7.60	96.78	95.53
29/04/13	2.09	78.00	160.00	4.16	2.06	6.31	7.70	12.00	90.13	92.50
01/05/13	2.02	74.00	230.00	4.36	2.13	6.30	6.00	12.00	91.89	94.78
17/06/13	3.10	77.00	100.00	3.53	3.73	6.33	19.00	37.00	75.32	63.00
19/06/13	2.58	90.00	110.00	3.53	3.05	6.30	7.00	23.00	92.22	79.09
24/06/13	2.57	110.00	88.00	3.47	1.03	6.31	8.30	15.00	92.45	82.95
26/06/13	2.80	110.00	77.00	3.49	3.09	6.31	14.00	15.00	87.27	80.52
15/08/13	2.77	160.00	220.00	3.59	7.74	6.46	25.00	16.00	84.38	92.73

NB:
(?) = Unknown - please specify.
Source: [103 Denmark, 2016]

The crystallisation produces a solid residue in the form of a sandy granulate. The surface of this granulate consists of either FeOOH or MnO_2 plus the metals removed from the water. The content of metals is normally between 1 % and 8 % of the total weight of the dry granulate. The granulate is tapped from the bottom of the reactor while the plant is in operation, approximately 1/50 of the total fluidised bed volume or approximately 10–20 l/week per 1 m^3/h capacity. The granulate is easily drained. Tests conducted on this solid residue showed that it can be classified as non-hazardous waste. [103 Denmark, 2016]

Cross-media effects

- Energy consumption.
- Residues handling and disposal.

Technical considerations relevant to applicability

Generally applicable.

Economics

The investment cost is EUR 0.2–2 million depending on the size/capacity. The operating cost depends on the concentration and type of metals to be removed. It varies from EUR 0.01 to EUR 2 per m^3 of treated waste water [103 Denmark, 2016].

Driving force for implementation

Environmental legislation requirements.

Example plants

DE63, DE66, DK02, FR017.

Reference literature

CWW BREF, [103 Denmark, 2016]

4.7 Treatment techniques for solid residues

~~The possibility of recovering the solid residues from waste incinerators is typically determined by~~ The options for recovery and reuse of solid residues depend on:

- the content of organic compounds ~~in the residues~~;
- the total content of heavy metals ~~in the residues~~;
- the leachability of metals, salts, and heavy metals ~~in the residues~~;
- physical characteristics, ~~suitability~~ e.g. particle size and strength~~, of the residues~~.

In addition, market factors, regulations and policies concerning their use, and specific local environmental issues also impact greatly on the extent to which residues can be recovered. ~~use is made.~~

~~Many~~ Considerable efforts have been made to improve the environmental quality of residues ~~from waste incineration~~ and to recycle or reuse ~~utilise~~ at least part of specific residue flows. Both in-process and post-treatment techniques are applied. In-process measures involve ~~aim at~~ changing the incineration parameters ~~in order~~ to improve burnout or to shift the metal distribution over the various residues. Post-treatment techniques include: ageing, mechanical treatment, washing, thermal treatment and stabilisation. The various techniques are discussed below.

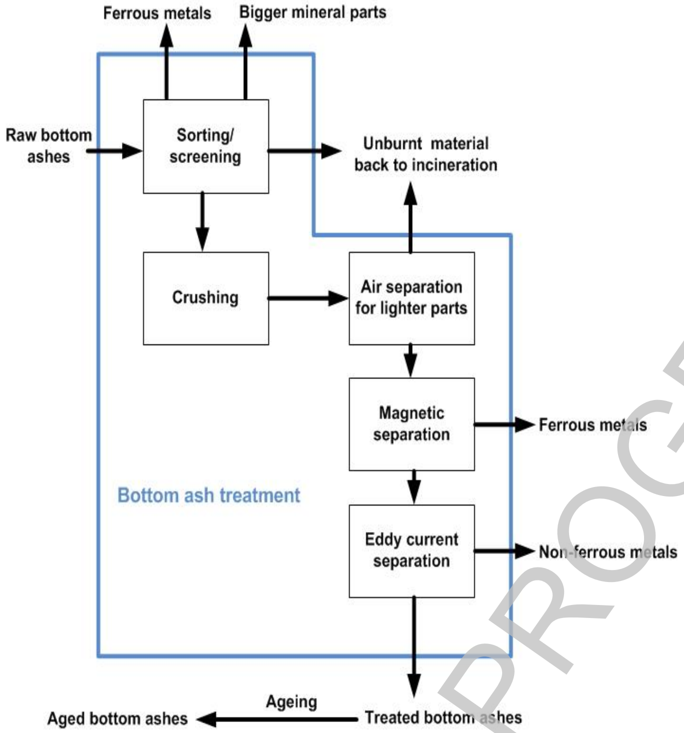
~~The *International Ash Working Group* (IAWG) identified~~ There are a number of principles which have to be considered when assessing the benefits but also the obstacles of a given treatment measure:

- Does the process result in a significant quality improvement?
- Does the process cause ~~impose~~ any significant health, safety or environmental impacts?
- Are there secondary residues and where do they end up?
- Is there a final product of a high quality?
- Is there a long-term market for that product?
- What is the cost of the process?

~~[4, IAWG, 1997]~~

~~For some of the residues produced by the incineration process, specific legislation may require those residues to be disposed of. Where this is the case,~~ If legislation requires certain residues to be sent for disposal, there is less incentive for adopting techniques which would improve the quality and recyclability of the residues. [64, TWGComments, 2003]

Figure 4.12 presents some mechanical treatment options for bottom ash. The combination of options that is used depends upon the composition of the waste feed material and the end uses of the treated ash.



Source: [82, Germany, 2014]

Figure 4.12: Flowsheet of IBA treatment and examples of some mechanical separations used for the treatment of bottom ash

~~4.7.1 Improving the burnout of bottom ash~~

To the TWG: this is already covered in Section 4.3.17

~~**Description**~~

~~Improving the residue burnout can be achieved by the optimisation of combustion parameters in order to bring the fixed carbon combustion to completion. This can be done using one or more of the measures identified in the thermal processing section (see Section 4.3).~~

~~Longer exposure of the waste to elevated temperatures in the combustion chamber, higher bed temperatures and physical agitation of the waste all combine to ensure that ashes produced are lower in organic species.~~

~~**Achieved environmental benefit**~~

~~The organic content of the bottom ash is expressed as (TOC) or (LOI) loss on ignition. These are key parameters for both the disposal and the use of bottom ash. Acceptance criteria for landfills generally state a maximum TOC level; and utilisation criteria generally state either a maximum TOC level or specific limit values for organic compounds. Improving the burnout will lower the residual carbon content and thus the TOC. The TOC is also related to the mobility of heavy metals in the ash. For instance, copper leaches in the form of organo-copper complexes. Improving the burnout will, therefore, also reduce copper leaching.~~

~~TOC determination in accordance with the standard EN 13137 also detects elementary carbon as TOC, which does not cause any problems on landfills. The TOC of bottom ashes comprises mainly elementary carbon, but to a certain extent, organic compounds are also found. [74, TWGComments, 2004]~~

~~**Cross-media effects**~~

~~An elevation of the combustion temperature, together with the fuel bed temperature, is reported to cause increased formation of CaO in the bottom ash. This causes an increase in the pH value of the bottom ash. The pH value of fresh bottom ashes often exceeds 12 [Vehlow, 2002 #38].~~

~~This increase of pH may also increase the solubility of amphoteric metals such as lead and zinc, which are present in high quantity in bottom ashes. The bottom ash pH may decrease after the combustion phase by ageing (see Section 4.7.5). The pH increase may be critical; in particular, as lead is amphoteric it can be dissolved at pH 11 – 12 and then be leached.~~

~~The application of pretreatment to increase burnout will incur additional energy consumption (and emissions) at the pretreatment stage, and therefore associated additional cost. These may be very significant where extensive pretreatment is carried out e.g. RDF production.~~

~~If additional fuels are required to support the burnout, their consumption is a cross media impact.~~

~~Operational data~~
~~See operational data in Section 4.3 on thermal processing.~~

~~Applicability~~
~~This technique is applicable both in new and existing installations.~~

~~Economics~~
~~Basic pretreatment (limited shredding of some components or mixing in bunkers) of waste may not be expensive and can have a significant effect on burnout in some cases.~~

~~Addition of higher calorific waste streams (e.g. plastics, automotive shredder residues, wood wastes) or fuels to improve burnout can vary greatly in price according to the material required and the possibility of mixing the different streams. This practice may increase CO emissions and reduce the throughput of MSW.~~
~~[74, TWGComments, 2004]~~

~~Redesign or replacement of combustion chambers and components can be very costly for existing plants, but can be easily considered as part of the overall design concept for all new processes or those being substantially reconstructed.~~

~~Optimisation of the plant for different wastes may require additional regulation devices e.g. instrument, control element, control loop etc. These can lead to further costs in addition to any pretreatment.~~

~~Some techniques can result in lower organic carbon-in-ash levels than required by EC/2000/76. Significant increases in cost may be seen in order to *guarantee* the lowest TOC levels that are achieved. Reducing carbon levels is not normally a requirement for the re-use of solid wastes. [74, TWGComments, 2004]~~

~~Driving force for implementation~~
~~Regulations setting limit values on the TOC of residues for its use and disposal.~~

~~Example plants~~
~~Optimisation of burnout, using various procedures, is part of standard operation control in many European incinerators.~~

~~Reference literature~~
~~[Vehlow, 2002 #38], [64, TWGComments, 2003]~~

4.7.2 Segregation of the bottom ash from flue-gas cleaning ~~treatment~~ residues

Description
Bottom ash is handled and treated separately from the other residues produced from the incineration of waste.

Technical description
The physical and chemical properties of bottom ash mean that it is more suitable for beneficial use than FGC residues. Mixing FGC residues with bottom ash will limit the options for the subsequent use of the bottom ash and therefore should be avoided.

FGC residues have a higher metal content, metal leachability and organic content than bottom ash. Mixing FGC residues with bottom ash will reduce the environmental quality of the bottom ash and so should be avoided.

~~The mixing of flue-gas treatment residues with bottom ash causes contamination of the bottom ash. Due the higher metal content, metal leachability and organic content of the FGC residues, the environmental quality of the bottom ash is reduced. This limits the options for the subsequent use of the bottom ash.~~

Segregation of the FGC residue from the bottom ash enables further treatment of the bottom ash (e.g. by dry treatment or by washing out of water-soluble salts, heavy metals in the ash extractor) to yield a material suitable for the intended use.

Segregation of bottom ash and FGC residues requires ~~consists in~~ the separate collection, storage and transportation of both residue streams. This involves dedicated storage silos and containers, and specific handling systems for the fine and dusty FGC residue.

A mixed stream of bottom ash and FGC residue cannot be processed ~~does not allow processing~~ into a material suitable for recovery and leaves no other option for the whole residue stream but landfilling. [74, TWGComments, 2004]

Achieved environmental benefits
Reduced use of natural raw materials such as sand and gravel when bottom ash is used as a replacement material. ~~Use of bottom ash as a replacement for natural building materials e.g. sand, gravel are replaced~~ [74, TWGComments, 2004]

Environmental performance and operational data
Separate transportation, storage and handling systems are required.

Cross-media effects
None reported ~~identified~~.

Technical considerations relevant to applicability
This technique is generally applicable. ~~applies to both new and existing plants.~~

Economics
Cost reductions may be seen where bottom ash ~~use~~ markets exist.

Bottom ash is typically 12–13 % by mass of the waste input and FCG residues are 2–3 %. Mixing the two streams means sending 15 % by mass of the waste input to landfill, whereas keeping them separate may allow 12–13 % to be sold and only 2–3 % sent, incurring the costs of disposal, to landfill.

~~FGC residue disposal may be higher, but volumes are greatly reduced (FGC residue volumes on their own are typically 2 - 3 % of mass of waste input, whereas when combined with bottom ash this will be around 15 %)~~

Driving force for implementation

- Increased possibilities for bottom ash recycling and possible cost reductions.
- Environmental legislation requirements.

~~This is current practice, and even required, by regulations in some EU countries.~~

Example plants

Widely adopted practice at incineration plants throughout Europe.

Reference literature

[64, TWGComments, 2003]

~~4.7.3 Separation of the dust removal stage from other flue-gas treatments~~

[*For the TWG: This is already in the Section 4.5.2.1*].

~~**Description**~~

~~Removal of dusts before the air pollution control stages (those for acid gas and dioxin removal) using ESPs, cyclones or bag filters, without the addition of reagents (additives), allows consideration to be given to the treatment and subsequent recovery of the removed dusts. Where a boiler is installed, the separate collection, transfer and storage of boiler dust serves the same purpose, although with a lower collection efficiency.~~

~~The segregated ashes can be returned to the combustion stage for further destruction of any PCDD/F which may lead to a reduction in the overall dioxin outputs from the installation. However fly ash recirculation may cause risk of fouling in the furnace and occasionally concentration of pollutant contained in the ash. [74, TWGComments, 2004]~~

~~**Achieved environmental benefits**~~

~~Separation of fly ash and FGT residues may allow their separate further treatment and/or recovery (if allowed by local regulations) and hence reduce quantities requiring final disposal.~~

~~It is possible to reduce overall dioxin outputs from the process by reducing outputs in solid residues by fly ash recirculation to the combustor. Non-thermal treatments for fly ashes (either separated fly ash or combined with other treatment residues) generally do not change the overall PCDD/F mass balance but concentrate the PCDD/F into smaller amounts of residues.~~

~~**Cross-media effects**~~

~~Pre-dedusting may improve the reliability of semi-dry flue-gas cleaning and other FGT systems.~~

~~Pre-dedusting with a bag filter will result in higher pressure drops and therefore greater energy consumption than with ESPs.~~

~~**Operational data**~~

~~Reduced particulate carry over to subsequent abatement stages (especially wet scrubbing systems) may improve their operability and decrease size and costs at that stage.~~

~~**Applicability**~~

~~Applicable to all new installations and existing processes replacing flue-gas treatment systems.~~

~~**Economics**~~

~~Cost of additional process units and operating resources may be offset by reduced FGT residue disposal costs.~~

~~**Driving force for implementation**~~

~~Where local standards for leachability (and content of substances) are such that they allow the inclusion of fly ashes with bottom ashes, the technique will be easy to apply.~~

~~High disposal costs for FGT residues will encourage uptake of the technique in order to reduce the total quantities of FGT residues requiring disposal.~~

~~The ease of availability (and hence low cost) of disposal options for fly ash/FGT residue mixtures will prevent uptake of the technique.~~

~~**Example plants**~~

~~Widely used technique at modern waste incineration plants in Europe.~~

~~**Reference literature**~~

~~From discussions during EIPPCB site visits.~~
~~[64, TWGComments, 2003]~~

4.7.4 Bottom ash screening and crushing

Description

Mechanical treatment operations intended to prepare materials for subsequent use, e.g. construction as a foundation material or road construction as a fill material.

Technical description

~~The various~~ Mechanical treatment operations for bottom ash are intended to prepare materials for road and earthworks construction that possess satisfactory geotechnical characteristics and do not cause damage to the road works. ~~Several operations can occur during the preparation process:~~ The treatment operations than can be applied are:

- manual sorting,
- granulometric separation by screening;
- size reduction by crushing ~~large elements or otherwise breaking them up~~;
- removal of low-density unburned fractions by air separation.
- ~~air-stream separation to eliminate light unburned fractions.~~

Manual sorting is used to remove large components (e.g. non-ferrous metals, stainless steel and unburned items) from bottom ash before any subsequent treatment.
Manual sorting typically entails workers standing along a slow-moving conveyer belt holding the material to be sorted. [82, Germany 2014]

Three types of screen are encountered:

- rotary (or drum) screens;
- flat screens (vibrating or not);
- star screens: screening is achieved by movement over a series of rollers equipped with star-shaped arms on each axis.

Primary screens used to prepare bottom ash aggregate typically have a mesh of 40 mm diameter and ~~and are in most cases equipped with a mesh sized 40 mm in diameter. This yields~~ produce ~~a~~ 0–20 mm aggregate material.

~~A crusher can be installed in the treatment line to break up large chunks, generally at the exit from the first screening. Half of the facilities are equipped with crushing apparatus, some use equipment at the site (shovel, loader, rock crusher, etc) to smash blocks.~~
~~Breaking up large chunks has several advantages:~~

Half of the installations are equipped with a crusher to break up large chunks, which is usually located after the first screen. The benefits of using a crusher are:

- it reduces the amount of heavy rejects;
- it increases the proportion of rough crushed material ~~ings~~ in the material which give backbone to the aggregate; and
- it improves its geotechnical qualities.

~~Separation of light unburned fractions or air stream~~ Air separation is achieved by blowing or by aspiration. Air-separation uses differences in density, particle size and particle shape to sort commingled materials. These characteristics often overlaps, it implies that the feedstock has to be prepared in such a way that a parameter for separating it is sufficiently clear. In addition, a narrow range of particle sizes is needed for an effective separating result. Using air separation also helps to improve the mineral fraction. [82, Germany 2014]

Achieved environmental benefits

The main environmental benefit of installing a mechanical treatment process is the reduction of the volume of rejects and wastes, and therefore a higher overall ~~global~~ recovery rate.

Environmental performance and operational data

No information provided.

Cross-media effects

- Energy consumption.
- Noise and dust emissions~~ are the most notable cross-media effects~~.

Technical considerations relevant to applicability

The technique is generally applicable, provided that there is a market for the treated bottom ash.

~~The technique is, in principle, applicable to all incineration installations producing an ash requiring treatment before it can be used, or where such treatment may allow increased use.~~

Economics

The cost-effectiveness of installing a system for breaking up heavy rejects ~~is to be evaluated on the basis of projected~~ depends on the quantities involved and the disposal costs that are avoided. It is estimated that the payback period for a crusher is in the order of 2 years for 5 % of rejects to be crushed, for 40 000 t/yr of bottom ash, and 7 years for 20 000 t/yr.

Driving force for implementation

The reasons for implementation are economic and regulatory.

~~Quality policy: it allows to reach a global recovery rate of more than 95 % for a bottom ash management facility, it produces less rejects and a product of a higher geotechnical quality, and is cost effective.~~

Example plants

No information provided.

Reference literature

[64, TWGComments, 2003] See 'Bottom ash management facilities for treatment and stabilisation of incineration bottom ash', ADEME, November 2002

4.7.5 Separation of metals from bottom ash

Description

Ferrous metals are removed using magnetic separation and non-ferrous metals are removed using eddy current separation.

Technical description

Both ferrous and non-ferrous metals may be extracted from bottom ash.

Ferrous metals separation is performed using a magnet. The ash is spread out on a moving belt or vibrating conveyor and all magnetic particles are attracted by a suspended magnet. This ferrous metals separation may be performed on the raw ash after it leaves the ash extractor. Efficient ferrous metals separation requires a multi-step treatment with intermediate size reduction and screening.

Non-ferrous metal separation is performed using an eddy current separator. A rapidly rotating coil induces a magnetic field in non-ferrous particles, which causes them to be ejected from the material flow. The technique is effective for particle sizes of 4–30 mm and requires the material to be well spread on the moving belt. The separation is performed after ferrous metals segregation, particle size reduction and screening.

Achieved environmental benefits

The separation of metals is a necessary step to allow recycling of the various ash compounds. The ferrous fraction can be recycled, generally after separation of impurities (e.g. dust), as steel scrap for electric arc ~~blast~~ furnaces. The non-ferrous metals are processed externally by further separation according to metal type, and may then be melted down for reuse. ~~re-melted~~. After metals separation, the resulting ash fraction has a lower metal content and is more suitable for processing ~~may be processed~~ to yield an inert secondary construction material.

Environmental performance and operational data

The amount of recovered metals depends on the composition of the waste input. For ferrous metals, data from Belgium suggest a recovery rate of 55–60 % (mass of metal recovered/mass of metal input). [Vrancken, 2001 #39] This recovery rate is supported by data from IAWG, which give a residual ferrous content of 1.3 % to 25.8 % in bottom ash that is considered for utilisation or disposal. [74, TWGComments, 2004].

For non-ferrous metals, using eddy current separation after size reduction and screening allows a 50 % recovery rate (mass recovered/mass input). The actual value is dependent on the metal and the operational conditions of the furnace. Non-ferrous metals, such as lead and zinc, are found in the boiler ash and the flue-gas cleaning residue. Aluminium, copper, chromium and nickel preferentially stay in the bottom ash. Oxidation of these metals (e.g. Al to Al_2O_3) during combustion will hamper the effective separation by eddy current separators. The separated non-ferrous fraction shows the following composition: 60 % Al, 25 % other metals, 15 % residue. The other metals are mainly copper, brass ~~messing~~, zinc and stainless steel. [Vrancken, 2001 #39]

Specifications for the bottom ash to be recycled may include the total metals content. The most problematic metals from the point of view of leaching from the bottom ash are copper, molybdenum and zinc.

Cross-media effects

Increase in energy consumption.

~~Ferrous metals separation uses a small amount of energy.~~

~~Non-ferrous separation requires size separation, size reduction and spreading of the material. This involves electrical energy use.~~

Technical considerations relevant to applicability
Magnetic separation of ferrous metals is generally applicable. ~~in all new and existing installations.~~

~~Non-ferrous metals separation requires space and sufficient throughput and may be performed by an external (centralised) bottom ash processing installation.~~

The applicability of non-ferrous metals separation may be restricted by lack of space or low throughput. The technique may be carried out off site at a dedicated bottom ash processing installation.

The applicability of the technique is strongly related to the metal content of the waste fed to the furnace. This, in turn, is highly influenced by the collection regime and pretreatment that the waste has undergone before being fed to the furnace. For example, areas with extensive and well-performing ~~adhered to~~ segregation schemes for municipal wastes may remove significant quantities of metals from the furnace feed, making metals recovery from bottom ash less financially viable. Pretreatment of MSW to create RDF will have a similar effect.

At some hazardous waste plants, shredded drums are removed using magnets prior to combustion. *To the TWG: Is this technique still used and, if so, how is the hazardous waste removed from the steel drum fragments?*

Economics
The metal fractions can be sold to scrap dealers. Prices depend on the purity (ferrous) and composition (non-ferrous) of the material.

~~Prices for ferrous scrap are determined by stock exchange.~~ The market price for ferrous scrap ~~this material~~ is generally in the range of EUR 0.01–0.05/kg.

Non-ferrous scrap needs further processing into pre-metal fractions. Prices for non-ferrous scrap depend on the amount of impurities (i.e. amount of processing needed) and the composition (i.e. price for final products). The content of aluminium and the market price of secondary aluminium are the main determining factors. The price of the non-ferrous fraction from MSW bottom ash treatment is in the range of EUR 0.10–0.60/kg. [Vrancken, 2001 #39]

Driving force for implementation
~~Interest of scrap market (i.e. market prices) in the produced fractions~~.
The driving forces for implementation are economic:

- The revenue for the various fractions produced.
- After metals separation, the resulting ash fraction has a lower metal content and is more suitable for processing to yield an inert secondary construction material. For example, residual non-ferrous metals may cause damage when bottom ash is reused in road works, due to swelling. ~~such as swelling.~~

~~Increased marketability of cleaned bottom ash.~~

Example plants
Ferrous metals separation is performed in most European incinerators, either on site ~~(mainly post combustion)~~ or at external bottom ash treatment plants. [74, TWGComments, 2004]

Non-ferrous metals separation is performed at various bottom ash treatment plants in the Netherlands, Germany, France and Belgium.

Reference literature
[39, Vrancken, 2001], [4, IAWG, 1997], [64, TWGComments, 2003] [74, TWGComments, 2004]

4.7.6 Bottom ash treatment using ageing

Description

After metals separation, bottom ash is stored in the open air or in specific buildings to reduce both the residual reactivity and the leachability of the metals. Stockpiles are wetted and turned regularly to favour the leaching of salts and carbonatisation. CO_2 from the air and water from humidity, rain or water spraying are the main reactants.

Technical description

Carbonation (the reaction between CO_2 and hydroxides in the alkaline bottom ash) is one of the key reactions in the ageing for bottom ash. The purpose of the ageing therefore is to reduce the remaining reactivity and to improve the technical properties. The leaching of bottom ash reduces after ageing, especially the leaching of metals such as Cu, Cr, Pb and Zn. [89 Belgium 2016]

The storage is generally performed in stockpiles on a concrete floor. Drainage and run-off water are collected for treatment. The stockpiles may be wetted, if required, using a sprinkler or hose system in order to prevent dust formation and emissions and to favour the leaching of salts and carbonisation if the bottom ashes are not sufficiently wet. The leaching and drain water is collected and it is snet to a waste water treatment plant.

The stockpiles may be turned regularly to ensure the homogeneity of the processes that occur during the ageing process (uptake of CO_2 from the air due to the moisture, draining of excess water, oxidation, etc.) and to reduce the residence time of every batch of bottom ash in the dedicated facilities.

In practice, an ageing period of 6 to 20 weeks is commonly observed (or prescribed) for treated bottom ash before utilisation as a construction material or in some cases before landfilling. [74, TWGComments, 2004]

In some cases, the entire process is performed inside a closed building. This assists with dust, odour, noise (from machinery and vehicles), and leachate control. In other cases, the ~~entire~~ process is totally or partially performed outdoors. This generally allows more space to easily handle bottom ash, and can give more air circulation for bottom ash to mature, [64, TWGComments, 2003] and may avoid the release of explosive hydrogen in combination with aluminium during the ageing process. [74, TWGComments, 2004] Aluminium in the bottom ash will react with $Ca(OH)_2$ and water to form aluminium hydroxide and hydrogen gas. The main problem of ~~formation of~~ aluminium hydroxide formation is the volume increase ~~as this causes inflation~~ caused by the swelling of the material. ~~The gas production will cause technical problems if fresh bottom ash is used directly for construction purposes. Thus, ageing is needed to allow utilisation of the bottom ash.~~

Achieved environmental benefits

Increased resource efficiency where bottom ash substitutes raw materials.

Environmental performance and operational data

The impact of ~~storage and~~ ageing on leaching can be classified as:

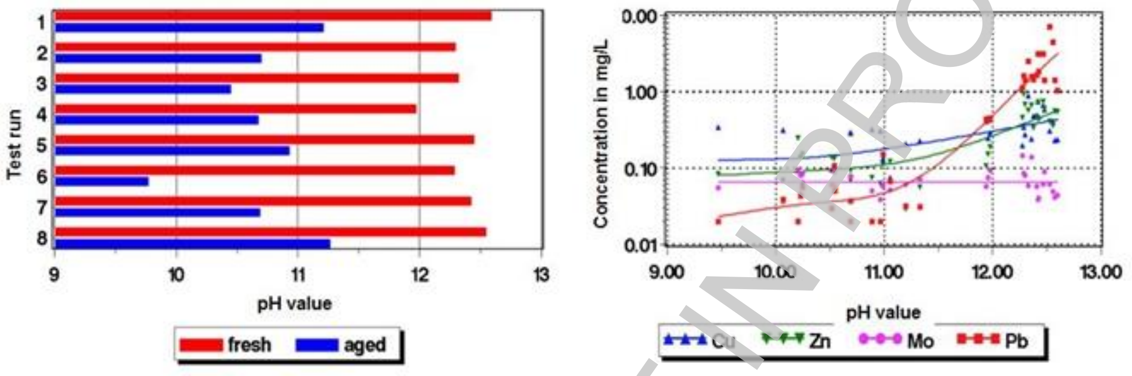
- lowering of the pH due to uptake of CO_2 from the air or the biological activity;
- establishing of anoxic, reducing conditions due to the biodegradation of residual organic matter or to hydrogen evolution;
- ~~local reducing conditions due to hydrogen evolution~~
- particle cohesion and other changes in mineral phases due to the hydration ~~causing~~.

[4, IAWG, 1997]

All these effects reduce the leachability of metals and cause the stabilisation of the bottom ash. This makes the bottom ash more suited for recovery or disposal (landfilling). [74, TWGComments, 2004]

Data from a test programme in a full-scale German waste incineration plant illustrate the effect of 12 weeks of ageing on the pH of bottom ashes and on the test results obtained by the DEV S4 method. Figure 4.13(a) shows that the pH of the fresh bottom ashes in the DEV S4 test typically exceeds 12 and drops by about two units during the ageing process.

As can be seen in Figure 4.13(b), this pH change has no effect on the leaching properties of molybdenum, which is present mainly as molybdate. The leaching stability of copper and zinc is moderately improved in the aged material whereas the leaching of lead is reduced by almost two orders of magnitude.



Source: [Vehlow, 2002 #38]

Figure 4.13: Effect of ageing on the leachability of selected metals: (left) effect on pH; (right) leaching as a function of pH

The French Bureau of Mines conducted a study over 18 months on the ageing (and its effect on leaching) of a 400-tonne stockpile of bottom ashes and reached similar conclusions to this German study. [64, TWGComments, 2003]

If longer ageing periods (e.g. > 20 weeks) are used for ferrous metal-free bottom ash without turning, the aged bottom ash will become increasingly solidified. [74, TWGComments, 2004]

Cross-media effects

- Run-off water from rain or sprinkling may contain salts or metals and will need treatment. The water can be recirculated or used in the incinerator as process water.
- Odour and dust controls may be required.
- Vehicle and machinery noise may be an issue in some locations.
- Anti-explosive devices at indoor ageing facilities may be required. [74, TWGComments, 2004]

Technical considerations relevant to applicability

Generally applicable.

~~This technique can be applied to all new and existing installations producing bottom ashes. It is mainly used in practice for MSWI. [74, TWGComments, 2004]~~

~~For some waste streams the ash content may not improve sufficiently from treatment to permit its beneficial use – in such cases the driver for use of the technique may be simply to improve disposal characteristics.~~

Economics

The cost of ageing is low compared to the rest of the treatment installation. [74, TWGComments, 2004]

Savings are made in disposal costs by recycling. [74, TWGComments, 2004]

Driving force for implementation

Legislation providing leaching limit values for recycling of bottom ash as a secondary raw material or for landfilling. [74, TWGComments, 2004]

Example plants

Various bottom ash treatment plants in the Netherlands, Germany, France and Belgium.

Reference literature

[Vehlow, 2002 #38], [4, IAWG, 1997], [64, TWGComments, 2003]

4.7.7 Bottom ash treatment using dry treatment systems

Description

Dry bottom ash treatment ~~installations~~ combines the techniques of ~~ferrous~~ metals separation, size reduction and screening, ~~non-ferrous metals separation,~~ and may be combined with ageing of the treated bottom ash. The product is a dry aggregate with a controlled grain size (e.g. 0–4 mm, 0–10 mm, 4–10 mm), which may be used as a secondary construction material.

Technical description

The process consists of: ~~the following subsequent steps~~:

- cooling ~~down the temperature of~~ the bottom ash with ~~in~~ air;
- ferrous metals separation;
- sieving;
- crushing of coarse fraction;
- sieving;
- ferrous metal separation;
- non-ferrous metal separation;
- ageing.

[74, TWGComments, 2004]

Achieved environmental benefits

The technique produces a dry aggregate ~~material~~ that may be used as a secondary construction material and scrap metal fractions that can be sold for reuse, thus reducing the amount of residue sent for disposal.

Environmental performance and operational data

Post-treatment slag quality data are shown in the tables below, for an installation using the following process steps ~~techniques~~:

- raw slag kept in dry storage for 4–6 weeks;
- preliminary sieving of particles > 150 mm;
- removal of ferrous metals from < 150 mm fraction;
- further sieve separation (< 22 mm, 22–32 mm, > 32 mm);
- < 22 mm fraction marketed as sand substitute;
- > 32 mm fraction sent to hand picking and separators to remove non-incinerable and ferrous fractions, crushing and recirculation;
- 22–32 mm fraction undergoes air separation of light fractions and ferrous metal removal;
- separated metal fractions undergo sieving, cleaning and storage before complete re-pass through the process separately from the slag.

Table 4.87: Slag output concentration data reported for an example slag treatment facility

	Output slag content (mg/kg)
As	150
Cd	10
Cr	600
Cu	600
Pb	1 000
Ni	600
Zn	1
Hg	0.01

Source: TWG Comments

Table 4.88: Slag output eluate data reported for an example slag treatment

	Output slag eluate data (ug/l)
As	-
Cd	5
Cr	200
Cu	300
Pb	50
Ni	40
Zn	300
Hg	1

Source: TWG Comments

Another example of the IBA treatment process carried out by a Danish plant is the follows:

- screening of IBA to produce two size fractions: above and below 50 mm;
- removal of ferrous metal using a magnet;
- removal of non-ferrous metal using an eddy current separator;
- the > 50 mm residue is hand-sorted and crushed;
- combustible material is returned to the incinerator as feedstock.

The plant capacity is 80 tonnes of bottom ashes per hour (equivalent to 350 tonnes of waste incinerated per hour). The plant uses diesel as an energy source, consuming 0.3 l per tonne of bottom ashes processed (equivalent to 0.05 l per tonne of waste incinerated).The plant recovers 90 wt-% of the metal present in the bottom ashes, which represent 8 wt-% of the treated bottom ash. [104, Denmark, 2015]

Cross-media effects
Dust and noise emissions.
~~The installation consumes electrical energy and may generate dust emissions and noise.~~

Technical considerations relavent to applicability
The technique is generally applicable. ~~to new and existing installations.~~

Economics
In order to be economically viable, a minimum throughput is needed (*to the TWG: do you have any figure?*). For small waste incineration plants, ~~-scale installations~~ an external (centralised) bottom ash treatment may be used.

The main benefit is derived from avoiding disposal costs; apart from that, the economy of the bottom ash treatment operation depends on the market price of the produced fractions. Treated bottom ash will generally be sold, transportation included, at zero cost. Revenue is created by the quality of the non-ferrous and ferrous metal fractions. Aluminium is the product with the highest market value. The amount and purity of the aluminium produced is an important factor in the overall economics of the installation.

Data from a MSWI plant in Sweden using various dry ash treatments and ageing

- The tax for landfilling the ash is approximately EUR 40/t.
- The stone and gravel which is separated at the earlier stages of the treatment process has a commercial value of around EUR 6/t.
- The commercial value of the treated bottom ash residue as a construction material is around EUR 2.5/t.

Data from a MSWI plant in Portugal using ferrous removal and 1–2 days storage prior to landfill

- The cost of depositing the residues in the self-owned landfill is approximately EUR 2/t. This site is geographically near the incineration plant and thus transport costs are low.
- The cost of depositing the residues in the site owned by the external company is EUR 2/t transport and EUR 9/t disposal – total EUR 11/t.

Data from a different MSWI plant in Portugal using ferrous and non-ferrous metal removal followed by 3 months stabilisation prior to final landfill

- The commercial value of the ferrous metal is around EUR 102.13/t.
- Landfill costs: EUR 28/t.
- Bottom ash transport to landfill: EUR 3/t.
- Note: trials are under way with a view to certification of the use of ash in road construction.

Driving force for implementation
Legislation on recycling of residues as secondary raw materials.

Example plants
~~Several sites in~~ Denmark, ~~the~~ Netherlands, Germany, Belgium and France.

Reference literature
[4, IAWG, 1997], [Vrancken, 2001 #39] , [64, TWGComments, 2003], [104, Denmark 2015]

4.7.8 Bottom ash treatment using wet treatment systems

Description
The use of a wet bottom ash treatment system allows the production of a material for recycling with minimal leachability of metals and anions (e.g. salts). The incineration ashes are treated by size reduction, sieving, washing and metals separation. The main feature of the treatment is the wet separation of a 0–2 mm fraction.

Technical description
Wet bottom ash treatment aims to remove metals, in order to reduce both the metal content and metal leaching. Other constituents of concern are soluble salts, mainly alkali and earth-alkali chlorides and sulphates. Approximately 50 % of the chloride content can be reduced by washing the ashes. ~~The simplest way to do this is by washing in the ash quench tank, as is already performed in some German plants.~~

~~The sulphate solubility is controlled by the solubility equilibrium of the predominant earth-alkali sulphates. Stabilisation or removal is then difficult. [Vehlow, 2002 #38]~~

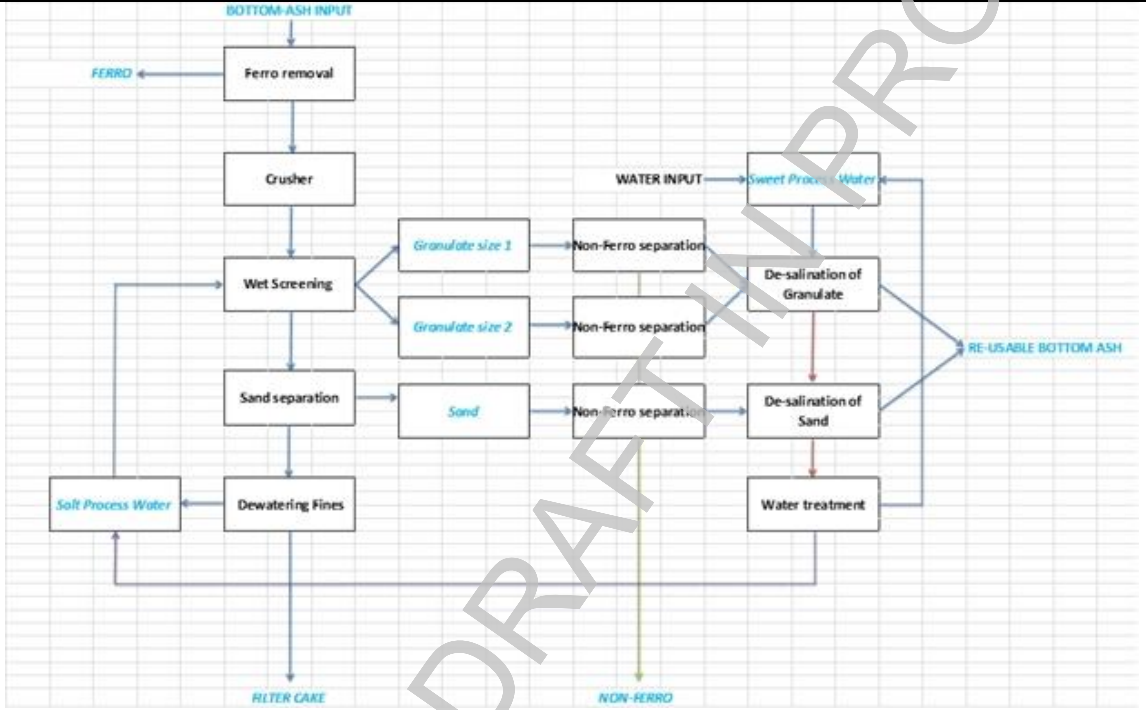
Usually the wet treatment system is made up of a dry step where the bottom ashes generated by the incineration of waste are treated to remove the large ferrous metals and dry crushed to reach the size required by the wet process.

After this first step, the IBA is washed and separated into different fractions with water using a rotating drum or a jigger. The separated lightweight part mainly formed of unburned materials, plastic and paper is usually retured to the incineration.

A granulated fraction is treated to remove the ferrous and non-ferrous metals and the remaning washed mineral part can be recovered.

The fine fraction contains most of the contaminants and is disposed of.

An example of bottom ash wet process is shown in Figure 4.14.



Source: [105 Netherlans 2016]

Figure 4.14: Flow diagram of a bottom ash wet treatment

~~As the majority of leachable components and organic compounds remain with the fine fraction, this results in a reduced leachability of the remaining product fraction (>2 mm).~~

Achieved environmental benefits

The technique produces a material that is suitable for use ~~may be used~~ and reduces the amount of residue for disposal.

Environmental performance and operational data

The relative yield of the various fractions depends on the waste input composition. Operational data from a working installation are given in Table 4.89.

Table 4.89: Relative yield of various output fractions of wet bottom ash treatment

Residue type	% ($mass_{output}/mass_{bottom\ ash\ input}$)
Residue for disposal (0–2 mm)	47
Product for reuse (2–60 mm)	34
Ferrous metals	12
Non-ferrous metals	2
Unburned back to incinerator	5
Source: [Vrancken, 2001 #39]	

Table 4.90 below shows an example of the leaching results of the produced granulates.

Table 4.90: Example of leaching results of the produced granulates

	Emission (mg/kg). L/S=10 (cumulative)	
	2–6 mm granulates	6–50 mm granulates
As	0–0.1	< 0.05
Cd	0–0.025	< 0.01
Cr	0.005–0.053	< 0.053
Cu	0.19–0.85	0.24–0.55
Pb	0.04–0.12	< 0.10
Ni	0.0007–0.005	< 0.057
Zn	0.61–1.27	< 0.16
NB: Data from column leaching test NEN7343. *Source:* [64, TWGComments, 2003] TWGComments, 2004 #74]		

Other post-treatment slag quality data are shown in Table 4.91 and Table 4.92 below for an installation using the following techniques:

- water washing of slag in incinerator slag bath at the furnace exit (water reduces salt levels in slag);
- removal of ferrous and large ~~big~~ particles by sieving and manual separation;
- storage for > 1 day for CO_2 reaction (ageing);
- further sieving, breaking, separation (e.g. > 32 mm fraction separate milling);
- ferrous and non-ferrous removal;
- > 10 mm fraction is recirculated after air separation of light (e.g. plastic) fraction;
- storage of product for 3 months.

Table 4.91: Slag output concentration (mg/kg) data reported for an example slag treatment facility

	Output slag content (mg/kg)	
	Range	Average
As	25–187	74
Cd	1.1–16.7	3.7
Cr	84–726	172
Cu	1 676–29 781	6 826
Pb	404–4 063	1 222
Ni	61–661	165
Zn	788–14 356	2 970
Hg	0.01–0.37	0.7
Source: ?		

Table 4.92: Slag output eluate (ug/l) data reported for an example slag treatment

	Output slag eluate data (ug/l)	
	Range	**Average**
As	< 6.0–16.1	5.3
Cd	< 0.5–2.5	0.8
Cr	1–113	15.2
Cu	14–262	60.7
Pb	8–59	11.4
Ni	< 4.0–11.6	2.9
Zn	< 5.0–230	19.4
Hg	< 0.2–< 0.2	< 0.2
Source: ?		

A plant in the Netherlands uses the following wet treatment process:

- Dry removal of large ferrous metal objects using magnets, screening of IBA to remove large pieces, crushing of large pieces to smaller than 20 mm, removal of small ferrous metal objects using magnets.

- Separation into different fractions with water using a rotating drum sieve. After this separation, the main fractions are IBA sand (0–4 mm) and IBA granulate (4–20 mm).

- The IBA sand fraction is pumped into hydrocyclones to separate the fine fraction (< 0.063 mm). After this separation by weight, the next treatment step is separation by density. The sand is processed in a rising water column, where fines and organic parts are separated, and collected in the same tank with the fines from the hydrocyclone separation.
  The IBA sand is dewatered on a screen then passed over an eddy current separator to remove the non-ferrous metals. It is then quenched into a dewatering screw to remove the final adherent salt water and small fines. The quench tank is fed with fresh water, with a liquid to solid ratio of at least 1 m^3 per tonne to remove all the remaining contaminants. The IBA sand is then dewatered with a dewatering screen and can be stored ready for use or combined with the IBA granulate.

- The IBA granulate fraction is treated in a log washer, where the scrubbing treatment removes the organic fraction and all the fines that stick to the surface of the mineral fraction. The fines and organic fraction are collected together with the fine fraction from the IBA sand treatment.
  The IBA granulate is dewatered to separate it from the salt water, then passed over an eddy current separator to remove the non-ferrous metals. It is then washed with fresh water in a dewatering screen to remove the last adherent salts and fines. The liquid to solid ratio of the fresh water is at least 1 m^3 per tonne. The IBA granulate is then dewatered with a dewatering screen and can be stored ready for use or combined with the IBA sand.

- The fine fraction (0–0.063 mm) (IBA sludge) consists of both organic material and very fine mineral particles and contains a high concentration of contaminants. The fine fraction is treated with flocculants and separated from the water stream in a pre-thickener. The sludge is dewatered in a belt press or a chamber filter press and sent for disposal to landfill.

Another example of a wet process, in an Austrian plant, is given below:

The initial treatment steps are: screening of IBA and/or FBA to remove large pieces (> 55 mm) and long pieces such as pipes and cables; removal of large ferrous metal objects from both fractions (> 55 mm and < 55 mm) using overhead conveyor magnets; crushing of the < 55 mm fraction is an option that can be used to increase the metal recovery rate in the subsequent wet treatment stage.

The wet treatment process uses a jigger to separate the < 55 mm IBA/FBA into four fractions of different densities:

- **Floating materials (paper, plastics and lightweight minerals):** this fraction is dewatered and either transported back to the incinerator as feedstock or landfilled.
- **Heavy fraction (metals and minerals with a density > 4 kg/dm^3):** this fraction is a mixture of different metals (copper, brass, stainless steel, zinc, tin, precious metals) and minerals. This fraction is washed, concentrated and transported to a copper smelter.
- **Light fraction (metals and minerals with a density < 4 kg/dm^3):** this fraction is a mixture of minerals (ash, stones and concrete), aluminium and traces of some other metals. This fraction is fed into a drum magnet to separate ferrous metals then an eddy current separator to remove non-ferrous metals such as aluminium and stainless steel. The aluminium concentrate can be used in an aluminium smelter or scrap treatment plants. The remaining mineral fraction can be landfilled, used as a building material in road construction or as an aggregate in concrete.
- **Sludge:** The sludge from the jigger is dewatered using a centrifuge and mixed with the mineral fraction. The further use of the dewatered material in road construction is possible.

Cross-media effects

The wet treatment can result~~s~~ in the production of a fine fraction (0–2 mm) for disposal~~ or recovery~~. ~~Depending on the applicable legislation, metal leaching of this fraction may be in excess of the limit values.~~ Additionally, a waste water fraction is produced. This waste water may be fed back into the incinerator as process water, if the quality is compatible with the process. [74, TWGComments, 2004]

Technical considerations relavent to applicability

The technique is generally applicable. ~~The technique is applicable to new and existing installations.~~

Applicability may be limited when ambient temperatures are below 5 °C unless precautions are taken to prevent the water freezing. [107 Austria 2015]

Economics

In order to be economically viable, a certain minimum throughput is needed. For small waste incineration plants, ~~scale installations~~ an external (centralised) bottom ash treatment is often used. The economy of the bottom ash treatment operation depends on the market price of the produced fractions. Treated bottom ash will generally be sold at zero cost. Revenue is created by the quality of the non-ferrous and ferrous metal fractions. Aluminium is the product with the highest market value. The amount and purity of the aluminium produced is an important factor in the overall economics of the installation.

According to the data from the Austrian plant, for a plant treating 40 t/day of bottom ash:

- the capital cost is EUR 2 million, which is EUR 5–10/tonne of ash processed in a year;
- the operating cost is EUR 5–10/tonne;
- the total cost is EUR 10–20/tonne for 1 year of operation.

Driving force for implementation

Legislation for recycling of residues as secondary raw materials.

Example plants

~~Indaver, Beveren (~~BE07~~)~~, HVC Groep, Dordrecht MWI line 5 (NL), and the Austrian plant.

Reference literature
[Vehlow, 2002 #38], [Vrancken, 2001 #39], [4, IAWG, 1997], [64, TWGComments, 2003], [105 Netherlands 2016], [107 Austria 2015]

4.7.9 Techniques to reduce emissions to air form the treatment of incineration slags and bottom ashes

Description
The techniques to consider are:

- to enclose equipment such as shredder, sieve, conveyor belts, wind shifter, air-aeraulic separator;
- to keep such equipment under negative pressure;
- to treat the extracted air with a bag filter.

Technical description
Air emissions from the IBA treatment plants are mainly dust and metals coming from bottom ash handling, shredding, sieving, and air separation. Enclosed equipment working under negative pressure is used in order to prevent emissions to air. The sucked air is sent to a bag filter. In order to reduce the bag filter dust load, in some cases a cyclone is used as a first de-dusting step.

Achieved environmental benefits

- Reduction of diffuse emissions.
- Reduction of dust emissions.

Environmental performance and operational data
Table 3.55 shows the dust emission levels of some EU plants with the techniques applied to reduce emissions to air and the emission sources.

Cross-media effects
Increase in energy use.

Technical considerations relevant to applicability
Generally applicable.

Economics
No information provided

Driving force for implementation
Environmental and health regulation requirements.

Example plants
CZ B-01, DE B-05, DE.B-10, IT.B-01, IT.B-02.

Reference literature
[81, TWG 2016]

4.7.10 Waste water

Waste water comes mainly from the wet process, washing processes, storage areas and where slags and bottom ashes are stored outside from the contaminated rainwater. Process waste water contains salts and metals as well as suspended solids and organic substances including PCDD/F.

Techniques to consider for the treatment of waste water from the IBA treatment plants are:

- Oil Separation
- Neutralisation
- Sedimentation
- Chemical Precipitation
- Filtration

These techniques are described in CWW BREF Section 3.3.2.3.

Table 3.56 summarises the levels of emissions to water reported through the data collection.

~~4.7.11 Bottom ash treatment using thermal systems~~

To the TWG: from the description, this seems more suitable for the treatment of fly ashes. Is there new information on plants in or outside the EU?

~~Description~~

~~Various techniques have been adapted from the glass manufacturing and nuclear waste treatment industries for the thermal treatment of ashes. The temperatures applied are in the range of 1100 to 2000 °C. Much higher temperatures are sometimes employed for plasma systems. Plasma systems are used for the vitrification and melting of a variety of inorganic waste streams including bottom and fly ash – temperatures used for plasma arc vitrification are generally in the range of 1400 to 1500 °C, with the power supplied electrically.~~

~~The molten products (i.e. slag and metal) may be continuously overflowed or intermittently tapped as required.~~

~~Achieved environmental benefits~~

~~This technique results in a reduced volume (reduced by 33 – 50 %), very low leaching, and extremely stable residue, that can be readily recycled as an aggregate.~~

~~PCDD/F levels in the treated ash are reduced. The following PCDD/F inputs and emissions are reported for the plasma destruction of MSW incinerator fly ash. Fly ash output arises from the baghouse used to treat process off-gas:~~

~~Ash input~~	~~50 ngTEQ/g~~
~~Slag output~~	~~<0.001 ngTEQ/g~~
~~Fly ash output~~	~~<0.005 ngTEQ/g~~
~~Flue-gas output~~	~~<0.05 ngTEQ/m^3~~

~~Cross-media effects~~

~~Very high energy consumption is reported 0.7 – 2 kWh./kg of ash treated. [IAWG, 1997 #4]~~

~~Power requirements are typically; AC submerged arc furnace 650 – 1000 kWh/t-ash; DC plasma furnace 600 – 800 kWh/t-ash.~~

~~In France, a concern is the outlet of the vitrified residue, due to lack of clear regulation. It is not permitted to use it and it must be removed for landfill. The available (permitted) outlet is based on ash origin and not its properties.~~
~~The flue-gas issued from thermal treatment of solid residues can itself emit high level of pollutants such as NO_X, TOC, SO_X, dust, heavy metals etc. Therefore flue-gas treatment is also required to remove pollutants from the ash treatment stage of gases (or to treat the flue-gas in the FGT of the nearby incinerator plant).~~

~~The process is reported to be complex and the availability may be critical.~~
~~[74, TWGComments, 2004]~~

~~Operational data~~

~~Plasma furnaces operate with power densities of 0.25 to 0.5 MW/m^2 and have melting rates of 300 kg/hr/m^2. Process footprints are usually small.~~

~~Tolerance to feedstock variation is reported. Electrode consumption with DC plasma is reported as 2kg/t ash treated. FGT is required for the process off gases.~~

~~**Applicability**~~
~~Although used in Japan, these techniques have had little penetration into other markets owing principally to their high cost, and perceived lack of benefit when existing systems already produce a product of sufficient quality.~~

~~Plasma treatment is applied to the treatment of combined incinerator and fly ashes. If the chemical residues of FGT are added increased FGT is required.~~

~~**Economics**~~
~~Compared to other techniques, external thermal treatment costs are reported to be high.~~

~~**Table 4.93: Relative costs of some ash treatment techniques**~~

~~**Treatment technique used**~~	~~**Cost (EUR/t of bottom ash)**~~	~~**Cost (EUR/t of MSW)**~~
~~Direct landfill~~	~~35~~	~~12~~
~~Pretreatment for utilisation~~	~~20~~	~~7~~
~~Fusion (fossil fuel, no pretreatment)~~	~~100~~	~~30~~
~~Fusion (fossil fuel, scrap removal)~~	~~130~~	~~45~~
~~Fusion (electric heating)~~	~~120~~	~~40~~
~~Fusion processes in Japan~~	~~100~~	~~30~~
~~*Fusion processes estimates (IAWG)*~~	~~180~~	~~60~~

~~*Source: [Vehlow, 2002 #38]*~~

~~Vitrification costs are highly sensitive to the unit cost of electricity. Treatment costs are reported to be in the range EUR 100 to 600/t of ash. Investment costs can be up to EUR 20 million for a plant of capacity 1 – 1.5 t/hr.~~

~~**Driving force for implementation**~~
~~Implemented where the leaching standards required for recycled aggregates, or for disposal in landfill, are severe.~~

~~**Example plants**~~
~~Many examples in Japan (estimated 30 – 40 plants). Some experience in Europe, e.g. France~~

~~**Reference literature**~~
~~[38, Vehlow, 2002], [4, IAWG, 1997], [64, TWGComments, 2003]~~

~~4.7.12 High temperature (slagging) rotary kiln~~

~~This technique is already described (see comments in Section 4.3.16) in relation to its combustion related impacts. The impact it has upon the solid residue produced are also noted in that section.~~

To the TWG: FGC residue treatments are covered by the WT BREF

~~4.7.13 FGT residue treatments~~

~~The following sections refer specifically to the treatment of FGT residues, and not to bottom ash treatment.~~

~~It may be noted that in some cases FGT residues are sent for controlled storage e.g. in Salt mines. The scope of this BREF document does not extend to the consideration of such storage~~

~~and it is not therefore considered any further. It is however noted that such an option is available and permitted in some members states.~~

~~4.7.13.1 Cement solidification of FGT residues~~

~~Description~~
~~Generally the residues are mixed with mineral or hydraulic binders (e.g. cement, coal fly ash, etc.), additives to control the properties of the cement (generally, to lower the Pb leachability, silica based reagents are used, and to lower other metals, sulphide based reagents are used), and enough water to ensure that hydration reactions will take place for binding of the cement. The residues are thereby incorporated in the cement matrix. Typically, the residues will react with water and the cement to form metal hydroxides or carbonates which are usually less soluble than the original metal compounds in the residue matrix.~~

~~Cement-based solidification techniques rely on equipment that is readily available. The mixing and handling associated with the processes are well developed and the technique is robust with respect to variations in residue characteristics.~~

~~The solidified product is generally either landfilled in surface level or underground facilities, or utilised as backfilling material in old salt mines. Note that, in some cases mine deposition is prohibited by locally applicable legislation, in other cases it is carried out by direct filling of untreated residues that are packed into suitable containers (e.g. in big bags).~~
~~[64, TWGComments, 2003]~~

~~Achieved environmental benefits~~
~~The main advantage of cement solidification is the reduced contact between water and the residue and to some extent the possible formation of less soluble metal hydroxides or carbonates. The solidified product is relatively easy to handle, and the risk of dusting is very low. The release of heavy metals from the products in a short-term perspective is typically relatively low, however, the high pH of cement-based systems can result in significant leaching of amphoteric metals (Pb and Zn).~~

~~The drawbacks of this method are that leaching of soluble salts is not hampered and that this will eventually result in physical disintegration of the solidified product, thus allowing further leaching.~~

~~The addition of cement and additives increases the amount of waste to be handled; typically about 50 % of the residue dry weight is added as cement and additives and 30 to 100 % of the total dry weight is added as water [4, IAWG, 1997]. Thus, the residue output from fly ash is typically increased from 20 - 30 kg/t waste input to about 40 - 60 kg/t waste, including addition of water corresponding to 50 % of the total dry weight.~~

~~Cross-media effects~~
~~The technique does in some cases facilitate utilisation of the residues as backfilling or construction material in the mining industry.~~

~~The use of this technique implies consumption of cement, additives and water.~~

~~Operational data~~
~~Energy and water consumption varies and is not quantified. The operation and control of equipment used by the technique is considered relatively simple and comparable with standard practices in concrete industry.~~

~~Applicability~~
~~Solidification is typically performed at dedicated plants located near the end-destination of the product; thus, individual incinerators have no need to install solidification equipment. The~~

~~technique can be used on all types of FGT residues. Solidification with cement has also been used on many other types of hazardous wastes, including for the disposal of low-level radioactive waste.~~

~~Economics~~

~~In most cases, the residues can be delivered to existing plants. Treatment costs for cement solidification alone may vary a lot according to the country, and they are estimated to be about EUR 25 per tonne residue [38, Vehlow, 2002].~~

~~Driving force for implementation~~

~~The technique is relatively simple and the necessary technical knowledge is readily available. Also, the leaching characteristics of the solidified product are improved considerably compared to the untreated residues. Stabilisation of FGT residues by cement solidification has also been used and is considered acceptable by authorities in many countries worldwide.~~

~~Example plants~~

~~The technique is probably the most common method for the treatment of FGT residues and is widely used in Europe and Japan.~~

~~The main types of cement solidification are listed below:~~

~~Table 4.94: Variations in solidification treatments for FGT residues between some countries~~

~~**Country**~~	~~**Characteristics**~~
~~Germany~~	~~Several salt mining companies in Germany accept FGT residues and perform cement solidification on these by using residues as filler material. The solidified residues are chiefly utilised as backfilling material or for reinforcement. Cement solidification is, for some of the mines, performed at one central plant using varying recipes according to final destination and requests. From the central solidification plant, the product is transported to the recipient mine.~~ ~~(Normally the residues are transported to the mines where they are used as filling material for the concrete production needed for the mine.)~~
~~Switzerland~~	~~A variation of cement solidification is used in Switzerland where residues are washed with water and dewatered prior to mixing with cement. This has the benefit of removing most of the soluble salts from the residues thus improving the longevity of the solidified product. After solidification, the residues are deposited at surface level landfills before hardening. In some plants, the mixture is cast into moulds to produce blocks, that are transported to surface landfills.~~
~~Sweden~~	~~At one landfill site in Sweden (Hogdalan) cement solidified FGT residues are cast into blocks and placed at a surface level landfill after hardening.~~
~~France~~	~~Since 1992, FGT residues and fly ash from dust removal treatments have been solidified/stabilised using mineral and hydraulic binders (e.g. cement, coal fly ash, etc.) and additives before landfilling. In 2001, 90 % of the 353 kt of these residues produced were concerned and were treated in 12 plants located in 12 of the 14 French surface level landfills for hazardous waste. Since 2001, two new solidification/stabilisation plants have been created increasing the treatment capacity approximately from 600 kt/yr to 700 kt/yr. No solidified/stabilized wastes are landfilled in mines. In August 2002, a new treatment was industrially implemented: with a capacity of 50 kt/yr, which works on the dry sodium bicarbonate FGT residues to purify them and recycle them in a soda ash plant; see full description at section 4.7.13.5. [74, TWGComments, 2004]~~
~~Source: [48, ISWA, 2003], [64, TWGComments, 2003]~~	

~~4.7.13.2 Vitrification and melting of FGT residues~~

~~Description~~

~~Vitrification and melting result in mobilisation of volatile elements such as Hg, Pb and Zn during the treatment process; this, in some processes, is used in combination with other parameters to produce a recyclable product low in heavy metals.~~

~~The techniques employed for vitrification and melting of residues are similar in many respects. The main difference is mainly the cooling process, and also, but less important, the use of specific additives to favour glassy or crystalline matrix.~~

~~Several techniques for heating the residues are used: electrical melting systems, fuel fired burner systems and blast melting. They differ in the way energy is transferred and by the oxidation or reduction state during operation and the quantities of off-gas produced.~~

~~Generally, techniques are inspired from furnaces used in iron and steel production. In all systems, the residues are fed into a reaction chamber usually by a charger system. The melting process can be operated in such a way that a continuous cooler layer at the top of the smelter is maintained in order to confine the smelting process, or the entire residue amount in the reaction chamber can be in a molten state.~~
~~Depending of the melting system, metal alloys can be recovered from the reaction chamber. Zinc (Zn) and lead (Pb) can be recovered. Depending on the temperatures in the reaction chamber and the state of oxidation or reduction of the gas phase, heavy metals (especially Cd and Pb) will be volatilised and removed by the off-gas. All process configurations need off-gas treatment systems to reduce emissions.~~

~~Working in oxidising conditions avoids the separation of phases and the formation of metal droplets in the melt, whereas reducing conditions enhance phase separation and metal segregation and volatilisation.~~

~~For burner driven processes, the process conditions are mostly neutral but the off-gas volumes are huge. Consequently the off-gas or fume treatment equipment has to be oversized.~~

~~For electric driven processes, i.e. resistor heating, electric arc or transferred arc plasma torches, the process conditions are reducing. The fume volume is small but this can be problematic too, because the concentration of metals and other volatilised substances in the off-gas is very high and condensation may occur in the fume duct. Often carrier gas is introduced to avoid this phenomenon.~~

~~With plasma torches (i.e. non transferred arc plasma torches) the process conditions are strongly oxidising. The fumes volume is medium, no carrier gas is needed, and the size of fume treatment equipments remains reasonable.~~

~~Achieved environmental benefits~~
~~Melted and vitrified products generally have very good leaching properties. Swiss studies where vitrified, vitro-crystalline and so-called sintered products were tested, have shown that sintered products also tend to reach the same level of stability with regard to leaching. Vitrification typically yields the most stable and dense products. Generally, organic compounds such as dioxins are destroyed in the process.~~

~~An inherent advantage of these processes is the destruction of organic pollutants such as dioxins. Due to the release of vaporised heavy metals from the process, thermal treatment requires an additional flue-gas treatment system, which can take place on the same FGT facilities of the MSW incineration plant.~~

~~A major drawback to these methods, is that they require substantial amounts of energy and may, therefore be costly. There may also be a problem of a market outlet for these treated residues.~~

~~Cross-media effects~~
~~Vitrification and melting result in mobilisation of volatile elements such as Hg, Pb and Zn during the treatment process.~~

~~Thermal treatment processes use very substantial amounts of energy. Additionally, the processes produce solid residues from off-gas treatment. The flue-gas issued from thermal treatment of solid residues emit pollutants such as NO_X, TOC, SO_X, dust, heavy metals etc. and flue-gas treatment is required to remove those pollutants (or treat the flue-gas in the FGT of the nearby incinerator plant when possible).~~

~~There may also be a problem of a market outlet for the treated residues. These residues have a limited use in comparison with granulates coming from cold bottom ash treatment installations; the reason for this being the physical constitution which does not allow great stability in building/construction applications.~~

~~Operational data~~

~~Typically, approx. 700 - 1200 kWh/t is used of treated residue to reach and maintain the elevated temperatures, but up to approx. 8000 kWh/t has been reported (Ecke et al., 2000). Energy consumption and operation varies with furnace type and plant design.~~

~~Usually, the residue input must comply with certain quality requirements, for example: water content <5 %, unburned contents <3 %, metal content <20 % by weight, and ash size <100 mm (Kinto, 1996). Thermal treatment facilities in general reduce residue volume to about one fifth of the input volume (TWGComments 2003). Melting increases the density of the products to typically 2.4 - 2.9 t/m³.~~

~~It is reported that these processes may be complex and the availability critical.~~

~~Applicability of the technique~~

~~Thermal treatment is widely used, mostly in Japan and the US, for treatment of bottom ashes as well as combinations of bottom ash and FGT residues. Due to high contents of salts and heavy metals in the FGT residues, separate treatment of FGT residues can cause need for extensive off-gas treatment, thus, reducing the overall benefits of separately treating these residues.~~

~~Economics~~

~~Typically, the technique is expensive compared to other treatment options. Treatment costs are reported to be in the order of EUR 100 - 600/t of residue [4, IAWG, 1997, 38, Vehlow, 2002], Ecke et al., 2001. Investment costs can be about EUR 10 - 20 million for a plant with a capacity of 1 – 2 t/hr.~~

~~Driving force for implementation~~

~~The main reason for implementing the technique is good leaching properties of the final product, transforming the toxic residue into an inert product, especially for vitrifying; and the significant reduction in volume.~~

~~In densely populated areas, such as Japan, landfill capacity can be a scarce resource and landfilling, thus, relatively costly. Organic compounds, such as dioxins and furans (with municipal waste, 90 % or more of the dioxins and furans produced during incineration, are concentrated in the FGT residues and fly ashes) are almost completely destroyed and the inorganic compounds (i.e. heavy metals) are closely bonded at the atomic scale, in an durable matrix with a very long lifetime.~~

~~Example plants~~

~~Thermal treatment including melting and vitrification is mostly used in Japan where it is estimated that about 30 - 40 plants are operated, however examples in the US and Europe can also be found [4, IAWG, 1997]~~

~~Table 4.95: FGT vitrification processes used in the US and Japan~~

~~Country~~	~~Characteristics~~
~~US~~	~~A vitrification process proposed by Corning, Inc. [4, IAWG, 1997] includes initial steps of water extraction, dewatering and drying at 500 °C before addition of glass forming additives and melting. The initial washing and drying was done to remove chlorides and residual organic carbon.~~

~~Japan~~	~~According to Ecke et al. (2000) and Sakai and Hiraoka (1997) plants for thermal treatment of both bottom ash and FGT residues included:~~			
		~~In operation~~	~~Planned~~	~~Capacity (tonne/day)~~
	~~Electric melting:~~			
	~~Electric arc~~	~~4~~	~~2~~	~~655~~
	~~Plasma arc~~	~~4~~	~~2~~	~~183~~
	~~Electric Resistance~~	~~2~~	~~3~~	~~148~~
	~~Burner:~~			
	~~Reflecting surface~~	~~12~~		~~209~~
	~~Rotating surface~~	~~5~~		~~84~~
	~~Blast melting:~~			
	~~Coke bed~~	~~3~~		~~170~~
	~~Residual carbon combustion~~	~~1~~		~~15~~
	~~Total~~	~~31~~	~~7~~	~~1464~~
~~Source:~~ ~~[48, ISWA, 2003]~~				

~~A 0.5 MW plasma melting process treating both fly ash and bottom ash has been operational in Cenon, near Bordeaux, France, since 1997. It is reported that this plant does not treat bottom ash but only fly ash from the electrostatic precipitator. In addition, the boiler ash cannot be treated because of the sulphur and halogen content.~~

~~Reference literature~~
~~[64, TWGComments, 2003], [48, ISWA, 2003]~~

~~4.7.13.3 Acid extraction of boiler and fly ash~~

~~Description~~
~~Boiler and fly ash are treated with the acidic effluent from the first (acidic) stage of a wet scrubber. The treated residues are then washed and normally remixed with bottom ash prior to landfill disposal. [64, TWGComments, 2003]~~

~~This process, known as the FLUWA process, combines an acid extraction of soluble heavy metals and salts by using the (acidic) scrubber blowdown. Before using the scrubber liquid, mercury is removed by either a filtration (when activated carbon is introduced into the scrubber) and/or a specific ion exchanger. Both boiler ash and fly ash are treated this way. The L/S ratio in the extraction step is approx. 4; pH is controlled at 3.5 by the addition of hydrated lime. Within the residence time of approx. 45 minutes, sulphate (from the~~ ~~SO_2~~ ~~scrubber) is precipitated to gypsum. The residue is dewatered, then countercurrent washed on a belt filter and finally landfilled, normally as a mixture with bottom ash.~~

~~The filtrate has to be treated in order to remove the heavy metals by neutralisation, precipitation and ion exchange. The dewatered and rinsed filter cake contains about 25 % zinc and is, therefore, recycled in metallurgical processes.~~

~~Achieved environmental benefits~~
~~The process removes a significant part of the total amount of heavy metals from the residues (Cd: ≥85 %; Zn: ≥85 %; Pb, Cu: ≥33 %; Hg: ≥95 %). The leachability of the residue is reduced by a factor~~ ~~10^2 – 10^3~~~~. Zinc, cadmium and mercury are recycled. Ecotoxicity tests (MICROTOX, Ceriodaphnia, Algae growth, mortality of worms & lettuce germination) are reported to be positive. [74, TWGComments, 2004]~~

~~Cross-media effects~~
~~The dioxin content of the bottom ash increases when the treated ash is disposed combined with bottom ash; however, the leaching properties of the mixture are even better because of the higher density.~~

~~Salt and metals from the FGT residues are transferred to a waste water stream, that may then require treatment before discharge.~~

~~Operational data~~
~~Start-up of the first plant was 1996. Most of the plants operate 24 hr/d and adapt the weekly operational period (4 – 7 days) according to the arising FGT residues.~~

~~Applicability of the technique~~
~~The system can be used only on incinerators with a wet FGT system that can discharge the treated waste water.~~

~~Economics~~
~~Process costs of treating the FGT residues: about EUR 150 – 250/t (including charges for recycling the zinc filter cake, equivalent to EUR 10 - EUR 13/ t of waste). [74, TWGComments, 2004]~~

~~Driving force of implementation~~
~~The technique provides a method to treat residues according to the Swiss legislation, and at a competitive price to the main alternative option, which is to export to German mines.~~

~~Example plants~~

~~Table 4.96: Examples of plants using the acid extraction process for FGT residue treatment~~

~~Plant (all MSW)~~	~~Country~~	~~Start-up year~~
~~Berne~~	~~Switzerland~~	~~1996~~
~~Buchs SG~~	~~Switzerland~~	~~1997~~
~~Emmenspitz~~	~~Switzerland~~	~~1998~~
~~Liberec~~	~~Czech Republic~~	~~1999~~
~~Niederurnen~~	~~Switzerland~~	~~2001~~
~~Thun~~	~~Switzerland~~	~~2003~~
~~Lausanne~~	~~Switzerland~~	~~2005~~
~~*Source:* ([ISWA, 2003 #48]~~		

~~A number of other more or less similar techniques also make use of acid extraction.~~

~~Table 4.97: Characteristics of some acid extraction processes used for FGT residue treatment~~

~~Process~~	~~Characteristics~~
~~MR~~	~~The MR-process, (Stubenvoll, 1989) similar to the 3R-process, combines acid extraction with thermal treatment. First boiler and fly ash is washed with the first stage wet scrubber solution and dewatered. Then the residues are treated in a rotary kiln for one hour at approx. 600 °C destroying dioxins and volatilise Hg. The off-gas is treated in an activated coal filter. The waste water is treated to remove heavy metals. The scrubber solution from the second scrubber is used to wash bottom ash and neutralise acidic effluent streams [4, IAWG, 1997].~~
~~AES~~	~~The Acid Extraction Sulphide process (AES) combines fly ash and NaOH-scrubber solution with water at L/S 5. After mixing, the pH is adjusted to about 6 – 8 with HCl to extract heavy metals, and NaHS is added to bind heavy metals as sulphides. Then a coagulation agent is added and the slurry is dewatered. The filter cake is landfilled, and the waste water is treated in a subsequent treatment unit to remove heavy metals ([4, IAWG, 1997]; Inoue and Kawabata, 1997).~~
~~3 R Process~~	~~The 3R process (Vehlow et. al. 1990) is similar to the FLUWA process by using acid scrubber solution to extract heavy metals followed by a dewatering step. However, the solids are returned to the combustion chamber. Similar to the FLUWA-process, the produced waste water requires treatment.~~
~~*Source:* [48, ISWA, 2003]~~	

~~Reference literature~~
~~[48, ISWA, 2003, 64, TWGComments, 2003]~~

~~4.7.13.4 Treatment of FGT residues arising from dry sodium bicarbonate FGT process for use in the soda ash industry~~

~~Description~~
~~The FGT residues from dry sodium bicarbonate FGT are stored in silos pending treatment. The residues are then dissolved with a controlled pH and with certain additives. The suspension formed is passed through a filter press which separates out the insoluble: heavy metal hydroxides, activated carbon and fly ashes. In this way, a raw brine and a filtration cake are obtained.~~
~~The raw brine then passes through a sand filter and into a column of activated carbon which absorbs any organic compounds which may be present. The final traces of heavy metals are eliminated in two ion-exchange resin columns in order to achieve a grade of NaCl brine of a quality that may be used in an industrial soda ash process.~~

~~The filtration cake, which is the only remaining waste, is landfilled. The total amount is no more than 2 to 4 kg per tonne of incinerated MSW.~~

~~The purified brine and the filtration cake are the only end-products. The washing water, the resin regeneration reagents, etc. are fully recycled in the dissolution process, so the plant does not produce any aqueous waste.~~

~~Achieved environmental benefits~~
~~Treatment of the residues reduces the final quantity requiring landfill.~~

~~The brine produced may be used in an industrial soda ash process.~~

~~Cross-media effects~~
~~The process requires additional energy and raw material consumption.~~

~~Care is required to ensure pollutants captured in the FGT residues are not remobilised for release to the environment.~~

~~The technique generates a small amount of residue which may then help to reduce transport requirements. [74, TWGComments, 2004]~~

~~Operational data~~
~~The plant is managed according to a quality management system, which assures, among others, the raw materials control on one side, and the purified brine control on the other.~~

~~On arrival at the plant, the sodium based FGT residues are analysed to check that their composition matches the acceptance specifications.~~

~~The purified brine produced by the installation is regularly analysed for conformity with specifications before being sent to the soda ash production unit.~~

~~Applicability~~
~~Only applicable to the residues arising from the dry sodium bicarbonate FGT system.~~

~~Economics~~
~~The technique is patented.~~

~~When compared to the solidification and landfilling of FGT residues:~~
~~(1) the solidification is eased by the separation of the soluble fraction, and~~

~~(2) the quantity of ultimate residues is reduced.~~

~~The process is competitive with alternatives in some countries.~~

~~Operational costs are reported to be low and investment costs of the treatment plant are the key factor – to minimise this, the process may be implemented in centralized units serving numerous incineration plants. [74, TWGComments, 2004]~~

~~Driving force for implementation~~
~~High disposal costs for FGT treatment residues are an important driver for the use of the process.~~

~~Example plants~~
~~The industrial pilot plant was designed to demonstrate the feasibility of the purification and recycling process, at a mid scale. Its design capacity was, therefore, of 350 kg residues/h, or 2800 tonnes/yr. Practically, after some extension works, the platform now has a permit for the processing of 13000 t/yr. It is the main service provider for various Italian incineration plants.~~

~~Reference literature~~
~~[59, CEFIC, 2002, 64, TWGComments, 2003, 73, Rijpkema, 2000]~~

~~4.7.13.5 Treatment of FGT residues arising from dry sodium bicarbonate FGT process using hydraulic binders~~

~~Description~~
~~The FGT residues from dry sodium bicarbonate FGT are stored in silos pending treatment. Then the residues are mixed with hydraulic binders, and then placed in an aqueous solution with certain additives. The suspension formed in this way passes through a filter press which separates out the insolubles (containing in particular most of the heavy metals). The resulting products are brine and a filter cake.~~

~~The brine is then further purified so that it may be re-used in the manufacture of sodium carbonate (soda ash).~~

~~The filtration cake containing hydraulic binders solidifies into an inert matter (according to French standards) which is appropriate for tipping on an adequate landfill site.~~

~~The process does not produce any liquid waste: the only outgoing flows are the recyclable brine and the filtration cake.~~

~~Achieved environmental benefits~~
~~The purified salts are recycled in a closely located soda ash plant, in the form of brine, replacing part of the salt supply to this soda ash plant.~~

~~The ultimate residues are already stabilised and solidified when they go out of the plant, and they are transported to a licensed landfill for storage.~~

~~Cross-media effects~~

~~The technique generates a small amount of residue. Transport can limit the use of this technique as it depends on the distance between the incinerator and the residue treatment unit. Moreover to recover the brine the unit of production of bicarbonate should also be located nearby to minimise transport impacts. [74, TWGComments, 2004]~~

~~Operational data~~

~~The plant is managed according to a quality management system, which assures, among others, the raw materials control on one side, and the purified brine control on the other.~~

~~On arrival at the plant, the residues are analysed to check that their composition matches the acceptance specifications.~~

~~The purified brine produced by the installation is regularly analysed for conformity with specifications before being sent to the soda ash production unit.~~

~~**Applicability**~~
~~Only applicable to the residues arising from the dry sodium bicarbonate FGT system.~~

~~**Economics**~~
~~This technology is patented.~~

~~When compared to the solidification and landfilling of FGT residues:~~
~~(1) the solidification is eased by the separation of the soluble fraction, and~~
~~(2) the quantity of ultimate residues is reduced.~~

~~The process is competitive with alternatives in some countries.~~

~~Operational costs are reported to be low and investment costs of the treatment plant are the key factor – to minimise this, the process may be implemented in centralized units serving numerous incineration plants. [74, TWGComments, 2004]~~

~~**Driving force for implementation**~~
~~High disposal costs for FGT treatment residues are an important driver for the use of the process.~~

~~**Example plants**~~
~~This plant is based in France and has a capacity of 50 kt/yr of flue-gas cleaning residues.~~

~~**Reference literature**~~
~~[59, CEFIC, 2002, 64, TWGComments, 2003, 73, Rijpkema, 2000]~~

4.8 Noise

The noise aspects of waste incineration are comparable with other ~~heavy~~ industries and with power generation plants. It is common for municipal waste incineration plants to be installed in completely closed buildings. This normally includes reception and unloading of waste, mechanical pretreatment, flue-gas treatment, treatment of residues, etc. ~~generally with~~ The only activities that are normally located outside the building are the ~~Only~~ cooling facilities and the long-term ~~time~~ storage of bottom ash. ~~are normally located in the open air.~~

The most important sources of external noise are:

- trucks for the transport of waste, chemicals and residues;
- crane operations in the bunker;
- mechanical pretreatment of waste;
- exhaust fans, extracting flue-gases from the incineration process and resulting in noise from the outlet of the stack;
- noise related to the cooling system (for evaporation cooling and especially for air cooling);
- noise related to transport and treatment of bottom ash (if on the same site);
- noise from the turbine generator set.
  [74, TWGComments, 2004]

~~Other installation parts~~ The other activities do not ~~are~~ usually produce ~~not~~ significant ~~for~~ external noise ~~production~~ but may contribute to the ~~a~~ general external noise produced by the installation. ~~production by the plant buildings.~~

~~The areas of incineration installations that are~~ The main sources of noise, the noise levels they give rise to and some specific noise abatement techniques are given in
Table 3.75.

The degree of noise protection and measures taken are often very specific to the location and risk of impacts.

~~4.9 Good practice for public awareness and communication~~

~~Public acceptance of incineration plants varies greatly from one location to another. Developers sometimes encounter significant public opposition to new sites. Provision of information to the local population is important. This is true of during plant operational, as well as for newly developing sites.~~

~~The following techniques have been used:~~

- ~~placing advertisements in local newspapers~~
- ~~leaflet distribution to households~~
- ~~displays in public areas e.g. libraries and local administration offices~~
- ~~public meetings~~
- ~~focus group discussions~~
- ~~guided tours across the plant with a brief description via film or other presentation.~~
  ~~[74, TWGComments, 2004]~~

~~Operational plants have achieved success in this area by:~~

- ~~holding regular meetings with local representatives~~
- ~~holding open days for public visits~~
- ~~placing real time emissions data on the internet~~
- ~~displaying real time emissions data on display panels at the site entrance.~~

5 BEST AVAILABLE TECHNIQUES (BAT) CONCLUSIONS

Scope

These BAT conclusions concern the following activities specified in Annex I to Directive 2010/75/EU:

5.2 Disposal or recovery of waste in waste incineration plants:
  (a) for non-hazardous waste with a capacity exceeding 3 tonnes per hour;
  (b) for hazardous waste with a capacity exceeding 10 tonnes per day.

5.2 Disposal or recovery of waste in waste co-incineration plants:
  (a) for non-hazardous waste with a capacity exceeding 3 tonnes per hour;
  (b) for hazardous waste with a capacity exceeding 10 tonnes per day;
whose main purpose is not the production of material products and:

- which combust only waste, other than waste defined in Article 3(31)(b) of Directive 2010/75/EU; or
- where more than 40 % of the resulting heat release comes from hazardous waste; or
- which combust mixed municipal waste.

5.3 (a) Disposal of non-hazardous waste with a capacity exceeding 50 tonnes per day involving the treatment of slags and/or bottom ashes from the incineration of waste.

5.3 (b) Recovery, or a mix of recovery and disposal, of non-hazardous waste with a capacity exceeding 75 tonnes per day involving the treatment of slags and/or bottom ashes from the incineration of waste.

These BAT conclusions do not address the following:

- Pre-treatment of waste prior to incineration; this may be covered by the BAT conclusions for Waste Treatment (WT).
- Treatment of incineration fly ashes and other residues resulting from flue-gas cleaning (FGC). These may be covered by the BAT conclusions for Waste Treatment (WT).
- Incineration or co-incineration of exclusively gaseous waste.
- Treatment of waste in plants covered by Article 42(2) of Directive 2010/75/EU.

Other BAT conclusions and reference documents which could be relevant for the activities covered by these BAT conclusions are the following:

- Waste Treatment (WT);
- Economics and Cross-Media Effects (ECM);
- Emissions from Storage (EFS);
- Energy Efficiency (ENE);
- Industrial Cooling Systems (ICS);
- Monitoring of Emissions to Air and Water from IED installations (ROM);
- Large Combustion Plants (LCP).

Definitions

For the purposes of these BAT conclusions, the following general **definitions** apply:

Term	**Definition**
	General terms
Bottom ash treatment plant	Plant treating slags and/or bottom ashes from the incineration of waste in order to separate and recover the valuable fraction and to allow the beneficial use of the remaining fraction
Clinical waste	Infectious or otherwise hazardous waste arising from healthcare institutions (e.g. hospitals)
Existing plant	A plant that is not a new plant
Fly ash	Particles from the incineration chamber or formed within the flue-gas stream that are transported in the flue-gas
Gross electrical efficiency	Ratio between the gross electrical output of the turbine and the waste/fuel energy input expressed as the lower heating value
Gross heat efficiency	Ratio between the gross heat output and the waste/fuel energy input. The energy input is expressed as the lower heating value; the gross heat output is expressed as the sum of: • the generated electricity output of the turbine • for direct export of steam and/or hot water, the exported thermal power less the thermal power of the return flow • the thermal power to primary heat exchangers
Hazardous waste	Hazardous waste as defined in Article 3(2) of Directive 2008/98/EC
Incineration plant	Either a waste incineration plant as defined in Article 3(40) of Directive 2010/75/EU, or a waste co-incineration plant as defined in Article 3(41) of Directive 2010/75/EU, covered by the scope of these BAT conclusions
Major plant upgrade	A major change in the design or technology of a plant with major adjustments or replacements of the process and/or abatement technique(s) and associated equipment
Municipal solid waste	Solid waste from households (mixed or separately collected) as well as solid waste from other sources that is comparable to household waste in nature and composition
New plant	A plant first permitted following the publication of these BAT conclusions or a complete replacement of a plant on the existing foundations following the publication of these BAT conclusions
Other non-hazardous waste	Non-hazardous waste that is neither municipal solid waste nor sewage sludge
Residues	Substances or objects generated by the activities covered by the scope of this document, as waste or by-products
Sewage sludge	Residual sludge from the storage, handling and treatment of domestic, urban or industrial waste water, except if this residual sludge constitutes hazardous waste
Slags and/or bottom ashes	Solid residues removed from the furnace once wastes have been incinerated

Term	Definition
Pollutants and parameters	
As	The sum of arsenic and its compounds, expressed as As
Cd	The sum of cadmium and its compounds, expressed as Cd
Cd+Tl	The sum of cadmium, thallium and their compounds, expressed as Cd+Tl
CO	Carbon monoxide
Cr	The sum of chromium and its compounds, expressed as Cr
Cu	The sum of copper and its compounds, expressed as Cu
Dust	Total particulate matter (in air)
HCl	All inorganic gaseous chlorine compounds, expressed as HCl
HF	All inorganic gaseous fluorine compounds, expressed as HF
Hg	The sum of mercury and its compounds, expressed as Hg
N_2O	Dinitrogen monoxide (nitrous oxide)
NH_3	Ammonia
NH_4-N	Ammonium nitrogen, expressed as N, includes free ammonia (NH_3) and ammonium ($NH4^+$)
Ni	The sum of nickel and its compounds, expressed as Ni
NO_X	The sum of nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2
PAHs	Polycyclic aromatic hydrocarbons
Pb	The sum of lead and its compounds, expressed as Pb
PCBs	Polychlorinated biphenyls
PCDD/F	Polychlorinated dibenzo-*p*-dioxins and -furans
POPs	Persistent Organic Pollutants as defined in Regulation (EC) No 850/2004 of the European Parliament and of the Council and amended by Commission Regulation (EU) No 756/2010
Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V	The sum of antimony, arsenic, lead, chromium, cobalt, copper, manganese, nickel, vanadium and their compounds, expressed as Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V
SO_2	Sulphur dioxide
SO_4^{2-}	Dissolved sulphate, expressed as SO_4^{2-}
TOC	Total organic carbon, expressed as C (in water)
TSS	Total suspended solids. Mass concentration of all suspended solids (in water), measured via filtration through glass fibre filters and gravimetry
Tl	The sum of thallium and its compounds, expressed as Tl
TVOC	Total volatile organic carbon, expressed as C (in air)
Zn	The sum of zinc and its compounds, expressed as Zn

Acronyms

For the purposes of these BAT conclusions, the following **acronyms** apply:

Acronym	**Definition**
EMS	Environmental management system
FGC	Flue-gas cleaning
OTNOC	Other than normal operating conditions
SCR	Selective catalytic reduction
SNCR	Selective non-catalytic reduction

General considerations

Best Available Techniques

The techniques listed and described in these BAT conclusions are neither prescriptive nor exhaustive. Other techniques may be used that ensure at least an equivalent level of environmental protection.

Unless otherwise stated, these BAT conclusions are generally applicable.

Emission levels associated with the best available techniques (BAT-AELs) for emissions to air

Emission levels associated with the best available techniques (BAT-AELs) for emissions to air given in these BAT conclusions refer to concentrations, expressed as mass of emitted substances per volume of flue-gas under the following standard conditions: dry gas at a temperature of 273.15 K and a pressure of 101.3 kPa, and expressed in the units mg/Nm^3, µg/Nm^3, ng I-TEQ/Nm^3 or ng WHO-TEQ/Nm^3.

The reference oxygen levels used to express BAT-AELs in this document are shown in the table below.

Activity	Reference oxygen level (OR)
Incineration	11 vol-%
Bottom ash treatment	No correction for the oxygen level

The equation for calculating the emission concentration at the reference oxygen level is:

$$E_R = \frac{21 - O_R}{21 - O_M} \times E_M$$

Where:

E_R: emission concentration at the reference oxygen level O_R;
O_R: reference oxygen level in vol-%;
E_M: measured emission concentration;
O_M: measured oxygen level in vol-%.

For averaging periods, the following **definitions** apply:

Averaging period	Definition
Half-hourly average	Average value over a period of 30 minutes of continuous measurement
Daily average	Average over a period of 24 hours of valid half-hourly averages obtained by continuous measurement
Average over the sampling period	Average value of three consecutive measurements of at least 30 minutes each (^{1})
Long-term sampling average	Average value over a sampling period of 2 to 4 weeks

(^{1}) For any parameter where, due to sampling or analytical limitations, a 30-minute measurement is inappropriate, a more suitable sampling period may be employed. For PCDD/F and dioxin-like PCBs, one sampling period of 6 to 8 hours is used in the case of short-term sampling.

When waste is co-incinerated together with non-waste fuels, the BAT-AELs for emissions to air given in these BAT conclusions apply to the entire flue-gas volume generated.

Emission levels associated with the best available techniques (BAT-AELs) for emissions to water

Emission levels associated with the best available techniques (BAT-AELs) for emissions to water given in these BAT conclusions refer to concentrations (mass of emitted substances per volume of waste water), expressed in the units mg/l or ng I-TEQ/l. The BAT-AELs refer to daily averages, i.e. 24-hour flow-proportional composite samples. Time-proportional composite sampling can be used provided that sufficient flow stability is demonstrated.

The BAT-AELs for emissions to water apply at the point where the emission leaves the installation.

Energy efficiency levels associated with the best available techniques (BAT-AEELs)

An energy efficiency level associated with the best available techniques (BAT-AEEL) refers to the ratio between the plant´s gross energy output(s) and the energy input into the thermal treatment unit(s), including waste and other fuels, at actual plant design and for the plant operated at full load.

BAT-AEELs are expressed as a percentage. The waste/fuel energy input is expressed as lower heating value.

Destruction efficiency

The equation for calculating the destruction efficiency (DE) of POPs contained in the waste is:

$$\boxed{DE = 1 - \frac{POP_{slag} + POP_{fash} + POP_{water} + POP_{fgas}}{POP_{waste}}}$$

Where:

- POP_{waste} is the mass of POPs in the waste prior to incineration;
- POP_{slag} is the mass of POPs remaining in the incineration slag/bottom ash;
- POP_{fash} is the mass of POPs ending up in the fly ashes and in dry FGC residues;
- POP_{water} is the mass of POPs ending up in the waste water from FGC and in the related waste water treatment sludge;
- POP_{fgas} is the mass of POPs emitted with the flue-gas.

Content of unburnt substances in bottom ashes/slags

The content of unburnt substances in the slags and/or bottom ashes can be expressed either as loss on ignition or as the TOC mass fraction as a percentage, on a dry basis.

5.1 BAT conclusions

5.1.1 Environmental management systems

[To the TWG: the following description of the general EMS features is based on standard text agreed at the level of the IED Article 13 Forum and used in recent documents such as the BAT conclusions for CWW, IRPP, NFM, REF, etc. The possibilities for changes are therefore limited.]

BAT 1. In order to improve the overall environmental performance, BAT is to implement and adhere to an environmental management system (EMS) that incorporates all of the following features:

i. commitment of the management, including senior management;
ii. definition, by the management, of an environmental policy that includes the continuous improvement of the environmental performance of the installation;
iii. planning and establishing the necessary procedures, objectives and targets, in conjunction with financial planning and investment;
iv. implementation of procedures paying particular attention to:

    a. structure and responsibility;
    b. recruitment, training, awareness and competence;
    c. communication;
    d. employee involvement;
    e. documentation;
    f. effective process control;
    g. planned regular maintenance programmes;
    h. emergency preparedness and response;
    i. safeguarding compliance with environmental legislation;

v. checking performance and taking corrective action, paying particular attention to:

    a. monitoring and measurement (see also the JRC Reference Report on Monitoring of emissions to air and water from IED-installations – ROM);
    b. corrective and preventive action;
    c. maintenance of records;
    d. independent (where practicable) internal and external auditing in order to determine whether or not the EMS conforms to planned arrangements and has been properly implemented and maintained;

vi. review, by senior management, of the EMS and its continuing suitability, adequacy and effectiveness;
vii. following the development of cleaner technologies;
viii. consideration for the environmental impacts from the eventual decommissioning of the installation at the stage of designing a new plant, and throughout its operating life including:

    a. avoiding unnecessary underground structures;
    b. incorporating features that facilitate dismantling;
    c. choosing surface finishes that are easily decontaminated;
    d. using an equipment configuration that minimises trapped chemicals and facilitates drainage or cleaning;
    e. designing flexible, self-contained equipment that enables phased closure;
    f. using biodegradable and recyclable materials where possible;

ix. application of sectoral benchmarking on a regular basis.

Specifically for incineration plants and, where relevant, bottom ash treatment plants, BAT is to also incorporate the following features in the EMS:

x. waste stream management plan (see BAT 10 and BAT 11);
xi. residues management plan including measures aiming to:
    a. minimise the generation of residues;
    b. optimise the reuse, regeneration, recycling and/or energy recovery of the residues;
    c. ensure the proper disposal of residues;
xii. OTNOC management plan (see BAT 19);
xiii. accident management plan (see BAT 2);
xiv. odour management plan where odour nuisance at sensitive receptors is expected and/or has been substantiated, including:
    a. a protocol for conducting odour monitoring in accordance with EN standards (e.g. EN 13725); it may be complemented by measurement/estimation of odour exposure (e.g. according to EN 16841-1 or EN 16841-2) or estimation of odour impact;
    b. a protocol for response to identified odour incidents, e.g. complaints;
    c. an odour prevention and reduction programme designed to identify the source(s); to measure/estimate odour exposure; to characterise the contributions of the sources; and to implement prevention and/or reduction measures;
xv. noise management plan (see also BAT 36) where noise nuisance at sensitive receptors is expected and/or has been substantiated, including;
    a. a protocol for conducting noise monitoring;
    b. a protocol for response to identified noise and vibration incidents;
    c. a noise and vibration reduction programme designed to identify the source(s), to measure/estimate noise and vibration exposure, to characterise the contributions of the sources and to implement prevention and/or reduction measures.

Applicability
The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) is generally related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have (determined also by the type and the amount of waste processed).

[This BAT conclusion is based on information given in Section 4.1.1]

BAT 2. In order to prevent the occurrence of accidents and to reduce the environmental consequences when accidents occur, BAT is to set up and implement an accident management plan (see BAT 1).

Description
An accident management plan is part of the EMS (see BAT 1) and identifies hazards posed by the installation and the associated risks and defines measures to address these risks. It considers the inventory of pollutants present or likely to be present which could have environmental consequences if they escape.

The accident management plan includes the setting up and implementation of a fire prevention, detection and control plan, which is risk-based and includes the use of automatic fire detection and warning systems, and of manual and/or automatic fire intervention and control systems. The fire prevention, detection and control plan is relevant in particular for:

- waste storage and pretreatment areas;
- furnace loading areas;
- electrical control systems;
- bag filters;
- fixed adsorption beds.

The accident management plan also includes, in particular in the case of installations where hazardous wastes are received, personnel training programmes regarding:

- explosion and fire prevention;
- fire extinguishing;
- knowledge of chemical risks (labelling, carcinogenic substances, toxicity, corrosion, fire) and transportation.

[This BAT conclusion is based on information given in Section 4.2.4.7]

5.1.2 Monitoring

BAT 3. BAT is to determine the gross electrical efficiency and/or the gross total heat efficiency of the incineration plant by carrying out a performance test at full load (1), according to EN standards, after the commissioning of the plant and after each modification that could significantly affect the gross electrical efficiency and/or the gross total heat efficiency of the plant. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

(1) In the case of cogeneration plants, if all of the steam produced at full load is converted to electricity, the gross electrical efficiency is determined. If, for technical reasons, not all of the steam produced at full load can be converted to electricity, the gross total heat efficiency is determined instead.

BAT 4. BAT is to monitor key process parameters relevant for emissions to air and water including those given below.

Stream	Parameter(s)	Monitoring
Flue-gas from incineration	Flow, oxygen content, temperature, pressure, water vapour content (1)	Continuous measurement
Waste water from flue-gas treatment	Flow, pH, temperature	
Waste water from bottom ash treatment	Flow, pH, conductivity	

(1) The continuous measurement of the water vapour content of the flue-gas is not necessary if the sampled flue-gas is dried before analysis.

BAT 5. BAT is to monitor emissions to air with at least the frequency given below and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

Substance/ Parameter	**Process**	**Standard(s)** ([1])	**Minimum monitoring frequency**	**Monitoring associated with**
NO_X	Incineration	Generic EN standards	Continuous	BAT 29
NH_3	When SNCR and/or SCR is used	Generic EN standards	Continuous	BAT 29
N_2O	• Incineration in fluidised bed furnaces • When SNCR is operated with urea	EN 21258	Once every year	BAT 29
CO	Incineration	Generic EN standards	Continuous	BAT 29
SO_2	Incineration	Generic EN standards	Continuous	BAT 28
HCl	Incineration	Generic EN standards	Continuous	BAT 28
HF	Incineration	Generic EN standards	Continuous ([2])	BAT 28
Dust	Bottom ash treatment	EN 13284-1	Once every year	BAT 27
	Incineration	Generic EN standards and EN 13284-2	Continuous	BAT 26
Metals and metalloids except mercury (As, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sb, Tl, V)	Incineration	EN 14385	Once every six months	BAT 26
Hg	Incineration	Generic EN standards and EN 14884	Continuous ([3])	BAT 31
TVOC	Incineration	Generic EN standards	Continuous	BAT 30
PCDD/F	Incineration	No EN standard available for long-term sampling, EN 1948-2, EN 1948-3	Once every month ([4])	BAT 30
Dioxin-like PCBs	Incineration	No EN standard available for long-term sampling, EN 1948-2, EN 1948-4	Once every month ([5])([6])	BAT 30
Benzo[*a*]pyrene	Incineration	No EN standard available	Once every year	BAT 30

([1]) Generic EN standards for continuous measurements are EN 15267-1, EN 15267-2, EN 15267-3, and EN 14181. EN standards for periodic measurements are given in the table or in the footnotes.

([2]) The continuous measurement of HF may be replaced by periodic measurements with a minimum frequency of once every six months if the HCl emission levels are proven to be sufficiently stable. No EN standard is available for the periodic measurement of HF.

([3]) For incineration plants with a capacity of < 100 000 tonnes/year incinerating exclusively non-hazardous waste, and for plants incinerating wastes with intrinsically low and constant mercury content (e.g. sewage sludge, mono-streams of waste of controlled composition), the continuous monitoring of emissions can be replaced by long-term sampling or periodic monitoring with a minimum frequency of once every six months. In the latter case the relevant standard is EN 13211.

([4]) The monitoring frequency of once every month refers to monitoring carried out by long-term sampling. For incineration plants incinerating exclusively non-hazardous waste and for incineration plants where PCCD/F emission levels are proven to be sufficiently stable, the monthly long-term sampling of PCDD/F emissions can be replaced by periodic measurements with a minimum monitoring frequency of once every six months. In this case the relevant standard for sampling is EN 1948-1.

(5) The monitoring frequency of once every month refers to monitoring carried out by long-term sampling. For incineration plants burning exclusively non-hazardous waste and for incineration plants where PCB emission levels are proven to be sufficiently stable, the monthly long-term sampling of PCB emissions can be replaced by periodic measurements with a minimum monitoring frequency of once every six months. In this case the relevant standard for sampling is EN 1948-1.

(6) Where emissions of dioxin-like PCBs are demonstrated to represent less than 20 % of the toxic equivalent of PCDD/F expressed as WHO-TEQ, the monitoring of PCBs does not apply.

BAT 6. BAT is to appropriately monitor emissions from the incineration plant during OTNOC.

Description

The monitoring can be carried out by direct emission measurements or by monitoring of surrogate parameters if this proves to be of equivalent or better scientific quality than direct emission measurements. Emissions during start-up and shutdown while no waste is being incinerated may be estimated based on at least one measurement campaign per year carried out during a planned start-up/shutdown operation.

BAT 7. BAT is to monitor emissions to water from FGC and/or bottom ash treatment with at least the frequency given below and in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

Substance/Parameter	Process	Standard(s)	Minimum monitoring frequency	Monitoring associated with
Total organic carbon (TOC)	FGC Bottom ash treatment	EN 1484	Once every month	BAT 34
Total suspended solids (TSS)	FGC Bottom ash treatment	EN 872		
As	FGC	Various EN standards available (e.g. EN ISO 11885 or EN ISO 17294-2)		
Cd	FGC			
Cr	FGC			
Cu	FGC			
Mo	FGC			
Ni	FGC			
Pb	FGC Bottom ash treatment			
Sb	FGC			
Tl	FGC			
Zn	FGC			
Hg	FGC	Various EN standards available (e.g. EN ISO 12846 or EN ISO 17852)		
NH_4-N	Bottom ash treatment	Various EN standards available (i.e. EN ISO 11732, EN ISO 14911)		
Chloride (Cl^-)	Bottom ash treatment	Various EN standards (i.e. EN ISO 10304-1, EN ISO 15682)		
SO_4^{2-}	Bottom ash treatment	EN ISO 10304-1		
PCDD/F	FGC Bottom ash treatment	No EN standard available		

BAT 8. BAT is to monitor the total organic carbon content of bottom ashes/slags and/or their loss on ignition in accordance with EN 13137 and/or EN 15169. The minimum monitoring frequency is once every three months.

BAT 9. For the incineration of hazardous waste containing POPs, BAT is to monitor the POP destruction efficiency at least once every year in accordance with EN standards. If EN standards are not available, BAT is to use ISO, national or other international standards that ensure the provision of data of an equivalent scientific quality.

Description
The POP destruction efficiency is determined by analysing the POP content in:

- waste prior to incineration;
- incineration slags and bottom ashes;
- fly ashes and dry FGC residues;
- waste water from FGC and in the related waste water treatment sludge;
- flue-gas.

Applicability
Only applicable if the POP levels in the wastes prior to incineration exceed the concentration limits defined in Annex IV to Regulation (EC) No 850/2004 as amended by Commission Regulation (EU) No 756/2010.

To the TWG: please provide information to confirm the proposed BAT 9 based on established practices.

5.1.3 General environmental and combustion performance

BAT 10. In order to improve the overall environmental performance of the incineration plant, as part of the waste stream management plan (see BAT 1), BAT is to use all of the techniques (a) to (d) given below, and, where relevant, also techniques (e) and (f).

	Technique	**Description**
a.	Determination of the types of waste that can be incinerated	Based on the characteristics of the incineration plant, identification of the types of waste which can be incinerated in terms of, for example, the physical state and the acceptable ranges of calorific value, humidity, ash content, size.
b.	Set-up and implementation of waste characterisation and pre-acceptance procedures	These procedures aim to ensure the technical (and legal) suitability of waste treatment operations for a particular waste prior to the arrival of the waste at the plant. They include procedures to collect information about the waste input and may include waste sampling and characterisation to achieve sufficient knowledge of the waste composition. Waste pre-acceptance procedures are risk-based considering, for example, the hazardous properties of the waste, the risks posed by the waste in terms of process safety, occupational safety and environmental impact, as well as the information provided by the previous waste holder(s).
c.	Set-up and implementation of waste acceptance procedures	Acceptance procedures aim to confirm the characteristics of the waste, as identified in the pre-acceptance stage. These procedures define the elements to be verified upon the delivery of the waste at the plant as well as the waste acceptance and rejection criteria. They may include waste sampling, inspection and analysis. Waste acceptance procedures are risk-based considering, for example, the hazardous properties of the waste, the risks posed by the waste in terms of process safety, occupational safety and environmental impact, as well as the information provided by the previous waste holder(s). The elements to be monitored for each type of waste are detailed in BAT 12.
d.	Set-up and implementation a waste tracking system and inventory	A waste tracking system and inventory aim to track the location and quantity of waste in the plant. It holds all the information generated during waste pre-acceptance procedures (e.g. date of arrival at the plant and unique reference number of the waste, information on the previous waste holder(s), pre-acceptance and acceptance analysis results, nature and quantity of waste held on site including all identified hazards), acceptance, storage, treatment and/or transfer off site. The waste tracking system is risk-based considering, for example, the hazardous properties of the waste, the risks posed by the waste in terms of process safety, occupational safety and environmental impact, as well as the information provided by the previous waste holder(s). The waste tracking system includes clear labelling of wastes that are stored in places other than the waste bunker or sludge storage tank (e.g. in containers, drums, bales or other forms of packaging) such that they can be identified at all times.
e.	Waste segregation	Wastes are kept separated depending on their properties in order to enable easier and environmentally safer storage and incineration. Waste segregation relies on the physical separation of different wastes and on procedures that identify when and where wastes are stored.
f.	Verification of waste compatibility prior to mixing or blending of waste	Compatibility is ensured by a set of verification measures and tests in order to detect any unwanted and/or potentially dangerous chemical reactions between wastes (e.g. polymerisation, gas evolution, exothermal reaction, decomposition) upon mixing or blending. The compatibility tests are risk-based considering, for example, the hazardous properties of the waste, the risks posed by the waste in terms of process safety, occupational safety and environmental impact, as well as the information provided by the previous waste holder(s).

BAT 11. In order to improve the overall environmental performance of the bottom ash treatment plant, as part of the waste stream management plan (see BAT 1), BAT is to set up and implement an output quality management system.

Description

Setting up and implementing an output quality management system, so as to ensure that the output of the bottom ash treatment is in line with expectations, using existing EN standards where available. This management system also allows the performance of the bottom ash treatment to be monitored and optimised.

BAT 12. In order to improve the overall environmental performance, BAT is to monitor the waste deliveries as part of the waste acceptance procedures (see BAT 10) including the elements given below.

Waste type	**Monitoring**
Municipal solid waste and other non-hazardous waste	• Radioactivity detection • Weighing of the waste deliveries • Visual inspection • Periodic sampling of individual deliveries and analysis of key properties/substances (e.g. calorific value, content of halogens and metals/metalloids). For municipal solid waste, this involves separate unloading
Sewage sludge	• Weighing of the waste deliveries • Visual inspection • Periodic sampling and analysis of key properties/substances (e.g. calorific value, water and ash content)
Hazardous waste	• Radioactivity detection • Weighing of the waste deliveries • Visual inspection • Unpacking and visual inspection of baled waste deliveries • Control and comparison of individual waste deliveries with the declaration of the waste producer • Sampling of the content of: ○ all bulk tankers ○ randomly selected drums/bales in drummed and other packaged waste deliveries and analysis of: ○ combustion parameters (including calorific value and flashpoint) ○ waste compatibility, to detect possible hazardous reactions upon blending or mixing wastes, prior to storage ○ key substances including PCBs, halogens and sulphur, metals/metalloids
Clinical waste	• Radioactivity detection • Weighing of the waste deliveries

[This BAT conclusion is based on information given in Sections 4.2.3.1, 4.2.3.2, 4.2.3.3, 4.2.3.4, 4.2.3.5]

BAT 13. In order to reduce the environmental risks associated with the reception, handling and storage of waste, BAT is to use both of the techniques given below.

	Technique	**Description**
a.	Impermeable surfaces and segregated drainage	Depending on the risks posed by the waste in terms of soil or water contamination, the surface of the waste reception, handling and storage areas is concrete-based or made impermeable to the liquids concerned, and fitted with segregated drainage
b.	Adequate storage capacity	Measures are taken to avoid accumulation of waste, such as: • the maximum waste storage capacity is clearly established and not exceeded, taking into account the characteristics of the wastes (e.g. regarding the risk of fire) and the treatment capacity; • the quantity of waste stored is regularly monitored against the maximum allowed storage capacity; • the maximum residence time of waste is clearly established

[This BAT conclusion is based on information given in Sections 4.2.4.1, 4.2.4.2, 4.2.4.5]

BAT 14. In order to reduce the environmental risk associated with the storage and handling of clinical waste, BAT is to use technique (a) and either technique (b) or (c)-given below.

	Technique	**Description**
a.	Automated waste handling	The use of non-manual waste handling and loading systems
b.	Use of sealed, puncture-resistant containers	Clinical waste is delivered in sealed and robust, puncture-resistant combustible containers that are never opened throughout storage and handling operations
c.	Cleaning and disinfection of containers	Waste containers that are to be reused are cleaned in a designated cleaning area and disinfected in a facility specifically designed for disinfection. Any solid residues from the cleaning operations are incinerated

[This BAT conclusion is based on information given in Section 4.2.4.1]

BAT 15. In order to improve the overall environmental performance, to reduce the content of unburnt substances in slags and bottom ashes, and to reduce emissions to air from the incineration of waste, BAT is to use an appropriate combination of the techniques given below.

	Technique	**Description**	**Applicability**
a.	Waste blending and mixing	See Section 5.2.1	Not applicable to infectious clinical waste. Blending and mixing is not applicable where undesired reactions may occur between different types of waste.
b.	Advanced control system	See Section 5.2.1	Generally applicable
c.	Optimisation of the incineration process	See Section 5.2.1	Optimisation of the design of the incineration chamber is not applicable to existing furnaces

BAT-associated environmental performance levels

The TOC content in slags and bottom ashes associated with BAT is 1–3 wt-%.
The loss on ignition of slags and bottom ashes associated with BAT is 1–5 wt-%.

The associated monitoring is in BAT 8.

[This BAT conclusion is based on information given in Sections 4.2.5.1, 4.3.6, 4.3.9, 4.3.17, 4.3.24, 4.7.1]

BAT 16. In order to improve the overall environmental performance of the incineration plant and to reduce emissions to air, BAT is to set up and implement procedures for the adjustment of the plant's settings, e.g. though the advanced control system (see description in Section 5.2.1), as and when needed and practicable, based on the characterisation and control of the input waste (see BAT 12).

BAT 17. In order to improve the overall environmental performance of the incineration plant, BAT is to set up and implement operational procedures (e.g. organisation of the supply chain, continuous rather than batch operation, preventive maintenance) to limit as far as practicable shutdown and start-up operations.

[This BAT conclusion is based on information given in Section 4.1.2]

BAT 18. In order to reduce emissions to air and water, BAT is to ensure, by appropriate design, operation and maintenance, that the flue-gas cleaning system and the waste water treatment plant are used at optimal capacity and availability.

BAT 19. In order to reduce the frequency of the occurrence of OTNOC and to reduce emissions to air and/or to water from the incineration plant during OTNOC, BAT is to set up and implement a risk-based OTNOC management plan as part of the environmental management system (see BAT 1) that includes all of the following elements:

- identification of potential OTNOC, of their root causes (e.g. failure of emission abatement systems, including identification of equipment critical to the protection of the environment ('critical equipment')) and of their potential consequences, and regular review and update of the list of identified OTNOC following the periodic assessment below;
- appropriate design of critical equipment (e.g. compartmentalisation of the bag filter, supplementary burners to heat up the flue-gas and obviate the need to bypass the bag filter on start-up, etc.);
- set-up and implementation of a preventive maintenance plan for critical equipment;
- monitoring and recording of emissions during OTNOC and associated circumstances (see BAT 6);
- periodic assessment of the emissions occurring during OTNOC (e.g. frequency of events, duration, amount of pollutants emitted) and implementation of corrective actions if necessary.

5.1.4 Energy efficiency

BAT 20. In order to increase resource efficiency and enable the recovery of energy from the incineration of waste, BAT is to use a heat recovery boiler.

Description

The energy contained in the flue-gas is recovered in a heat recovery boiler producing hot water and/or steam, which may be exported, used internally, and/or used to produce electricity.

Applicability

In the case of plants dedicated to the incineration of hazardous waste, the applicability may be limited by:

- the stickiness of the fly ashes;
- the corrosiveness of the flue-gas.

BAT 21. In order to increase the energy efficiency of the incineration plant, BAT is to use a combination of the techniques given below.

	Technique	Description	Applicability
a.	Thermal drying of sewage sludge	After mechanical dewatering, sewage sludge is further dried using low-grade heat prior to incineration	Applicable within the constraints associated with the availability of low-grade heat
b.	Reduction of the flue-gas flow	The flue-gas flow is reduced through, e.g.: • improving the primary and secondary air distribution; • recirculation of raw flue-gas (extracted before the FGC); see Section 5.2.2; • oxygen-enriched combustion air. A smaller flue-gas volume reduces the energy demand of the plant (e.g. for induced draft fans).	Generally applicable
c.	Minimisation of heat losses	Heat losses are minimised through: • thermal insulation of furnaces and boilers; • recovery of heat from the cooling of slags and bottom ashes	Generally applicable
d.	Optimisation of the boiler design	The heat transfer in the boiler is improved by optimising, for example, the: • flue-gas velocity and distribution; • water/steam circulation; • convection bundles; • cleaning devices for the convection bundles.	Applicable to new plants and to major retrofits of existing plants
e.	Low flue-gas temperature at boiler exit	Special corrosion-resistant heat exchangers are used to recover additional energy from the flue-gas, reducing its temperature at the boiler exit	Applicable within the constraints of the operating temperature of the downstream FGC system

f.	High steam conditions	The higher the steam conditions (temperature and pressure), the higher the electricity conversion efficiency allowed by the steam cycle. Working at increased steam conditions (e.g. above 45 bar, 400 °C) requires the use of special steel alloy or refractory cladding to protect the boiler sections that are exposed to the highest temperatures.	Applicable to new plants and to major retrofits of existing plants, where the plant is mainly oriented towards the generation of electricity. The applicability may be limited by: • the stickiness of the fly ashes; • the corrosiveness of the flue-gas.
g.	Cogeneration	Cogeneration of heat and electricity where the heat (mainly from the steam system) is used for producing hot water/steam to be used in industrial processes/activities or in a public network for district heating/cooling	Applicable within the constraints associated with the local heat and power demand
h.	Flue-gas condenser	A heat exchanger where the water vapour contained in the flue-gas condenses, transferring the latent heat to water at a sufficiently low temperature (e.g. return flow of a district heating network). The flue-gas condenser also provides co-benefits by reducing emissions to air (e.g. of dust and acid gases). The use of heat pumps can increase the amount of energy recovered from flue-gas condensation	Applicability may be limited by the demand for low-temperature heat, e.g. by the availability of a district heating network with a sufficiently low return temperature

Table 5.1: BAT-associated energy efficiency levels (BAT-AEELs) for incineration

Type of waste incinerated	BAT-AEELs		
	Gross electrical efficiency (%) (1) (2)		Gross heat efficiency (%) (3)
	New plant	Existing plant	New or existing plant
Municipal solid waste and other non-hazardous waste	25–35	20–35	72–91(4)
Sewage sludge	15– > 21(5)	12–21	60–70 (5)
Hazardous waste (6)	16–32	14–32	65–89

(1) The BAT-AEELs for gross electrical efficiency apply to plants producing only electricity and to cogeneration plants mainly oriented towards the production of electricity.
(2) The higher end of the BAT-AEEL range can be achieved with high steam conditions (pressure, temperature).
(3) The BAT-AEELs for gross heat efficiency apply to plants producing only heat (steam and/or hot water) and to cogeneration plants mainly oriented towards the production of heat.
(4) A gross heat efficiency exceeding the higher end of the BAT-AEEL range (even above 100 %) can be achieved where a flue-gas condenser is used.
(5) For the incineration of sewage sludge, the gross electrical efficiency is highly dependent on the water content.
(6) The BAT-AEELs do not apply if a heat recovery boiler is not applicable.

The associated monitoring is in BAT 3.

[This BAT conclusion is based on information given in Sections 4.4.1, 4.4.2, 4.4.5, 4.4.8, 4.4.9, 4.4.11, 4.4.15, 4.4.16, 4.4.17, 4.4.19]

(To the TWG: Based on the performances of actual plants, the data collected do not allow the proposal of a BAT-AEEL range for electrical efficiency of new sewage sludge incineration plants and a lower end of the BAT–AEEL range for heat efficiency of sewage sludge incineration plants. The proposed values are based on expert judgement).

5.1.5 Emissions to air

5.1.5.1 Diffuse emissions

BAT 22. In order to prevent or reduce diffuse emissions, including odour emissions, from bulk waste storage areas including tanks and bunkers and from waste pretreatment areas, BAT is to enclose those areas, keep them under negative pressure, and use the extracted air as combustion air for incineration. When the incinerator is not available (e.g. during maintenance), BAT is to minimise the amount of waste in storage and/or to use an alternative abatement technique (e.g. a wet scrubber).

Description

Solid and pasty wastes are kept in enclosed buildings from which incineration air is drawn; liquid waste tank vents are ducted to the incineration air feed.

During shutdown periods the amount of waste in storage is minimised, e.g. by interrupting or reducing waste deliveries, as part of the waste stream management plan (see BAT 1).

[This BAT conclusion is based on information given in Section 4.2.4.4]

BAT 23. In order to prevent diffuse emissions of volatile compounds from the handling of gaseous and liquid wastes, BAT is to feed them into the furnace by direct injection.

Description

Direct injection is carried out by connecting the waste container to the furnace feeding line. The container is then emptied by pressurising it with nitrogen or, if the viscosity is low enough, by pumping the liquid.

[This BAT conclusion is based on information given in Section 4.2.5.9]

5.1.5.2 Channelled emissions

BAT 24. In order to improve the environmental performance of the incineration plant and to reduce emissions to air, BAT is to optimise the combustion performance, the flue-gas flow through the FGC system, and the injection of reagents by using flow modelling.

Applicability

Generally applicable to new plants and to major retrofits of existing plants.

[This BAT conclusion is based on information given in Section 4.3.2]

BAT 25. In order to reduce peak emissions to air from the incineration of waste while limiting the consumption of reagents and the amount of residues generated from dry sorbent injection and semi-wet absorbers, BAT is to use technique (a) and also, where appropriate, technique (b) given below.

	Technique	Description	Applicability
a.	Optimised and automated reagent dosage	The use of continuous HCl and/or SO_2 monitoring (or of other parameters that may prove useful for this purpose) upstream and/or downstream of the FGC system for the optimisation of the automated reagent dosage	Generally applicable
b.	Recirculation of reagents	The recirculation of a proportion of the collected FGC solids to reduce the amount of unreacted reagent(s) in the residues. The technique is relevant in particular in the case of FGC techniques with a high stoichiometric ratio	Generally applicable to new plants. Applicable to existing plants within the constraints of the size of the bag filter

[This BAT conclusion is based on information given in Sections 4.5.3.7, 4.5.3.11]

5.1.5.2.1 Emissions of dust, metals and metalloids

BAT 26. In order to reduce emissions to air of dust, metals and metalloids from the incineration of waste, BAT is to use one or a combination of the techniques given below.

	Technique	Description	Applicability
a.	Bag filter	See Section 5.2.2	Applicable within the constraints associated with the overall pressure drop and the operating temperature profile of the FGC system configuration
b.	Electrostatic precipitator	See Section 5.2.2	Generally applicable
c.	Dry sorbent injection	See Section 5.2.2. Not relevant for the reduction of dust emissions. Adsorption of metals by injection of activated carbon or other reagents	Generally applicable
d.	Wet scrubber	See Section 5.2.2. Wet scrubbers are not used to remove the main dust load but, installed after other abatement techniques, to further reduce the concentrations of dust, metals and metalloids in the flue-gas	There may be economic restrictions to retrofitting existing plants burning non-hazardous waste with a capacity of < 250 000 tonnes/year

Table 5.2: BAT-associated emission levels (BAT-AELs) for emissions to air of dust, metals and metalloids from incineration

Parameter	BAT-AEL (mg/Nm^3)	Averaging period
Dust	2–5 (1)	Daily average
Cd + Tl	0.01–0.02	Average over the sampling period
Sb + As + Pb + Cr + Co + Cu+ Mn + Ni + V	0.05–0.3	Average over the sampling period

(1) The higher end of the BAT-AEL range is 7 mg/Nm^3 for existing plants where a bag filter is not applicable.

The associated monitoring is in BAT 5.

[This BAT conclusion is based on information given in Sections 4.5.2.1, 4.5.2.2, 4.5.2.3, 4.5.2.4]

BAT 27. In order to reduce dust emissions to air from the treatment of slags and bottom ashes, BAT is to carry out these activities in enclosed equipment under negative pressure and to treat the extracted air with a bag filter (see Section 5.2.2).

Table 5.3: BAT-associated emission levels (BAT-AELs) for dust emissions to air from the treatment of slags and bottom ashes

Parameter	BAT-AEL (mg/Nm^3)	Averaging period
Dust	2–5	Average over the sampling period

The associated monitoring is in BAT 5.

[This BAT conclusion is based on information given in Section 4.7.9]

5.1.5.2.2 Emissions of HCl, HF and SO_2

BAT 28. In order to reduce emissions of HCl, HF and SO_2 to air from the incineration of waste, BAT is to use one or a combination of the techniques given below.

	Technique	Description	Applicability
a.	Wet scrubber	See Section 5.2.2	There may be economic restrictions to retrofitting existing plants burning non-hazardous waste with a capacity of < 250 000 tonnes/year
b.	Semi-wet absorber	See Section 5.2.2	Generally applicable
c.	Dry sorbent injection	See Section 5.2.2	Generally applicable
d.	Direct desulphurisation	See Section 5.2.2	Only applicable to fluidised bed furnaces
e.	Boiler sorbent injection	See Section 5.2.2	Generally applicable

Table 5.4: BAT-associated emission levels (BAT-AELs) for emissions to air of HCl, HF and SO_2 from incineration

Parameter	BAT-AEL (mg/Nm^3)		Averaging period
	New plant	Existing plant	
HCl	2–6 (1)	2–8 (1)	Daily average
HF	< 1	< 1	Daily average or average over the sampling period
SO_2	10–30	10–40	Daily average

(1) The lower end of the BAT-AEL range can be achieved when using a wet scrubber; the higher end of the range may be associated with the use of dry sorbent injection.

The associated monitoring is in BAT 5.

[This BAT conclusion is based on information given in Sections 4.5.3.1, 4.5.3.2, 4.5.3.3, 4.5.3.4, 4.5.3.5, 4.5.3.6, 4.5.3.7, 4.5.3.8, 4.5.3.9, 4.5.3.10]

5.1.5.2.3 Emissions of NO_X, N_2O, CO and NH_3

BAT 29. In order to reduce NO_X emissions to air while limiting the emissions of CO and N_2O from the incineration of waste and the emissions of NH_3 from the use of SNCR and/or SCR, BAT is to use a combination of the techniques given below.

	Technique	Description	Applicability (1)
a.	Optimisation of the incineration process	See Section 5.2.1	Generally applicable
b.	Flue-gas recirculation	See Section 5.2.2	Generally applicable
c.	Low-NO_X burners	See Section 5.2.2	Only applicable to liquid waste
d.	Selective non-catalytic reduction (SNCR)	See Section 5.2.2	Generally applicable
e.	Selective catalytic reduction (SCR)	See Section 5.2.2	There may be economic restrictions to retrofitting existing plants
f.	Catalytic filter bags	See Section 5.2.2	Not applicable to existing plants that are not fitted with a bag filter
g.	Optimisation of the SNCR/SCR design and operation	Optimisation of the reagent to NO_X ratio, of the homogeneity of reagent distribution and of the size of reagent drops	Only applicable where SNCR and/or SCR is used for the reduction of NO_X emissions

Table 5.5: BAT-associated emission levels (BAT-AELs) for NO_X and CO emissions to air from incineration and for NH_3 emissions from the use of SNCR and/or SCR

Parameter	BAT-AEL (mg/Nm^3)		Averaging period
	New plant	Existing plant	
NO_X	50–120 (1)	50–150 (1) (2)	Daily average
CO	10–50	10–50	
NH_3	3–10 (3)	3–10 (3) (4)	

(1) The lower end of the BAT-AEL range can be achieved when using SCR.
(2) The higher end of the BAT-AEL range is 180 mg/Nm^3 where SCR is not applicable.
(3) The lower end of the BAT-AEL range can be achieved when using SCR.
(4) For existing plants fitted with SNCR without wet abatement techniques, the higher end of the BAT-AEL range is 15 mg/Nm^3.

The associated monitoring is in BAT 5.

[This BAT conclusion is based on information given in Sections 4.3.2, 4.3.4, 4.3.9, 4.3.11, 4.3.12, 4.3.19, 4.3.24, 4.3.25, 4.5.4.1, 4.5.4.2, 4.5.4.3, 4.5.4.4, 4.5.4.5]

5.1.5.2.4 Emissions of organic compounds

BAT 30. In order to reduce emissions to air of organic compounds including PCDD/F and PCBs from the incineration of waste, BAT is to use techniques (a), (b), (c), (d), and one or a combination of techniques (e) to (i) given below.

	Technique	**Description**	**Applicability**
a.	Optimisation of the incineration process	See Section 5.2.1. Optimisation of incineration parameters to promote the oxidation of organic compounds including PCDD/F and PCBs present in the waste, and to prevent their and their precursors' (re)formation	Generally applicable
b.	Control of waste feed	Knowledge and control of the specifications of the waste being fed into the incineration chamber, including their combustion characteristics, to ensure homogeneous, stable and optimal incineration conditions	
c.	On-line and off-line boiler cleaning	Efficient cleaning of the boiler bundles to reduce the dust residence time and accumulation in the boiler, thus reducing PCDD/F formation in the boiler A combination of on-line and off-line boiler cleaning techniques is used	
d.	Flue-gas quenching	Use of a quench system for the rapid cooling of the flue-gas from temperatures above 400 °C to below 250 °C before dust abatement to prevent the *de novo* synthesis of PCDD/F	
e.	Dry sorbent injection	See Section 5.2.2. Adsorption by injection of activated carbon or other reagents, generally combined with a bag filter where a reaction layer is created in the filter cake and the solids generated are removed	
f.	Fixed-bed adsorption	Adsorption by passing the flue-gas through a fixed-bed filter where activated coke or activated lignite is used as the adsorbent	The applicability may be limited by the overall pressure drop associated with the flue-gas cleaning system configuration
g.	Multi-layer SCR	Where SCR is used for NO_X abatement, the adequate sizing of a multi-layer SCR system provides for effective PCDD/F and PCB control	There may be economic restrictions to retrofitting existing plants
h.	Catalytic filter bags	See Section 5.2.2	Not applicable to existing plants that are not fitted with a bag filter
i.	Carbon adsorption in wet scrubber	PCDD/F and PCBs are adsorbed by carbon sorbent added to the wet scrubber, either in the scrubbing liquor or in the form of impregnated packing elements. The technique is particularly used to prevent and/or reduce the re-emission of PCDD/F accumulated in the scrubber (the so-called memory effect) occurring especially during shutdown and start-up periods	Not applicable to existing plants that are not fitted with a wet scrubber

Table 5.6: BAT-associated emission levels (BAT-AELs) for emissions to air of TVOC, PCDD/F and dioxin-like PCBs from incineration

Parameter	Unit	BAT-AEL		Averaging period
		New plant	Existing plant	
TVOC	mg/Nm^3	3–10	3–10	Daily average
PCDD/F (¹)	ng I-TEQ/Nm^3	< 0.01–0.04	< 0.01–0.06	Average over the sampling period or long-term sampling average
PCDD/F + dioxin-like PCBs (¹)	ng WHO-TEQ/Nm^3	< 0.01–0.06	< 0.01–0.08	Average over the sampling period or long-term sampling average
(¹) Either the BAT-AEL for PCDD/F or the BAT-AEL for PCDD/F + dioxin-like PCBs applies.				

The associated monitoring is in BAT 5.

[This BAT conclusion is based on information given in Sections 4.3.2, 4.3.6, 4.3.19, 4.4.19, 4.5.5.2, 4.5.5.3, 4.5.5.4, 4.5.5.6, 4.5.5.7, 4.5.5.8, 4.5.5.9]

5.1.5.2.5 Emissions of mercury

BAT 31. In order to reduce mercury emissions to air from the incineration of waste, BAT is to use one or a combination of the techniques given below.

	Technique	Description	Applicability
a.	Wet scrubber (low pH)	See Section 5.2.2. A wet scrubber operated at a pH value below 1. The mercury removal rate of the technique can be enhanced by adding reagents and/or adsorbents to the scrubbing liquor, e.g.: • oxidants such as hydrogen peroxide to transform metallic mercury to a water-soluble oxidised form • sulphur compounds • carbon sorbent to adsorb metallic mercury	There may be economic restrictions to retrofitting existing plants burning non-hazardous waste with a capacity of < 250 000 tonnes/year
b.	Boiler bromine addition	Bromide added to the waste or injected into the furnace is dissociated at high temperatures into elemental bromine to enhance the oxidisation of mercury while the flue-gas passes through the boiler, thereby promoting the transformation of elemental gaseous mercury to $HgBr_2$, which is water-soluble and highly adsorbable. The technique is used in combination with a downstream abatement technique such as a wet scrubber or an activated carbon injection system	Generally applicable
c.	Dry sorbent injection	See Section 5.2.2. Adsorption by injection of activated carbon or other reagents, generally combined with a bag filter where a reaction layer is created in the filter cake and the solids generated are removed	Generally applicable
d.	Fixed-bed adsorption	Adsorption by passing the flue-gas through a fixed-bed filter where activated coke or activated lignite is used as the adsorbent	The applicability may be limited by the overall pressure drop associated with the flue-gas cleaning system configuration

Table 5.7: BAT-associated emission levels (BAT-AELs) for emissions of mercury to air from incineration

Parameter	**BAT-AEL (µg/Nm^3)**		**Averaging period**
	New plant	**Existing plant**	
Hg	5–20	5–25	Daily average, Long-term sampling average, or Average over the sampling period
NB: The lower end of the BAT-AEL ranges can be achieved when using fixed-bed adsorption or a wet scrubber enhanced with the use of oxidants; the higher end of the BAT-AEL ranges can be achieved when using dry sorbent injection.			

As an indication, the half-hourly average mercury emission levels will generally be:

- 15–40 µg/Nm^3 for existing plants
- 15–35 µg/Nm^3 for new plants.

The associated monitoring is in BAT 5.

[This BAT conclusion is based on information given in Sections 4.5.5.7, 4.5.6.1, 4.5.6.2, 4.5.6.3, 4.5.6.5, 4.5.6.6, 4.5.6.7, 4.5.6.8]

5.1.6 Emissions to water

BAT 32. In order to prevent the contamination of uncontaminated water and to reduce emissions to water, BAT is to segregate waste water streams and to treat them separately, depending on the pollutant content.

Description
Waste water streams (e.g. surface run-off water, cooling water, waste water from flue-gas treatment and from bottom ash treatment) are segregated to be treated separately based on their pollutant content and on the combination of treatment techniques required. Uncontaminated water streams are segregated from waste water streams that require treatment.

Applicability
Generally applicable to new plants.

Applicable to existing plants within the constraints associated with the configuration of the water collection system.

[This BAT conclusion is based on information given in Sections 4.6.9 and 4.6.14]

BAT 33. In order to reduce water usage and to prevent or reduce the generation of waste water from the incineration plant, BAT is to use one or a combination of the techniques given below.

	Technique	Description	Applicability
a.	Waste-water-free FGC techniques	Use of FGC techniques that do not generate waste water (e.g. dry sorbent injection or semi-wet absorber, see Section 5.2.2)	Generally applicable
b.	Recycling of boiler drain water	Recycling of boiler drain water (e.g. for its use in a wet scrubber, or a quench system)	Generally applicable
c.	Recycling of waste water from the wet scrubber	The waste water originating from the wet scrubber is treated and recycled to the wet scrubber	Only applicable to plants fitted with a wet scrubber

[This BAT conclusion is based on information given in Sections 4.6.3, 4.6.6, 4.6.8]

BAT 34. In order to reduce emissions to water from flue-gas cleaning and/or from the treatment of slags and bottom ashes, BAT is to use an appropriate combination of the techniques given below, and to use secondary techniques as close as possible to the source in order to avoid dilution.

	Technique	Typical pollutants prevented/abated
	Primary techniques	
a.	Optimisation of the incineration process (see BAT 15) and/or of flue-gas treatment systems (e.g. SNCR/SCR, see BAT 29 (g))	Organic compounds including PCDD/F, ammonia
b.	Separate treatment of waste water arising from different wet scrubbing stages (acidic and alkaline)	Acids, alkalis, sulphate
	Secondary techniques (1)	
Preliminary and primary treatment		
c.	Equalisation	All pollutants
d.	Neutralisation	Acids, alkalis
e.	Physical separation, e.g. screens, sieves, grit separators, primary settlement tanks	Gross solids, suspended solids
Physico-chemical treatment		
f.	Adsorption on activated carbon	Organic compounds including PCDD/F, mercury
g.	Chemical precipitation	Dissolved metals/metalloids, sulphate
h.	Oxidation	Sulphide, sulphite, organic compounds
i.	Ion exchange	Dissolved metals/metalloids
j.	Stripping	Ammonia/ammonium
k.	Reverse osmosis	Ammonia/ammonium
Final solids removal		
l.	Coagulation and flocculation	Suspended solids, particulate-bound metals/metalloids
m.	Sedimentation	Suspended solids, particulate-bound metals/metalloids
n.	Filtration	Suspended solids, particulate-bound metals/metalloids
o.	Flotation	Suspended solids, particulate-bound metals/metalloids
(1) The descriptions of the techniques are given in Section 5.2.3.		

Table 5.8: BAT-AELs for direct emissions to a receiving water body

Parameter		Process	Unit	BAT-AEL (daily average)
Total suspended solids (TSS)		FGC Bottom ash treatment	mg/l	10–30
Total organic carbon (TOC)		FGC Bottom ash treatment		15–40
Metals and metalloids	As	FGC		0.01–0.05
	Cd	FGC		0.005–0.03
	Cr	FGC		0.02–0.08
	Cu	FGC		0.03–0.15
	Hg	FGC		0.001–0.01
	Ni	FGC		0.03–0.15
	Pb	FGC Bottom ash treatment		0.02–0.08
	Tl	FGC		0.005–0.03
	Zn	FGC		0.01–0.5
NH_4-N		Bottom ash treatment		10–30
SO_4^{2-}		Bottom ash treatment		400–1000
PCDD/F		FGC Bottom ash treatment	ng I-TEQ/l	0.01–0.1

The associated monitoring is in BAT 7.

[This BAT conclusion is based on information given in Sections 4.6.10, 4.6.11, 4.6.12, 4.6.13, 4.7.10]

5.1.7 Material efficiency

BAT 35. In order to increase resource efficiency and improve the recovery of useful materials from the incineration residues, BAT is to handle and treat bottom ashes separately from fly ashes and from other FGC residues, and to use a combination of the techniques given below.

	Technique	Description	Applicability
a.	Screening and sieving	Oscillating screens, vibrating screens and rotary screens are used for an initial classification by size before further treatment	Generally applicable
b.	Aeraulic separation	Aeraulic separation uses differences in density, particle size and particle shape to sort commingled materials. A narrow range of particle sizes is needed for effective separation.	Generally applicable
c.	Recovery of ferrous and non-ferrous metals	Different techniques are used, including: • magnetic separation for ferrous metals • eddy current separation non-ferrous metals • induction all-metal separation	Generally applicable
d.	Ageing	The ageing process stabilises the mineral fraction of the bottom ashes by uptake of atmospheric CO2, draining of excess water and oxidation. Bottom ashes, after metal separation, are stored in open air or in covered buildings for several weeks, generally on a concrete floor allowing for drainage and run-off water to be	Generally applicable

		collected for treatment. The stockpiles may be wetted, if required, to prevent dust emissions and to favour the leaching of salts and the carbonisation if the bottom ashes are not sufficiently wet.	
e.	Washing	Washing of bottom ashes enables the production of a material for recycling with minimal leachability of metals and anions (e.g. salts).	Generally applicable
f.	Crushing	Mechanical treatment operations intended to prepare materials for subsequent use, e.g. road and earthworks construction.	Generally applicable

[This BAT conclusion is based on information given in Section 4.7.2, 4.7.4, 4.7.5, 4.7.7, 4.7.8]

5.1.8 Noise and vibration

BAT 36. In order to prevent or, where that is not practicable, to reduce noise and vibration emissions, BAT is to use one or a combination of the techniques given below.

Technique		**Description**	**Applicability**
a.	Appropriate location of equipment and buildings	Noise levels can be reduced by increasing the distance between the emitter and the receiver and by using buildings as noise screens	Generally applicable to new plants. In the case of existing plants, the relocation of equipment may be restricted by lack of space or by excessive costs
b.	Operational measures	These include: • improved inspection and maintenance of equipment • closing of doors and windows of enclosed areas, if possible • equipment operated by experienced staff • avoidance of noisy activities at night, if possible • provisions for noise control during maintenance activities	Generally applicable
c.	Low-noise equipment	This includes low-noise compressors, pumps and fans	Generally applicable when the equipment is new or replaced
d.	Noise attenuation	Noise propagation can be reduced by inserting obstacles between the emitter and the receiver. Appropriate obstacles include protection walls, embankments and buildings	Generally applicable to new plants. In the case of existing plants, the insertion of obstacles may be restricted by lack of space
e.	Noise-control equipment/ infrastructure	This includes: • noise-reducers • equipment insulation • enclosure of noisy equipment • soundproofing of buildings	Generally applicable to new plants. In the case of existing plants, the applicability may be restricted by lack of space

[This BAT conclusion is based on information given in Section 4.8]

5.2 Descriptions of techniques

5.2.1 General techniques

Technique	Description
Advanced control system	The use of a computer-based automatic system to control the combustion efficiency and support the prevention and/or reduction of emissions. This also includes the use of high-performance monitoring of operating parameters and of emissions.
Optimisation of the incineration process	Optimisation of the temperature, flow rates and points of injection of the primary and secondary combustion air to effectively oxidise the organic compounds while reducing the generation of NO_X. Optimisation of the design and operation of the combustion chamber (e.g. flue-gas temperature, flue-gas and waste residence time, oxygen level, waste agitation).
Waste blending and mixing	Wastes are blended and/or mixed prior to incineration, e.g. by: • bunker crane mixing; • a feed equalisation system; • blending of compatible liquid and pasty wastes (subject to prior compatibility testing as required); in order to ensure stable combustion conditions, to increase the burnout and the destruction efficiency, and/or to reduce pollutant emissions. In some cases, solid wastes are shredded prior to mixing.

5.2.2 Techniques to reduce emissions to air

Technique	**Description**
Bag filter	Bag or fabric filters are constructed from porous woven or felted fabric through which gases are passed to remove particles. The use of a bag filter requires the selection of a fabric suitable for the characteristics of the flue-gas and the maximum operating temperature.
Boiler sorbent injection	Direct injection of dedicated alkaline reagents into the boiler at a high temperature, in the boiler post-combustion area, to achieve partial abatement of the acid gases. The technique is highly effective for the removal of SO_2 and HF, and provides additional benefits in terms of flattening emission peaks.
Catalytic filter bags	Filter bags are either impregnated with a catalyst, or the catalyst is directly mixed with organic material in the production of the fibres used for the filter medium. Such filters can be used to reduce PCDD/F emissions as well as, in combination with a source of NH_3, to reduce NO_X emissions.
Direct desulphurisation	The addition of magnesium- or calcium-based adsorbents to the bed of a fluidised bed furnace. The surface of the sorbent particles reacts with the SO_2 in the fluidised bed boiler.
Dry sorbent injection	The injection and dispersion of a dry powder sorbent in the flue-gas stream. Alkaline sorbents (e.g. sodium carbonate, sodium bicarbonate, hydrated lime) are injected to react with acid gases (HCl, HF and SO_2). Activated carbon is injected or co-injected to adsorb in particular PCDD/F and mercury. The resulting solids are removed, most often with a bag filter.
Electrostatic precipitator	Electrostatic precipitators operate such that particles are charged and separated under the influence of an electrical field. Electrostatic precipitators are capable of operating under a wide range of conditions. Abatement efficiency may depend on the number of fields, residence time (size), and upstream particle removal devices. They generally include between two and five fields.
Flue-gas recirculation	Recirculation of part of the flue-gas to the combustion chamber to replace part of the fresh combustion air, with the dual effect of cooling the temperature and limiting the O_2 content for nitrogen oxidation, thus limiting the NO_X generation. It implies the supply of flue-gas from the furnace into the flame to reduce the oxygen content and therefore the temperature of the flame.
Low-NO_X burners	The technique is based on the principles of reducing peak flame temperatures; low-NO_X burners are designed such as to delay but improve the combustion and increase the heat transfer (increased emissivity of the flame). The air/fuel mixing reduces the availability of oxygen and reduces the peak flame temperature, thus retarding the conversion of fuel-bound nitrogen to NO_X and the formation of thermal NO_X, while maintaining high combustion efficiency.
Selective catalytic reduction (SCR)	Selective reduction of nitrogen oxides with ammonia or urea in the presence of a catalyst. The technique is based on the reduction of NO_X to nitrogen in a catalytic bed by reaction with ammonia (in general, aqueous solution; the ammonia source can also be anhydrous ammonia or a urea solution) at an optimum operating temperature of around 300–450 °C. Several layers of catalyst may be applied. A higher NO_X reduction is achieved with the use of several layers of catalyst. 'In-duct' or 'slip' SCR combines SNCR with downstream SCR which reduces ammonia slip from SNCR.
Selective non-catalytic reduction (SNCR)	Selective reduction of nitrogen oxides to nitrogen with ammonia or urea at high temperatures and without catalyst. The operating temperature window is maintained between 800 °C and 1000 °C for optimal reaction.
Semi-wet absorber	Also called semi-dry. An alkaline aqueous solution or suspension (e.g. lime milk) is added to the flue-gas stream to capture the acidic compounds from the flue-gas. The water evaporates and the reaction products are dry. The residue may be recirculated to improve reagent utilisation. This technique includes a range of different designs, including *flash-dry* processes which consist of injecting water (providing for fast gas cooling) and reagent at the filter inlet.
Wet scrubber	Use of a liquid, typically water or an aqueous solution/suspension, to capture pollutants from the flue-gas, in particular acidic compounds by absorption, as well as other soluble compounds and solids. Different types of scrubber designs are used, e.g. jet scrubbers, rotation scrubbers, Venturi scrubbers, spray scrubbers and packed tower scrubbers.

5.2.3 Techniques to reduce emissions to water

Technique	**Description**
Adsorption on activated carbon	The removal of soluble substances (solutes) from the waste water by transferring them to the surface of solid, highly porous particles (the adsorbent). Activated carbon is typically used for the adsorption of organic compounds and mercury.
Chemical precipitation	The conversion of dissolved pollutants into insoluble compounds by adding chemical precipitants. The precipitates are subsequently separated by sedimentation, flotation or filtration. If necessary, this may be followed by microfiltration or ultrafiltration. Typical chemicals used for metal precipitation are lime, dolomite, sodium hydroxide, sodium carbonate, sodium sulphide and organosulphides. Calcium salts (other than lime) are used to precipitate sulphate or fluoride.
Coagulation and flocculation	Coagulation and flocculation are used to separate suspended solids from waste water and are often carried out in successive steps. Coagulation is carried out by adding coagulants with charges opposite to those of the suspended solids. Flocculation is carried out by adding polymers, so that collisions of microfloc particles cause them to bond thereby producing larger flocs.
Equalisation	Balancing of flows and pollutant loads at the inlet of the final waste water treatment by using central tanks. Equalisation may also be decentralised or carried out using other management techniques.
Filtration	The separation of solids from waste water by passing it through a porous medium. It includes different types of techniques, e.g. sand filtration, microfiltration and ultrafiltration.
Flotation	The separation of solid or liquid particles from waste water by attaching them to fine gas bubbles, usually air. The buoyant particles accumulate at the water surface and are collected with skimmers.
Ion exchange	The removal of ionic pollutants from waste water and their replacement by more acceptable ions by transferring them to an ion exchange resin. The pollutants are temporarily retained and afterwards released into a regeneration or backwashing liquid.
Neutralisation	The adjustment of the pH of the waste water to neutral (approximately 7) by adding chemicals. Sodium hydroxide (NaOH) or calcium hydroxide ($Ca(OH)_2$) is generally used to increase the pH whereas sulphuric acid (H_2SO_4), hydrochloric acid (HCl) or carbon dioxide (CO_2) is used to decrease the pH. The precipitation of some substances may occur during neutralisation.
Oil-water separation	The removal of free oil from waste water by mechanical treatment using devices such as the American Petroleum Institute separator, a corrugated plate interceptor, or a parallel plate interceptor. Oil-water separation is normally followed by flotation, supported by coagulation/flocculation. In some cases, emulsion breaking may be needed prior to oil-water separation.
Oxidation	The conversion of pollutants by chemical oxidising agents to similar compounds that are less hazardous and/or easier to abate. In the case of waste water from the use of wet scrubbers, air may be used to oxidise sulphite (SO_3^{2-}) to sulphate (SO_4^{2-}).
Reverse osmosis	A membrane process in which a pressure difference applied between the compartments separated by the membrane causes water to flow from the more concentrated solution to the less concentrated one.
Sedimentation	The separation of suspended solids by gravitational settling.
Stripping	The removal of volatile pollutants (e.g. ammonia) from waste water by contact with a high flow of a gas current in order to transfer them to the gas phase. The pollutants are removed from the stripping gas in a downstream treatment and may potentially be reused.

6 EMERGING TECHNIQUES

An emerging technique is understood in this document as a novel technique that has not yet been applied in any industrial sector on a commercial basis. This chapter contains those techniques that may appear in the near future and that may be applicable to the waste incineration sector.

~~6.1 Use of steam as a spraying agent in post combustion chamber burners instead of air~~

For the TWG: if possible please provide up-to-date information on this technique.

~~**Reference**~~

~~[40, EURITS, 2003]~~

6.2 ~~Application involving the r~~ Reheating of turbine steam

For the TWG: is it an emerging technique for the WI sector? If possible, please provide up-to-date information.

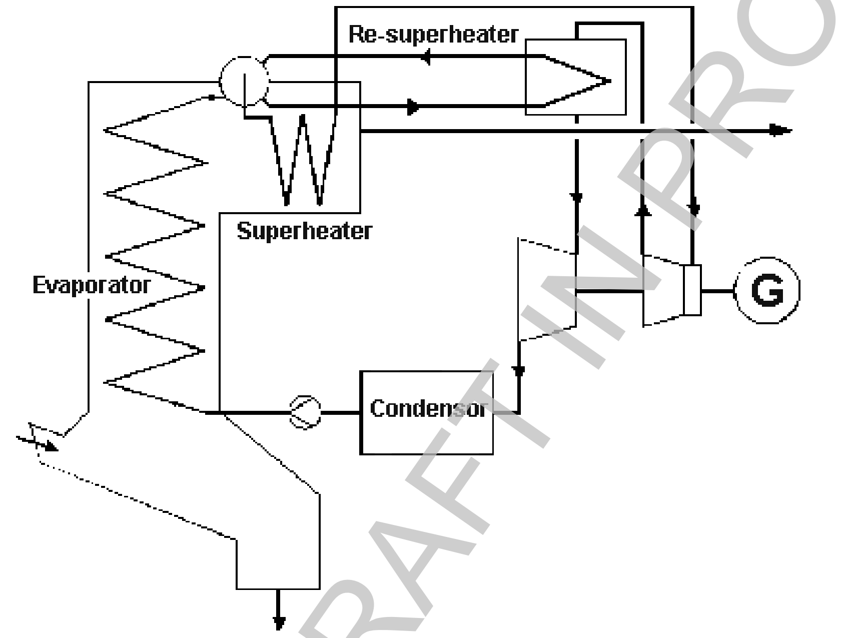
Description

Reheating steam after the first pass through the steam turbine to increase electricity production.

Technical description

[2, infomil, 2002] p 49

Another option to increase the efficiency of electricity production is the reheating of turbine steam after its first passage through the turbine. For this application, the steam temperature is limited to 400 °C, but the steam pressure increases. The figure below provides a simplified process scheme for this option.



Source: [2, infomil, 2002]

Figure 6.1: Example of the reheating of steam

After the first passage through the high-pressure section of the turbine, the resulting steam is superheated again and subsequently used in the turbine's mid- and low-pressure sections.

Usually, after expanding in the HP turbine, the steam has a lower pressure (typically 20 % of the pressure it had on entering) and is reheated with flue-gas in the boiler to the same temperature. According to the simplified drawing (see Figure 6.1), the steam is heated with either boiler water or saturated steam.

Achieved environmental benefits

Increased electrical efficiency by approximately 2–3 %.

Environmental performance and operational data

This option has never been used for ~~municipal~~ waste incineration, although technological risks are considered to be limited.

Cross-media effects

None reported.

Technical considerations related to applicability
No information provided.

Economics
Application may be influenced by economic feasibility, which is mainly determined by the additional investment costs and by electricity prices.

Driving force for implementation
Increased electrical energy efficiency.

Example plants
No information provided.

Reference literature
[2, infomil, 2002], p49

6.3 Other measures in the crude flue-gas area for reducing dioxin emissions

For the TWG: are they still emerging techniques? If possible, please provide up-to-date information on these techniques preferably using the WIQ main Annex 1.

[1, UBA, 2001] A reduction in dioxins can be achieved through the following measures in the crude flue-gas area, which seek to reduce dioxin formation by inhibiting the reactions or reducing the presence of dusts in the temperature range between 450 °C and 200 °C:

- addition of inhibitors to the waste - efficiency is limited and secondary reactions require consideration;
- employment of hot gas dedusters - so far there is only little experience from pilot tests:
    - dedusting using ceramic filters or cyclones at temperatures of approximately 800 °C,
    - dedusting at temperatures above 450 °C, e.g. with hot gas electrostatic filters;
- reduction of deposits of airborne dust in the flue-gas path by effective cleaning of flue-gas vents, boiler, heating plates - a well-proven maintenance-related issue.

6.4 Oil scrubber for the reduction of polyhalogenated aromatics and polyaromatic hydrocarbons (PAHs) in the flue-gases from incineration plants

For the TWG (especially Germany): please provide up-to-date information on this technique. Is there any example WI plant?

Description

Oil is used as scrubbing liquor in a wet scrubber to absorb organic compounds.

Technical description

Dioxins and furans have very low solubility in water and therefore they are not removed in wet scrubbers to a significant and reliable extent. Any removal which does take place is generally due to the removal of PCDD/F that are adsorbed onto particulate matter removed in the wet scrubber. At best, there is some depletion by condensation of, predominantly, the higher molecular weight hexa- to octa- species from the gas phase into the relatively cold wash liquor. However, dioxins and furans (and many other organic species) are more lipophilic. A high-boiling partly unsaturated oil or an oil-water emulsion of such oil therefore provide suitable scrubbing media.

Achieved environmental benefits

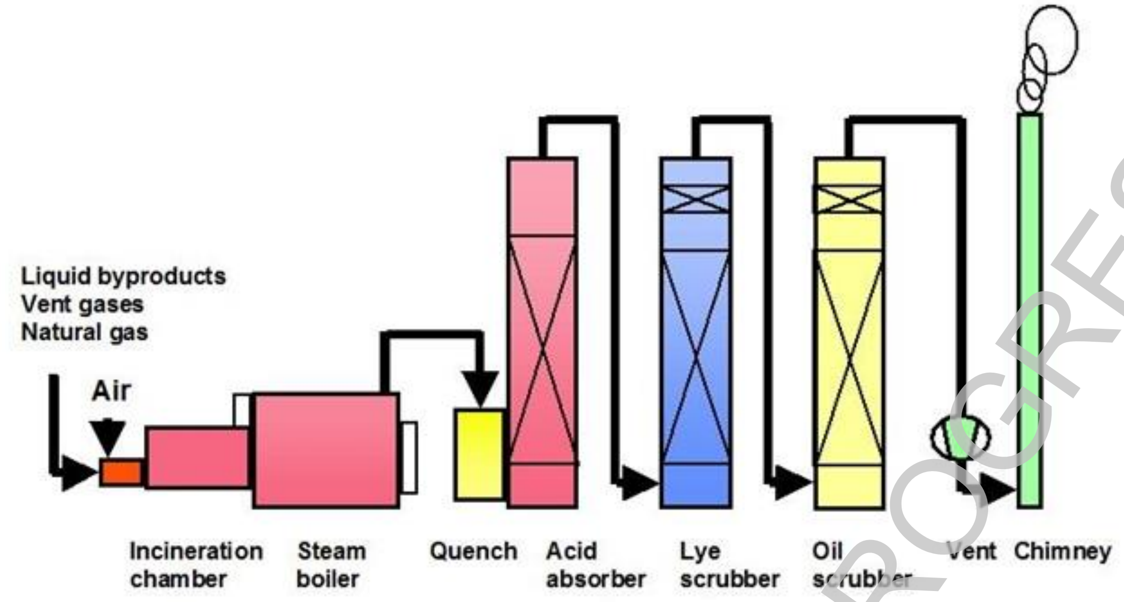
Reduction of emissions to air of organic compounds.

Environmental performance and operational data

The oil/emulsion and absorbed dioxins and furans are exchanged and disposed of as soon as they reach a limit value of 0.1 mg/kg. The supply quantity is determined so that there is an exchange three to four times a year. This helps prevent excessive ageing of the oil. The contaminated liquor is incinerated in the furnace. To do this, the oil is pumped into a slop wagon (a mobile tank with safety installations) and from there fed directly into a burner in the incineration plant.

This process includes a countercurrent scrubber column as its tertiary cleaning stage with a closed oil circuit (see Figure 6.2).

To minimise the number of oil-carrying plant components, a sump is used as a scrubbing media reservoir. The circulation flow rate is determined according to the packing cross-section. The oil/emulsion is heated by a heat exchanger to approximately 15–20 °C above the flue-gas temperature to prevent water from condensing from the vapour-saturated gas.



Source: [1, UBA, 2001]

Figure 6.2: Schematic of a waste incineration plant with a downstream oil scrubber for dioxin deposition

Cross-media effects

No information provided.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

Reduction of emissions of organic compounds.

Example plants

No information provided.

Reference literature

[1, UBA, 2001]

6.5 Production of sodium carbonate using the ~~of~~ CO_2 in flue-gases ~~for the~~

For the TWG (especially Germany): is this still a technique to consider for the WI sector? Please provide up-to-date information.

Description

Caustic soda reacts with the CO_2 in the cleaned flue-gas to produce a solution of sodium carbonate.

Technical description

[1, UBA, 2001] When ~~If~~ the flue-gas is brought into contact with caustic soda solution, the carbon dioxide reacts with the sodium hydroxide to form sodium carbonate. The liquid is odourless and colourless. The carbonate solution may be used as a raw material, e.g. chemical plants, paper industry.

In this process, the flue-gas quantity required for the generation of carbonate is drawn off in a controlled flow at the end of flue-gas cleaning and directed into a CO_2 absorption column. The absorption column is made of glass-fibre-reinforced plastic material and contains plastic packing material. Caustic soda solution is added to the head of the column. The caustic soda runs through the packing material and makes contact with the flue-gas rising in the reverse current. This causes carbon dioxide and sodium hydroxide to react and form sodium carbonate and water.

$$CO_2 + 2\ NaOH \rightarrow Na_2CO_3 + 2\ H_2O$$

The flue-gas escapes from the column into the atmosphere via a mist eliminator. The mist eliminator may be cleaned using soft water (fresh water) which is supplied on demand via a flow controller.

The carbonate solution is drawn from the sump of the column and pumped to the consumer installations with a pump via a level control installation. Quantity, pH value, NaOH and carbonate concentration are recorded with adequate measuring devices. The concentration values serve to control the caustic soda quantity to the column.

There is however a significant consumption of caustic soda; and the release of CO_2, generated in the soda production process, should also be considered.

Achieved environmental benefits

Reduction of CO_2 emissions.

Environmental performance and operational data

No information provided.

Cross-media effects

No information provided.

Technical considerations relevant to applicability

Generally applicable.

Economics

No information provided.

Driving force for implementation

Production of sodium carbonate.

Example plants

No information provided.

Reference literature

No reference literature provided.

6.6 ~~Increased bed temperature, combustion control and oxygen addition in a grate incinerator~~

For the TWG: Information provided by Austria is that this technique has been operating successfully at the Arnoldstein MWI since 2004, so they proposed that it should be considered an established technique. The information has now been added to Section 4.3.13.

~~Description~~
~~The basic concept of this process (known as the SYNCOM plus process) is the integrated sintering of ash in the waste bed of a grate based energy from the waste incinerator.~~

~~Higher bed temperatures are used to melt or sinter 50 – 80 % of the bottom ash. The unmelted fraction protects the grate from clogging.~~

~~An infrared camera signal is used to control the under fire air heating and oxygen enrichment in such a way that an appropriate range of waste bed temperatures is maintained.~~

~~Reverse acting grates are best suited to the technique because they maintain a cover of un-melted ash that protects the grate from the higher temperatures employed.~~

~~The non-sintered fraction is separated by a screening and washing process and then recirculated to the combustion process.~~

~~In addition 75 % of fly ashes (boiler ash and first stage dust removal step ash - not FGC residues from acid gas cleaning) may be re-circulated to the combustion stage. The high bed temperatures and wet mechanical treatment of the discharged granulate ash ensures that the fly ash re-circulation does not contaminate the granulate product.~~

~~Achieved environmental benefits~~
~~A completely sintered, well burned out, low leaching residue is produced:~~

~~Table 6.1: Residue quality using SYNCOM system~~

	~~Conventional WTE plants~~	**~~SYNCOM~~**	**~~SYNCOM plus~~**
~~Loss on ignition~~	~~2 %~~	~~1 %~~	~~0.1 %~~
~~Leaching of lead (mg/l)~~	~~0.2~~	~~0.05~~	~~0.01~~
~~PCDD/F content (ng TEQ/kg)~~	~~15~~	~~8~~	~~0.3~~
~~Source:~~ ~~[36, Gohlke, 2002]~~			

~~The system also:~~

- ~~reduces overall plant dioxin discharges (<5ug I-TEQ/t of waste input)~~
- ~~reduces volumes of fly ashes~~
- ~~reduces flue-gas volumes by approx. 35 %.~~

~~Cross-media effects~~
~~Consumption of oxygen.~~

~~Operational data~~

~~Applicability~~
~~Applicable to grate incinerators.~~

~~Economics~~
~~5 – 10 % increase in overall plant investment costs.~~
~~Reductions in disposal costs for residues, with income possible from sales of granulate as an aggregate replacement.~~

~~Driving force for implementation~~

~~Example plants~~
~~Coberg, Germany~~
~~Under construction: Arnoldstein, Austria and others in Japan~~
~~Large scale pilot plant in Japan with Mitsubishi Heavy Industries.~~

~~Reference literature~~
~~[36, Gohlke, 2002]~~

6.7 The PECK combination process for MSW treatment

For the TWG: please provide up-to-date information on this technique.

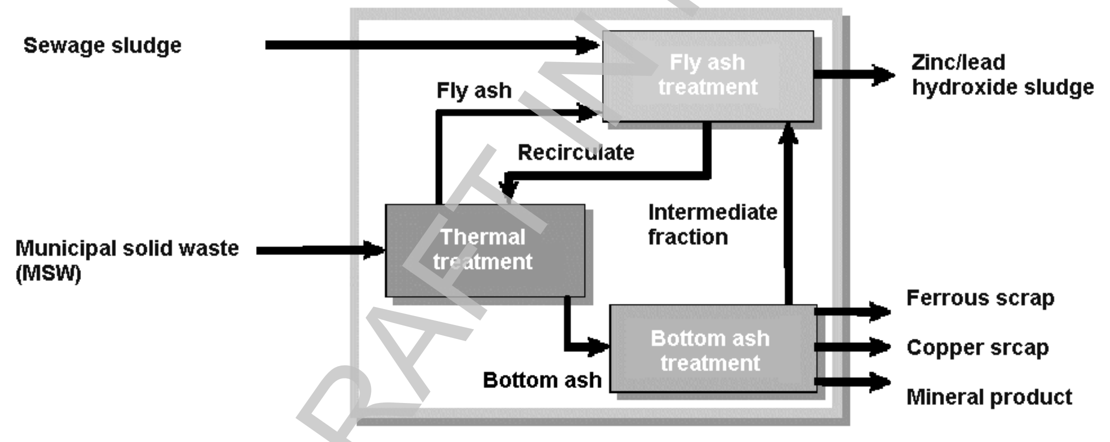
Description

Incineration of MSW in a two-stage process consisting of gasification followed by high-temperature incineration in a rotary kiln. Fly ash is mixed with sewage sludge and fed into the rotary kiln. The high temperature in the rotary kiln produces a semi-vitrified bottom ash with low leachability. Ferrous and non-ferrous metals are recovered from the bottom ash.

Technical description

The main features of this process are:

- use of a first-stage sub-stoichiometric gasifying grate at 950 °C;
- recycling of treated fly ashes to the grate (see fly ash pretreatment description below);
- followed by a rotary kiln with a gas temperature of 1 400 °C (1 300 °C bed) with an excess air ratio of 1.1 to 1.3 over stoichiometric;
- the high temperature in the rotary kiln melts the mineral materials;
- water quench of residues to form a glass-like phase.

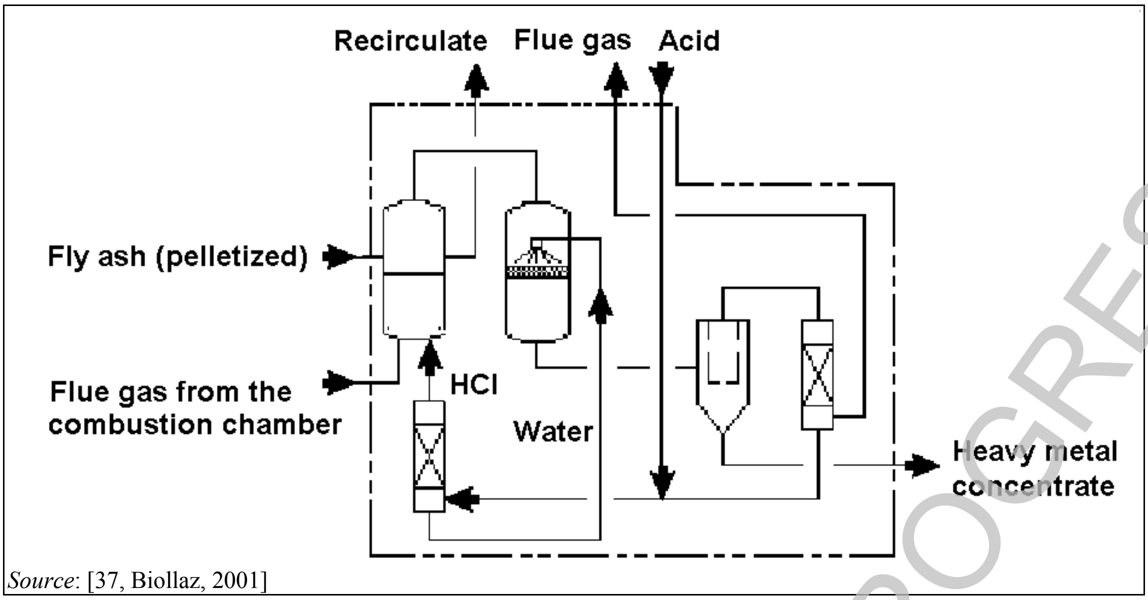


Source: [37, Biollaz, 2001]

Figure 6.3: Basic components of the PECK process

Fly ash pretreatment

Before recirculating to the grate, fly ashes collected in the boiler and ESP are mixed with dewatered sewage sludge and fed to a pelletiser. The resulting dry pellets are treated in a fluidised bed reactor, where chlorination and evaporation of the metals take place at 900 °C. The evaporation reactor is heated by flue-gas from the post-combustion chamber. This gas stream has a temperature sufficiently high to operate the reactor. Only a small portion of the total flue-gas is used, i.e. approximately 2 %.



Source: [37, Biollaz, 2001]

Figure 6.4: Fly ash treatment in the PECK process

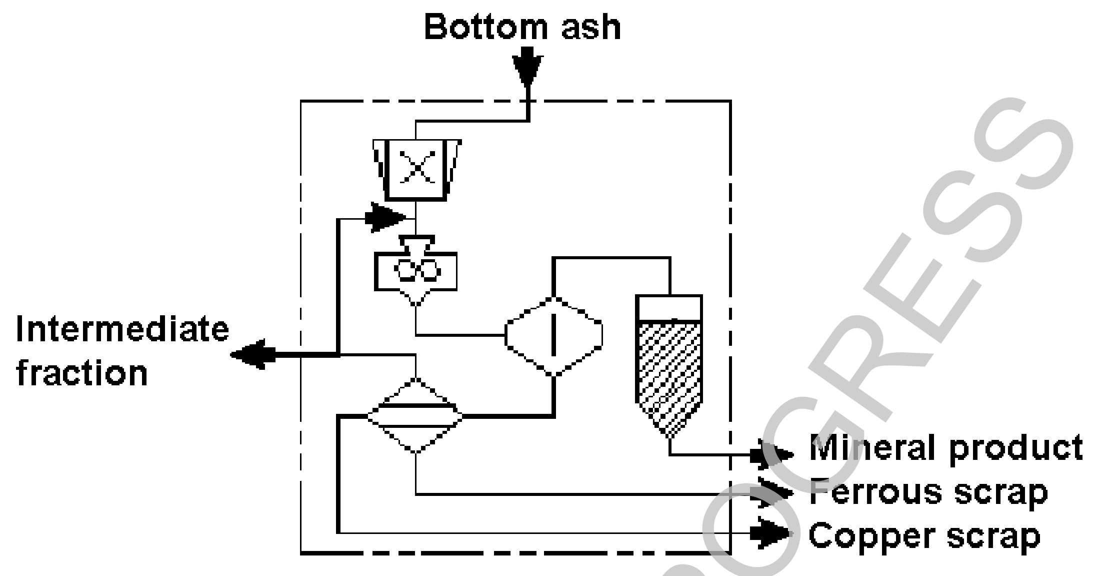
The evaporated metals leave the fluidised bed reactor together with the flue-gas. By a partial quench, the heavy metals are condensed and filtered afterwards. After this, surplus hydrochloric acid is separated from the flue-gas in the scrubber. The flue-gas is then fed back to the scrubber of the incineration plant for final cleaning and leaves the plant via the stack. Hydrochloric acid is produced in an internal loop from the washing water of the scrubber of the fly ash treatment by a distillation system. Hydrochloric acid make-up comes from the scrubber of the incineration plant. The depleted washing water is used as quenching water.

The depleted fly ash, the recirculate, is removed from the evaporation reactor and fed back through a buffer silo to the grate. The filtered heavy metal concentrate is then transported to the zinc and lead refining industry.

Bottom ash treatment

Directly after the high-temperature process, the bottom ash is quenched in a water bath and forms glass-like phases. After the separation of scrap metal, the bottom ash is crushed in a hammer crusher. The crusher has a discharge grate with a 16 mm gap and a discharge for oversize ferrous scrap. This scrap is separated manually into valuable material fractions.

Afterwards, further breakage is achieved in a ball mill which is followed by an air classifier with a separation cut of approximately 0.5 mm. The milling and separation unit also works as a dryer which is operated with surplus heat from the thermal process. The oversize scrap from the separator is fed to a magnetic separator and an eddy current unit, separating the ferrous metals from the non-ferrous metals, such as copper.



Source: [37, Biollaz, 2001]

Figure 6.5: Bottom ash treatment in the PECK process

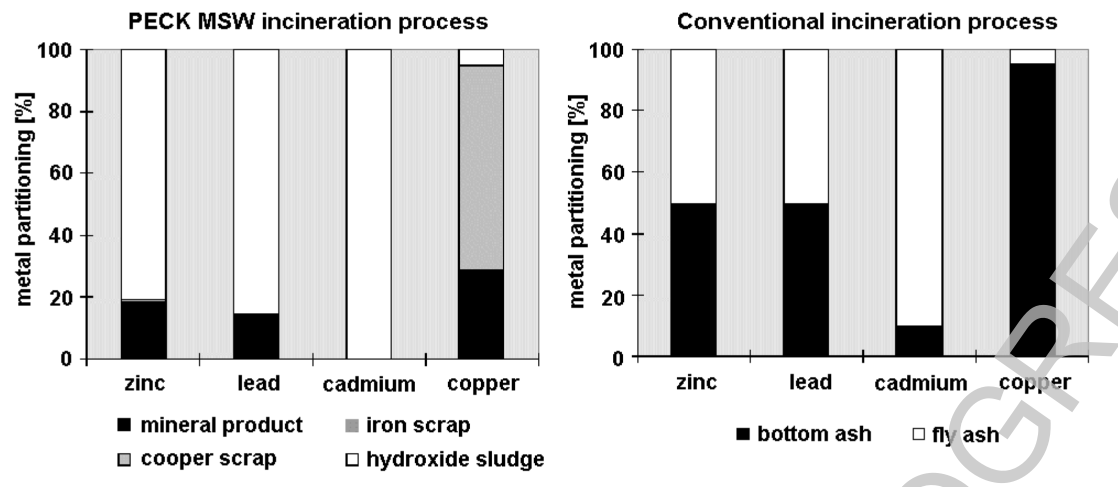
Since the efficiency of the eddy current separation of non-ferrous metal drops sharply at particle sizes below approximately 4 mm, the metal fines accumulate in the grinding circuit. Therefore, a small amount of the circulating load is bled off into the fly ash treatment process. This product fraction, the so-called intermediate fraction, consists of approximately 1 % of the entire bottom ash that is being processed. The air classifier undersize scrap is recovered by cyclones and electrostatic filters and stored in silos.

Achieved environmental benefits

The key environmental benefits over and above conventional MSWI processes are:

- production of a semi-vitrified lower leaching bottom ash residue;
- vitrification is an internal process - no external energy is required;
- reduced fly ash volumes;
- reduction in overall dioxin outputs by destruction in the incinerator;
- concentration of heavy metals into a smaller volume of solid waste (possibly recoverable);
- emissions of oxides of nitrogen to air are reduced by the air staging process.

Partitioning of the heavy metals zinc, lead, cadmium and copper between the different output flows is shown in Figure 6.6 below and is compared to conventional incinerators. It can be seen that the process leads to reduced heavy metals in the mineral residues compared to conventional incinerators. Therefore the objective of metal-depleted mineral residues is achieved. At the same time, the majority of these heavy metals are concentrated into potentially recyclable metal concentrates.

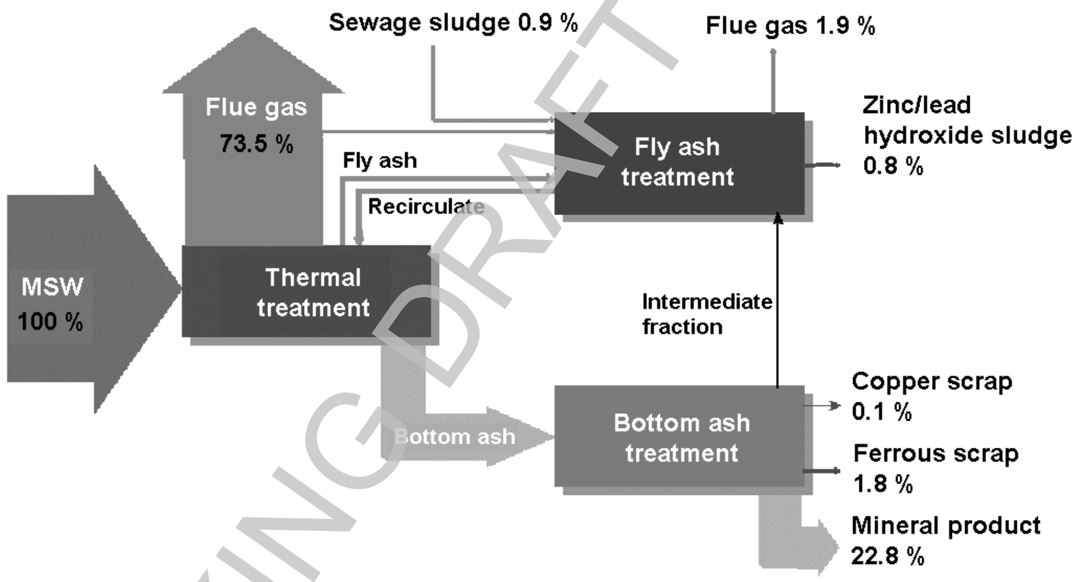


Source: [37, Biollaz, 2001]

Figure 6.6: Comparison of metals partitioning between a conventional grate MSWI and the PECK process

Environmental performance and operational data

The most relevant mass flows within the PECK process are shown in Figure 6.7 below. The flows are normalised to the input stream 'MSW', which corresponds to 100 %. The most relevant material flows produced by the MSWI are the flue-gas and the mineral product.



Source: [37, Biollaz, 2001]

Figure 6.7: Material flow mass balance for the PECK process

The flue-gas contains the combustion products from the organic material of MSW and water. The bottom ash, i.e. the mineral product, consists of minerals such as silica and calcium originally contained in MSW, and sewage sludge. The heavy metals are concentrated in the output flows hydroxide sludge, ferrous and copper scrap. The heavy metals flow via the mineral product and the purified flue-gas are negligible.

The bed temperature of the rotary kiln (1 300 °C) is low enough to prevent iron from melting and forming unwanted alloys, e.g. with copper.

Cross-media effects
No adverse effects identified.

The overall electrical efficiency of the PECK process is supposed to be comparable to that of conventional MSWI including the internal electricity consumption.

Technical considerations relevant to applicability
The process has been developed for municipal solid waste but could in principle be applied to other wastes.

The process is preferably equipped with a conventional wet flue-gas purification unit. HCl is needed for the treatment of the fly ash and can be recovered from the washing water.

Economics
Lower operational costs for the waste treatment are obtained, as the costs for the disposal of residues are significantly reduced, while the investment and operating costs are higher than conventional MSW incinerators.

Driving force for implementation
The main driving forces for the adoption of this technique are:

- the need to improve bottom ash quality;
- the need to reduce quantities of fly ash;
- the high prices for residue disposal.

Example plants
The process is reported to have been investigated at a MSWI in Basel, Switzerland.

Reference literature
[37, Biollaz, 2001]

~~6.8 $FeSO_4$ stabilisation of FGC residues~~

For the TWG: This technique has been deleted because it is not for the incineration bottom ash/slag.

~~Description~~

~~This stabilisation involves a five-step procedure, where the residues are first mixed with a $FeSO_4$ solution and then aerated with atmospheric air at liquid/solid ratio of 3 l/kg, in order to oxidise Fe(II) to Fe(III) and precipitate iron oxides. This step also includes extraction of soluble salts. The pH of The suspension is then maintained at pH 10 - 11 for about 0.5 to 1 hour to allow dissolved heavy metals to bind to the precipitated iron oxides. The fourth step of the process is dewatering of the treated residues and finally a washing step to exchange remaining water and remove remaining salts. The final stabilised product has a water content of about 50 %.~~

~~Achieved environmental benefits~~

~~The main advantage is improved leaching properties of the final product. The leaching characteristics of treated residues are shown to be very good (Lundtorp, 2001), and it is expected that low release of heavy metals can be maintained for extended periods of time, as iron oxides are known to endure in geological time frames. The pollution potential of the treated residues is well documented and the treated residues are expected to be less prone to physical disintegration than cement stabilised products, since most of the salts are removed. The stabilised residues typically have far better leaching properties than cement solidified residues.~~

~~The process reduces the amount of residue by about 10 % per dry weight.~~

~~Environmental performance and operational data~~

~~The process has been demonstrated on a pilot scale at a plant, treating residues in batches of about 200 kg dry weight. Parameters such as - water consumption, mixing of water and residues, Fe(II) oxidation rate, reaction time, pH and a pH controlling additive - have all been optimised. It has been demonstrated that the process is robust with respect to the properties of the residue input, although some variations in process parameters arise. Typical process data are for 1 tonne of residue: 10 - 50 kg Fe, 20 - 50 minutes aeration, 30 - 60 minutes reaction time, H_2SO_4 or $FeSO_4$ as the pH controlling additives, optimum pH of 10 - 11, and a water consumption of 3 - 4 m^3. In the current set up, dewatering of the treated residues was achieved by using a plate and frame filter press.~~

~~Cross-media effects~~

~~No reutilisation strategies have yet been demonstrated.~~

~~The process produces waste water with a high content of salts and relatively low concentrations of metals, because Fe(II) is present in the extraction step. The waste water can, in most cases, be discharged to a marine recipient after a simple treatment or can be de-ionised by crystallisation.~~

~~Technical considerations relevant to applicability~~

~~The stabilisation unit can be implemented as an integrated part of the incinerator but may also exist as a centralised treatment plant handling residues from several incinerators. The technique has been demonstrated on semi-dry FGC residues as well as fly ash alone and fly ash combined with sludge from the wet scrubbers (Bamberg product); all with good results.~~

~~Economics~~

~~Treatment cost for a stabilisation process, called Ferrox, is estimated to about EUR 65/tonne with a plant capacity of 20 000 tonne/yr; including investment costs.~~

~~Driving force of implementation~~

~~The main reason for implementing this technology is the very good leaching properties of the treated residues, and the fact that this is expected to last in the long term.~~

~~Example plants~~

~~The process has only been demonstrated at pilot scale, although it has also been designed for full-scale operation. No full-scale plants have yet been established.~~

~~6.9 CO_2 stabilisation of FGC residues~~

For the TWG: This technique has been deleted because it is not for the incineration bottom ash/slag.

~~Description~~

~~This stabilisation resembles in many respects the $FeSO_4$ stabilisation process, however the chemical agents used here are CO_2 and/or H_3PO_4. The process involves a two-step procedure. The residues are first washed at L/S 3 l/kg, in order to extract soluble salts, and then dewatered and washed again in a plate and frame filter press at L/S 3 l/kg. The residues are then re-suspended, and CO_2 and/or H_3PO_4 is added. The stabilisation reactions are allowed to occur for 1 – 1.5 hours while the pH decreases, and another hour where the pH is maintained around pH 7.~~

~~Finally, the residues are dewatered again and washed at the filter press with another 3 l/kg. The final product has a water content of about 50 %. The use of CO_2 and H_3PO_4 as the stabilising agent ensures that the heavy metals are bound as carbonates or phosphates.~~

~~Achieved environmental benefits~~

~~CO_2 stabilisation shows very good leaching properties similar to the Ferrox stabilisation. Metal carbonates and phosphates are known to generally have low solubility, and the leaching characteristics of CO_2 stabilised residues are expected to remain good for extended periods of time. The pollution potential of the treated residues is documented in detail. The physical disintegration of the treated residues in the long-term is expected to be less significant with this technique than with cement stabilisation, since most of the salts are removed. CO_2 stabilised residues typically have far better leaching properties than cement solidified residues.~~

~~The CO_2 stabilisation process reduces the amount of residue by about 15 % per dry weight.~~

~~Environmental performance and operational data~~

~~The process has been demonstrated at pilot scale at a plant treating residues in batches of about 200 kg dry weight. Parameters such as water consumption, mixing of water and residues, CO_2 and H_3PO_4 addition, reaction time, pH and pH controlling approach have all been optimised. It has been demonstrated that the process is robust with respect to the properties of the residue input, although some variations in process parameters arise. Depending on residue composition, either CO_2 or H_3PO_4 or both have been used. It has also been demonstrated that flue-gases from the incineration plant can be used as the CO_2 source.~~

~~The typical process requirements for the treatment of 1 tonne of residues are: 5 – 20 kg of CO_2, 0 – 40 kg H_3PO_4 and 3 m^3 of water.~~

~~Cross-media effects~~

~~No reutilisation strategies have yet been demonstrated. The process produces waste water from the first dewatering step. All other process water is recycled in the process. The waste water needs to be treated for dissolved heavy metals in a standard unit, for example using pH adjustment and TMT addition.~~

~~Technical considerations relevant to applicability~~

~~The stabilisation unit can be implemented as an integrated part of the incinerator but may also exist as a centralised treatment plant handling residues from several incinerators. The technique has been demonstrated on semi-dry FGC residues as well as on fly ash alone and on fly ash combined with sludge from the wet scrubbers (Bamberg product); all with good results.~~

~~Economics~~

~~The treatment cost for a CO_2 stabilisation using this process is estimated to be about EUR 80/tonne ash with a plant capacity of 200 000 tonne/yr; including investment costs.~~

~~Driving force for implementation~~

~~The main reason for implementing this technology is the very good leaching properties of the treated residues and the fact that this is expected to last in a long-term perspective.~~

~~**Example plants**~~

~~The process has only been demonstrated in pilot scale, although it has also been designed for full-scale operation. No full-scale plants have yet been implemented.~~

~~6.10 Overview of some other emerging FGC residue treatment techniques~~

For the TWG: These techniques have been deleted because they are not for the incineration bottom ash/slag. According to the description given of the 'Treatment for supply to cement industry' the bottom ash is not treated but it is fed without treatment into the cement kiln.

~~Treatment for supply to cement industry~~
~~This system converts bottom ash, fly ash and neutralisation residues into a material that can be used in cement kilns.~~

~~In this process, combined neutralisation residues and fly ash (as found with dry and semi-wet FGC systems without pre-dedusting) are first washed with water to remove the highly leachable chlorides. The insoluble fraction is fed to the cement kiln together with the bottom and fly ash, substitution (in part) for limestone. The waste water is then cleaned in a WWT plant to precipitate the heavy metals. The filter cake is then fed to the cement kiln if the HM content is below acceptance levels, or may be further treated. The cleaned waste water is discharged to a municipal sewage system.~~

~~Another process (only at the pilot plant stage) also aims to supply materials to the cement industry. In this case, residue form lime based dry and semi-dry FGC systems are separated to give an inert fraction (approximately 70 wt %) that is mainly oxides for use in the cement kiln, a further fraction (approximately 25 wt %) of sodium and calcium chlorides, and the remaining fraction that contains the heavy metals. The process involves a number of steps including washing, soda contact and filtering.~~
[64, TWGComments, 2003]

~~Heavy metal evaporation process~~
~~Fly ash is heated to around 900 ºC in an atmosphere enriched with hydrochloric acid. The heavy metals are volatilised as chlorides and then condensed on a filter where they concentrate to such an extent that recycling may be possible. The remaining fly ash is thus cleaned and may be used for construction. When sited on an existing incineration site the flue-gases evolved may be treated in the existing FGC system, and the HCl may be drawn from a wet scrubber.~~

~~The process has not been demonstrated on a commercial scale plant.~~
~~[64, TWGComments, 2003]~~

~~Hydro-metallurgical treatment + vitrification~~
~~In this process hydrometallurgical treatment allows the removal of heavy metals and salts. The subsequent vitrification of the fly ash produces a slag which may be used for construction.~~

~~The process is reported to be applicable to several ash compositions and to have been demonstrated on a semi-industrial scale. The process is applied at one MSWI in France burning 120 000 tonnes MSW/yr and producing 3 500 tonnes/yr of treated FGC residues from this treatment process.~~
~~[TWGComments, 2003 #64,[64, TWGComments, 2003, 73, Rijpkema, 2000]~~

6.11 Application of membrane technology for use in waste water treatment plants for wet scrubber effluents

For the TWG: please provide up-to-date information on this technique.

Description and technical description
See Section 2.6.4.3.

Achieved environmental benefits
Information not provided.

Environmental performance and operational data
Information not provided.

Cross-media effects
Information not provided.

Technical considerations relevant to applicability
Information not provided.

Economics
Information not provided.

Driving force for implementation
Information not provided.

Example plants
Information not provided.

~~6.12 Combined dry sodium bicarbonate + SCR + scrubber FGT systems~~

For the TWG: This is not a new technique. It is one of many possible combinations of techniques (basically, addition of a polishing scrubber, already described in Chapters 2 and 4), and it is unclear why it should be singled out as an emerging technique.

~~Description~~
~~This technique consists in combining dry FGT with sodium bicarbonate with a SCR system and a scrubber.~~

~~As sodium bicarbonate presents a wide operating temperature range (140 – 300 °C) and leads to SO$_X$ emissions below 20 mg/Nm^3 (SO$_3$ included), it ideally combines with an SCR without reheating the FG; although FG reheat maybe needed if stack temperature is too low after wet scrubber. [74, TWGComments, 2004]~~

~~A scrubber placed after the SCR will remove the remaining HCl. As the amount of HCl removed is very low, the purge can be easily re-injected up-stream (before the injection of sodium bicarbonate) where it is completely vaporised.~~

~~The result is a FGT system without intermediate reheating steps and without liquid effluents.~~

~~Achieved environmental benefits~~
~~Reduction of emissions to air as follows:~~

~~Substance(s)~~	**~~Reduction~~**	**~~Achieved emission ranges~~**				**~~Comments~~**
	~~Efficiency range (%)~~	**~~½ hour average mg/Nm^3)~~**	**~~24 hour average mg/Nm^3)~~**	**~~Annual average mg/Nm^3)~~**	**~~Specific emission (g/tonne waste input)~~**	
~~HCl~~			~~<5~~			~~Very stable outlet concentrations are seen~~
~~HF~~			~~<1~~			
~~SO$_2$~~			~~<20~~			
~~NO$_X$~~			~~<70~~			

~~Table 6.2: Emission levels associated with the use of combined dry sodium bicarbonate and SCR FGT system~~

~~The system combines two well known FGT technologies and has the following characteristics:~~

- ~~SO$_2$ and HCl emissions at the stack are low~~
- ~~the sodium bicarbonate excess is reduced because of the downstream scrubber; no gas reheating is generally needed; there are no liquid effluents to treat because the purge is re-injected upstream~~
- ~~emissions are low even under fluctuating inlet concentrations.~~

~~Cross-media effects~~
~~Cross-media effects are identified in the following table:~~

~~Table 6.3: Cross-media effects associated with the use of combined dry sodium bicarbonate and SCR FGT system~~

~~Criteria~~	**~~Units~~**	**~~Range of achieved values~~**	**~~Comments~~**
~~Energy Requirements~~	~~kWh/t waste input~~		~~FG reheat maybe needed if stack temperature is too low after wet scrubber~~

~~**Reagent Consumption**~~	~~kg/t waste input~~	~~9 – 14~~	~~For one tonne MSW~~
~~**Reagent stoichiometry**~~	~~Ratio~~	~~≤1.2~~	
~~**Residue – type**~~		~~Solid~~	~~FGT residues with fly ash or separated if pre-dedusting. Recycling is possible~~
~~**Residue – amount**~~	~~kg/t waste input~~	~~6 – 15~~	~~From one tonne MSW without filter and boiler dust~~
~~**Water consumption**~~	~~l/t waste input~~	~~<450~~	
~~**Effluent production**~~	~~l/t waste input~~	~~0~~	~~Purge re-injected upstream (<40 l/t waste input)~~
~~**Plume visibility**~~	~~+/o/-~~	-	

~~Additional FGT systems may be necessary, e.g. extra PCDD/F and Hg removal devices. [74, TWGComments, 2004]~~

~~**Operational data**~~

~~**Table 6.4: Operational data associated with the use of combined dry sodium bicarbonate and SCR FGT system**~~

~~**Criteria**~~	~~**Description of factors affecting criteria**~~	~~**Evaluation (high/medium/low) or data**~~	~~**Comment**~~
~~**Complexity**~~	• ~~additional process units required~~ • ~~critical operational aspects~~ • ~~risk of clogging~~	~~M/L~~	~~The number of process units is greater than dry systems, but smaller than other systems~~
~~**Flexibility**~~	• ~~ability of technique to operate under range of input conditions~~	~~H~~	~~Very robust – two FGT techniques makes it able to achieve emission reduction under fluctuating inlet concentrations~~
~~**Skill requirements**~~	• ~~notable extra training or manning requirements~~	~~M/L~~	~~Simple system.~~ ~~Bag filter requires good management~~

~~Compared to dry systems with SCR, the scrubber and the water circuit are the only process units added.~~

~~**Applicability**~~

~~The applicability of this technique is assessed in the following table:~~

~~**Table 6.5: Assessment of the applicability of the combined dry sodium bicarbonate and SCR FGT system**~~

~~**Criteria**~~	~~**Evaluation/comment**~~
~~**Waste type**~~	• ~~can be applied in principle to any waste type~~ • ~~particularly suited to highly variable inlet gas compositions (e.g. hazardous wastes)~~
~~**Plant size range**~~	• ~~not restricted but generally applied to medium/large plants~~
~~**New/existing**~~	• ~~not restricted~~ • ~~applied when converting existing wet FGT systems to EC/2000/76~~
~~**Inter-process compatibility**~~	• ~~high operating temperatures make the process very compatible with SCR as no reheating of FG is needed~~

~~Key location factors~~	~~low plume visibility~~ ~~no liquid effluent is produced~~ ~~residue can be recycled~~ ~~safe reagent~~

~~Economics~~
~~Higher capital costs than dry systems due to the addition of a scrubber. Similar capital costs if a scrubber in good condition already in place (e.g. converting existing wet FGT to EC/2000/76)~~

~~Low operational costs due to:~~

- ~~no need to reheat FG before entering the SCR (low emissions of SO_2/SO_3 and temperature around 200 °C)~~
- ~~no liquid effluents to treat~~
- ~~very low excess of sodium bicarbonate.~~

~~Driving force for implementation~~
~~This technique is suitable when:~~

- ~~existing wet FGT systems must comply with EC/2000/76 (introduction of SCR)~~
- ~~hazardous waste with a highly variable inlet gas composition must be incinerated~~
- ~~FGT must comply with emission limit values lower than EC/2000/76.~~

~~Example plants~~
~~Information not supplied.~~

~~Reference literature~~
~~[64, TWGComments, 2003]~~

6.13 Flameless pressurised oxycombustion

Description

Waste is incinerated by flameless combustion in a pressurised atmosphere of oxygen, carbon dioxide and water vapour, at temperatures of 1250–1500 °C.

Technical description

The operating conditions inside the oxidation reactor (residence time: > 2.5 seconds, temperature of 1250–1500 °C and pressure of 4–15 absolute bar) enable the complete incineration of the inlet organic compounds (with negligible production of undesirable organic by-products such as PAHs, PCDD/F and PCBs). The high combustion temperature melts the non-combustible materials, forming vitrified slags. This high temperature also represents a condition which thermodynamically and kinetically inhibits sulphur dioxide conversion into sulphur trioxide.

In steady-state conditions, flue-gases leaving the reactor are at a temperature within 1250–1500 °C. A fraction of the flue-gas is recycled into the reactor to control the combustion temperature. Another fraction is mixed by the quencher together with the hot flue-gases coming from the reactor in order to have a compatible boiler inlet temperature (600–750 °C).

Slags flow on the bottom of the reactor, leaving through a heated conduit to avoid solidification. In that way, such molten material falls down into a water quencher where it solidifies in vitreous form, shattering into grains of sizes of 0.1–3 mm.

Flue-gases are treated to reduce the amount of dust and acids. The flue-gas flow rate is smaller due to the use of pure oxygen, instead of air.

Liquid and solids with water and sludge wastes can be fed to the reactor.

Heat recovery is performed, producing steam at high pressure and temperature (up to 600 °C and 240 bar) and using the flue-gas water vapour condensation that contributes about 10–15 % to the overall thermal balance. Overall, the thermal efficiency of the plant can be as high as 95–99 % (input waste energy as LHV).

Achieved environmental benefits

Reduction of emissions to air, and production of inert slags.

Environmental performance and operational data

A two-stage wet scrubber is use to clean the flue-gas, followed by a condensation scrubber to recover the flue-gas latent heat. The condensed water is also recovered in the process. Limestone is used in the scrubber second stage. The emissions to air from the process are reported in Table 6.6.

Table 6.6: Emissions to air of the flameless pressurised oxycombustion process using three different waste types

Parameter	Unit	Emission values		
		19.13.01*	**19.12.12**	**16.03.05***
Dust	mg/Nm^3	0.8	9.6	4.6
Hg	mg/Nm^3	0.001	0.003	
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V	mg/Nm^3	0.08	0.1	0.07
Cd + Tl	mg/Nm^3	<0.001	<0.001	0.00001
PCDD/F	ng I-TEQ/Nm^3	0.001	0.001	<0.0008
Dioxin-like PCBs	ng WHO-TEQ/Nm^3	0.0001	0.0001	0.00006
PAHs	ng/Nm^3	<10	<10	<25
HCl	mg/Nm^3	0.9	NA	<0.008
NO_X	mg/Nm^3	141	180	21.5
SO_X	mg/Nm^3	<7	1.1	<5
HF	mg/Nm^3	0.2	NA	0.55
Source: [IT 2015]				

Table 6.7 reports the results of the leaching test done on the slag produced by the flameless pressurised oxycombustion process using three different waste types.

Table 6.7: Leaching test of the slag produced by the flameless pressurised oxycombustion process using three different waste types

Parameter	**Unit**	**Emission values**		
		19.13.01*	**19.12.12**	**16.03.05***
pH (final)		NA	3.32	NA
Total dissolved solids	mg/l	25	36	< 100
Dissolved organic carbon (DOC)	mg/l	< 0.125	0.615	< 10
Chlorides	mg/l	< 0.004	0.357	0.003
Fluorides	mg/l	0.001	< 0.0105	0.01
Sulphates	mg/l	0.047	0.283	0.04
Antimony	mg/l	0.000144	0.00123	0.002
Arsenic	mg/l	0.000187	0.000392	< 0.01
Barium	mg/l	< 0.001 2	0.00307	< 0.001
Cadmium	mg/l	0.000087	< 0.000072	< 0.001
Chromium	mg/l	0.00498	0.017	0.02
Mercury	mg/l	< 0.000044	< 0.000054	0.005
Molybdenum	mg/l	0.00187	0.00305	0.04
Nickel	mg/l	0.00181	0.00319	< 0.003
Lead	mg/l	0.000235	0.00604	0.05
Copper	mg/l	0.00306	0.0206	< 0.05
Selenium	mg/l	0.000158	< 0.000324	NA
Zinc	mg/l	< 0.004	0.0144	NA
Phenol Index	mg/l	< 0.0497	< 0.0493	NA
Source: [IT 2015]				

Parasitic power consumption ranges from 50 kWh to 110 kWh per tonne of waste (corresponding to 10–20 % of recovered gross power production).

Cross-media effects

None reported.

Technical considerations relevant to applicability

Generally applicable.

Economics

Investment cost: EUR 25–30 million.

Operating cost: EUR 5.5 million per year (for a 15 MW_{th} plant, with a nominal capacity of 80 000 tonnes/year of municipal solid waste, corresponding to an operating cost of EUR 68.75 per tonne).

The possible savings are calculated considering the reference value of 0.26 m^3/tonne of waste treated and it is the sum of sludge and water waste produced. Consequently, fixing 80 000 tonnes per year of input waste, the general disposal cost for water waste and sludge is EUR 1 456 000 per year.

Fixing the amount of waste to process (80 000 tonnes per year) and a disposal cost equivalent to EUR 70 per tonne of waste, the following possible savings were estimated:

- Waste water: EUR 410 000 per year.
  Waste water production for a 15 MW_{th} plant is 1 300 tonnes per year and is equivalent to 0.016 m^3/tonne of waste processed. Consequently, the disposal costs per year for waste water are equivalent to EUR 91 000 per year and the savings estimated are EUR 410 000 per year.
- Sludge: EUR 790 000 per year.
  Sludge production for a 15 MW_{th} plant is 2600 tonnes per year and is equivalent to 0.032 m^3/tonne of waste processed. Consequently, the disposal costs per year for sludge are equivalent to EUR 182 000 per year and the savings estimated are EUR 790 000 per year.
- Cooling water
  In contrast to traditional incinerators, cooling water is not consumed in this process.
- Net energy production: EUR 2.2–3.5 per year.
  The net energy production is 31 000 MWh/yr, equivalent to 0.39 MW/tonne of waste processed.

Driving force for implementation

No information provided.

Example plants

Isotherm Gioia del Colle (IT).

Reference literature

[93, Italy 2015]

7 CONCLUDING REMARKS AND RECOMMENDATIONS FOR FUTURE WORK

To be updated

~~7.1 Timing of the work~~

~~The first plenary meeting of the TWG was held in December 2001. The first draft was then sent for consultation in May 2003. Nearly 4000 comments were submitted on the first draft. These were assessed and integrated into the document and the second draft, including proposals for BAT conclusions, was sent out in April 2004. A similarly very large number of comments were received on the second draft document. The majority of these were assessed prior to the final plenary meeting of the TWG which was held in November 2004. Four weeks before the final plenary meeting a completely revised version of the BAT chapter was supplied to the working group in the meeting background paper. This paper also contained a lengthy and thorough assessment of the comments made, and the rationale for the revised BAT proposed to the TWG. The final plenary TWG meeting focused upon agreeing the BAT conclusions. After the final meeting there were short consultations on the modified sections relating to BAT conclusions and on the concluding remarks and executive summary.~~

~~One year before the start of this information exchange Directive 2000/76/EC on the incineration of waste (WID) was finalised. WID sets binding operational and performance standards for the majority of situations where wastes are thermally treated, including where wastes are treated in dedicated waste treatment installations (which were the subject of this information exchange on BAT) and where wastes are co-incinerated in other installations (which were not part of the scope of this work). The standards set out in WID are, in the main, applicable to new installations from 2002 and to existing installations from 28 December 2005. The work on the BREF has therefore coincided with a period when the industry and Member States have been taking the steps required to implement the WID. Information from experience of implementing WID has to some degree been fed into the BAT information exchange. However, although data was supplied from those Member States who have for some years applied standards similar to those in the WID, with the WID being in the process of implementation, the information supplied was partial, and therefore incomplete.~~ **~~It is recommended that the revision of the BREF draw specifically from Member State and Industry experience of implementing WID, examining in particular the difference between newly constructed installations and those that have been upgraded.~~** ~~This may then usefully result in more detailed BAT conclusions regarding the techniques and performance that might be expected in each of these situations.~~

~~The~~ **~~suggested date for the revision of this BAT reference document is 2010~~**~~, with commencement of information gathering to commence at least one year prior to this date.~~

~~7.2 Sources of information and information gaps~~

~~During this information exchange Member States and industry submitted a very large number of documents. Over 350 electronic information sources were submitted in total, with a similar number provided as hard copy either by post or by hand during meetings and site visits. The total number of pages of information supplied ran into many thousands. Some of the information was overlapping and therefore, not all of the documents supplied are referenced in the BREF.~~

~~Some very substantial contributions were made at an early stage of the project, which formed the cornerstones for the first chapters including the techniques to be considered in the determination of BAT (Chapter 4). In particular:~~

- ~~detailed BAT documents were provided by Germany, Austria and Netherlands~~
- ~~industry provided emissions and technique surveys specifically produced for the BREF project~~
- ~~reports on particular techniques were provided by organisations, industry and many Member States~~
- ~~individual TWG members dedicated large amounts of their own time to reading and commenting on the drafts produced and to producing contributions for the project.~~

~~EIPPCB and TWG members together made site visits to 29 installations in 9 different countries: Belgium, Denmark, Finland, Germany, Japan, Norway, Portugal, Spain and Sweden. These site visits were held early in the project and helped to give an understanding of the industry as a whole and of specific techniques. A standard data sheet was developed to gather information during these visits and reports on the visits were made available to the TWG by posting them on the members' workspace. Throughout the project there was very good and open communication with active TWG members in industry and Member States, although not all TWG members played an active role in the project. The consultation rounds on the draft BREF provided a great deal of specific constructive feedback from the TWG members. Such comments were crucial to the development of the BREF, although they were also accompanied by a very large number of comments expressing desires or opinions that were difficult to use where they were not well supported by information.~~

~~The project generated huge interest throughout, reflecting the great interest that the subject generally attracts. At the time of the second plenary TWG meeting there were an unprecedented 109 TWG members. Consultations on the first and second drafts of the BREF generated an equally unprecedented number of comments, with over 7500 comments submitted using the EIPPCB consultation spreadsheet, and very many pages of separate submissions. Because of the large amount of work required to deal with just the comments that were received by the consultation deadlines, the EIPPCB was not able to give full consideration to those contributions that were received after the consultation periods closed. Although the majority of TWG members submitted their comments within the consultation periods set (standard 8 weeks plus extra for vacation periods) some were unable to do so, and stated that the consultation periods were too short. Amongst the submissions received after the deadline, of particular note were 33 varied documents submitted by industry during the months following the close of consultation on the second draft. These documents split the BREF into various sections and provided the combined comments and suggested revisions of a number of the industry experts. While some of these submissions were used, the need to prioritise comments received during the consultation period meant that this was not the case with all. It is therefore~~ **~~recommended that these submissions should be fully reviewed and taken into account when the BREF is reviewed~~**~~.~~

~~Good data was submitted on emissions, particularly emissions to air, although averaging periods and data standardisation sometimes differed, or were not given. Emissions data regarding the majority of the priority substances released to air was plentiful and of good quality, reflecting the standardisation and greater consistency of monitoring and reporting brought about by~~

~~European level regulation. However, a lack of confidence in data quality prevented the establishment of quantitative BAT emission levels for the majority of those substances not included in Directive 2000/76/EC.~~

~~Quantitative cost data was supplied regarding gate fees, treatment costs, the costs of entire installations and of individual techniques. The majority of this was derived from individual studies. However, because of variations in the way in which cost data is compiled, the data supplied were mostly difficult to compare and thus the construction of cost curves for various techniques was generally not possible.~~ ~~**It is recommended that the revision of the BREF is preceded by studies that establish and gather the data that on a wider basis allows a more precise assessment of:**~~

- ~~**the impact of plant size on the economics of the adoption of various techniques e.g. SCR**~~
- ~~**the comparative affordability and benefits of the adoption of techniques in the sub-sectors of the industry (i.e. municipal, hazardous, sewage sludge etc.)**~~
- ~~**comparative emissions avoided with the cost of applying various techniques**~~
- ~~**the change in waste treatment costs that result from the use of various emission reduction techniques with respect to plant type and size.**~~

~~Cross-media effects were often not well quantified, and in many cases only a qualitative statement could be made. Data on raw material consumption was provided for some techniques but availability and quality was variable – this may be a reflection of the general (and arguably suitable) emphasis of the industry upon controlling emissions rather than consumptions.~~

~~Early on in the project it was noted that the incineration sector comprised a number of sub-sectors and the scope of the information exchange was derived during discussions in the first plenary meeting. However, the information exchanged was predominantly concerning the municipal and merchant hazardous waste sub-sectors. Relatively little information was provided concerning the other identified sub-sectors e.g. clinical waste, industrial wastes, mixed waste incinerators. The final document reflects the balance of the information provided and this resulted in relatively little information regarding some sub-sectors. The evidence presented in the BREF was considered sufficient to conclude on general BAT conclusions for the sector as a whole, with some sub-sector specific conclusions, but did not support the drawing of more detailed sub-sector specific emission levels.~~

~~In finalising the BAT conclusions it was noted that plant size has a great influence upon the economic viability of certain techniques, with small installations suffering far greater increases in cost per unit of waste treated than larger installations. The need to take account of the general applicability of the BAT conclusions in relation to the actual large variation in installation sizes seen, lead to the quantitative BAT associated operational emission levels ranges being broadened. This is therefore a factor to take into account when comparing the actual performance of individual installations against the BAT performance ranges given. In order to provide a more detailed understanding of the installation size and type size relationship to BAT,~~ ~~**it is recommended that the revision of the BREF seeks to establish BAT associated emission performance ranges that more closely take account of plant size and waste type factors. In addition, it is also recommended that the revision examines whether it is possible to draw more specific BAT conclusions for:**~~

- ~~**mixed waste installations (e.g. techniques used and possible benefits of mixing various waste streams)**~~
- ~~**industrial non-hazardous waste installations.**~~

~~Very little quantitative emission was supplied regarding the raw gas concentrations seen after the combustion stage (i.e. prior to gas cleaning). This made it impossible to carry out a detailed comparative evaluation of the techniques used at the combustion stage. Therefore, the conclusions drawn on this are largely derived from a consensus of expert opinion and overall installation performance, rather than a hard evaluation of techniques applied and mass balance~~

~~data at the combustion stage. In particular it was not possible to evaluate the impact on combustion performance and emissions that might arise from detailed combustion design features. Because the emphasis of IPPC is upon techniques that prevent pollution (as opposed to abatement techniques) it is therefore~~ ~~**recommended that the revision of the BREF should study combustion design features in more detail with a view to evaluating their role in pollution prevention.**~~

~~7.3 Degree of Consensus reached~~

~~The conclusions of the work were agreed at the final TWG meeting in November 2004. There was a very good general level of consensus. There was full agreement, and no split views, in relation to the technique related BAT. There was also generally good consensus upon the quantitative BAT, although the operational emission levels associated with the use of BAT did give rise to some split views. One Member State and the Environmental NGO recorded split views in relation to many of the BAT associated emission levels for releases to both air and water. Their rational for these split views included, the data in the BREF, and several examples of installations achieving emission levels below those agreed by the remainder of the TWG as BAT.~~

~~7.4 Other specific notes and issues~~

~~7.4.1 Existence of installations with operational emission levels below those concluded as BAT~~

~~There are a number of installations in Europe that, for some of the emission parameters listed, already achieve operational levels below the lower end of the ranges given in Table 5.2 and Table 5.4 (BAT associated operational emission ranges for releases to air and water). However, the TWG concluded that these lower emission values could not be described as "generally achievable using BAT". The rationale for this was that, whilst achieved in some specific situations, local variations in waste types and economic situations, meant that such lower emission levels were not considered to be BAT in general for the sector as a whole.~~

~~7.4.2 Comprehensiveness of Error! Reference source not found. on selection criteria for FGT systems (BAT Error! Reference source not found.)~~

~~**Error! Reference source not found.** in Chapter 5 is not considered to be comprehensive as other subdivisions of the FGT systems mentioned are known to exist. In particular, the evaluation of each of the FGT systems presented, may change according to the FGT reagents used e.g. typically lime, sodium bicarbonate or sodium hydroxide.~~

~~7.4.3 Use of dry FGT systems at certain hazardous waste incinerators (BATError! Reference source not found.)~~

~~BAT **Error! Reference source not found.** states that at hazardous waste incinerators feeding wastes of "highly varying compositions and sources, the use of wet FGT, as described in 4.5.3.1, is generally BAT…". The TWG noted that dry FGT is also applied at some hazardous waste incinerators treating such wastes, that such installations comply with WID emission levels and that dry systems may have specific local advantages where there are particular restrictions e.g. on the use or discharge of water. Hence, although insufficient information was available to judge whether dry systems were also BAT for such HWIs, it may be the case that they offer overall advantages in some local circumstances.~~

~~7.4.4 Impacts of energy pricing and policies on energy efficiency~~

~~In some European Member States green electricity schemes support, to varying degrees, the production of electricity from waste. The TWG noted that such subsidies were much less common for the supply of heat/steam, although they too represent a potential means of energy recovery. It was also noted that the absolute and relative prices (the price actually received by the operator including any subsidy) for electricity or heat/steam sales had a great influence upon the energy recovery strategy adopted and hence the actual design of installation.~~

~~Although electricity supply on its own is often the energy recovery option selected, CHP and heat/steam supply to reliable consumers provides a greater opportunity to increase the percentage recovery of the energy value of the waste. It may then be seen that policy measures such as "green steam" subsidies, and policies that improve the availability to incineration installations of customers/contracts for heat/ steam use (e.g. land use planning policy, energy policy, renewable energy quota obligations and subsidies, supply of district heating/cooling networks) can play a very important role in enhancing the overall ability of the waste incineration sector to improve its energy efficiency at both an installation and sector level.~~

~~In some locations, the adoption of such policies and measures is undertaken in part because of the contribution that waste derived energy may make in replacing energy that would otherwise~~

~~be derived from fossil fuel derived energy sources. Where the energy production replaced is largely or wholly of fossil fuel origin, this may then be translated as savings in total carbon dioxide emissions from energy supply.~~

~~7.4.5 Competition and regulatory impacts across waste treating industrial sectors~~

~~The incineration industry in Europe is exposed to greatly varying degrees of competition depending on waste type, geography, local legislation and policy. At one extreme installations are publicly owned, operated and funded, may have long-term contracts guaranteeing waste supply and energy purchase, and are permitted to increase charges for incoming wastes in order to raise capital for any required upgrades. At the other extreme, installations are entirely privately funded and operate in a global market for wastes, without any such security.~~

~~Where competition for wastes exists, within the limits set by legislative controls on waste movements, waste holders can send their wastes to the installation of their choice, and the relative cost of the options available will, in general, be a key driver that ultimately determines the installation selected. This being the case, installations with lower costs may be expected to "win" more contracts and hence treat more wastes.~~

~~The enforcement of environmental regulations, and the detail of the standards and emission values that those regulations require, themselves determine the techniques, investments and hence costs that are borne by the regulated industry. Therefore it can be clearly seen that, when a given waste may be treated in various sectors, the relative regulatory controls may, in a free market, have a significant impact on the destination of the waste. Ultimately, this may then lead to a situation where installations with higher environmental requirements (and higher costs) are penalised. It can therefore be seen that, in such situations, particular care is required when considering the emission values and other requirements that are to be placed upon all industries competing in such markets. This issue is also noted in WID (recital 10).~~

~~7.4.6 Development and implementation of waste strategies~~

~~The degree to which incineration is utilised as a waste treatment option varies greatly from Member State to Member State and from region to region. In general those Member States with the highest levels of landfill have the lowest levels of incineration. The progressive implementation of Directive 1999/31/EC on the landfill of waste will result in reductions in the amount of biodegradable waste going to landfill. Particularly where reliance upon landfill has been the greatest, alternative waste treatment and disposal capacity will need to be provided for those wastes whose production is not prevented. In such cases, an expansion in thermal treatment capacity may therefore be anticipated, accompanied to some degree by an expansion in other treatments, including recycling.~~

~~The development and effective implementation of waste strategies at various levels (Member State, Regional and Local) is an important tool that can help ensure that effective, well planned and organised waste management is provided, whilst ensuring waste management hierarchies are observed. Such plans may help developers of thermal treatment installations to:~~

a) ~~ensure that the size of the installations they propose are complimentary to the waste strategy in place~~
b) ~~identify suitable locations for installations.~~

~~7.4.7 Markets and standards for bottom ash and other residues~~

~~The degree of utilisation of thermal treatment residues in Europe varies greatly. In some cases almost all bottom ash is sent for disposal, in others a very large proportion is used, often for construction purposes after treatment. In general, the Member States that have been able to increase ash use (usually for bottom ash but sometimes also for certain fractions of fly ashes e.g. boiler ash) and thereby reduce disposal, are those that have developed appropriate standards for the use of ash, and for their sampling and quality testing.~~

~~In some cases Member States have extended policy further to the identification of zones where the various grades of incineration ash may be used as aggregate replacement, the environmental protection measures required when they are used, and the differing levels of quality testing required depending upon the environmental risk in the zone concerned. In such a way it has been found possible to address the potential pollution concerns regarding such uses of waste materials. The standards developed, seek to address these pollution concerns, and may then themselves become additional criteria for thermal treatment installation developers to consider when choosing those techniques and treatments that have a particular impact upon residue quality.~~

~~Such measures are generally seen to improve the market for the use of bottom ash and therefore reduce the amount of waste going for disposal, whilst also displacing the use of the raw minerals they replace. In other cases, member states adopt measures that aim to improve the landfill behaviour of the incineration residues.~~

~~The other main residues from waste incineration are those arising from flue-gas treatment. These are partially recovered in some cases (some industrial processes are used to recover certain fractions of some FGT residues), but in general the residues are sent for disposal, often by landfill and commonly following specific treatments. In some cases FGT residues are placed in salt mines where they are used as backfill. The price of FGT treatment, disposal or recovery can have some impact upon the techniques adopted for FGT, with higher recovery/treatment/disposal prices generally encouraging the adoption of wet flue-gas treatment systems which can produce lower quantities of solid residues than other systems. This situation is not however simple, and as indicated by the BAT conclusions in this document, the selection of FGT systems requires a multi-criteria assessment that considers a very wide range of drivers (e.g. water consumption and release, energy consumption, etc) in order to arrive at a balanced overall solution.~~

~~7.4.8 Co-ordinated education and demonstration of health/environmental impacts~~

~~In this document it is reported that the results of European health impact assessment studies, on the basis of current evidence and modern emission performance, suggest that the local impacts of incinerator emissions to air are either negligible or not detectable. However, despite this evidence it is the perception of incineration, and its impacts that presents one of the major challenges to the sector, particularly in respect of new developments. Despite significant efforts on the part of developers and local authorities to provide information concerning the impacts and risks, proposals for new installations, in many cases, remain the cause of great public concern. Concern over new development is not however unique to waste incineration. To some degree other waste treatments plants, non waste industries, commercial, retail and infrastructure developments may all meet public and political resistance. During this information exchange, some information was submitted in relation to the actions that have been taken by the industry in order to address public concerns. It is clear that this is a matter which, although of greater significance in some locations than others, is of general interest to the European incineration industry. It is therefore~~ **~~recommended that the industry and those with responsibility for developing and implementing waste strategies continue to develop their strategy in this area.~~**

~~7.5 Suggested topics for future R&D projects~~

~~In addition to the subjects already noted in this Concluding Remarks chapter, for the revision of the BREF the following topics were suggested for further investigation, with a view to establishing BAT conclusions where possible:~~

- ~~information regarding the techniques used to, and costs of, upgrading existing installations – such information may be derived from experience of implementing WID in Member States and might usefully be compared with the costs/performance at new installations~~
- ~~the more detailed cost information that is required to undertake a more precise assessment of variations in technique affordability with plant size and waste type~~
- ~~information regarding smaller installations – very little information was provided regarding small installations~~
- ~~installations that treat industrial non-hazardous wastes and those that treat mixtures of wastes~~
- ~~a more detailed evaluation of the impact on pollution prevention of detailed combustion design features e.g. grate design~~
- ~~further information on emerging techniques~~
- ~~ammonia consumption and emission (mainly to air and water) levels for different FGT systems (mainly wet, semi-wet and dry) and their relative~~ ~~NO_X~~ ~~reduction efficiency~~
- ~~the impact of the dust removal temperature range upon PCDD/F releases to air and residues~~
- ~~further experiences with continuous emissions monitoring for Hg (to air and water).~~

~~Other important recommendations for further work beyond the scope of this BREF but arising from the information exchange are:~~

- ~~the need for consideration of the overall impact of competition for waste treatment, in particular competition from industries co-incinerating wastes – a study of such might usefully include consideration of: relative reliability of, and risks to, the supply of the waste management service; overall emissions and energy recovery according to various degrees of diversion, and; consider and identify key risk factors e.g. waste fuel quality assurance~~
- ~~it may be useful to assess the impact on adopted waste strategies (i.e. the balance of technologies used on a national scale), and on achieved thermal treatment installation efficiencies, of the degree of integration of energy and waste management policy in EU Member States (and other countries). Such studies may identify how policy on energy and waste interact and give examples, both positive and negative~~
- ~~the need to understand in more detail of the impact of absolute and relative energy prices (electricity and heat) upon the typically achieved energy efficiency of installations, and the role and impact of subsidies and taxation schemes~~
- ~~the identification of the typical barriers to developing new installations and the approaches that have proved successful~~
- ~~the development of suitable standards for the use of bottom ash – such standards have proved helpful in improving markets for the use of bottom ash~~
- ~~the costs and benefits of further reducing emissions from the waste incineration industry when compared to reductions at other industrial and anthropogenic sources of pollution.~~

~~The EC is launching and supporting, through its RTD programmes, a series of projects dealing with clean technologies, emerging effluent treatment and recycling technologies and management strategies. Potentially these projects could provide a useful contribution to future BREF reviews. Readers are therefore invited to inform the EIPPCB of any research results which are relevant to the scope of this document (see also the preface of this document).~~

8 ANNEXES

8.1 Economic overview of MSWI - Member State information

For the TWG: to be updated

This Section of the BREF is taken largely from data already published by the European Commission [43, Eunomia, 2001]. The information refers only to MSWI.

Austria

Information concerning costs of incineration technologies and options in Austria are presented in Section 8.2.

Belgium

The waste policy in the three Belgian regions is aimed at the maximisation of the reduction of residual waste.

Flanders Region

The waste policy target in Flanders is a maximum production of 150 kg/yr per capita of residual waste by the year 2007.

The average gate fee for the incineration of municipal waste was EUR 87.5 per tonne in 2000. The Flemish government adds a levy to this tariff of EUR 6/t when energy recovery takes place and of EUR 12.7/t without energy recovery.

The landfilling of municipal waste (with the exception of non-recyclable sorted bulky waste) and the incineration of separately collected fractions (old paper and cardboard; glass packaging; metal packaging; plastic bottles and plastic packaging waste; drinks packaging; vegetable waste; vegetables, fruit and garden waste) has been legally prohibited by the Flemish government since 1st July 1998. The landfilling of combustible bulky waste has been forbidden since 1st July 2000. Only exceptionally is the landfilling of municipal waste still allowed – in 2000 789425 tonnes MSW was incinerated and 190412 tonnes MSW sent to landfill.

Brussels Capital Region

The cost price for incineration of residual household waste in the SIOMAB -incineration plant (operator: Net Brussels) of Neder-Over-Heembeek is calculated at EUR 37.18 per tonne (source: B.I.M., 1997). A better estimate of the real cost of incineration in the SIOMAB plant is probably the price charged by Net Brussels to municipalities in the Brussels Region for incineration of municipal waste. This price is EUR 62 per tonne.

Recent figures show that circa 40 000 tonnes of Flemish waste is incinerated in this installation, together with the municipal waste from the Brussels Region (source: OVAM, 2001).

Walloon Region

In the Plan Wallon des Déchets, reference costs based upon current facilities were estimated at EUR 67 per tonne.

Denmark

65 % of waste from households was incinerated in 1999, equivalent to about 2 million tonnes. All incineration plants recover energy, either in the form of electricity and heat, or just as heat (distributed in district heating systems).

Prices for incineration of one tonne of domestic waste range from 500 – 740 DKK = EUR 66 - 99, excluding VAT, but including waste tax. Waste tax on incineration is 330 DDK = EUR 44 as of January 2001. These prices include plant investment costs and investment costs for CHP, and the plants are used to generate district heating (which gives a lower net cost per tonne and lower gate fee). Bottom ash is typically recycled (75 %) and the rest is sent to landfill. Flue-gas cleaning residues are hazardous waste and presently sent to Norway/Germany where they are deposited in landfills/mines, or sent to special/hazardous waste management sites (where the costs per tonne are higher).

Finland

The Finnish waste incineration policy has mainly centred on the production of refuse-derived fuels for co-incineration (or other thermal treatment) in existing power and heat stations. This policy is being pursued (in part) in order to minimise costs, in a situation where there is already a large infrastructure for the distribution of heat from bio-mass and conventional fuel generating stations.

France

Key factors explaining variation in costs are reported as:

- capacity
- utilisation rate
- type of energy recovery (electricity, heat, co-generation)
- type of disposal and transportation of residues.

The following figures are extracted from an assessment carried out in 2002 on the 42nd, and most recently constructed, MSWI built in France:

- investment costs: EUR 3.6 million/(t/h)
- operational costs: EUR 32/t average – however this cost is very variable, ranging from 18 to 42 EUR/t.

Operational costs may be derived as follows:

- 33 EUR/t of fixed costs (personnel, insurance, etc.)
- 13 EUR/t for waste elimination (bottom ash, fly ash) and
- -14 EUR/t of revenues from energy or residue sales.

The total resulting cost per tonne of waste treated is equal to 78 EUR/t (pay-off time of 15 years, an investment paid off at 100 % by a bank loan at 6 % interest rate, and a plant operating 8 000 hours per year). [64, TWGComments, 2003]

Key influences identified for future variation in costs:

- technological developments
- evolution of regulations on emissions.

Germany

Almost all of the thermal treatment facilities in Germany are waste incinerators. The capacity of other treatment options, such as pyrolysis plants are negligible. Most MSW incinerators in operation are grate incinerators. There is a great variety in plant size, flue-gas treatment and the further use of the generated energy. The costs of a grate incinerator with a capacity of 200 000 tonnes per year and dry and wet flue-gas treatment generating electricity is given below in Table 8.2.

Generally, gate fees for waste incineration are in a range of EUR 64 to 460/t. In other sources a range of EUR 89 to 351/t is given. 50 % of all data on costs of waste incinerators are in a range of EUR 123 to 256/t (according to UBA).

The costs for different sized grate incinerators vary widely. They indicate scale economics. Table 8.2.

Table 8.1 gives an overview of the range of specific costs depending on the capacity of a grate incinerator with the same technical specification as the plant in Table 8.2.

Table 8.1: Treatment costs for a MSW Grate Incinerator with varying capacity

Capacity (t/yr)	Specific treatment costs EUR/tonne
50 000	230
100 000	140
200 000	105
300 000	85
600 000	65
Source: [43, Eunomia, 2001]	

The key factors contributing to the costs of waste incineration at present are identified as:

- choice of technology and the technical equipment (especially flue-gas treatment) of the plant
- plant size
- capacity and its utilisation
- plant availability
- the gate fee paid by Local Authorities. This is influenced by whether or not the Local Authority has to pay fees to the operator of the plant for a certain amount of waste, which they have to deliver to the plant. While contracts are often based on a definite amount of waste and are valid for a long period of time, the amount of waste has decreased within recent years
- the income from supplied energy. The amount of electricity and heat being generated and sold varies widely depending on the plant technology and the location of the plant
- the costs for chemicals and the disposal of residues from incineration.

A detailed cost breakdown for a 200 000 tonne MSW facility in Germany is given in Table 8.2

Table 8.2: Grate MSW incinerator costs 200 000 t/yr Germany

TOTAL INVESTMENT	**Investment (EUR)**	**Payback Period (y/s)**	**Rate %**	**Annualised cost (EUR/yr)**	**Specific costs (EUR/t)**
Site costs	368 000		7	25 700	0.13
Development of site	341 000	25	7	29 200	0.15
Construction costs	21 629 000	25	7	1 856 000	9.28
Technical installations and machinery	69 740 000	15	7	7 657 100	38.29
Electro technical installations	13 280 000	15	7	1 458 000	7.29
Fees	7 349 000	17	7	752 800	3.76
Pre-financing	9 219 000	17	7	944 200	4.72
TOTAL	**121 925 000**			**12 723 000**	**63.61**
OPERATIONAL COSTS, independent of input	EUR	Percentage		Annual costs EUR/yr	Specific costs EUR/t
Construction	21 970 000	1		219 700	1.10
Technical installations and machinery	69 740 000	4		2 789 600	13.95
Electro technical installations	13 280 000	2.5		332 000	1.66
Taxes and insurance	105 357 000	1		1 053 600	5.27
Management	2 863 000	10		286 300	1.43
Auxiliary materials	3 341 000	5		167 100	0.83
		number	EUR/person		
Labour		80	35 790	2 863 200	14.32
TOTAL				**7 711 500**	**38.56**
OPERATIONAL COSTS, input dependent					
		EUR per m^3/yr	EUR/m^3		
Process water		51 200	0.15	7 900	0.04
Gas		1 381 440	0.20	282 500	1.41
		t/yr	/t		
CaO		1 000	79.2	79 200	0.40
Ammonia		400	97.1	38 900	0.19
	kg/t input				
Treatment of slag	334	66 800	28.1	1 878 500	9.39
Treatment of ashes	8	1 600	255.6	409 000	2.05
Treatment of filter dust	22	4 400	255.6	1 124 800	5.62
TOTAL				**3 820 800**	**19.10**
	MWh/t input	MWh/yr	EUR/MWh	EUR/yr	EUR/t
Credits for electricity	0.35	70 700	46.0	3 253 300	16.27
TOTAL Cost Per Year				21 002 000	105
Cost per tonne input					
Source: [43, Eunomia, 2001]					

Key factors expected to influence future costs:

- many of the plants that have been built in recent years are equipped with simplified technology for flue-gas treatment. Assuming that future incinerators will be equipped with the less complex technology it can be expected that costs will decrease

- the regulation of waste treatment requires an end of the disposal of non-pretreated waste with more than 5 % carbon content in landfills from the year 2005 onwards. A lack of capacity for waste incineration could be seen after this date and consequently gate fees of incinerators might increase.

Greece

At present, no thermal treatment of municipal solid waste takes place in Greece.

Ireland

There are currently no thermal treatment plants for municipal waste in operation in Ireland. Recent waste management plans include the construction of these.

An estimate of the cost to build and operate an MSW incineration plant of 200 000 tonne capacity is presented below (based on Directive 2000/76/EC standards). This data is based on comparative experience in Denmark and the United Kingdom, but with reference to Irish conditions.

Table 8.3: Estimated cost to build and operate a mass-burn MSW incineration plant of 200000 tonne capacity in Ireland

Capital investments	**EUR**
Civil works and buildings	23 741 660
Mech. and Electrical Equipment	45 388 468
Other	15 108 329
Total	**84 238 458**
Operating costs	**EUR**
Fixed	
Personnel	954 297
Maintenance and replacement	890 522
Unforeseen	125 527
Total	**1 988 422**
Variable	
Maintenance and replacement	839 782
Chemicals	890 522
Other (consumables and residues)	1 174 520
Other (unspecified)	293 630
Total	**3 198 454**
Variable costs per tonne	16

Source: [43, Eunomia, 2001]

Italy

In 1999, incineration covered 7.2 % of total municipal waste treatment in Italy. Most facilities at that time were reported to have been designed (and were being operated) according to poor standards regarding energy recovery (average 10 %) and emissions. Gate fees were varying widely, usually in the range 40 - 80 EUR/tonne.

3 major factors are reported to affect costs:

- funds to cover - partially or totally - the costs of construction (this allowed owners to avoid cost items referring to depreciation and interest)
- subsidies for the energy produced - subsidies for energy from waste have been paid for some years in Italy. Initially, under the scope of the 'CIP6' provisions (deemed to boost the internal

energy production), more recently with the 'green certificates'. (Decree 79/99 and Decree 11 Nov 99, whose rationale is to foster the production of energy from non-conventional sources other than fossil fuels, thus contributing to the Kyoto commitments). The level of both subsidies is around 0.139 EUR/kWh and enables contracted facilities to cut down the fees by some 40 EUR/tonne (around 30 EUR/tonne more than normal prices paid for energy in Italy) - if operating at a medium to low energy recovery rate. Revenues and incidences on the gate fee are, of course, higher at higher energy recovery rates
- contributions for burning of packaging materials - as a means to 'recover' packaging itself - paid by the mandatory Consortium of Packaging Producers (CONAI), set at 58 EUR/tonne, applies only on 30 % – 40 % of the waste being burned, which represents the percentage of combustible packaging out of total MSW at the site (to be assessed through sorting analyses). Such contribution, defined in 1998, has to be cut progressively, year by year, to EUR 3.5/tonne. Therefore, at present, this contribution increases revenues by EUR 16.5/tonne.

A national increase in incineration (mass burn and RDF) is forecast as consequence of legislative moves to reduce landfilling.

The latest generation of incineration facilities show some common features:

- all facilities recover energy (also in compliance with provisions of the national Waste Management Act that mandates it)
- throughputs are usually much larger than before (in the range 400 to 1 000 t/d and more, e.g. Brescia, the new Milan facility, while previous facilities usually were at 100 – 400 t/d)
- many of the new facilities are well integrated in strategies for the abatement of the wet fraction inside the waste to be burned, both through source separation/composting and/or a screening step (e.g. Milan, Parona) that yields a mechanically sorted organic fraction to be later biologically stabilised. This last feature makes incineration more similar to MBT/RDF production with a fitting burning facility
- as a consequence, designed calorific values in normal operational conditions are therefore more and more set towards 10.5 – 12.5 MJ/kg (old facilities were most often around 8.5 MJ/kg).

Model calculations for an Italian example:

For a facility with the following main features:

- combustion technology: mobile grate
- designed calorific value: 2 900 kcal/kg (input waste coming from a screening step - though this has not been considered among costs, and treatment/disposal of the organic undersieve fraction has not been considered, either)
- energetic yield: around 25 %
- throughput: 1 000 tonnes per day, three lines
- 300 operating days a year
- systems for abatement of emission fit for the purpose of fully complying with the Directive on Incineration
- rejects (by weight): 18 % bottom ashes; 3 % fly ashes; 20 % residues from gas cleaning.

The gate fee would be between EUR 41.3 and 90.3/tonne depending upon the subsidies awarded.

Table 8.4: Incinerator costs in Italy based on model calculations

	Unit	Unit cost (EUR)	Total cost (in EUR)	Payback period	Interest rate (%)	Yearly depreciation (EUR)	Specific cost
Investment costs **Preliminary surveys, project, approval, etc.**			12 300 000		7 %		
			4 132 000				
Land purchase (m^2)	200 000	20.66		20	7 %	390 100	
Site preparation (excavation, levelling, access roads, link to technological networks)			1 240 000	20	7 %	117 000	
Civil works			42 360 000	20	7 %	3 998 000	
Other civil works (sewerage, internal water supply network, fencing, etc.)			1 550 000	20	7 %	146 300	
Treatment and control equipment			80 060 000	7	7 %	14 860 000	
Complementary works			4 649 000	20	7 %	438 800	
Other equipment			516 500	7	7 %	95 840	
		Total depreciation			**EUR 2 004 179 944**		**EUR 66.81**
Operating costs							
Maintenance							
Equipment and machinery (5 %)			4 003 000				
Civil works (1 %)			485 500				
Other equipment (5 %)			25 830				
Manpower:							
Accountants	7	35 000	245 000				
Directors	4	60 000	240 000				
Workers	69	30 000	2 070 000				
Consumables:							
Water (m^3)	80 000	0.26	20 660				
Combustible oil (litres)	270 000		62 500				
Combustible raw gas (N cubic meters)	5 233 800	0.15	811 000				
Electric Energy (MWh)			206 600				
Chemicals and lubricants			1 043 000				
Other consumables			929 800				
Disposal of residues:							
Bottom ash(tonnes)	54 000	75.41	4 072 000				
Fly ashes and other residues (salts, exhausted activated carbon filters, etc., tonnes)	15 000	12913	1 937 000				
Other residues (other filters, exhausted catalysts, etc.)			129 100				
General expenses			377 500				
Miscellaneous (analyses, etc.)			516 500	**Specific cost (EUR/tonne)**			
Total operating cost		**18 220 000**		**60.73**			
TOTAL YEARLY COST		**38 260 000**		**127.53**			
Source: [43, Eunomia, 2001]							

Key factors expected to influence future **costs** and/or **fees** are likely to be:

- full implementation of the Incineration Directive 2000/76/EC
- future reduction in the level of subsidies for the production of energy
- increased competition due to the privatisation of the market for energy. This may reduce income from energy and create upward pressure on waste charges/costs.

Luxembourg

There is one thermal treatment facility, a municipal waste incinerator, in Luxembourg. The waste syndicate SIDOR is responsible for this MSWI. Gate fees of the facility and the amount of waste incinerated in the year 1999 are given in Table 8.5 below.

Table 8.5: Fees and expected amount of waste to be incinerated at SIDOR facility, Luxembourg in 1999

Waste	Amount (t)	Gate fees (EUR/t)
Household waste	78 000	96.7
Bulky waste	8 000	128.9
Green waste	550	96.7
Market waste	530	96.7
Commercial waste	33 000	178.5
Waste from water treatment (not sludges)	450	96.7
Production waste	150	198.3
TOTAL	120 700	120.7
Source: [43, Eunomia, 2001]		

Specific operational costs of the incinerator are given in
Table 8.6 below. Values for the year 1998 are given. Those for 1999 are estimated. Taxes are included.

Table 8.6: Specific operational costs of the SIDOR MSWI in Luxembourg 1998 and 1999

	EUR/t in 1999 (estimated)	EUR/t in 1998
Incineration, depreciation	30.8	
Margin 5 %	1.5	
Total	32.3	33.2
Flue-gas treatment, depreciation	13.2	
Margin 5 %	0.7	
Total	13.9	13.1
Additional flue-gas treatment, depreciation	10.1	
Margin 5 %	0.5	
Total	10.6	10.2
Operation of new installations		
By-pass (estimated)	1.4	
Homogenisation of waste (estimated)	1.0	
Total	2.4	0
Treatment of bottom ash	14.7	
Not combustible residues	0.6	
Margin 5 %	0.7	
Total	16.1	17.4
Disposal of residues from flue-gas treatment	6.9	
Margin 5 %	0.3	
Total	7.2	11.6
Auxiliary materials		
Lime: 13 kg/tonne of waste	1.2	
NH_3:4 kg/tonne of waste	0.4	
Oil: 7 l/tonne of waste	1.0	
Gas: 13 m^3/tonne of waste	2.4	
Other 8 kg/tonne of waste	1.5	
Margin 10 %	0.7	
Total	7.2	7.5
Other costs	12.4	
Margin 5 %	1.2	
Total	13.6	13.6
Credits for electricity (estimated)	-12.4	-10.0
TOTAL OPERATIONAL COSTS	**91.0**	**96.6**
Source: [43, Eunomia, 2001]		

Some additional information related to the MSWI of the years 1998 and 1999 (estimated) is given below. The budget is based on 123152 tonnes of waste in 1998 and 120680 tonnes in 1999.

Table 8.7: Extract from the budget Of SIDOR for the years 1998 and 1999

Item	EUR in 1998	EUR/t in 1998	EUR in 1999	EUR/t in 1999
Extraordinary expenses				
Installation for waste homogenisation, studies and tests	248 000	2.0		
Installation for waste homogenisation, investment			273 000	2.3
Ordinary earnings				
Selling of metal scrap	917	0.007	868	0.0007
Ordinary expenses				
Operational costs installation for waste homogenisation			124 000	1.0
Operational costs additional installations for flue-gas treatment and incineration (incl. by-pass)	1 204 000	9.8	1 492 000	12.4
Operational costs - flue-gas treatment	1 569 000	12.7	1 731 000	14.3
Operational costs - incineration	3 657 000	29.7	4 030 000	33.4
Assurances	223 000	1.8	223 000	1.8
Costs for publication for sensitisation of the public and for education of workers	248 000	2.0	372 000	3.1
Maintenance of electricity generator	1 980	0.02	1 980	0.02
Labour costs (SIDOR)	118 000	1.0	128 000	1.1
Social security contribution of the employer	26 000	0.2	28 000	0.2
Office costs	15 000	0.1	15 000	0.1
Administration costs	20 000	0.2	22 000	0.2
Buying of electricity	9 900	0.1	9 900	0.1
Guard	112 000	0.9	112 000	0.9
Emission control (periodic measuring)	248 000	2.0	248 000	2.1
Source: [43, Eunomia, 2001]				

Key factors explaining the costs of waste incineration at present are:

- additional technical equipment of the plant
- the credits for electricity
- treatment of residues
- amount of waste to be incinerated.

Key factors expected to influence future costs:

- see key factors at present.

The Netherlands

The Netherlands has, for some time, had some of the tightest sets of regulatory standards for incinerators in Europe. Incinerator gate fees in 1996 were approximately EUR 110. More recent figures from OVAM suggest that gate fees varied from EUR 85 – 161 in 2003. There are high levels of recycling of the ash residues produced at Dutch plants. Only flue-gas cleaning residues are not routinely recycled.

Table 8.8: Capital investment and treatment costs for MSWI in NL

Waste treatment technology	Specific capital investment (EUR/t annual capacity)	Treatment costs [(2)] (EUR/t treated)
Incineration	450 – 550 [(1)]	approx. 100
(1) 40 % is due to cleaning of flue-gas (2) Depreciation plus operation and maintenance (O and M) costs		
Source: F. M. L. J. Oorthuys and A. J. F. Brinkmann (1999) Benefits of Separation of Municipal Solid Waste, EXPOAMBIENTE '99, 10 – 14 November 1999, Lisbon, Portugal. *Source:* [43, Eunomia, 2001]		

A recent study used some assumptions (including a 15 % efficiency gain) to derive figures for the Netherlands of EUR 77 per tonne for a new 648 kt/yr facility, with sensitivity analysis suggesting a range between EUR 63 – 94 (for the same plant). The revenue from energy sales was assumed to be EUR 36 per tonne, equivalent to approximately EUR 0.05 per kWh. No information was given concerning the costs of ash treatment and disposal, although it is known that bottom ash is largely recycled in the Netherlands.

[74, TWGComments, 2004] Market prices for electricity are approximately 0.0271 EURO/kWh with a potential benefit for the renewable part (50 %) of 0.029 EURO/kWh. (Overall 0.042 EURO/kWh). The revenues are approximately 15 - 20 EURO/tonne. Costs for bottom ash recovery are approximately 9 EURO/tonne bottom ash.

Portugal

European Investment Bank loans of EUR 45.4 million and EUR 42 million were awarded for incineration plants in Oporto (LIPOR) in 1999, and Lisbon (Valorsul) in 1998, respectively. A recent paper seeking to model disposal costs in the EU suggested figures of EUR 46 – 76/tonne, similar to those quoted for Spain below.

Spain

The reported gate fees for incineration of MSW were reported at EUR 18 – 51 per tonne. Figures from Catalonia are EUR 28.5 per tonne though this takes into account only operating costs, and excludes depreciation on civil works, equipment and investment. The Ministry for the Environment estimates costs at EUR 52 – 73 per tonne.

Incineration benefits from a special subsidy for the electricity that has been produced. The effect of this is to reduce the above quoted costs to EUR 34 – 56 per tonne.

Sweden

Sweden has 23 incinerators, 6 of which are larger ones (capacity of 200 000 per year or more), the rest average a capacity of 40 000 tonnes/yr. There are plans for almost as many more, as present and future changes is waste regulations improve the competitiveness of incineration (e.g. landfill tax, bans on landfilling of combustible waste and kitchen waste).

There are three incinerators with the capability of producing electricity in Sweden, but generally it is considered that the price of electricity has to increase in order to render this profitable. Almost all incinerators produce heat for district heating.

The incinerators in Sweden are mainly grate incinerators, the rest are fluidised bed incinerators. Some general size-cost relations are presented below for examples of Swedish incinerators producing electricity and heating:

Table 8.9: Cost breakdown for various incinerators in Sweden

	Heating	Power/heating	Heating	Power/heating
Capacity, tonnes/yr	40 000	40 000	300 000	300 000
Effect, MW	15	15	114	114
Investment EUR	13 340 000	24 250 000	52 490 000	95 440 000
Annuity, 7 %, 15 years lifetime	1 464 000	2 662 000	5 763 000	10 480 000
Operators	16	21	33	43
Staff costs EUR	640 000	840 000	1 320 000	1 720 000
Limestone and chemicals EUR	100 000	10 000	750 000	750 000
Operating and maintenance (2 % of investment) EUR	333 000	606 000	1 312 000	2 386 000
Landfilling of bottom ash (incl. tax, EUR 40/tonne) EUR	320 000	320 000	2 400 000	2 400 000
Revenues:				
Electricity (EUR 0.03/kWh) EUR	0	2 818 000	0	5 770 000
Heat (EUR 0.02/kWh) EUR	1 835 000	1 360 000	13 760 000	10 200 000
Gate fees (EUR 23/tonne)	920 000	920 000	6 900 000	6 900 000
Total costs/tonne	**71.4**	**113.2**	**38.5**	**59.1**
Total revenues/tonne	**68.9**	**127.4**	**68.9**	**76.2**
Net revenue/tonne	**-2.6**	**14.2**	**30.4**	**17.1**
Source: [43, Eunomia, 2001]				

Assumptions made in the calculations in Table 8.9:
There are 7 100 running hours/yr, the heating plant produces heat at 85 % efficiency, the heating and power plant produces heat at 63 % efficiency and electricity 22 % efficiency. The costs and revenues for heat, electricity, gate fees, and landfilling are uncertain. The actual investment costs naturally vary depending on site, state of the market, etc.

Bottom ash is not recycled and therefore has to be landfilled in Sweden, thus entailing a cost rather than generating a revenue.

United Kingdom

The majority of thermal treatment operations in the UK are mass burn incinerators. Some of these were designed to be combined heat and power plants but in practice, heat supply has been limited. This section therefore concentrates on mass burn facilities generating electricity only. There are fluidised bed plants as well as standard grate incinerators in operation. In addition, gasification and pyrolysis plants are being developed, whilst two facilities manufacture RDF for off-site use.

Contract prices for incineration plant show considerable variation. So do estimates of costs reported in the literature. For example:

1. a 1995 study looked at plant of 100 kt/yr, 200 kt/yr and 400 kt/yr, respectively. Again, all ash residues (350 kg per tonne waste) were assumed to be disposed of to landfill at GBP 10 per tonne. Ferrous metal sales were assumed to be 120 000 per year, equivalent to GBP 20 per tonne for ferrous metal at 6 kg recovery per tonne of input. Using a discount rate of 10 %, and with gate fees calculated for both, a plant supplying electricity only (450 kWh/tonne), and a plant supplying combined heat and power, the results are shown in Table 8.10.

Table 8.10: UK gate fees for different incinerator capacities and energy outputs

	Gate fee required to cover costs (EUR/tonne)					
	100 kt/yr		200 kt/yr		400 kt/yr	
	Elect.	CHP	Elect.	CHP	Elect.	CHP
Pool price (EUR 0.04/kWh)	75.2	83.2	57.6	64	44.8	49.6
(EUR 0.064/kWh for 15 yr.)	65.6	75.2	48	56	36.8	41.6
Source: [43, Eunomia, 2001]						

2. another study assessed costs for plant of different sizes (110 kt/yr, 225 kt/yr, 400 kt/yr and 600 kt/yr) assuming that bottom ash (30 % input) and fly ash (4 % of input) would both be disposed of at GBP 10 per tonne, electricity (600 kWh/tonne) sold at EUR 0.048/kWh, ferrous metal sold at EUR 32 per tonne (6 kg recovered per tonne input waste), and 19 % of waste eligible for packaging recovery credit sales at EUR 24 per tonne. With a cost of capital of 15 %, gate fees to generate the required rate of return were calculated at EUR 91.2 (110 kt/yr), EUR 65.4 (225 kt/yr) and EUR 50.7 (400 kt/yr) and EUR 42.2 (600 kt/yr).

In all cases, the capital expenditures (which drive the cost side of the equation) vary significantly. What is included, and the manner in which this is accounted for varies across the studies.

An attempt to provide a more detailed breakdown was designed to illustrate sensitivities to key variables and is given below. It is reported that relative to earlier studies:

- United Kingdom incinerators will have had to improve the performance of flue-gas treatment since the days of earlier studies
- a source of revenue is now available where it was not before. Incinerators are allowed to issue PRNs in respect of the packaging content of waste recovered (which has been estimated, for the purposes of calculating the quantity of packaging recovered, at 19 % of input wastes). However, given the debates over whether this revenue will continue in the longer term, it might not be accounted for in calculations of costs by private contractors (since they may not be able to depend on this revenue over the plant's life)
- the previous regime in respect of renewable energy allowed energy from waste plants to benefit from Non-Fossil Fuel Obligation (NFFO) contracts which offered price support for electricity delivered by the plant. The new Renewables Obligation removes this possibility for incinerators (though it seems possible that pyrolysis and gasification plants will benefit from such support).

Table 8.11: **Breakdown of estimated United Kingdom incinerator costs**

Capacity t/yr			**100 000**	**200 000**	**Unit Costs**	
Utilisation as % capacity			95 %	95 %	100 000 t/yr	200 000 t/yr
			95 000	190 000		
CAPITAL EXPENDITURE						
Acquisition			EUR 1 120 000	EUR 1 920 000		
Handling, furnace, civil works, gas treatment boiler						
and power generation			EUR 32 000 000	EUR 46 000 000		
Planning			EUR 1 600 000	EUR 2 400 000		
Project development			EUR 2 696 000	EUR 3 896 000		
Total capital expenditure			EUR 56 620 000	EUR 81 820 000		
Total capital expenditure excl. vehicles			EUR 51 200 000	EUR 7 360 000		
Annualised capital expenditure			EUR 5 344 000	EUR 7 723 000	EUR 56.26	EUR 40.64
Annualised capital expenditure excl. vehicles						
OPEX						
Labour			EUR 1 120 000	EUR 1 440 000	EUR 11.79	EUR 7.58
Fuel						
Electricity						
Maintenance			EUR 1 024 000	EUR 1 472 000	EUR 10.78	EUR 7.74
Other			EUR 640 000	EUR 1 280 000	EUR 6.74	EUR 6.74
Disposal of rejects			0	0	EUR 0.00	EUR 0.00
Bottom Ash	*12.8*	*0.24*	EUR 291 800	EUR 583 700	EUR 3.07	EUR 3.07
Fly Ash/APC residues	*88*	*0.044*	EUR 367 800	EUR 735 700	EUR 3.87	EUR 3.87
Total annualised costs			EUR 8 528 000	EUR 1 271 000	EUR 92.50	EUR 69.65
REVENUES	Unit Price	Quantity per tonne				
Net energy (kWh)	0.0360	500	- EUR 1 710 000	- EUR 3 420 000	- EUR 18.00	- EUR 18.00
Material sales (Fe)	0	0.04	0	0	EUR 0.00	0.00
Packaging recovery revenues	32	0.19	- EUR 433 200	- EUR 866 400	- EUR 4.56	- EUR 4.56
COSTS NET OF REVENUES			**EUR 6 385 000**	**EUR 8 428 000**	**EUR 69.94**	**EUR 47.09**

Source: [43, Eunomia, 2001]

- in the UK there is some uncertainty as to how implementation of the Landfill Directive will affect the costs of landfilling ash residues. In some countries increasing quantities of bottom ash are recovered for use in construction. It was assumed in earlier studies that fly ash and air pollution control would be disposed of for EUR 35 per tonne (inclusive of EUR 16 landfill tax). However, if they require stabilisation before landfilling this would increase the disposal costs of this residue. Note the breakdown assumes a cost for fly ash disposal of EUR 55 per tonne; and
- it is assumed that although steel is recovered from the plant, its quality is such that it may not attract a positive price.

Key factors explaining current variation in costs:

The gate fee paid by Local Authorities is strongly influenced by whether or not the Local Authority is successful in bidding for PFI (Public Finance Initiative) credits. PFI credits effectively subsidise the capital cost of incineration plants enabling local authorities to purchase them when they might otherwise be unable to do so. The plant in Table 7.12 might see its gate fee (to a Local Authority) halved under this scheme.

Key Factors expected to influence future costs:

The following factors may affect gate fees in future:

- incinerators currently obtain packaging recovery income for 19 % of the material combusted. Removing this option (if the recovery obligation were removed from the Packaging Directive) would increase the gate fee up by around EUR 4.8 (though future prices could make this 'loss' greater of smaller)
- the Landfill Directive requires an end to co-disposal and the pretreatment of landfilled waste. United Kingdom government has yet to decide upon what the requirements for pretreatment will entail for fly ash. A requirement to solidify ash in cement or glass would increase costs by as much as EUR 38 per tonne (since the estimated treatment cost for fly ash disposal would increase by a factor of 5 – 10). Even without this, the potential scarcity of hazardous waste landfills makes it unclear where fly ash can be landfilled.

8.2 Economic overview – some technological aspects of MSWI

For the TWG: the information in this section is out dated. Please provide updated information

This annex presents the supplied data concerning the costs of some MSW incineration facilities. The economic aspects of various types of MSW plants/situations are considered. These are:

- discharge and storage costs at a MSWI
- firing system and boiler selection and sizing at a MSWI
- various configurations of the water steam cycle for energy recovery at a MSWI
- selected options for flue-gas treatment at MSWI
- cost estimations for whole MSWI plants using grate technology
- costs of fluidised bed plants for MSW (including pretreatment costs)
- gasification and pyrolysis systems for MSW.

NOTE: The figures given in this annex 8.2 are to be taken as examples and estimates only. They are provided to give the reader an idea of cost structures and inter-relationships, but MUST NOT be taken as accurate representations. Significant variation in cost is seen from site to site. Other combinations are also possible. [64, TWGComments, 2003]

As already noted, the costs of a waste incineration plant basically depend on the following factors:

- plant design
- size
- local infrastructure
- specific boundary conditions for waste disposal
- possibility for energy utilisation.

The main components are:

- repayment of investment
- maintenance and re-investment costs
- labour costs
- other fixed costs, such as administration and insurance
- operating costs proportional to throughput, such as chemical supply and waste disposal
- revenues from energy production proportional to throughput.

Existing Installations:

The cost of retrofitting systems at existing installations is higher than the costs at new installations. This is related to the higher cost of the technical implementation of these techniques rather than techniques themselves.

The additional factors that can further increase costs at existing installations are:

- additional engineering effort
- additional civil engineering
- cost of destruction and removal of old equipment
- connection cost
- production losses of the existing plant, etc.

These can amount to an additional cost increase of 25 – 50 %. [64, TWGComments, 2003]

Assumptions made in the study:

In the study [3, Austria, 2002] from which this annex is drawn, the thermal output is considered the key parameter for the investment and operating costs, and not the mass throughput. The thermal output determines the size of the boiler and primarily the flue-gas volume and therefore the size of the flue-gas cleaning devices.

For a better understanding of this chapter some parameters were fixed as follows:

- calorific value of the waste: 10 MJ/kg
- ash content of the waste: 30 %
- chlorine concentration in the raw gas before flue-gas cleaning: 1 000 mg/Nm^3
- SO_2 concentration in the raw gas: 600 mg/Nm^3 (Note: a high assumption for MSW, normally nearer 200 mg/Nm^3 [64, TWGComments, 2003])
- specific air requirement per tonne waste: 4 500 m^3
- specific flue-gas volume after flue-gas cleaning: 5 500 Nm^3/tonne of waste.

To calculate the required induced draught fan power, combustion air with a temperature of 50 °C and a pressure increase of 40 mbar is taken as a basis. The fan efficiency was uniformly assumed to be 70 %.

On the basis of these assumptions, specific costs for particular plant sub-units have been estimated and are given per tonne of combusted waste. As in practise, different boundary conditions for the particular plants apply and each plant represents more or less a prototype, so only a rough estimate can be presented.

The investment costs that are described in this paper are based on order prices of the last five years (predominantly Austrian and German plants, which were constructed under comparable boundary conditions).

8.2.1 Discharge and storage costs for MSWI

In densely populated regions, waste is delivered to the waste incineration plants by refuse collection vehicles. There it is directly dumped into the waste bunker. Therefore, only weighing installations, traffic areas and waste bunkers have to be erected as installations for delivery and storage. The size, and consequently the costs, of these traffic areas and waste bunkers are mainly determined by the plant capacity and the storage volume of the bunker.

Primarily these costs arise from expenses for building above ground level and foundation work. In this case, the investment costs are not directly proportional to the bunker and plant sizes but have to be calculated with the exponent 0.7. For example, doubling the bunker volume will increase costs by a factor: size$^{0.7}$ [3, Austria, 2002]

As to a plant with a yearly waste throughput of about 300 000 tonnes, the construction costs for traffic areas and bunkers are about EUR 10 million. For different plant sizes, costs presented in Table 8.12 have been estimated.

Table 8.12: Specific costs for discharge and storage facilities as a function of throughput when waste is delivered by refuse collection vehicles

Parameter	Throughput		
	100 000 t/yr	**200 000 t/yr**	**300 000 t/yr**
Investment costs (EUR)	about 4.6 M	about 7.5 M	about 10 M
Specific investment costs (EUR/t)	4.74	3.86	3.43
Specific maintenance costs (EUR/t)	0.46	0.38	0.33
Specific costs for delivery with refuse collection vehicles (EUR/t)	**5.2**	**4.24**	**3.77**
Source: [3, Austria, 2002]			

In less densely populated regions some of the waste may be delivered by train. This then makes the erection of track works and installations for discharge, such as container crane systems and dump devices, necessary. Investment cost for a complete crane system is about EUR 3.5 million (for 300 000 t/yr). Crane systems for smaller plants are not much cheaper, since their costs depend on the standardised dimensions of the containers. However, costs for tracks will decrease with decreasing plant size.

For different plant sizes costs presented in

Table 8.13 have been estimated. Yearly maintenance costs uniformly were rated at 3 % of investment costs.

Table 8.13: Specific costs for discharge and storage facilities as a function of throughput when waste is delivered by train

Parameter	Throughput		
	100 000 t/yr	200 000 t/yr	300 000 t/yr
Investment costs (EUR)	c. 3 million	about 4 M	about 5 M
Specific investment costs (EUR/t)	3.09	2.06	1.72
Specific maintenance costs (EUR/t)	0.90	0.60	0.50
Specific costs of train discharge (EUR/t)	**3.99**	**2.66**	**2.22**
Source: [3, Austria, 2002]			

If one part of the waste is delivered by train and the other part is delivered by refuse collection vehicles, overall costs have to be added

8.2.2 Firing system and boiler costs for MSWI

The firing system and the boiler comprises the following components:

- installation for feeding and dosing of waste
- supply of combustion air
- combustion grate with combustion chamber
- transport and storage installations for ash and slag
- flue-gas ducts until feed-water preheater
- waste heat boiler including feed-water supply and fresh steam delivery.

Cost determining factors for the firing system and the boiler are:

- the type of the grate system
- the desired boiler efficiency and
- the design of the waste heat boiler.

If water-cooled grates are installed and the flue-gas temperature after the waste heat boiler is 160 °C (which increases boiler efficiency to 90 %) and if high steam parameters are applied, the average investment costs can be up to 20 % higher.

For a line with a yearly throughput of about 150 000 tonnes, investment costs for the firing system and the boiler without costs for construction and for electronic, monitoring, regulation and control equipment are about EUR 16 million. Costs for heating surfaces are proportional to the size of the plant, whereas costs for other equipment depend on the plant size, so that on average investment costs will depend on size by a factor of about size$^{0.8}$.[3, Austria, 2002]

Thus for different plant sizes specific costs shown in Table 8.14 below have been estimated. Costs are generally independent of the number of combustion lines.

Table 8.14: Specific costs for a grate firing system and the boiler of waste incineration plants as a function of throughput

Parameter	Throughput		
	75 000 t/yr	100 000 t/yr	150 000 t/yr
Investment costs (EUR)	c. 9.2 million	c. 11.6 million	c. 16 million
Specific investment costs (EUR/yr)	12.63	11.94	10.98
Yearly maintenance costs in per cent of investment costs (%/yr)	4.00	4.00	4.00
Specific maintenance costs (EUR/yr)	4.90	4.60	4.30
Average overall consumption of electricity (normal operation) (kWh/t)	27	27	27
Costs of electricity (EUR/t)	0.67	0.67	0.67
Accumulating bottom ash and boiler ash (kg/t)	271.50	271.50	271.50
Disposal costs of bottom ash and boiler ash (EUR/t)	19.16	19.16	19.16
Specific costs for firing and boiler (EUR/t)	**37.37**	**36.42**	**35.08**
Source: [43, Eunomia, 2001] [3, Austria, 2002]			

Operating costs for the firing system that are directly proportional to the waste throughput arise from:

- energy consumption for air and flue-gas conveying and for feed-water supply
- disposal/recycling costs for bottom ash.

The specific energy consumption for the firing system and the boiler is about 27 kWh/t at a steam pressure of about 50 bar. If the steam pressure is increased to 75 bar the energy demand will rise by about 4 kWh/t.

As to the disposal costs for bottom ash it was assumed that both can be disposed of on a landfill for residual waste. If boiler ash could not, and was disposed of underground, disposal costs would rise by about EUR 2/t.

About 3.2 tonnes of steam per tonne waste are produced in general. Proceeds from steam production are outlined in Section 8.2.3 on the water-steam cycle.

8.2.3 Water-steam cycle costs for MSWI

The water-steam cycle of a waste incineration plant comprises the following components: water treatment plant, condensate system, turbine with cooling system and heat decoupling system.

Different systems are installed in waste incineration plants. At some plants the major part of the energy is fed into the district heating network and electricity is only produced to cover their own needs. At other plants, emphasis is placed on the production of electricity. The kind of plant and the possibilities for energy delivery primarily determine the proceeds from energy production. Therefore this cost overview is presented in such a way that energy proceeds can be totally attributed to the water-steam cycle. Therefore, five technical systems have been distinguished. The energy yield attained in practise depends on a great number of parameters such as boiler design, heat-exchanger surfaces, utilisation of low pressure steam for feed-water and air preheating and turbine design.

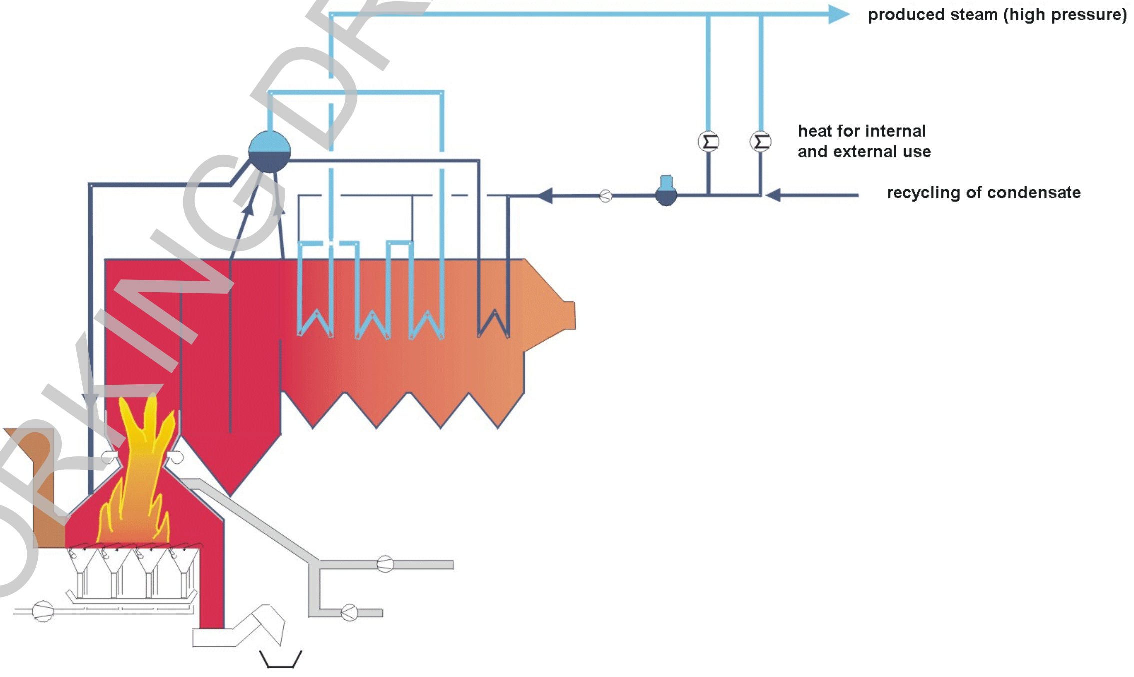
In the following section a comparison of different systems shall be made under standardised boundary conditions.

The main cost factors of the water-steam cycle are described on the basis of the following assumptions:

- yearly operating hours: 7500 h
- in every case a boiler efficiency of about 80 % is assumed so that an energy output of 2.2 MWh per tonne waste results (calorific value of the waste: 10 MJ/kg). This value can vary by plus/minus 10 % depending on the plant
- the investment costs were derived from that of comparable plants. Depending on the actual boundary conditions, significant deviations may occur
- the specific investment costs were calculated on the basis of a rate of interest of 6 % over a duration of 15 years. This period was chosen as the probability for re-investment costs are high after 15 years operation
- yearly maintenance costs uniformly were rated at 3 % of investment costs
- heat and electricity delivery were adjusted to the steam parameters. Depending on the type of turbine and the type and operation of the water-steam cycle deviations may occur
- the use of assumed steam pressures of 50 Bar and 80 Bar is higher than the 40 Bar standard commonly used at many MSWI plants, to avoid corrosion without requiring special measures
- proceeds from delivered energy mainly depend on the kind of energy and the particular energy demand. For feeding electricity into the grid, normally a price of c. EUR 25 per MWh (selling price) is paid. For feeding heat into the district heating system, c EUR 6 per MWh is paid. If the plant is situated at a site where a demand for electricity and heat exists, the income can be about EUR 45 per MWh (purchase price) for electricity and about EUR 10 per MWh for heat. Consequently for the options EUR 1 - 25 per MWh for electricity and EUR 6 per MWh for heat delivery were taken as relevant values. In comparison, EUR 45 per MWh for electricity and EUR 10 per MWh for heat delivery are paid for options 6, 7 and 8. Option 6 technically corresponds to option 2, option 7 technically corresponds to option 4 and option 8 technically corresponds to option 5.

<u>Option 1: Pure heat decoupling:</u>

If only heat is produced, the investment costs comprise expenses for water, condensate treatment and for heat transformation. If no other infrastructure exists, cooling systems for emergency situations have to be installed.



Source: [3, Austria, 2002]

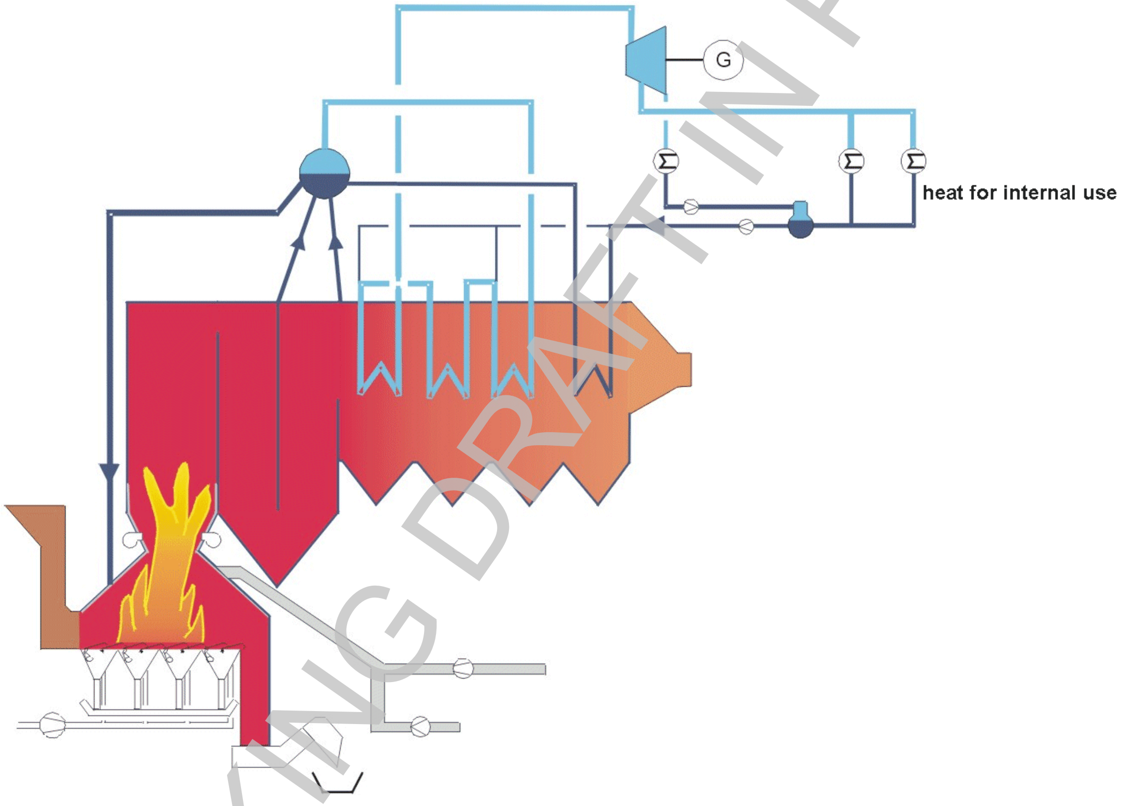
Figure 8.1: Water-steam cycle, option 1

Table 8.15: Specific costs of a water-steam cycle with pure heat decoupling and feeding into district heating systems as a function of waste throughput

Parameter	Throughput 100 000 t/yr	200 000 t/yr	300 000 t/yr
Investment costs (EUR)	c. 3 million	c. 4.5 million	c. 6 million
Specific investment costs (EUR/t)	3.09	2.32	2.06
Specific maintenance costs (EUR/t)	0.90	0.68	0.60
Heat delivery (MWh t^{-1})	2.2	2.2	2.2
Specific proceeds from heat production (EUR/t)	13.2	13.2	13.2
Rated proceeds from water-steam cycle (EUR/t)	**9.21**	**10.21**	**10.54**
Source: [3, Austria, 2002]			

Option 2: Steam extraction turbine applying steam parameters of 50 bar and 400 °C:

In this case investment costs comprise costs for water and condensate treatment, for heat decoupling, and for the turbine and cooling systems. If no other infrastructure exists re-cooling systems for emergency situations also need to be installed (Figure 8.2).



Source: [3, Austria, 2002]

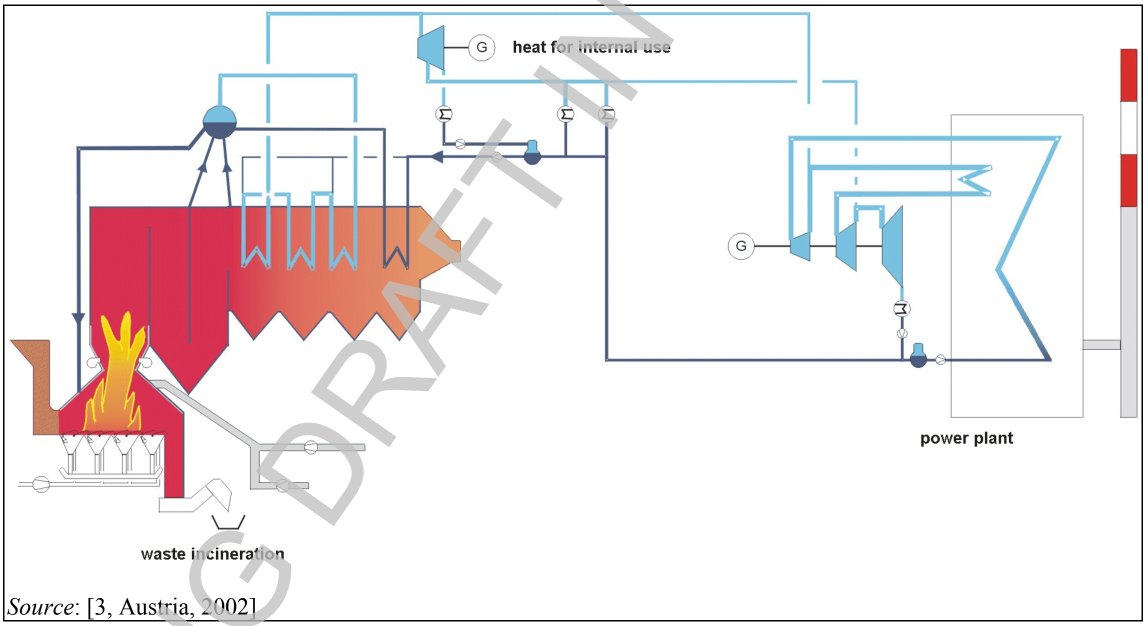
Figure 8.2: Water-steam cycle, option 2 and 6

Table 8.16: Specific costs of a water-steam cycle comprising a steam extraction turbine as a function of waste throughput

Parameter	Throughput		
	100 000 t/yr	**200 000 t/yr**	**300 000 t/yr**
Investment costs (EUR)	c. 8 million	c. 12 million	c. 16 million
Specific investment costs (EUR/t)	8.24	6.18	5.49
Specific maintenance costs (EUR/t)	2.40	1.80	1.60
Heat delivery (MWh t^{-1})	0	0	0
Specific proceeds from heat production (EUR/t)	0	0	0
Electricity delivery (MWh t^{-1})	0.44	0.44	0.44
Specific proceeds from electricity production (EUR/t)	11	11	11
Rated proceeds from water-steam cycle (EUR/t)	**0.36**	**3.02**	**3.91**
Source: [3, Austria, 2002]			

Option 3: Steam extraction turbine combined with steam introduction into an adjacent thermal power plant:

In addition to the investment costs given in option 2, the costs for retrofit measures in the power plant, minus the existent infrastructure, have to be considered (Figure 8.3).



Source: [3, Austria, 2002]

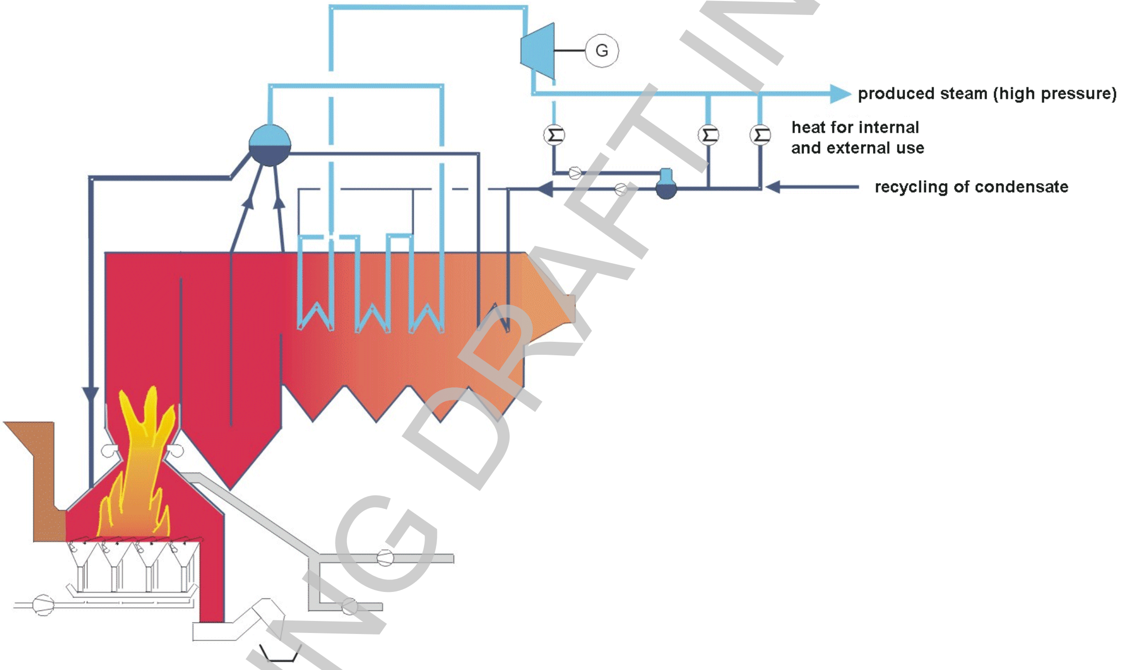
Figure 8.3: Water-steam cycle, option 3

Table 8.17: Specific costs of a water-steam cycle comprising a steam extraction turbine in combination with the steam system of an adjacent power plant as a function of waste throughput

Parameter	Throughput		
	100 000 t/yr	200 000 t/yr	300 000 t/yr
Investment costs (EUR)	c. 8.5 million	c. 12.5 million	c. 15 million
Specific investment costs (EUR/t)	8.75	6.44	5.15
Specific maintenance costs (EUR/t)	2.55	1.88	1.50
Heat delivery (MWh t^{-1})	0	0	0
Specific proceeds from heat production (EUR/t)	0	0	0
Electricity delivery (MWh t^{-1})	0.66	0.66	0.66
Specific proceeds from electricity production (EUR/t)	16.5	16.5	16.5
Rated proceeds from water-steam cycle (EUR/t)	**5.20**	**8.19**	**9.85**
Source: [3, Austria, 2002]			

Option 4: Cogeneration (CHP) applying steam parameters of 50 bar and 400 °C:

In addition to the investment costs given in option 2 the costs for a heat decoupling system needs to be considered (Figure 8.4).



Source: [3, Austria, 2002]

Figure 8.4: Water-steam cycle, options 4, 5, 7 and 8

Table 8.18: Specific costs of a water-steam cycle comprising cogeneration (CHP) and low steam parameters as a function of waste throughput

Parameter	Throughput		
	100 000 t/yr	200 000 t/yr	300 000 t/yr
Investment costs (EUR)	c. 9 million	c. 14 million	c. 18 million
Specific investment costs (EUR/t)	9.27	7.21	6.18
Specific maintenance costs (EUR/t)	2.70	2.10	1.80
Heat delivery (MWh t^{-1})	1.98	1.98	1.98
Specific proceeds from heat production (EUR/t)	11.88	11.88	11.88
Electricity delivery (MWh t^{-1})	0.22	0.22	0.22
Specific proceeds from electricity production (EUR/t)	5.50	5.50	5.50
Rated proceeds from water-steam cycle (EUR/t)	**5.41**	**8.07**	**9.40**
Source: [3, Austria, 2002]			

Option 5: Cogeneration (CHP) applying steam parameters of 80 bar and 500 °C:

In addition to the investment costs given in option 2, the cost increases for raised steam parameters and costs for the installations for heat decoupling have to be considered.

Table 8.19: Specific costs of a water-steam cycle comprising cogeneration (CHP) and high steam parameters as a function of waste throughput

Parameter	Throughput		
	100 000 t/yr	200 000 t/yr	300 000 t/yr
Investment costs (EUR)	c. 10 million	c. 15.5 million	c. 20 million
Specific investment costs (EUR/t)	10.30	7.98	6.86
Specific maintenance costs (EUR/t)	3.00	2.33	2.00
Heat delivery (MWh t^{-1})	1.87	1.87	1.87
Specific proceeds from heat production (EUR/t)	11.22	11.22	11.22
Electricity delivery (MWh t^{-1})	0.33	0.33	0.33
Specific proceeds from electricity production (EUR/t)	8.25	8.25	8.25
Rated proceeds from water-steam cycle (EUR/t)	**6.17**	**9.17**	**10.61**
Source: [3, Austria, 2002]			

Option 6: Steam extraction turbine applying steam parameters of 50 bar and 400 °C:

Contrary to option 2, the waste incineration plant is located at a site where energy can be substituted which would otherwise have to be purchased.

Table 8.20: Specific costs of a water-steam cycle comprising a steam extraction turbine (normal steam parameters) as a function of waste throughput when energy can be substituted

Parameter	Throughput		
	100 000 t/yr	200 000 t/yr	300 000 t/yr
Investment costs (EUR)	c. 8 million	c. 12 million	c. 16 million
Specific investment costs (EUR/t)	8.24	6.18	5.49
Specific maintenance costs (EUR/t)	2.40	1.80	1.60
Heat delivery (MWh t^{-1})	0	0	0
Specific proceeds from heat production (EUR/t)	0	0	0
Electricity delivery (MWh t^{-1})	0.44	0.44	0.44
Specific proceeds from electricity production (EUR/t)	19.8	19.8	19.8
Rated proceeds from water-steam cycle (EUR/t)	**9.16**	**11.82**	**12.71**
Source: [3, Austria, 2002]			

Option 7: Cogeneration (CHP) applying steam parameters of 50 bar and 400 °C:

Contrary to option 4, the waste incineration plant is in this case located at a site where energy can be substituted which would otherwise have to be purchased.

Table 8.21: Specific costs of a water-steam cycle comprising cogeneration (CHP - normal steam parameters) as a function of waste throughput when energy can be substituted

Parameter	**Throughput** **100 000 t/yr**	**200 000 t/yr**	**300 000 t/yr**
Investment costs (EUR)	c. 9 million	c. 14 million	c. 18 million
Specific investment costs (EUR/t)	9.27	7.21	6.18
Specific maintenance costs (EUR/t)	2.70	2.10	1.80
Heat delivery (MWh t^{-1})	1.98	1.98	1.98
Specific proceeds from heat production (EUR/t)	19.80	19.80	19.80
Electricity delivery (MWh t^{-1})	0.22	0.22	0.22
Specific proceeds from electricity production (EUR/t)	9.90	9.90	9.90
Rated proceeds from water-steam cycle (EUR/t)	**17.73**	**20.39**	**21.72**
Source: [3, Austria, 2002]			

Option 8: Cogeneration (CHP) applying steam parameters of 80 bar and 500 °C:

Contrary to option 5, the waste incineration plant is in this case located at a site where energy can be substituted which would otherwise have to be purchased.

Table 8.22: Specific costs of a water-steam cycle comprising cogeneration (CHP - high steam parameters) as a function of waste throughput when energy can be substituted

Parameter	**Throughput** **100 000 t/yr**	**200 000 t/yr**	**300 000 t/yr**
Investment costs (EUR)	c. 10 million	c.15.5 million	c. 20 million
Specific investment costs (EUR/t)	10.30	7.98	6.86
Specific maintenance costs (EUR/t)	3.00	2.33	2.00
Heat delivery (MWh t^{-1})	1.87	1.87	1.87
Specific proceeds from heat production (EUR/t)	18.70	18.70	18.70
Electricity delivery (MWh t^{-1})	0.33	0.33	0.33
Specific proceeds from electricity production (EUR/t)	14.85	14.85	14.85
Rated proceeds from water-steam cycle (EUR/t)	**20.25**	**23.25**	**24.69**
Source: [3, Austria, 2002]			

Discussion of water-steam cycle options 1 to 8:

Survey of specific proceeds from water-steam

Table 8.23: Survey of specific income from different options of the water-steam cycle as a function of waste throughput

Option	Variation in income in EUR per tonne of waste treated with option and throughput		
	100 000 t/yr	**200 000 t/yr**	**300 000 t/yr**
Option 1	9.21	10.21	10.54
Option 2	0.36	3.02	3.91
Option 3	5.20	8.19	9.85
Option 4	5.41	8.07	9.40
Option 5	6.17	9.17	10.61
Option 6	9.16	11.82	12.71
Option 7	17.73	20.39	21.72
Option 8	20.25	23.25	24.69
Source: [3, Austria, 2002]			

As shown in Table 8.23, increasing plant size results in higher proceeds from the water-steam cycle. For lower investments (pure heat decoupling - option 1), the dependence on the plant size is only marginal.

On the basis of rated costs, higher investments for a higher rate of electricity production, as is assumed in option 3 and 5 would be economically favourable. However, option 3 can only be realised at a site adjacent to a power plant with an approximately ten times higher thermal output and a yearly operating time of at least 5 000 h.

Option 5 is problematic in so far as corrosion problems occur when increased steam parameters are applied. In Table 8.23 a high availability is assumed for all options, although this is not expected in practice in the case of option 5. Here higher revision costs within the boiler system and additional downtime have to be considered. If these facts cause additional expenses of about EUR 2 million per year, specific costs will increase by EUR 7 per tonne in the case of a plant with a waste throughput of 300 000 t/yr.

The difference between sites with and without heat, demand at the same cost levels for energy (option 2 and 4) referred to a throughput of 300 000 tonnes per year is only about EUR 5.5/t. Proceeds from electricity production in a power plant and co-generation (CHP) are similar.

A significant increase of proceeds may be achieved by a suitable choice of plant location if produced energy can be used or if an existing energy demand can be covered (option 6 to 8).

8.2.4 Costs for some flue-gas treatment combinations used in MSWI

The economics of the process units that differentiate the following combinations of flue-gas cleaning technologies, are considered in this section. Information is taken from [3, Austria, 2002]:

Combination 1:

- electrostatic precipitator
- two-stage wet scrubbing with and without precipitation
- wet removal of fine dust, and
- catalytic plant (low-dust circuit).

Combination 2:

- fabric filter with dosage of lime and activated coke
- two-stage wet scrubbing with gypsum scrubber and
- downstream catalytic plant (low-dust circuit).

Combination 3:

- electrostatic precipitator
- two-stage wet scrubbing with NaOH scrubber
- fabric filter with dosage of lime and activated coke and
- downstream catalytic plant (low-dust circuit).

Combination 4:

- electrostatic precipitator
- two-stage wet scrubbing with precipitation
- activated coke absorber (cross current)
- downstream catalytic plant (low-dust circuit).

Combination 5:

- electrostatic precipitator
- two-stage wet scrubber
- wet removal of fine dust and
- activated coke absorber (countercurrent).

Combination 6:

- fluidised bed process
- fabric filter
- activated coke filter
- selective catalytic reduction.

8.2.4.1 Dry flue-gas cleaning

For dry flue-gas cleaning it is assumed that the dust concentration in the raw gas is 5 g/Nm^3 and that the flue-gas volume is 5 500 Nm^3/t.

The investment costs for the dedusting device include expenses for the filter itself, as well as for the silos, dust conveyors and dosing devices (if installed).
Operating costs mainly consist of costs for electricity consumption, disposal costs for the separated dust and costs for the adsorption reagents. Costs for the adsorption media also include disposal costs of accumulated waste.

In this assessment dedusting with an electrostatic precipitator is used in combination with a downstream wet electrostatic precipitator or a downstream activated coke plant.

The typical operational temperature range of an electrostatic precipitator is 180 – 230 °C. Specific costs of an electrostatic precipitator as a function of waste throughput are presented in Table 8.24, and the specific costs of wet dedusting systems are shown in Table 8.25.

Costs for dedusting with ESP

Table 8.24: Specific costs for dedusting with an electrostatic precipitator as a function of waste throughput

Parameter	Unit	Throughput per line 75 000 t/yr	 100 000 t/yr	 150 000 t/yr
Consumption of electricity				
Specific consumption	kWh/t	12	12	12
Specific costs of energy consumption	EUR/t	0.29	0.29	0.29
Disposal costs				
Specific amount of accumulated waste	kg/t	27.50	27.50	27.50
Specific costs for waste disposal	EUR/t	4.13	4.13	4.13
Maintenance and wear				
Share of investment costs	%	2	2	2
Specific costs of maintenance	EUR/t	0.27	0.24	0.21
Investment costs	EUR	1 000 000	1 200 000	1 600 000
Specific investment costs	EUR/t	1.37	1.24	1.10
Rated specific overall costs	**EUR/t**	**6.06**	**5.89**	**5.73**
Source: [3, Austria, 2002]				

Costs for a wet dedusting system

Table 8.25: Specific costs for wet dedusting as a function of waste throughput

Parameter	Unit	Throughput per line 75 000 t/yr	 100 000 t/yr	 150 000 t/yr
Consumption of electricity				
Average overall consumption (normal operation)	kWh/t	6	6	6
Costs of electricity consumption	EUR/t	0.16	0.16	0.16
Disposal costs				
Specific amount of accumulated waste	kg/t			
Specific costs for waste disposal	EUR/t			
Maintenance and wear				
Share of investment costs	%	1.5	1.5	1.5
Specific costs of maintenance	EUR/t	0.30	0.30	0.25
Investment costs	EUR	1 500 000	2 000 000	2 500 000
Specific investment costs	EUR/t	2.06	2.06	1.72
Rated specific overall costs	**EUR/t**	**2.52**	**2.52**	**2.12**
Source: [3, Austria, 2002]				

It has been shown that a dry flue-gas cleaning system with dosage of activated coke is the most cost-effective solution for pre-separation of mercury, PCDD/F and for dedusting. Another advantage of this process is that a large proportion of the heavy metals and dioxins and furans are already removed before the flue-gas enters the wet scrubbing system. For that reason the pollutant concentration in the accumulated gypsum is low.

Dry flue-gas cleaning with fabric filter

Table 8.26: Specific costs of a dry flue-gas cleaning system with fabric filters as a function of waste throughput

Parameter	Units	Throughput 75 000 t/yr	100 000 t/yr	150 000 t/yr
Consumption of electricity				
Specific consumption	kWh/t	9	9	9
Specific costs of energy consumption	EUR/t	0.22	0.22	0.22
CaO-consumption incl. waste disposal				
Specific consumption	kg/t	0.00	0.00	0.00
Stoichiometric factor		3	3	3
Specific costs for adsorption	EUR/t	0.00	0.00	0.00
Activated coke consumption				
Specific consumption	kg/t	1.00	1.00	1.00
Specific costs of activated coke	EUR/t	0.30	0.30	0.30
Disposal costs				
Specific amount of accumulated waste	kg/t	28.50	28.50	28.50
Specific costs for waste disposal	EUR/t	4.28	4.28	4.28
Maintenance and wear				
Share of investment costs	%	1	1	1
Specific costs of maintenance	EUR/t	0.15	0.15	0.13
Specific costs of filter wear	EUR/t	0.78	0.78	0.78
Investment costs	EUR	1 150 000	1 450 000	2 000 000
Specific investment costs	EUR/t	1.58	1.49	1.37
Rated specific overall costs	**EUR/t**	**7.30**	**7.21**	**7.08**
Source: [3, Austria, 2002]				

8.2.4.2 Absorption and adsorption plants for the separation of HCl, HF and SO_2

In the study from which this information is drawn [3, Austria, 2002] only wet processes are mainly used for separation of HCl, HF and SO_2. Data for one plant using a dry system for pre-separation is also given.

In cases where wet processes are applied, operating costs are influenced by the type and amount of adsorption media, by the energy consumption and by disposal costs for the waste. The investment costs for flue-gas ducts, scrubbers, droplet separators, heat-exchangers and reactors and for the whole infrastructure for handling of water, waste water, chemicals and residues are also included.

Assumptions made, are that 600 mg/Nm^3 SO_2 and 1 000 mg/Nm^3 HCl have to be separated from the raw gas. Under these conditions specific costs of a NaOH scrubber are about EUR 11/t, costs of scrubbers with precipitation are between 8 and 9 EUR/t and costs of a gypsum scrubber are between EUR 5 and 6/t, respectively.

The combination of a gypsum scrubber with a dry flue-gas cleaning system with activated coke adsorption is slightly more expensive than a dry plant for the separation of HCl, HF and SO_2 only (13.19 vs. 12.78 EUR/t) based on a throughput of 75 000 t/yr.

For plants with a waste throughput of about 100 000 t/yr per line, costs are approximately the same (EUR 12.69 vs. 12.63/t). For a throughput of about 150 000 t/yr per line, lower costs arise for the combination gypsum scrubber plus dry flue-gas cleaning system compared to dry adsorption only (EUR 12.15 vs. 12.44/t).
Some costs of absorption and adsorption plants are given in the tables below:

Dry flue-gas cleaning with adsorption

Table 8.27: Specific costs of a dry flue-gas cleaning system with adsorption as a function of waste throughput

Parameter	Units	Throughput per line		
		75 000 t/yr	100 000 t/yr	150 000 t/yr
Consumption of electricity				
Specific consumption	kWh/t	13	13	13
Specific costs of energy consumption	EUR/t	0.33	0.33	0.33
CaO-consumption incl. waste disposal				
Specific consumption	kg/t	14.44	14.44	14.44
Stoichiometric factor		1.50	1.50	1.50
Specific costs for adsorption	EUR/t	4.50	4.50	4.50
Activated coke consumption				
Specific consumption	kg/t	1.00	1.00	1.00
Specific costs of activated coke	EUR/t	0.30	0.30	0.30
Disposal costs				
Specific amount of accumulated waste	kg/t	28.50	28.50	28.50
Specific costs for waste disposal	EUR/t	4.28	4.28	4.28
Maintenance and wear				
Share of investment costs	%	1	1	1
Specific costs of maintenance	EUR/t	0.23	0.22	0.20
Specific costs of filter wear	EUR/t	0.78	0.78	0.78
Investment costs	EUR	1 725 000	2 175 000	3 000 000
Specific investment costs	EUR/t	2.37	2.24	2.06
Rated specific overall costs	**EUR/t**	**12.78**	**12.63**	**12.44**
Source: [3, Austria, 2002]				

Gypsum scrubber

Table 8.28: Specific costs of a gypsum scrubber as a function of waste throughput

Parameter	Units	Throughput per line		
		75 000 t/yr	100 000 t/yr	150 000 t/yr
Consumption of electricity				
Specific consumption	kWh/t	19	19	19
Specific costs of energy consumption	EUR/t	0.48	0.48	0.48
Reheating				
Temperature increase	°C	30	30	30
Heat demand	kWh/t	0.06	0.06	0.06
Specific costs	EUR/t	0.39	0.39	0.39
$CaCO_3$ consumption				
Specific consumption	kg/t	11.42	11.42	11.42
CaO-consumption				
Specific consumption	kg/t	1.89	1.89	1.89
Costs of neutralising agent	EUR/t	0.47	0.47	0.47
Disposal costs				
Specific amount of accumulated gypsum	kg/t	14.78	14.78	14.78
Specific amount of filter cake	kg/t	1.00	1.00	1.00
Specific costs	EUR/t	0.45	0.45	0.45
Maintenance and wear				
Share of investment costs	%	2	2	2
Specific costs	EUR/t	0.67	0.60	0.53
Investment costs	EUR	2 500 000	3 000 000	4 000 000
Specific investment costs	EUR/t	3.43	3.09	2.75
Rated specific overall costs	**EUR/t**	**5.89**	**5.48**	**5.07**
Source: [3, Austria, 2002]				

Scrubber with precipitation

Table 8.29: Specific costs of a scrubber with precipitation as a function of waste throughput

Parameter	Units	Throughput		
		75 000 t/yr	**100 000 t/yr**	**150 000 t/yr**
Consumption of electricity				
Specific consumption	kWh/t	19	19	19
Specific costs of energy consumption	EUR/t	0.48	0.48	0.48
Reheating				
Temperature increase	°C	30	30	30
Heat demand	kWh/t	0.06	0.06	0.06
Specific costs	EUR/t	0.39	0.39	0.39
NaOH- consumption				
Specific consumption	kg/t	2.75	2.75	2.75
CaO-consumption				
Specific consumption	kg/t	9.87	9.87	9.87
Costs neutralising of agent	EUR/t	2.07	2.07	2.07
Disposal costs				
Specific amount of accumulated gypsum	kg/t	8.87	8.87	8.87
Specific amount of filter cake	kg/t	10.85	10.85	10.85
Specific costs	EUR/t	2.16	2.16	2.16
Maintenance and wear				
Share of investment costs	%	2	2	2
Specific costs	EUR/t	0.67	0.60	0.53
Investment costs	EUR	2 500 000	3 000 000	4 000 000
Specific investment costs	EUR/t	3.43	3.09	2.75
Rated specific overall costs	**EUR/t**	**9.19**	**8.78**	**8.37**
Source: [3, Austria, 2002]				

8.2.4.3 NaOH scrubber

Table 8.30: Specific costs of a NaOH scrubber as a function of waste throughput

Parameter	Units	Throughput per line		
		75 000 t/yr	**100 000 t/yr**	**150 000 t/yr**
Consumption of electricity				
Specific consumption	kWh/t	19	19	19
Specific costs of energy consumption	EUR/t	0.48	0.48	0.48
Reheating				
Temperature increase	°C	30	30	30
Heat demand	MWh/t	0.06	0.06	0.06
Specific costs	EUR/t	0.39	0.39	0.39
NaOH- consumption				
Specific consumption	kg/t	6.88	6.88	6.88
CaO-consumption				
Specific consumption	kg/t	4.71	4.71	4.71
Costs for neutralising agent	EUR/t	3.77	3.77	3.77
Disposal costs				
Specific amount of accumulated gypsum	kg/t	0.00	1.00	2.00
Specific amount of filter cake	kg/t	25.64	25.64	25.64
Specific costs	EUR/t	3.85	3.91	3.97
Maintenance and wear				
Share of investment costs	%	1.5	1.5	1.5
Specific costs	EUR/t	0.36	0.33	0.30
Investment costs	EUR	1 800 000	2 200 000	3 000 000
Specific investment costs	EUR/t	2.47	2.27	2.06
Rated specific overall costs	**EUR/t**	**11.31**	**11.14**	**10.96**
Source: [3, Austria, 2002]				

8.2.4.4 Secondary NO_X reduction using SCR or SNCR

[3, Austria, 2002]
In addition to investment costs and costs for SCR commonly include: maintenance, flue-gas reheating, catalyst-exchange, ammonia/urea and electricity. Flue-gas reheating costs are dependent on catalyst operation temperature and the order in which flue-gas treatment techniques are applied i.e. if wet scrubbers are applied downstream of SCR systems, the inlet temperature to the SCR preheater can be lower and hence less reheat required. Application of SCR in high dust areas is rare in waste incineration facilities (for operational reasons) but has the advantage of avoiding reheating.

Included in the investment costs presented here are; the whole flue-gas path with heat transfer system, flue-gas pipe, catalyst box and bypass pipe as well as the whole NH_4OH system consisting of de-tanking equipment, storage, dosing station, evaporation and mixing. The overall costs of catalytic flue-gas cleaning (

Table 8.30) are about 3 EUR/t, which is two times higher than the costs for non-catalytic flue-gas cleaning (SNCR see Table 8.31).

SCR is generally used where emission limits are set below 100 mg/Nm^3 and gives performance typically in the range of 40 – 70 mg/Nm^3. Although emission concentrations below 70 mg/Nm^3 are reported in some cases, SNCR emission levels in the range of 120 – 180 mg/Nm^3 are more typical.

If the catalyst is also used for dioxin oxidation the catalyst volume and thus the position specific volume/catalyst wear will increase. However, the differences in overall costs are small.

Catalytic flue-gas cleaning (SCR)

Table 8.30: Specific costs of SCR as a function of waste throughput

Parameter	Units	Throughput per line		
		75 000 t/yr	100 000 t/yr	150 000 t/yr
Consumption of electricity				
Specific consumption	kWh/t	8	8	8
Specific costs of energy consumption	EUR/t	0.20	0.20	0.20
Reheating				
Temperature increase	°C	30	30	30
Heat demand	MWh/t	0.06	0.06	0.06
Specific costs	EUR/t	0.64	0.64	0.64
NH_4OH consumption (as NH_3 solution 25 %)				
Specific consumption	kg/t	2.44	2.44	2.44
Specific costs	EUR/t	0.37	0.37	0.37
Maintenance and wear				
Share of investment costs	%	1	1	1
Specific	EUR/t	0.16	0.15	0.13
Average life cycle	a	10.00	10.00	10.00
Specific costs catalyst wear	EUR/t	0.30	0.30	0.30
Investment costs	EUR	1 200 000	1 500 000	2 000 000
Specific investment costs	EUR/t	1.65	1.54	1.37
Rated specific overall costs	**EUR/t**	**3.32**	**3.20**	**3.02**
Source: [3, Austria, 2002]				

Note: Several members of the TWG commented that the SCR investment cost presented above were low compared to the current market.

Non-catalytic flue-gas cleaning (SNCR)

Table 8.31: Specific costs of SNCR as a function of waste throughput

Parameter	Units	Throughput per line		
		75 000 t/yr	100 000 t/yr	150 000 t/yr
Consumption of electricity				
Specific consumption	kWh/t	2	2	2
Specific costs of energy consumption	EUR/t	0.04	0.04	0.04
NH_4OH consumption (as NH_3 solution 25 %)				
Specific consumption	kg/h	4.88	4.88	4.88
Specific costs	EUR/t	0.73	0.73	0.73
Maintenance and wear				
Share of investment costs	%	2	2	2
Specific	EUR/t	0.19	0.16	0.13
Investment costs	EUR	700 000	800 000	1 000 000
Specific investment costs	EUR/t	0.96	0.82	0.69
Rated specific overall costs	**EUR/t**	**1.92**	**1.76**	**1.59**
Source: [3, Austria, 2002]				

8.2.4.5 Post treatment flue-gas polishing systems

At some plants, systems for the post treatment of flue-gases are installed after the dedusting and gas absorption or adsorption operations: These are generally a flow injection absorber (Table 8.32) with activated coke and lime or limestone as reagents and fixed-bed absorber (Table 8.33) using furnace coke.

In this case, reacted or loaded reagents are reburned in the combustion system. Thus operating costs are primarily the costs for the adsorption media and electricity consumption. Investment costs include flue-gas ducts, heat-exchangers, reactors and filters and the required infrastructure for delivery, storage and dosage of chemicals and for conveying, storage and landfilling of residues.

The costs of an additional flue-gas polishing stages are given below:

Flow injection absorber

Table 8.32: Specific costs of a flow injection absorber as a function of waste throughput

Parameter	Units	Throughput per line 75 000 t/yr	 100 000 t/yr	 150 000 t/yr
Consumption of electricity				
Specific consumption	kWh/t	9	9	9
Specific costs of energy consumption	EUR/t	0.22	0.22	0.22
CaO-consumption incl. salt disposal				
Specific consumption	kg/t	4.77	4.77	4.77
Stoichiometric factor		15.00	15.00	15.00
Specific costs for adsorption	EUR/t	1.09	1.09	1.09
Activated coke consumption				
Specific consumption	kg/t	1.00	1.00	1.00
Specific costs of activated coke	EUR/t	0.30	0.30	0.30
Disposal costs				
Specific amount of accumulated waste	kg/t	1.06	1.06	1.06
Specific costs for waste disposal	EUR/t	0.16	0.16	0.16
Maintenance and wear				
Share of investment costs	%	1	1	1
Specific costs of maintenance	EUR/t	0.15	0.15	0.13
Specific costs of filter wear	EUR/t	0.78	0.78	0.78
Investment costs	EUR	1 150 000	1 450 000	2 000 000
Specific investment costs	EUR/t	1.58	1.49	1.37
Rated specific overall costs	**EUR/t**	**4.28**	**4.18**	**4.05**
Source: [3, Austria, 2002]				

Activated coke plant

Table 8.33: Specific costs of an activated coke plant as a function of waste throughput

Parameter	Units	Throughput per line 75 000 t/yr	 100 000 t/yr	 150 000 t/yr
Consumption of electricity				
Specific consumption	kWh/t	10	10	10
Specific costs of energy consumption	EUR/t	0.25	0.25	0.25
Activated coke consumption				
Specific consumption	kg/t	2.00	2.00	2.00
Specific costs	EUR/t	0.60	0.60	0.60
Maintenance and wear				
Share of investment costs	%	1	1	1
Specific	EUR/t	0.37	0.36	0.33
Investment costs	EUR	2 800 000	3 600 000	5 000 000
Specific investment costs	EUR/t	3.84	3.71	3.43
Rated specific overall costs	**EUR/t**	**5.07**	**4.92**	**4.62**
Source: [3, Austria, 2002]				

8.2.5 Cost of some air emissions monitoring system

For the TWG: from Sections 2.8.3 and 2.8.4

Monitoring of PCDDs, PCDFs and PCBs

Cost data for long term sampling of PCDDs, PCDFs and PCBs (from Indaver):

Investment:	EUR 110 000 – 140 000
Testing of the system:	EUR 4 900 (estimation)
Analysis (26 samples/yr):	EUR 20 000/yr
Maintenance by the supplier (preventive):	EUR 2 500/yr

[For the TWG: Please provide updated information]

Monitoring of mercury

Cost data for continuous measurement of mercury (estimated):

Investment:	EUR 30 000
Testing of system:	EUR 5 000

[*For the TWG: Please provide updated information*]

Investment cost of the long term sapling for mercury is considerably cheaper than the continuous. It is 10-20% of the AMS. The operating cost is estimated to be approximately the same for the two methods. [80, Denmark 2015]

8.2.6 Cost estimations for some complete MSWI plants

[3, Austria, 2002]
In order to estimate the costs of whole plants, the following assumptions are made:

At a plant with a waste throughput of 100 000 t/yr an arrangement based on one line, for 200 000 t/yr two lines of 100 000 t/yr each and for 300 000 t/yr two lines of 150 000 t/yr each are assumed.

The investment costs that have been estimated here for the particular plant components, only refer to the systems engineering and hardware costs. Therefore, additional costs relating to construction, electrical and mechanical costs (EMC), and other infrastructure measurements need to be added. The following costs are estimated for these:

- construction costs + 20 % of plant cost
- EMC + 15 % of the plant cost.

Other investment costs such as costs for planning of the plant, and other infrastructure, differ marginally with plant size. Labour costs were calculated for the whole plant and, thus, have not been considered in the estimations for the particular plant components. In the cost calculations only expenses for those personnel that are directly necessary for the plant operation are included. Differences in the distribution and administration systems have been neglected.

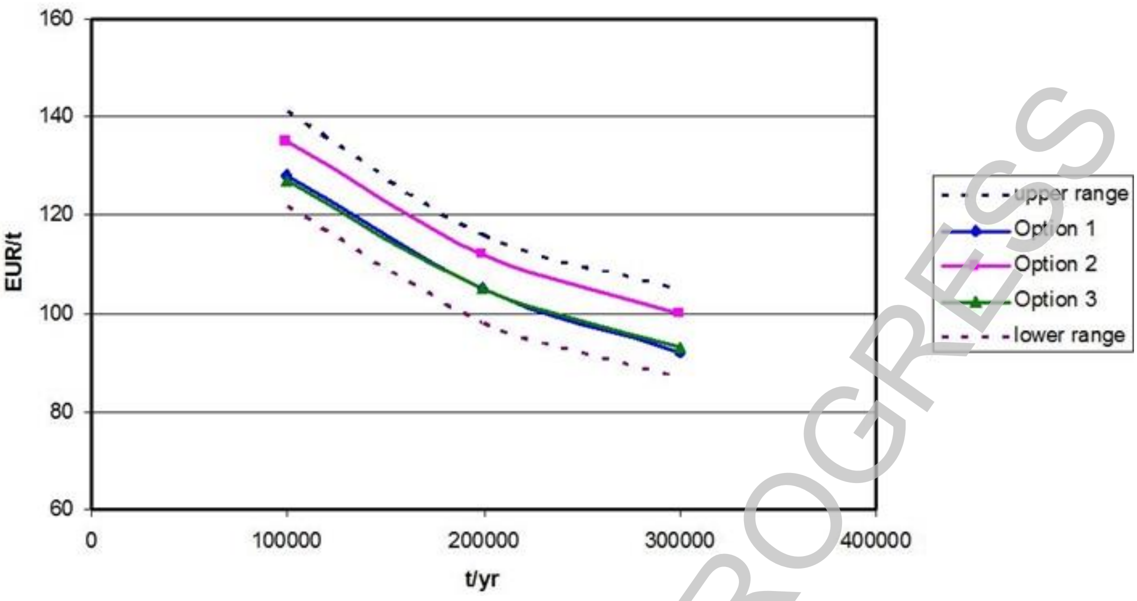
The investment costs were calculated statically based on a duration of 15 years and at a rate of interest of 6 %. Furthermore, full load operation of the plant with a yearly operating time of 7 500 h was assumed. In the rated costs, some aspects, such as costs for construction interests, leading personnel, administration, advertising, and insurance are not included. Thus costs calculated under these assumptions are at least 30 to 40 % too low and therefore calculated as *rated specific overall costs*. To make cost estimations more realistic, 40 % was added to the rated specific overall costs and the resulting cost were named *estimated specific overall costs*.

Cost estimations for different plants are based on the same simplified assumptions. Thus the relations of different plants correspond to practical experiences.

In the tables below, the following differences between plants are illustrated:
- different plant size
- different energy utilisation on the basis of uniform prices
- different flue-gas cleaning systems.

The assumptions made are described in the titles Table 8.34 of to Table 8.39.

The figure below shows examples of the impact of plant size and the energy utilisation option on the specific waste treatment costs of new MSWI installations:

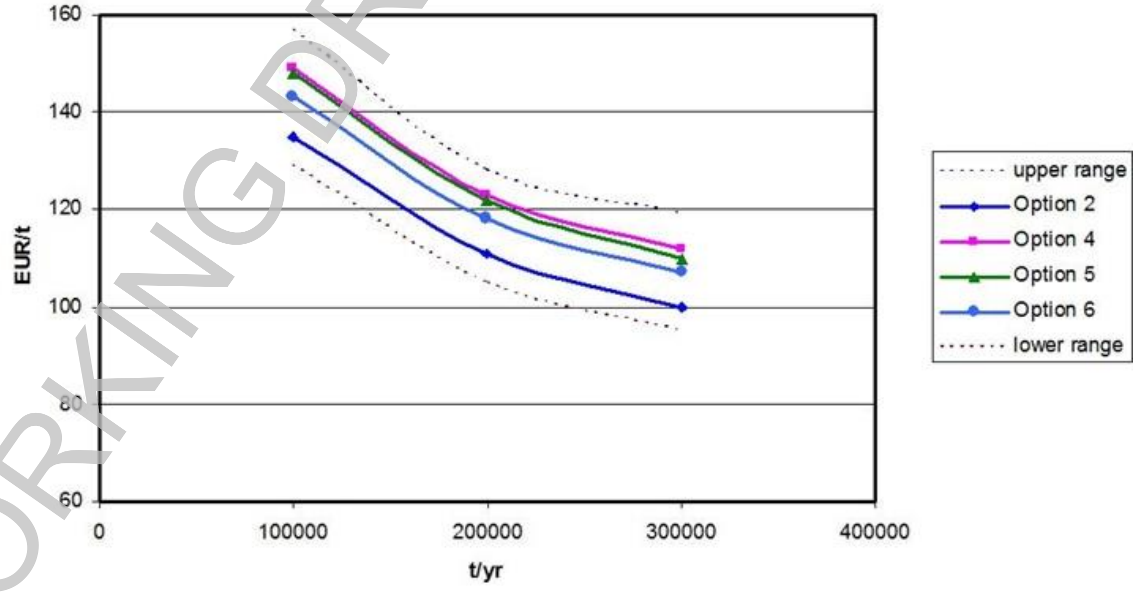


Source: [3, Austria, 2002], [64, TWGComments, 2003]

Figure 8.5: The impact of plant size and energy utilisation on the specific waste treatment costs of new MSWI installations

Plant size has a great influence on the overall costs of a plant. The maximum difference between small and large plants is about EUR 37 per tonne incinerated waste. The means of energy utilisation shifts the costs by about EUR 9 per tonne. Integration of steam in existing power plant (option 1) and cogeneration (option 3) lead to lower overall costs than pure electricity production (option 2).

Figure 8.6 shows the specific waste treatment cost structure for MSWI installations using different flue-gas treatment techniques, but with the same energy utilisation option:



Source: [3, Austria, 2002], [64, TWGComments, 2003]

Figure 8.6: The impact of varying FGC systems and plant sizes on the treatment costs of new MSWI installations using the same energy utilisation techniques

In the options that are shown in Figure 8.6, only electricity is produced from waste incineration. Again it is shown that the overall costs of a plant mainly depend on the size (maximum difference: EUR 37 per tonne), whereas the maximum difference as a function of the flue-gas cleaning system is EUR 13 per tonne.

On the whole, the range of overall costs shown in both figures is between 92 and 148 EUR per tonne of incinerated waste.

For smaller throughput plants (e.g. below 100 000 tonnes/yr), because the overall quantity of heat produced is lower, it can be easier to find a heat user. In such cases most of the heat produced by the plant may be sold. This income from heating energy may then reduce the gate fee for received waste to the level where the small scale of the plant actually becomes an economic advantage. For example: where steam sells at a price of 15 - 20 EUR/MWh, and 2 - 2.5 MWh of heat is produced per tonne of waste, this yields steam income in the range of EUR 30 – 50 per tonne waste. [64, TWGComments, 2003]

In rural regions, a plant capacity of 300 000 t/yr can corresponds to a waste collection area radius of about 80 – 100 km. For small plants the cost difference between direct delivery with the refuse collection vehicle and delivery with an overall logistic of collection, reloading to train and transport by train is between EUR 10 and 15/t. Thus lower logistic costs at small plants can compensate the higher specific treatment costs only to a small degree.

Table 8.34: Option 1: Costs of a grate firing system incorporating delivery by train, dry, wet and catalytic flue-gas treatment and with the steam cycle connected to that of an adjacent power plant as a function of throughput

Parameter	**Units**	**Throughput** **100 000 t/yr**	 **200 000 t/yr**	 **300 000 t/yr**
Costs for discharge and storage using refuse collection vehicles	EUR/t	5.20	4.24	3.77
Additional costs for discharge and storage using the train	EUR/t	3.99	2.66	2.22
Firing system and boiler	EUR/t	36.42	36.42	35.08
Water steam cycle (option 3)	EUR/t	5.20	8.19	9.85
Dry flue-gas cleaning	EUR/t	7.21	7.21	7.08
Gypsum scrubber	EUR/t	5.48	5.48	5.07
Catalytic flue-gas cleaning	EUR/t	3.20	3.20	3.02
Investment costs of systems engineering	EUR	33 650 000	59 100 000	78 000 000
Construction	EUR	6 730 000	11 820 000	15 600 000
EMC	EUR	5 048 000	8 865 000	11 700 000
Other investment costs	EUR	6 000 000	7 000 000	8 000 000
Specific costs for construction, EMC + others	EUR/t	18.30	14.25	12.12
Personnel costs	EUR/yr	1 700 000	1 800 000	2 000 000
Specific personnel costs	EUR/t	17.00	9.00	6.67
Rated overall costs	**EUR/t**	**91.60**	**74.27**	**65.16**
Estimated overall costs	**EUR/t**	**128**	**104**	**91**
Source: [3, Austria, 2002]				

Table 8.35: **Option 2: Costs of a grate firing system incorporating delivery by train, dry, wet and catalytic flue-gas treatment with power generation as a function of throughput**

Parameter	**Units**	**Throughput** **100 000 t/yr**	**200 000 t/yr**	**300 000 t/yr**
Costs for discharge and storage using refuse collection vehicles	EUR/t	5.20	4.24	3.77
Additional costs for discharge and storage using the train	EUR/t	3.99	2.66	2.22
Firing system and boiler	EUR/t	36.42	36.42	35.08
Water steam cycle (option 2)	EUR/t	0.36	3.02	3.91
Dry flue-gas cleaning	EUR/t	7.21	7.21	7.08
Gypsum scrubber	EUR/t	5.48	5.48	5.07
Catalytic flue-gas cleaning	EUR/t	3.20	3.20	3.02
Investment costs of systems engineering	EUR	33 150 000	58 600 000	79 000 000
Construction	EUR	6 30 000	11 720 000	15 800 000
EMC	EUR	4 973 000	8 790 000	11 850 000
Other investment costs	EUR	6 000 000	7 000 000	8 000 000
Specific costs for construction, EMC + others	EUR/t	18.12	14.16	12.24
Personnel costs	EUR/yr	1 700 000	1 800 000	2 000 000
Specific personnel costs	EUR/t	17.00	9.00	6.67
Rated overall costs	**EUR/t**	**96.26**	**79.35**	**71.22**
Estimated overall costs	**EUR/t**	**135**	**111**	**100**
Source: [3, Austria, 2002]				

Table 8.36: **Option 3: Costs of a grate firing system incorporating delivery by train, dry, wet and catalytic flue-gas treatment with cogeneration (CHP) as a function of throughput**

Parameter	**Units**	**Throughput** **100 000 t/yr**	**200 000 t/yr**	**300 000 t/yr**
Costs for discharge and storage using refuse collection vehicles	EUR/t	5.20	4.24	3.77
Additional costs for discharge and storage using the train	EUR/t	3.99	2.66	2.22
Firing system and boiler	EUR/t	36.42	36.42	35.08
Water steam cycle (option 4)	EUR/t	5.41	8.07	9.40
Dry flue-gas cleaning	EUR/t	7.21	7.21	7.08
Gypsum scrubber	EUR/t	5.48	5.48	5.07
Catalytic flue-gas cleaning	EUR/t	3.20	3.20	3.02
Investment costs of systems engineering	EUR	34 150 000	60 600 000	81 000 000
Construction	EUR	6 830 000	12 120 000	16 200 000
EMC	EUR	5 123 000	9 090 000	12 150 000
Other investment costs	EUR	6 000 000	7 000 000	8 000 000
Specific costs for construction, EMC + others	EUR/t	18.48	14.52	12.48
Personnel costs	EUR/yr	1 700 000	1 800 000	2 000 000
Specific personnel costs	EUR/t	17.00	9.00	6.67
Rated overall costs	**EUR/t**	**91.57**	**74.66**	**65.97**
Estimated overall costs	**EUR/t**	**128**	**104**	**92**
Source: [3, Austria, 2002]				

Table 8.37: Option 4: Costs of a grate firing system incorporating delivery by train, electrostatic precipitator, NaOH scrubber, flow injection absorber and catalytic plant with power generation as a function of throughput

Parameter	Units	Throughput		
		100 000 t/yr	200 000 t/yr	300 000 t/yr
Costs for discharge and storage using refuse collection vehicles	EUR/t	5.20	4.24	3.77
Additional costs for discharge and storage using the train	EUR/t	3.99	2.66	2.22
Firing system and boiler	EUR/t	36.42	36.42	35.08
Water steam cycle (option 2)	EUR/t	0.36	3.02	3.91
Electrostatic precipitator	EUR/t	5.89	5.89	5.73
NaOH scrubber	EUR/t	11.14	11.14	10.96
Flow injection absorber	EUR/t	4.18	4.18	4.05
Catalytic flue-gas cleaning	EUR/t	3.20	3.20	3.02
Investment costs systems of engineering	EUR	37 250 000	59 400 000	80 200 000
Construction	EUR	7 450 000	11 800 000	16 040 000
EMC	EUR	5 588 000	8 910 000	12 030 000
Other investment costs	EUR	6 000 000	7 000 000	8 000 000
Specific costs for construction, EMC + others	EUR/t	19.60	14.31	12.38
Personnel costs	EUR/yr	1 700 000	1 800 000	2 000 000
Specific personnel costs	EUR/t	17.00	9.00	6.67
Rated overall costs	**EUR/t**	**106**	**88**	**80**
Estimated overall costs	**EUR/t**	**148**	**123**	**112**
Source: [3, Austria, 2002]				

Table 8.38: Option 5: Costs of a grate firing system incorporating delivery by train, electrostatic precipitator, precipitation, activated coke absorber and catalytic plant with power generation as a function of throughput

Parameter	Units	Throughput		
		100 000 t/yr	200 000 t/yr	300 000 t/yr
Costs for discharge and storage using refuse collection vehicles	EUR/t	5.20	4.24	3.77
Additional costs for discharge and storage using the train	EUR/t	3.99	2.66	2.22
Firing system and boiler	EUR/t	36.42	36.42	35.08
Water steam cycle (option 2)	EUR/t	0.36	3.02	3.91
Electrostatic precipitator	EUR/t	5.89	5.89	5.73
Scrubber with precipitation	EUR/t	8.78	8.78	8.37
Activated coke absorber	EUR/t	4.92	4.92	4.62
Catalytic flue-gas cleaning	EUR/t	3.20	3.20	3.02
Investment costs of systems engineering	EUR	40 500 000	65 300 000	88 200 000
Construction	EUR	8 100 000	13 060 000	17 640 000
EMC	EUR	6 075 000	9 795 000	13 230 000
Other investment costs	EUR	6 000 000	7 000 000	8 000 000
Specific costs for construction, EMC + others	EUR/t	20.77	15.37	13.34
Personnel costs	EUR/yr	1 700 000	1 800 000	2 000 000
Specific personnel costs	EUR/t	17.00	9.00	6.67
Rated overall costs	**EUR/t**	**105.82**	**87.46**	**78.90**
Estimated overall costs	**EUR/t**	**147**	**122**	**110**
Source: [3, Austria, 2002]				

Table 8.39: Option 6: Costs of a grate firing system incorporating delivery by train, dry adsorption, activated coke absorber and catalytic plant with power generation as a function of throughput

Parameter	Units	Throughput		
		100 000 t/yr	200 000 t/yr	300 000 t/yr
Costs for discharge and storage using refuse collection vehicles	EUR/t	5.20	4.24	3.77
Additional costs for discharge and storage using the train	EUR/t	3.99	2.66	2.22
Firing system and boiler	EUR/t	36.42	36.42	35.08
Water steam cycle (option 2)	EUR/t	0.36	3.02	3.91
Dry adsorption	EUR/t	12.63	12.63	12.44
Activated coke absorber	EUR/t	4.92	4.92	4.62
Catalytic flue-gas cleaning	EUR/t	3.20	3.20	3.02
Investment costs of systems engineering	EUR	38 480 000	61 250 000	83 000 000
Construction	EUR	7 695 000	12 250 000	16 600 000
EMC	EUR	5 771 000	9 188 000	12 450 000
Other investment costs	EUR	6 000 000	7 000 000	8 000 000
Specific costs for construction, EMSR + others	EUR/t	20.04	14.64	12.72
Personnel costs	EUR/yr	1 700 000	1 800 000	2 000 000
Specific personnel costs	EUR/t	17.00	9.00	6.67
Rated overall costs	**EUR/t**	**103.04**	**84.69**	**76.61**
Estimated overall costs	**EUR/t**	**144**	**119**	**107**
Source: [3, Austria, 2002]				

8.2.7 Costs of fluidised bed combustion for MSW

The feedstock of a fluidised bed (FB) must be crushed or shredded before it can be processed in the FB combustion unit. Big inerts, glass and ferrous/non ferrous materials may also be extracted before feeding the combustion chamber to avoid clogging of air inlets and disruption in the fluidisation. The result is that the material fed to the combustion unit has a lower ash content (approximately 10 % instead of 25 %) than unsorted waste. [64, TWGComments, 2003]

The pretreatment required to prepare unsorted MSW for FBC typically costs EUR 10 to 30. This must be added when considering the overall treatment cost. [64, TWGComments, 2003]

Five FBC units were constructed in France between 1995 and 1997. Two separate technologies are employed: TMC dense fluidised bed (DFB) (Guerville, Doullens and Monthyon) and rotating fluidised bed (RFB) (by ABT/Lurgi in Gien and Sausheim). The following operational comments, some with an impact on costs issues, were noted [64, TWGComments, 2003]:

- availability ranges were low, from 65 % to 80 % for the best lines
- construction and commissioning phases were longer than initially anticipated
- excellent combustion performance was confirmed, unburnt matter content of less than 0.3 % in bottom ash
- energy efficiency is considerably lower than for grate-fired units
- a slight reduction in NO_X and low CO emissions
- other emissions similar to grate firing systems.

Load flexibility, absence of thermal inertia and the capacity to handle wastes with a high net calorific value are reported to be of low real benefit.

Total investment costs for the 5 French units vary between 1.5 and 5.8 million EUR/(t/h). Total operational cost vary between EUR 39 and 136/t MSW treated. [64, TWGComments, 2003]

The calorific value and ash content of the wastes treated in fluidised beds vary widely. The specific costs for combustion strongly depend on these two parameters. In order to obtain comparable figures, in this study the following assumptions were made [3, Austria, 2002] (see Tables 10.41 to 10.43 below):

- ash content of the prepared waste: 10 %
- calorific value of the prepared waste: 15 MJ/kg.

These parameters roughly correspond to those of sorted fractions from waste. For a comparison of the specific costs of combustion of unsorted waste on a grate firing system, plants with the same rated thermal input were investigated.

For fluidised bed combustion, estimations were based on a stationary fluidised bed reactor with a capacity of 70 000 t/yr and a circulating fluidised bed with a capacity of 200 000 t/yr in one line each using the waste parameters above.

These data correspond to grate firing systems with a capacity of 100 000 t/yr and 300 000 t/yr (calorific value of waste: 10 MJ/kg). However, in the latter case two combustion lines were assumed. Few plant constructors offer plants with a yearly capacity of 300 000 t per line.

Regarding the energy utilisation, option 2 was the basis for both firing systems.

Costs for flue-gas treatment have been assumed to be the same for both systems, and the same emission limit values applied. In reality, for processes observing the same emission limit values, the FGC costs are likely to be lower with FBC than with a grate incinerator processing the same throughput of waste. [64, TWGComments, 2003]
On the basis of the assumptions made in this study and a capacity of 70 000 t/yr of pretreated waste (fluidised bed), or 100 000 t/yr of untreated waste (grate firing), approximately the same specific treatment costs will arise based on the rated thermal input. Based on the mass throughput incineration costs of fluidised bed combustion systems are noticeably higher than those of a grate firing systems (see

Table 8.42). However, for larger plants, with a throughput of 200 000 t/yr treated waste (for fluidised bed combustion) or 300 000 t/yr untreated waste (for grate firing), specific costs related to the rated thermal input are shown in this study more favourable if fluidised bed combustion is applied. However, if waste first has to be separated into low and high calorific fractions and then subsequently crushed, ground, and separated, the subsequent combustion in a fluidised bed reactor will be less economically favourable in comparison to a grate firing. [64, TWGComments, 2003]

Table 8.40: Costs for the firing system and the boiler of waste incineration plants with fluidised bed combustion as a function of throughput (not including waste pretreatment costs)

Parameter	**Throughput**	
	70 000 t/yr	**200 000 t/yr**
Investment costs (EUR)	c. 10 million	c. 23 million
Specific investment costs (EUR/t)	14.71	11.84
Yearly maintenance costs as share of investment costs (%/yr)	3	3
Specific maintenance costs (EUR/t)	4.29	3.45
Average overall consumption of electricity (normal operation) (kW/t)	57	67
Costs of electricity (EUR/t)	1.44	1.67
Amount of bottom ash and boiler ash (kg/t)	100	100
Disposal costs of bottom ash and boiler ash (EUR/t)	6	6
Specific costs of firing and boiler (EUR/t)	**26.43**	**22.96**

Source: [3, Austria, 2002], [64, TWGComments, 2003]

Costs of a steam cycle: steam extraction turbine applying steam parameters of 50 bar and 400 °C (corresponding to option 2 and a grate firing system):

In addition to the presumptions made in option 2 for grate firing systems the higher calorific value is considered.

Table 8.41: Specific costs of a water-steam cycle comprising a steam extraction turbine (normal steam parameters) as a function of waste throughput

Parameter	Throughput	
	70 000 t/yr	200 000 t/yr
Investment costs (EUR)	c. 8 million	c. 16 million
Specific investment costs (EUR/t)	11.77	8.24
Specific maintenance costs (EUR/t)	3.43	1.40
Delivery of heat (MWh/t)	0	0
Delivery of electricity (MWh/t)	0.66	0.66
Specific proceeds from electricity production (EUR/t)	16.5	16.5
Rated proceeds from water-steam (EUR/t)	**1.30**	**5.86**
Source: [3, Austria, 2002]		

Comparison of costs of grate and fluidised bed systems with the same thermal output:

Table 8.42: Specific costs and income of waste treatment, firing, boiler and energy utilisation

Parameter	Units	Throughput (t/yr)			
		70 000	100 000	200 000	300 000
Grate firing system	EUR/t		36.01		31.18
	EUR/GJ		3.6		3.12
Fluidised bed without waste crushing and grinding	EUR/t	36.52		21.75	
	EUR/GJ	3.77		2.78	
Fluidised bed with waste crushing and grinding [1]	EUR/t	56.52		41.75	
[1] For crushing and grinding of waste an expense of 20 EUR/t was assumed. *Source:* [3, Austria, 2002]					

8.2.8 Gasification and pyrolysis system costs for MSW

This section is based on [43, Eunomia, 2001] and [64, TWGComments, 2003]

Gasification and pyrolysis are not as widely applied for wastes as conventional incineration. Cost data provided may therefore be subject to more variation than that provided for incineration installations.

There is one full-scale gasification plant in Finland, in the city of Lahti, which uses MSW-based recycled fuel. The gasification unit (50 MW) produces gas to be used in a larger, main boiler, which uses coal as main fuel.

The gasifier uses, in addition to selected waste from households, industrial wood based waste such as bark, sawdust, plywood and chipboard. The fraction from households is about 30 - 40 % of input energy.

Fuel receiving, processing (shredding and sieving) and feeding are connected to a gasifier. Energy waste from households is sorted and collected separately, and principally it needs only shredding to be made fuel. The gate fee for separately collected waste from households is zero.

The personnel of the main boiler operate and control the gasification process, so the gasifier does not have significant labour costs of its own. The flue-gas treatment process is in the main boiler, and it has not been included in the gasifier costs. These explain the relatively high profitability of the gasifier as represented in Table 8.43 below.
Investment and operating costs of fuel processing and gasification plant are also shown in Table 8.43 below. The gasification plant is owned and operated by a private sector company, Lahti Energy Ltd.

Capital costs include the profit of the contractor and process provider. VAT is excluded. Operating costs of the gasifier are the prime costs of operator, and do not include profit or VAT. It is important to note that, in the operating costs of fuel processing, including the profit of the contractor (services bought from the private sector), VAT is excluded. This can add significantly to costs.

Key factors expected to influence future costs:

The EU Directive (2000/76/EC) on the incineration of waste will increase the emission monitoring costs and also make the emission limits tighter.

Table 8.43: Capital and operating costs of the Lahti RDF gasification plant, Finland

Costs for Gasification plant Capacity 100 000 tonnes per year (total of all fuels input to gasifier)	**Cost/ EUR**
Capital costs:	
Fuel processing and feeding	4 205 000
Gasifier unit	7 568 000
Total capital costs	**11 770 000**
Operational Cost:	
Gasifier	213 600
Fuel processing and feeding	267 400
Fuel costs (other than waste from households)	883 000
Total operational costs	**1 364 000**
Total annual costs	**2 657 000**
Revenues per year:	
Electricity sales (0.034 EUR/kWh)	3 532 000
District heating sales (0.017 EUR/kWh)	1 766 000
Revenues total	**5 298 000**

NB: Depreciation Period = 15 years at interest rate = 7 %
Source: [43, Eunomia, 2001]

Current pyrolysis/gasification costs in the UK have been estimated (no projects have been brought into full-scale operation) at approximately EUR 40 – 160 per tonne with most suppliers falling in the range EUR 56 - 88 per tonne. Other evidence suggests the lower end of the range may apply for gasification technologies (i.e., in the order of EUR/40/t).

The only operating plant in Europe (Karlsruhe) has a gate fee of 140 EURO/t at a capacity of 225 000 t/yr. But as reported by the operator, the investment cost for this plant has increased by about EUR 40 million due to the modifications necessary. In addition, all figures reported so far, show a yearly throughput of waste of max. 50 % of the design capacity.

Hypothetical calculated costs for a 150 000 tonne pyrolysis plant are shown in Table 8.44.

Table 8.44: Hypothetical cost calculations for a pyrolysis plant in the Flanders Region of Belgium

	Costs per tonne for pyrolysis
COSTS	
Capital cost per tonne	EUR 64.99
Operational cost	EUR 58.96
Fixed	EUR 0.00
Variable	EUR 0.00
Overhead	EUR 17.34
Total	EUR 141.30
REVENUES	
Materials	- EUR 3.57
Electricity production	- EUR 4.77
Total	- EUR 8.34
NET COST	EUR 132.96
Quantity RDF (kg/tonne)	0
Source: [43, Eunomia, 2001]	

At the time of writing, the additional technological risk associated with the adoption of gasification and pyrolysis for many wastes, remains significantly greater than that for better proven, incineration type thermal treatments. The additional risks may diminish with proven market experience and evidence of reliability with commonly encountered waste inputs.

~~8.3 Example installation descriptions~~

~~This annex contains a selection of installation descriptions of entire operational installations. The installations that are included here were chosen because the descriptions provided were accompanied by thorough quantitative data (which also included here), and because together they cover a very wide range of situations, waste types and technologies. They are presented in order to provide examples of the actual overall design and performance levels achieved at those example installations. It is not intended that the examples themselves provide examples of what is BAT or is not BAT - the conclusions of the BREF technical working group on BAT are given in Chapter 5.~~

~~8.3.1 Examples of municipal waste incineration~~

~~8.3.1.1 Grate incinerator with SCR and steam distribution~~

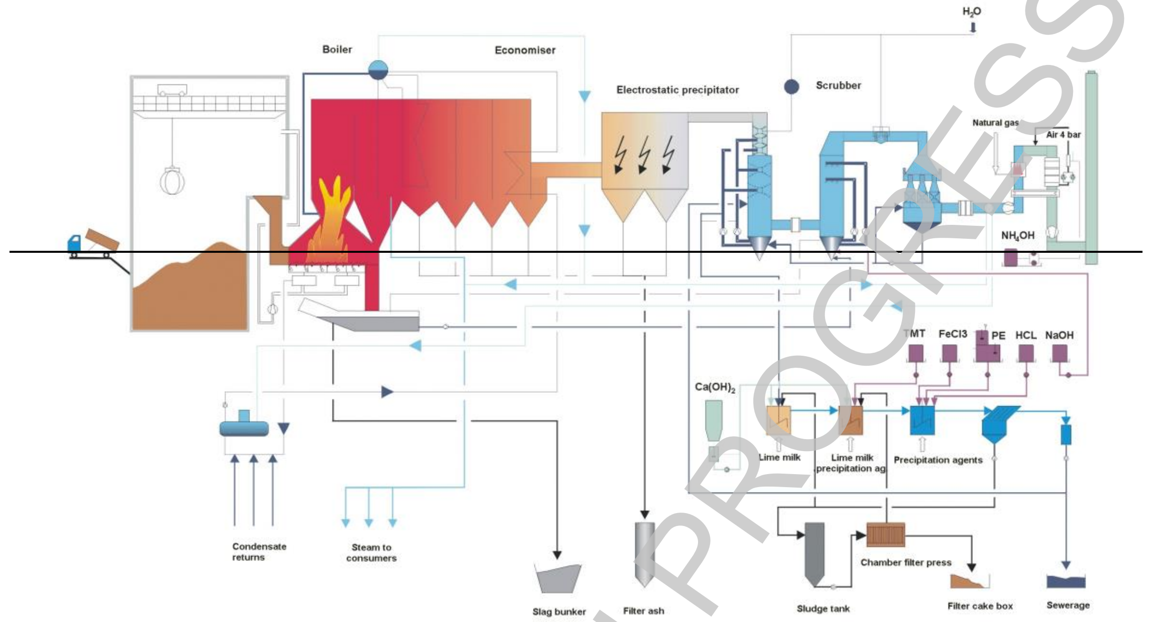
~~196 600 tonnes of domestic waste from Vienna City were incinerated in the waste incineration plant Flötzersteig in the year 2000. General data of this plant are presented in Table 8.45.~~

~~Table 8.45: General data of the waste incineration plant Flötzersteig (reference year: 2000)~~

~~Waste incineration plant Flötzersteig~~	
~~Operator~~	~~Fernwärme Vienna GmbH~~
~~Start up~~	~~1963~~
~~Firing technology~~	~~Grate firing~~
~~Waste throughput~~	~~196 600 t~~
~~Average net calorific value~~	~~8 862 kJ kg^{-1}~~
~~Average gross calorific value~~	~~9 400 kJ kg^{-1}~~
~~Theoretical rated thermal input~~	~~62 MW~~
~~Working hours line 1~~	~~8 011~~
~~Working hours line 2~~	~~8 066~~
~~Working hours line 3~~	~~8 207~~

~~A process flow diagram of one of the three incineration lines is shown in Figure 8.7. Each line consists of the following units:~~

- ~~waste bunker~~
- ~~firing system: Combined forward and backward moving grate~~
- ~~waste heat boiler~~
- ~~flue-gas cleaning devices consisting of: electrostatic precipitator, three-stage wet scrubber, catalytic flue-gas cleaning system for NO$_X$ and dioxin removal~~
- ~~multistage waste water treatment plant~~
- ~~steam distribution system.~~



~~**Figure 8.7: Process flow scheme of the waste incineration plant Flötzersteig**~~

~~Table 8.46 shows an input/output balance of the waste incineration plant Flötzersteig related to one tonne of waste.~~

~~**Table 8.46: Input and output flows of the waste incineration plant Flötzersteig (reference year: 2000)**~~

~~**Input related to one tonne of waste**~~		~~**Output related to one tonne of waste**~~	
~~Heat~~	~~283.6 kWh~~	~~Heat~~	~~1 980 kWh~~
~~Electricity~~	~~79.0 kWh~~	~~Electricity~~	-
~~Natural gas~~	~~16.38 m^3~~	~~Steam (p = 16 bar; T = 270 °C)~~	~~2.75 t~~
~~Fresh water~~	~~825 l~~	~~Slag~~	~~255.6 kg~~
~~Lime~~	~~2.46 kg~~	~~Metal scrap~~	-
~~Sodium hydroxide, 30 %~~	~~3.48 kg~~	~~Fly ash~~	~~15.6 kg~~
~~Ammonia, 25 %~~	~~1.87 kg~~	~~Filter cake (20 – 30 % H_2O)~~	~~0.93 kg~~
~~Precipitating agents~~	~~0.25 kg~~	~~Cleaned waste water~~	~~312.6 l~~
~~Polyelectrolyte~~	~~0.003 kg~~	~~Cleaned flue-gas (dry)~~	~~5 100 Nm^3~~
~~Hydrochloric acid~~	~~0.075 kg~~		

~~Acceptance, treatment and storage of waste~~

~~Domestic waste from Vienna is delivered by 230 refuse collection vehicles. Each vehicle contains 4 – 5 t waste on average. After weighing waste is dumped into the waste bunker that consists of a daily bunker and a bulk storage bunker. The size of the storage bunker is equivalent to the volume of a waste delivery over a period of three days.~~

~~Waste introduction and supply with combustion air~~

~~The storage bunker as well as three chutes (funnel tubes) are fed with waste grapples from two cranes. Waste is introduced by chutes, pushed onto the combustion grate and combusted with preheated air.~~

~~Utilisation of energy~~

~~The combustion grate is followed by a steam boiler (evaporator heating surface: 1 695 m^2) with superheater (370 m^2) and economiser (220 m^2). The produced superheated steam has a temperature of 270 °C and 16 bar.~~

~~Steam pipelines in accessible canals lead to proximate bulk purchasers. Residual heat is fed into the remote district heating network via two converting stations.~~

~~Flue-gas cleaning system and emissions to the air~~

~~*Electrostatic precipitator:* Each line is equipped with an electrostatic precipitator with two fields for separation of coarse particles. The dust load is reduced from about 3 000 mg Nm^{-3} to 20 – 40 mg Nm^{-3} and finally reduced to about 2 mg Nm^{-3} by the flue-gas cleaning system before the stack.~~

~~*Wet flue-gas cleaning:* Flue-gas from each line is washed by three scrubbers. In the first scrubber flue-gases are cooled from a temperature of 200 °C to 60 – 70 °C and saturated with steam. In the lower part of the scrubber a water film is created by circular nozzles so that HCl, HF, heavy metals, Hg and part of the residual dust are washed out. The pH of the washing water is held constant by addition of lime milk to a value of 1.5. In the second (pH neutral) scrubber SO_2 is separated by addition of NaOH whereby a mixture of Na_2SO_4 and Na_2SO_3 is produced. A part of the wash-water is routed to the wet slag removal where gypsum is precipitated and removed together with slag. Fine dust is separated in the third treatment step by a venturi scrubber.~~

~~*Catalytic* NO_X *removal and dioxin destruction:* Before entering the catalyst the flue-gas is reheated from 60 to 130 °C by means of steam heat exchangers. Previously after the entrance valve an evaporated aqueous ammonia solution is added to the raw gas. After reaction in the catalyst the flue-gas is cooled by a heat pipe and conducted to the stack via the flue-gas fan. Emission levels that can be achieved by these plants are presented in Table 8.47.~~

~~Table 8.47: Emissions to air from the waste incineration plant Flötzersteig (reference year: 2000)~~

~~Parameter~~	~~Emission (mg Nm^{-3})~~ [a]			~~Total mass (kg yr^{-1})~~ [b,d]	~~Specific emissions (g t^{-1})~~ [c,d]
	~~Min.~~	~~Average value~~	~~Max.~~		
~~Dust~~ *	~~0.5~~	~~2.1~~	~~9.1~~	~~2106~~	~~10.71~~
~~HCl~~ *	~~0.1~~	~~1.6~~	~~8.1~~	~~1604~~	~~8.16~~
~~HF~~		~~0.14~~		~~140.4~~	~~0.71~~
~~SO_2~~ *	~~0.1~~	~~10.4~~	~~53.6~~	~~10430~~	~~53.04~~
~~C_{org}~~ *	~~0.1~~	~~0.7~~	~~7.2~~	~~701.9~~	~~3.57~~
~~CO~~ *	~~1.2~~	~~15.2~~	~~98.3~~	~~15240~~	~~77.52~~
~~NO_X as NO_2~~ *	~~0.1~~	~~30.5~~	~~87.3~~	~~30580~~	~~155.6~~
~~Pb~~		~~0.044~~		~~44.12~~	~~0.22~~
~~Cr~~		~~<0.001~~		~~1~~	~~0.0051~~
~~Zn~~		~~0.114~~		~~114.3~~	~~0.58~~
~~Σ Pb + Cr + Zn~~		~~<0.159~~		~~159.4~~	~~0.81~~
~~As~~		~~<0.001~~		~~1~~	~~0.0051~~
~~Co~~		~~<0.001~~		~~1~~	~~0.0051~~
~~Ni~~		~~<0.001~~		~~1~~	~~0.0051~~
~~Σ As + Co + Ni~~		~~<0.003~~		~~3~~	~~0.0153~~
~~Cd~~		~~0.002~~		~~2~~	~~0.01~~
~~Hg~~		~~0.036~~		~~36.1~~	~~0.18~~
~~NH_3~~ *		~~0.58~~		~~581.56~~	~~2.96~~
~~PCDD+PCDF~~		~~0.018 ng Nm^{-3}~~		~~18.05 mg yr^{-1}~~	~~0.0918 µg t^{-1}~~

~~Parameter~~	~~Emission (mg Nm^{-3})~~ [a]			~~Total mass (kg yr^{-1})~~ [b,d]	~~Specific emissions (g t^{-1})~~ [c,d]
	~~Min.~~	~~Average value~~	~~Max.~~		

~~* Continuous measurement~~

[a] ~~Half hourly average values in mg Nm^{-3}; dioxin emissions are given in ng Nm^{-3} (11 % O_2; dry flue gas; standard conditions)~~

[b] ~~In kg yr^{-1}, dioxins in mg yr^{-1}~~

[c] ~~Emissions related to one tonne used waste in g t^{-1}; dioxin emissions in µg t^{-1}~~

[d] ~~Total mass and specific emissions are calculated based on average half hourly mean values, using the quantity of dry flue-gas (5 100 Nm^3 t$^{-1}_{waste}$) and the waste quantity (196 600 t yr^{-1}).~~

~~Waste water treatment and emissions to water~~

~~Waste water first passes a neutralisation step where a part of the heavy metals precipitates. The other part is precipitated in the precipitation step which is then followed by a flocculation step. Accumulated sludge is separated in a baffle plate thickener before it is dewatered in a chamber filter press. A partial flow of the cleaned waste water is routed to the clean water tank, the rest is conducted into the sewage.~~

~~Following values presented in Table 8.48 can be achieved by this multistage waste water treatment system.~~

~~Table 8.48: Waste water parameters of the waste incineration plant Flötzersteig after the waste water treatment (reference year: 2000)~~

~~Parameter~~	~~Measured value (mg l^{-1})~~
~~Temperature~~	~~<30 °C~~
~~Electric conductance~~	~~20 mS~~
~~pH~~	~~7.6~~
~~Undissolved matter~~	~~<30~~
~~Settleable solids~~	~~<10~~
~~As~~	~~<0.003~~
~~Cd~~	~~0.001~~
~~Chlorides (Cl)~~	~~10 000~~
~~Cyanides~~	~~<0.006~~
~~Cr~~	~~<0.05~~
~~Cu~~	~~0.11~~
~~Fluorides (F)~~	~~<0.006~~
~~Hg~~	~~<0.001~~
~~NH_4 (N)~~	~~3.16~~
~~Nitrate (NO_3)~~	~~33~~
~~Nitrite (NO_2)~~	~~0.14~~
~~Ni~~	~~<0.05~~
~~Pb~~	~~<0.01~~
~~Sulphate (SO_4)~~	~~325~~
~~Sulphides~~	~~<0.1~~
~~Sulphites~~	~~<1.0~~
~~Zn~~	~~0.4~~
~~AOX/EOX~~	~~1.02/<0.02~~
~~BTXE~~	~~<0.025~~
~~Total HC~~	~~0.05~~
~~Phenol~~	~~<0.01~~

~~Waste~~

~~*Slag:* At the end of the grate slag falls into the water filled wet deslagger where it is cooled. Afterwards it is transported to the slag bunker by a plate conveyor. From there slag is loaded onto trucks by using a crane and transported to a landfill.~~

~~*Fly ash:* Fly ash is transported to an intermediate silo using conveying screws. From there it is pneumatically conveyed into two ash silos.~~

~~Slag and ash are solidified by addition of water and cement and used for the erection of side walls for the landfill Rautenweg in Vienna.~~

~~*Filter cake from waste water treatment:* The filter cake from waste water treatment is filled into 'big bags' and disposed of underground.~~

~~The composition of above-mentioned waste fractions is shown in~~

~~Table 8.49. Results of leaching tests are given in Table 8.50.~~

~~**Table 8.49: Chemical data of wastes from the waste incineration plant Flötzersteig (reference year: 2000)**~~

~~**Parameter**~~	~~**Measured value**~~		
	~~**Slag**~~	~~**Fly ash**~~	~~**Filter cake**~~
~~Bulk density (kg m^{-3})~~	~~800 – 2300~~	~~500 – 800~~	
~~TOC (%) (air dried basis - ad)~~	~~1.5 – 2.5~~	~~1.5 – 2.0~~	
~~$\Sigma(SO_4+SO_3)$ (%) (ad)~~	~~1.5 – 8.0~~	~~4.5 – 17.0~~	
~~Cl (%) (ad)~~	~~0.2 – 0.5~~	~~7.5 – 11.5~~	
~~F (%) (ad)~~	~~0.01 – 0.1~~	~~0.1 – 0.3~~	
~~CO_3 (%) (ad)~~	~~3.0 – 15.0~~	~~2.5 – 15.0~~	
~~SO_4 (%) (ad)~~	~~1.5 – 5.0~~	~~4.5 – 12.5~~	
~~Total moisture (%) (ad)~~	~~15.0 – 40.0~~	~~0.1 – 0.5~~	
~~Loss on ignition (%) (ad)~~	~~1.5 – 4.5~~	~~0.5 – 3.0~~	
~~**Main components (mg kg^{-1}) (dry basis)**~~			
~~Si~~	~~130 000—220 000~~	~~65 000—130 000~~	
~~Al~~	~~40 000—110 000~~	~~40 000—70 000~~	~~27 500~~
~~Mg~~	~~10 000—25 000~~	~~10 000—25 000~~	~~29 700~~
~~Fe~~	~~20 000—40 000~~	~~10 000—20 000~~	~~55 100~~
~~Ca~~	~~120 000—160 000~~	~~150 000— -210 000~~	~~183 000~~
~~Na~~	~~15 000—30 000~~	~~30 000—50 000~~	~~2 250~~
~~K~~	~~10 000—25 000~~	~~45 000—120 000~~	~~3 040~~
~~**Heavy metals (mg kg^{-1}) (dry basis)**~~			
~~Zn~~	~~1 500—5 000~~	~~12 000—25 000~~	~~15 000~~
~~Pb~~	~~1 000—3 500~~	~~3 000—7 000~~	~~5900~~
~~Mn~~	~~400—1 000~~	~~400—900~~	~~388~~
~~Cr~~	~~200—500~~	~~400—900~~	~~238~~
~~Cd~~	~~5—15~~	~~200—800~~	~~451~~
~~As~~	~~3—15~~	~~3—30~~	~~19~~
~~Hg~~	~~0.3—3.0~~	~~5—40~~	~~1 590~~
~~Ni~~	~~50 – 700~~	~~100 – 700~~	~~313~~
~~**Organic compounds (µg kg^{-1})**~~			
~~Total PCDF~~	~~0.05 – 0.2~~	~~2 – 20~~	
~~Total PCDD~~	~~0.02 – 0.2~~	~~5 – 80~~	
~~TEQ~~	~~0.001 – 0.008~~	~~1.0 – 2.0~~	
~~Total PCB~~	~~<600~~	~~<600~~	
~~Total PAH~~	~~<50~~	~~<50~~	

~~**Table 8.50: Leaching tests; waste incineration plant Flötzersteig (reference year: 2000)**~~

~~**Parameter**~~	~~**Concentration (mg kg^{-1})**~~ [a]	
	~~**Slag**~~	~~**Fly ash**~~
~~Mg~~	~~<10~~	~~<10~~
~~Ca~~	~~1 300~~	~~15 000~~
~~SO_4~~	~~1 600~~	~~25 000~~
~~Cl~~	~~1 500~~	~~110 000~~
~~NH_3 as N~~	~~7~~	~~3~~
~~NO_3 as N~~	~~<3~~	~~<3~~
~~NO_2 as N~~	~~5~~	~~0.5~~
~~DOC~~	~~200~~	~~20~~
~~Fe~~	~~<0.5~~	~~<0.5~~
~~Mn~~	~~<0.5~~	~~<0.5~~
~~Ni~~	~~<0.5~~	~~<0.5~~
~~Cd~~	~~<0.01~~	~~0.02~~
~~Cr~~	~~<0.5~~	~~<0.5~~
~~Cu~~	~~2.5~~	~~0.5~~
~~Pb~~	~~60~~	~~120~~
~~Zn~~	~~1.5~~	~~5~~
~~Hg~~	~~<0.01~~	~~<0.01~~

[a] ~~Test details: Increased liquid to solid ratio (10: 1); distilled water (T = 20 °C); no pH control; maximum particle size 10 mm; results in mg per kg dry residue.~~

~~8.3.1.2 Grate incinerator with SCR and CHP~~

~~In the year 2000 268 900 tonnes of waste were combusted in the waste incineration plant Spittelau. General data of the waste incineration plant Spittelau are shown in~~

~~Table 8.51.~~

~~**Table 8.51: General data of the waste incineration plant Spittelau (reference year: 2000)**~~

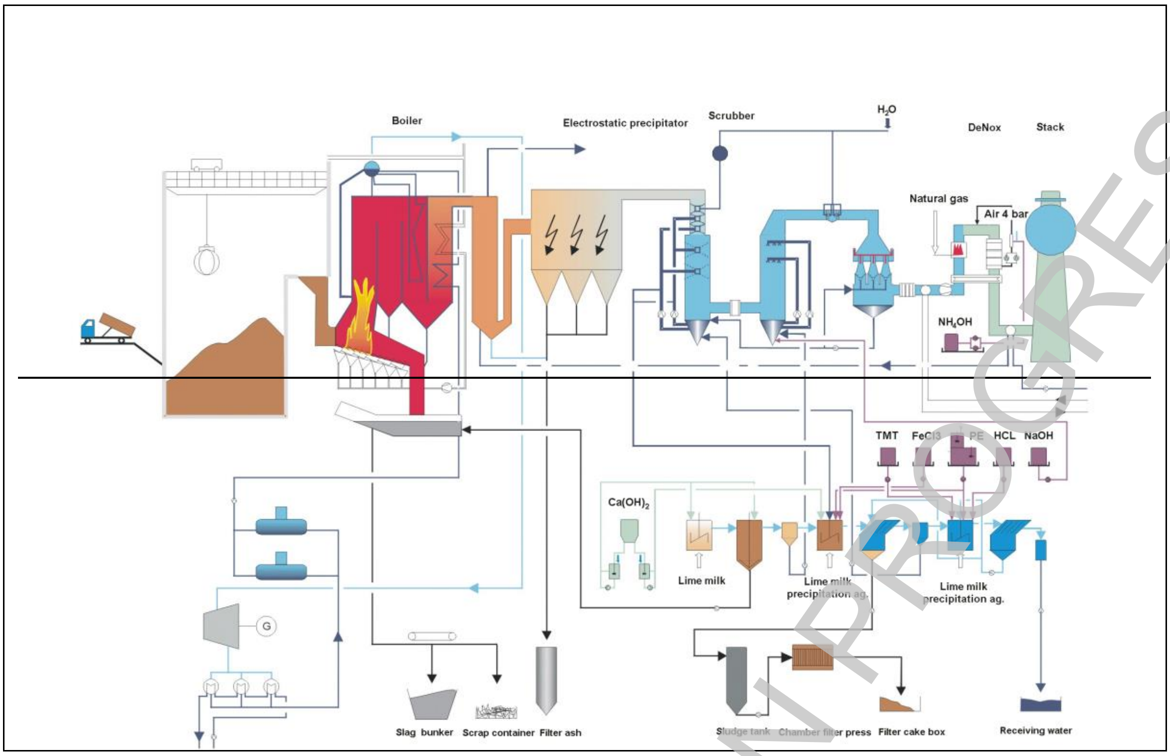
~~**Waste incineration plant Spittelau**~~	
~~Operator~~	~~Fernwärme Vienna GmbH~~
~~Start up~~	~~1971~~
~~Firing technology~~	~~Grate firing~~
~~Waste throughput~~	~~268 900 t~~
~~Average net calorific value~~	~~8 822 kJ kg^{-1}~~
~~Average gross calorific value~~	~~9 400 kJ kg^{-1}~~
~~Theoretical rated thermal input~~	~~85 MW~~
~~Working hours line 1~~	~~7 812~~
~~Working hours line 2~~	~~7 882~~

~~**Plant concept**~~

~~A process flow diagram of the waste incineration plant Spittelau is shown in Figure 8.8. Each line basically consists of the following units:~~

- ~~waste bunker~~
- ~~firing system: Reciprocating grate~~
- ~~waste heat boiler~~
- ~~flue-gas cleaning devices consisting of: Electrostatic precipitator, three-stage wet scrubber, catalyst for NO_X removal and dioxin destruction~~
- ~~multistage waste water treatment plant~~

- ~~steam turbine, generator and heat decoupling system.~~



~~**Figure 8.8: Process flow scheme of the waste incineration plant Spittelau**~~

~~Table 8.52 shows an input-output balance of the waste incineration plant Spittelau related to one tonne of waste.~~

~~**Table 8.52: Input-output flows of the waste incineration plant Spittelau (reference year: 2000)**~~

~~**Input related to 1 t waste**~~		~~**Output related to 1 t waste**~~	
~~Heat~~	~~27.6 kWh~~	~~Heat~~	~~1 857 kWh~~
~~Electricity~~	~~78.5 kWh~~	~~Electricity~~	~~150 kWh~~
~~Natural gas~~	~~20.1 m^3~~	~~Steam (p= 32 bar; T = 240 °C)~~	~~2.6 t~~
~~Fresh water~~	~~730 l~~	~~Slag~~	~~207 kg~~
~~Lime~~	~~2.9 kg~~	~~Metal scrap~~	~~22 kg~~
~~Sodium hydroxide, 30 %~~	~~2.25 kg~~	~~Fly ash~~	~~19 kg~~
~~Ammonia, 25 %~~	~~2.9 kg~~	~~Filter cake (15 – 20 % H_2O)~~	~~1 kg~~
~~Precipitating agents, 15 %~~	~~0.17 kg~~	~~Cleaned waste water~~	~~415 l~~
		~~Cleaned flue-gas (dry)~~	~~4 545 Nm^3~~

~~Acceptance, treatment and storage of waste~~

~~Domestic and similar industrial waste is delivered to the waste incineration plant Spittelau by 250 refuse collection vehicles per day. The vehicles are weighed on two weigh-bridges before waste is dumped into the waste bunker that has a volume of about 7 000 m^3.~~

~~Waste introduction and supply of combustion air~~

~~After mixing in the bunker waste is supplied to both combustion lines by two bridge cranes. Each crane grab has a capacity of 4 m^3. Waste is fed onto the grate that is located at the lower end of the combustion chamber through a filling slot using hydraulic locators.~~

~~Fresh air needed for combustion is sucked off from the waste bunker. Thus a slight vacuum is produced so that odour and dust emissions through the dumping devices to the ambient air are minimised.~~

~~Grate firing system~~

~~Up to 16 t waste per hour can be thermally treated on the sloped reciprocating grate with a total surface of 35 m~~^{2}~~. With the heat content of the combustion gases 90 tonnes of saturated steam per hour are produced.~~

~~Utilisation of energy~~

~~For electricity production steam is expanded in a backpressure turbine from 33 to 4.5 bar. The remaining energy of the steam is transferred to the return water of the remote district heating network in heat exchangers. On an yearly average more than 5 MW electricity for covering of own needs and for feeding into the public electricity network as well as 60 MW of district heat are produced~~

~~Flue-gas cleaning system and emissions to the air~~

~~*Electrostatic precipitator:* Hot flue-gas with a temperature of 180 °C leaves the heat exchanger, that follows the waste heat boiler. Then it is dedusted in a three field electrostatic precipitator to a concentration <5 mg Nm~~$^{-3}$~~.~~

~~*Wet flue-gas cleaning:* Dedusted flue-gas enters the quenching zone of the first wet scrubber, where it is cooled to saturation temperature (60 – 65 °C) by injection of fresh water. The first wet scrubber is built as cross flow scrubber working at a pH value of 1. Due to intensive contact between wash water and flue-gas HCl, HF, dust as well as heavy metals are separated. The second wet scrubber is designed for desulphurization and is operated at a pH of 7. Flue-gas is adiabatically expanded in the downstream electrodynamic venturi scrubber where fine dust particles are separated after charging by an electrode.~~

~~*Catalytic NO*~~$_X$~~*removal and dioxin destruction:* After reheating by a heat exchanger an evaporated aqueous solution of ammonia is added to the flue-gas. Flue-gas is further reheated to a reaction temperature of 280 °C by means of heat pipes and gas burners. In the catalyst (three layers) nitrogen oxides are converted to nitrogen and dioxins/furans are destroyed.~~
~~In a third heat exchanger flue-gases are cooled to 115 °C and discharged to the atmosphere via a 126 m high stack. The concentration of certain pollutants in the flue-gas is presented in Table 8.53.~~

~~Table 8.53: Emissions to air from the waste incineration plant Spittelau (reference year: 2000)~~

~~Parameter~~	~~Emission (mg Nm~~$^{-3}$~~)~~[a]			~~Specific emissions (g t~~$^{-1}$~~)~~[c,d]	~~Total mass (kg yr~~$^{-1}$~~)~~[b,d]
	~~Min.~~	~~Average value~~	~~Max.~~		
~~Dust~~[*]	~~0.0~~	~~0.8~~	~~12.6~~	~~3.64~~	~~977.8~~
~~HCl~~[*]	~~0.0~~	~~0.8~~	~~8.2~~	~~3.64~~	~~977.8~~
~~HF~~		~~<0.02~~		~~<0.1~~	~~<27.8~~
~~SO~~$_2$[*]	~~0.0~~	~~2.1~~	~~16.4~~	~~9.54~~	~~2 567~~
~~CO~~[*]	~~1.4~~	~~26.3~~	~~91.2~~	~~119.5~~	~~32 140~~
~~NO~~$_X$ ~~as NO~~$_2$[*]	~~0.0~~	~~22.9~~	~~92.8~~	~~104.0~~	~~27990~~
~~C~~$_{org}$[*]	~~0.0~~	~~0.5~~	~~19.2~~	~~2.27~~	~~611.1~~
~~Pb~~		~~0.012~~		~~0.054~~	~~14.67~~
~~Cr~~		~~<0.001~~		~~0.045~~	~~1.22~~
~~Zn~~		~~0.032~~		~~0.145~~	~~39.11~~
~~Σ Pb+Cr+Zn~~		~~<0.045~~		~~0.2~~	~~54.99~~
~~As~~		~~<0.001~~		~~0.0045~~	~~1.22~~
~~Co~~		~~<0.001~~		~~0.0045~~	~~1.22~~
~~Ni~~		~~<0.002~~		~~0.009~~	~~2.44~~
~~Σ As+Co+Ni~~		~~<0.004~~		~~0.018~~	~~4.88~~

~~Parameter~~	~~Emission (mg Nm^{-3})~~ [a]			~~Specific emissions (g t^{-1})~~ [c,d]	~~Total mass (kg yr^{-1})~~ [b,d]
	~~Min.~~	~~Average value~~	~~Max.~~		
~~Cd~~		~~0.001~~		~~0.0045~~	~~1.22~~
~~Hg~~		~~0.007~~		~~0.032~~	~~8.56~~
~~NH_3~~		~~0.7~~		~~3.18~~	~~855.5~~
~~PCDD+PCDF~~		~~0.02 ng Nm^{-3}~~		~~0.091 mg yr^{-1}~~	~~24.4 µg t^{-1}~~

~~[*] Continuous measurement; discontinuous values are arithmetic average values from a TÜV measurement (17.01.2001)~~

~~[a] Half hourly average values in mg Nm^{-3}; dioxin emissions in ng Nm^{-3} (11 % O_2; dry flue-gas; standard conditions)~~

~~[b] In kg yr^{-1}, dioxins in mg yr^{-1}~~

~~[c] Emissions related to one tonne used waste in g t^{-1}, dioxin emissions in µg t^{-1}~~

~~[d] Total mass and specific emissions are calculated based on average half hourly mean values, using the quantity of dry flue-gas (5 170 Nm^3 t$^{-1}_{waste}$) and the waste quantity (269 375 t yr^{-1}).~~

~~Waste water treatment and emissions to water~~

~~Dissolved heavy metals from the first scrubber become insoluble by adding lime milk, precipitating and flocculation agents. Then they are separated by means of a downstream laminar clarifier. After the precipitation and the separation step has been passed repeatedly the hydroxide sludge is dewatered. Gypsum from the discharged water of the second scrubbing step is precipitated by addition of lime milk and then precipitated in the clarification basin. Gypsum sludge is pumped into the wet deslagger. Sodium hydroxide that is recovered is recycled into the second scrubber. The cleaned waste water is directly released into the receiving water.~~

~~Values that can be achieved by this multistage waste water treatment plant are shown in Table 8.54.~~

~~Table 8.54: Waste water parameters of the waste incineration plant Spittelau after treatment (reference year: 2000)~~

~~Parameter~~	~~Measured value (mg l^{-1})~~
~~Temperature~~	~~47.8 °C~~
~~Fish toxicity GF~~	~~2.0~~
~~pH value~~	~~7.8~~
~~Filterable substances~~	~~<20~~
~~Settleable solids~~	~~<0.3 ml/l~~
~~Sight depth~~	~~>30.0 cm~~
~~Residue on evaporation~~	~~1.4 g l^{-1}~~
~~Colour~~	~~clear~~
~~Odour~~	~~neutral~~
~~Al~~	~~0.19~~
~~Ag~~	~~0.12~~
~~Ammonia (N)~~	~~3.3~~
~~As~~	~~<0.002~~
~~Ba~~	~~0.19~~
~~Ca~~	~~5 056~~
~~Cd~~	~~<0.001~~
~~Co~~	~~<0.05~~
~~Cr_{total}~~	~~<0.05~~
~~Cr (VI)~~	~~<0.05~~
~~Chlorine (free)~~	~~<0.05~~
~~Chlorine (total) Cl_2~~	~~<0.05~~
~~Chloride (Cl)~~	~~7 085~~
~~Cyanides (CN)~~	~~<0.006~~
~~Cu~~	~~<0.05~~
~~Fe~~	~~<0.05~~
~~Fluorides (F)~~	~~2.2~~

~~Parameter~~	~~Measured value (mg l^{-1})~~
~~Hg~~	~~<0.001~~
~~Mn~~	~~<0.05~~
~~Nitrate (NO_3)~~	~~4.8~~
~~Nitrite (NO_2)~~	~~0.07~~
~~Ni~~	~~<0.05~~
~~P~~	~~<0.05~~
~~Pb~~	~~<0.01~~
~~Sb~~	~~0.04~~
~~Sn~~	~~0.06~~
~~Sulphate (SO_4)~~	~~1 183~~
~~Sulphide~~	~~<0.1~~
~~Sulphite~~	~~<1.0~~
~~Tl~~	~~<0.01~~
~~V~~	~~<0.05~~
~~Zn~~	~~<0.06~~
~~EOX~~	~~<0.02~~
~~CSB~~	~~<75~~
~~BTX~~	~~<0.025~~
~~Total HC~~	~~0.21~~
~~Phenol~~	~~<0.01~~
~~Tensides~~	~~<0.02~~
~~Non-volatile lipophilic components~~	~~<20~~
~~TOC~~	~~4.3~~

~~Waste~~

~~*Slag:* At the end of the combustion grate slag falls into a water filled wet deslagger. From there the cooled slag is transported to the slag bunker by a belt conveyor.~~

~~*Filter ash:* Filter ash is transported to a silo using a mechano-pneumatic conveying system. Slag and filter ash are mixed with water and cement and used as slag/filter ash concrete in the landfill construction.~~

~~*Ferrous scrap:* Ferrous scrap is separated from cooled slag by an magnetic separator and supplied to the steel industry.~~

~~*Filter cake from waste water treatment:* Filter cake is filled into 'big bags' and disposed of underground.~~

~~The composition of above-mentioned waste fractions is shown in Table 8.55. Results of leaching tests are presented in~~
~~Table 8.56.~~

~~Table 8.55: Chemical data of waste fractions from the waste incineration plant Spittelau (reference year: 2000)~~

~~Parameter~~	~~Measured value~~		
	~~Slag~~	~~Fly ash~~	~~Filter cake~~
~~Bulk density (kg m^{-3})~~	~~800 – 1200~~	~~500 – 800~~	
~~TOC (%) (air dried basis - ad)~~	~~1.0 – 2.5~~	~~0.8 – 2.5~~	
~~$\Sigma(SO_4+SO_3)$ (%) (ad)~~	~~1.0 – 11.0~~	~~6.0 – 15.0~~	
~~Cl (%) (ad)~~	~~0.1 – 0.6~~	~~5.0 – 11.0~~	~~0.5 – 2.5~~
~~F (%) (ad)~~	~~0.01 – 0.1~~	~~0.1 – 1.5~~	~~0.5 – 1.5~~
~~CO_3 (%) (ad)~~	~~1.0 – 15.0~~	~~2.5 – 13.5~~	~~5.0 – 15.0~~
~~SO_4 (%) (ad)~~	~~1.0 – 8.0~~	~~6.0 – 11.0~~	~~15 – 30~~
~~Total moisture (%) (ad)~~	~~8.0 – 20.0~~	~~0.1 – 1.5~~	
~~Loss on Ignition (%) (ad)~~	~~1.0 – 4.5~~	~~0.5 – 3.0~~	

~~Parameter~~	~~Measured value~~		
	~~Slag~~	~~Fly ash~~	~~Filter cake~~
~~Main components (mg kg^{-1}) (dry basis)~~			
~~Si~~	~~140 000 – 280 000~~	~~70 000 – 160 000~~	~~10 000 – 70 000~~
~~Al~~	~~30 000 – 75 000~~	~~40 000 – 80 000~~	~~1 500 – 20 000~~
~~Mg~~	~~10 000 – 23 000~~	~~70 000 – 180 000~~	~~1 500 – 30 000~~
~~Fe~~	~~30 000 – 80 000~~	~~10 000 – 20 000~~	~~10 000 – 50 000~~
~~Ca~~	~~120 000 – 240 000~~	~~130 000 – -230 000~~	~~200 000 – -400 000~~
~~Na~~	~~10 000 – 45 000~~	~~15 000 – 65 000~~	~~1 000 – 10 000~~
~~K~~	~~10 000 – 25 000~~	~~30 000 – 75 000~~	~~500 – 5 000~~
~~Heavy Metals (mg kg^{-1}) (dry basis)~~			
~~Zn~~	~~1 200 – 5 500~~	~~7 000 – 20 000~~	~~700 – 4 500~~
~~Pb~~	~~500 – 5 500~~	~~2 500 – 7 000~~	~~100 – 2 000~~
~~Mn~~	~~300 – 1 100~~	~~500 - 800~~	~~100 – 900~~
~~Cr~~	~~100 - 500~~	~~400 - 700~~	~~20 – 100~~
~~Cd~~	~~2 – 10~~	~~50 - 500~~	~~5 – 100~~
~~As~~	~~2 – 15~~	~~5 – 30~~	~~0.5 – 15~~
~~Hg~~	~~0.3 – 3.0~~	~~5 – 50~~	~~100 – 2 000~~
~~Ni~~	~~50 – 400~~	~~50 - 200~~	~~20 – 160~~
~~Organic compounds (µg kg^{-1})~~			
~~Total PCDF~~	~~0.01 – 0.1~~	~~5 – 30~~	~~1.0 – 3.0~~
~~Total PCDD~~	~~0.01 - 0.2~~	~~5 – 35~~	~~4.0 – 8.0~~
~~TEQ~~	~~0.001 – 0.006~~	~~1.0 – 4.0~~	~~0.2 – 1.0~~
~~Total PCB~~	~~<600~~	~~<600~~	
~~Total PAH~~	~~<100~~	~~<100~~	

~~Table 8.56: Leaching tests; waste incineration plant Spittelau (reference year: 2000)~~

~~Parameter~~	~~Concentration (mg kg^{-1})~~ [a]		
	~~Slag~~	~~Fly ash~~	~~Gypsum~~
~~Mg~~	~~<10~~	~~<10~~	~~100~~
~~Ca~~	~~2 000~~	~~15 000~~	~~10 300~~
~~SO_4~~	~~100~~	~~25 000~~	~~1 900~~
~~Cl~~	~~2 500~~	~~100 000~~	~~4 400~~
~~NH_3-as N~~	~~10~~	~~5~~	
~~NO_3-as N~~	~~<3~~	~~<3~~	~~13~~
~~NO_2-as N~~	~~0.5~~	~~0.5~~	~~0.3~~
~~DOC~~	~~250~~	~~15~~	~~14~~
~~Fe~~	~~0.5~~	~~0.5~~	~~<0.7~~
~~Mn~~	~~<0.5~~	~~<0.5~~	~~<0.7~~
~~Ni~~	~~<0.5~~	~~<0.5~~	~~<0.7~~
~~Cd~~	~~0.01~~	~~0.2~~	~~0.01~~
~~Cr~~	~~<0.5~~	~~<0.5~~	~~<0.7~~
~~Cu~~	~~5~~	~~0.5~~	~~<0.7~~
~~Pb~~	~~20~~	~~250~~	~~0.18~~
~~Zn~~	~~1.5~~	~~15~~	~~<0.7~~
~~Hg~~	~~<0.01~~	~~<0.01~~	~~<0.01~~

[a] ~~Test details: Increased liquid to solid ratio (10: 1); distilled water (T = 20 °C); no pH control; maximum particle size 10 mm; results in mg per kg dry residue.~~

~~8.3.1.3 Grate incinerator with SCR, CHP and bottom ash treatment~~

~~In the year 2000, 40090 tonnes of domestic and trade waste, about 10 000 tonnes of trade waste, building waste and bulky refuse each as well as about 4 000 tonnes of residues from mechanical~~

~~treatment and 1 251 tonnes of food waste feeding stuff were combusted in the waste incineration plant at Wels.~~
~~General data of the waste incineration plant Wels - line 1 are shown in~~

~~Table 8.57.~~

~~**Table 8.57: General data of the waste incineration plant Wels (reference year: 2000)**~~

~~**Waste incineration plant Wels**~~	
~~Operator~~	~~Welser Abfallverwertung – Betriebsführung GmbH~~
~~Start up~~	~~1995~~
~~Firing technology~~	~~Grate firing~~
~~Waste throughput~~	~~75 680 t~~
~~Average gross calorific value~~	~~9.5 MJ kg^{-1}~~
~~Theoretical rated thermal input~~	~~33.5 MW~~
~~Working hours line 1~~	~~8 183~~

~~**Plant concept**~~

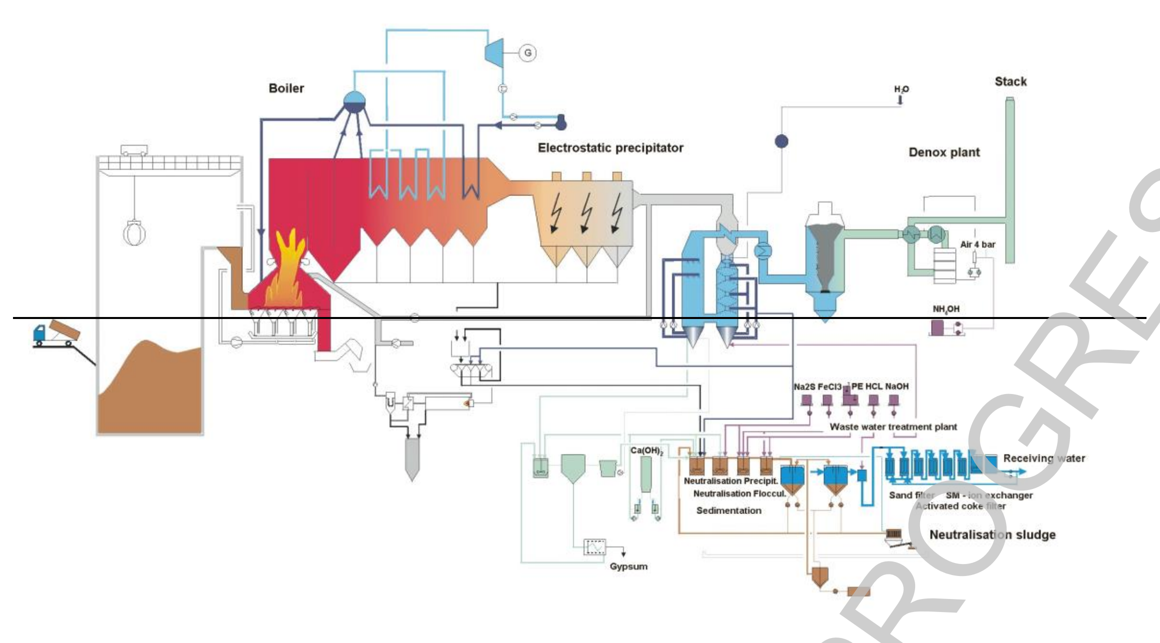
~~A process flow diagram of the waste incineration plant at Wels is shown below. The plant basically consists of the following units:~~

- ~~waste bunker~~
- ~~firing system: Grate firing (Combined forward and backward moving grate)~~
- ~~waste heat boiler~~
- ~~power generation and possibility of decoupling of district heat~~
- ~~flue-gas cleaning devices: Electrostatic precipitator, two-stage wet scrubber, activated coke filter, catalytic flue-gas cleaning system~~
- ~~residue treatment: Wet chemical/thermal ash treatment (thermal treatment not in operation), slag treatment~~
- ~~multistage waste water treatment plant.~~

~~Table 8.58 shows an input-output balance of the waste incineration plant Wels related to one tonne of waste.~~

~~**Table 8.58: Input and output of the waste incineration plant Wels (reference year: 2000)**~~

~~**Input related to 1 t waste**~~		~~**Output related to 1 t waste**~~	
~~Electricity~~	~~130 kWh~~	~~Electricity~~	~~599 kWh~~
~~Natural gas~~	~~4.5 m^3~~	~~Steam (p = 40 bar; T = 400 °C)~~	~~3.15 t~~
~~Fresh water~~	~~850 l~~	~~Slag~~	~~274 kg~~
~~Lime~~	~~6.4 kg~~	~~Ferrous scrap~~	~~17.2 kg~~
~~Sodium hydroxide, 30 %~~	~~3.0 kg~~	~~Fly ash~~	~~35 kg~~
~~Ammonia, 25 %~~	~~1.4 kg~~	~~Filter cake (28 % H_2O)~~	~~2.25 kg~~
~~Coke~~	~~1.2 kg~~	~~Gypsum~~	~~4.7 kg~~
~~Polyelectrolyte~~	~~0.006 kg~~	~~Cleaned waste water~~	~~358 l~~
~~Hydrochloric acid, 30 %~~	~~0.5 kg~~	~~Cleaned flue-gas (dry)~~	~~5 692 Nm^3~~
~~$FeCl_3$, 40 %~~	~~0.65 kg~~		
~~Na_2S~~	~~0.19 kg~~		



~~**Figure 8.9: Process flow scheme of the waste incineration plant Wels – line 1**~~

~~Acceptance, treatment and storage of waste~~

~~Waste for combustion is delivered by refuse collection vehicles, weighed and afterwards dumped into the waste bunker that has a capacity of 4 600 m^3. Waste is mixed using a grab crane.~~

~~Waste introduction and supply of combustion air~~

~~Every 15 minutes about 2 tonnes of waste are fed from the waste bunker via a slot and a locator onto the combined forward and backward moving grate. The main part of the primary combustion air is sucked off from the waste bunker by a fan and blown through the cooled grate bars into the waste bed lying beyond. When waste with low calorific value is combusted primary air is preheated to enhance combustion and ensure a high combustion temperature.~~

~~A part of the cooled flue gas is withdrawn after the electrostatic precipitator and recirculated into the combustion chamber. Thereby the oxygen content in the flame and thus formation of thermal NO$_X$ is lowered.~~

~~Grate firing system~~

~~Combined forward and backward moving grate.~~

~~Waste heat boiler~~

~~The combustion grate is followed by a boiler system, where flue-gases are cooled from a temperature of 950 °C to 650 °C. Afterwards flue-gases pass the convection zone where their energy content is used for steam production. There their temperature is reduced to 200 °C.~~

~~Utilisation of energy~~

~~A turbine with a rated power of 7.2 MW produces 45.5 million kWh electricity (reference year: 2000) which are partly used for covering own needs. The surplus of produced energy is fed into the public electrical system.~~

~~Flue-gas cleaning system and emissions to the air~~

~~*Electrostatic precipitator:* The major part of dust is separated from the flue-gas by electrostatic precipitation~~

~~*Wet flue-gas cleaning:* In the first acid step hydrochloric and hydrofluoric acid as well as mercury compounds and residual dust are absorbed in the acid washing water. The occurring absorption liquor is collected in the lower part of the scrubber. A partial flow of process water is continuously fed into the waste water cleaning system in order to prevent the concentration of pollutants. In the second scrubber~~ ~~SO_2~~ ~~is removed from flue-gas using lime and sodium hydroxide. A partial flow of circulating water is conducted over a precipitation station where a part of the formed sulphates is precipitated as gypsum.~~

~~*Activated coke filter*: In the activated coke filter traces of mercury, organic compounds, HCl and~~ ~~SO_2~~ ~~are adsorbed to activated coke. A part of the loaded filter material is continuously withdrawn and new activated coke is added.~~

~~*Catalyst*: After leaving the activated coke filter flue-gases are reheated to a temperature that is sufficient for catalytic denitrification and oxidation of organic compounds by means of a heat transfer system and a high pressure steam heat exchanger. Nitrogen oxides are reduced by injection of an aqueous solution of ammonia. After cooling flue-gases are routed to the stack.~~

~~Emission levels that can be achieved by the described flue-gas cleaning system are presented in Table 8.59.~~

~~Table 8.59: Emissions to air from the waste incineration plant Wels (reference year: 2000)~~

~~**Parameter**~~	~~**Emission (mg Nm**$^{-3}$**)**~~ [a]	~~**Total mass (kg yr**$^{-1}$**)**~~ [b,d]	~~**Specific mass (g t**$^{-1}$**)**~~ [c,d]
~~Dust~~ [*]	~~<0.5~~	~~<215~~	~~<2.85~~
~~HCl~~ [*]	~~<0.1~~	~~<43~~	~~<0.57~~
~~HF~~ [*]	~~<0.05~~	~~<22~~	~~<0.28~~
~~SO_2~~ [*]	~~<2~~	~~<863~~	~~<11.38~~
~~CO~~ [*]	~~20~~	~~8 616~~	~~114~~
~~NO_X as NO_2~~ [*]	~~54~~	~~23 260~~	~~307~~
~~Pb~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Cr~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Zn~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~As~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Co~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Ni~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Cd~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Hg~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Sb~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Cu~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Mn~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~V~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Sn~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Tl~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Se~~	~~<0.002~~	~~<0.86~~	~~<0.011~~
~~Σ HC~~ [*]	~~<1~~	~~<430.77~~	~~<5.69~~
~~NH_3~~	~~3.5~~	~~1508~~	~~19.92~~
~~PCDD + PCDF (I-TEQ)~~	~~0.003 ng Nm^{-3}~~	~~1.29 mg yr^{-1}~~	~~0.017 µg t^{-1}~~

[*] ~~Continuous measurement~~

[a] ~~Half hourly average values in mg Nm^{-3}; dioxin emissions are given in ng Nm^{-3} (11 % O_2; dry flue-gas; standard conditions)~~

[b] ~~In kg yr^{-1}, dioxin loads in mg yr^{-1}~~

[c] ~~Emissions related to one tonne used waste in g t^{-1}; dioxin emissions in µg t^{-1}~~

[d] ~~Total mass and specific emissions are calculated based on average half hourly mean values, using the quantity of dry flue-gas (5 692 Nm^3 t^{-1}$_{waste}$) and the waste quantity (75 680 t yr^{-1}).~~

~~Waste water treatment and emissions to water~~

~~The waste water treatment plant consists of a precipitating zone (neutralisation, precipitation, flocculation, sedimentation and sludge dewatering) and a filter zone, which has been erected in two lines (two-layer filter, activated coke filter, ion exchanger, pure water filter). The parameters of cleaned waste water are shown in Table 8.60. The cleaned waste water is released into the receiving water.~~

~~Table 8.60: Waste water parameters of the waste incineration plant Wels after waste water treatment (reference year: 2000)~~

~~Parameter~~	~~Measured value (mg l^{-1})~~
~~Temperature~~	~~<30 °C~~
~~pH value~~	~~6.8 <pH <9.0~~
~~Undissolved compounds~~	~~<25~~
~~Settleable solids~~	~~<0.2~~
~~Salt content~~	~~<35 g l^{-1}~~
~~As~~	~~<0.05~~
~~Cd~~	~~<0.05~~
~~Chlorides (Cl)~~	~~<20 g l^{-1}~~
~~Cyanides~~	~~<0.05~~
~~Cr~~	~~<0.1~~
~~Cu~~	~~<0.3~~
~~Fluorides (F)~~	~~<10~~
~~Hg~~	~~<0.01~~
~~NH$_4$ — N~~	~~<8~~
~~Nitrate (NO$_3$)~~	~~<40~~
~~Nitrite (NO$_2$)~~	~~<8~~
~~Ni~~	~~<0.5~~
~~Pb~~	~~<0.1~~
~~Sulphate (SO$_4$)~~	~~<1 200~~
~~Sulphides~~	~~<0.1~~
~~Sulphites~~	~~<8~~
~~Zn~~	~~<0.5~~
~~AOX/EOX~~	~~<0.1~~
~~Total HC~~	~~<3~~
~~Volatile chlorinated hydro carbons~~	~~<0.1~~
~~Saponifiable fats and oils~~	<4

~~Waste~~

~~*Slag:* Slag is washed with water and landfilled.~~

~~*Gypsum:* Gypsum occurring by desulphurization is dewatered and landfilled.~~

~~*Ash:* Ash that occurs in the electrostatic precipitators is conveyed to a silo for fly ash where it is intermediate-stored before wet chemical treatment.~~

~~Slag, ash and gypsum are landfilled.~~

~~*Ferrous scrap:* Ferrous scrap is separated from slag and delivered to a scrap dealer.~~

~~*Sludges:* Sludges that occur during waste water treatment are dewatered using a chamber filter press, filled into 'big bags' and disposed of underground.~~

~~8.3.1.4 Grate incinerator with SNCR de-NO$_X$, combined double filtration and wet scrubbing~~

~~Capacity approximately 320 000 tonnes/yr~~
~~2 incineration lines at 23 t/h each~~
~~Central flow furnace with multi-step feed grate~~
~~Incineration temperature 850 °C at a residence time >2 seconds~~
~~Start-up: 1999~~

~~Reduction of emissions into the air~~

~~The waste gas cleaning system consists of the following components:~~

- ~~SNCR~~
- ~~Boiler dust deposition~~
- ~~Tissue filter as current flow adsorber (adsorption of dioxins/furans on hearth furnace coke (HFC))~~
- ~~2-stage HCl scrubber~~
- ~~SO_2 scrubber~~
- ~~Tissue filter with HFC metering for the adsorption of remaining dioxins, furans and heavy metals.~~

~~Waste gas quantity line 1 76 140 m^3/h~~
~~line 2 78 460 m^3/h~~
~~Manufacturer: L & C Steinmüller GmbH~~

~~**Table 8.61: Average values measured in clean gas (operating values)**~~

~~**Parameter**~~	~~**Measure**~~	~~**Half-hour average value**~~	~~**Daily average value**~~	~~**Annual average value**~~
~~**Continuous measurement**~~				
~~Total dust~~	~~mg/m^3~~	~~<5~~	~~<2.5~~	~~0.4~~
~~HCl~~	~~mg/m^3~~	~~<10~~	~~<5~~	~~0.1~~
~~SO_X~~	~~mg/m^3~~	~~<50~~	~~<20~~	~~2.44~~
~~NO_X~~	~~g/m^3~~	~~<0.280~~	~~<0.12~~	~~0.082~~
~~Total C~~	~~mg/m^3~~	~~<15~~1)	~~<7~~	~~0.5~~
~~CO~~	~~mg/m^3~~	~~<60~~1)	~~<20~~	~~8.0~~
~~**Periodic measurement**~~				
~~HF~~	~~mg/m^3~~	~~<0.06~~	-	~~0.03~~
~~NH_3~~ 3)	-	-	-	-
~~Cd, Tl~~	~~mg/m^3~~	~~<0.001~~	-	~~0.0006~~
~~Hg~~ 2)	~~µg/m^3~~	~~<1~~	-	~~0.5~~
~~Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V,Sn~~	~~mg/m^3~~	~~<0.014~~	-	~~0.0081~~
~~PCDD/F, I-TEQ~~	~~ng/m^3~~	~~<0.011~~	-	~~0.0023~~

~~1) higher values only for a short time with starts/stops at low temperatures (only gas furnace)~~
~~2) continuous measurement behind the 1st tissue filter, emission measurement repeated~~
~~3) Individual measurement <1 mg/m^3~~
~~In all measurements, 100 % of the values specified were complied with.~~

~~Reduction of emissions into the water~~

~~Waste water from waste gas cleaning undergoes indirect condensation. Thus, the plant is operated with zero waste water discharge. The raw acid from the hydrochloric acid scrubber is~~

~~upgraded to 30 % hydrochloric acid in a hydrochloric acid reprocessing plant. Mixed salts are used in liquid form (brine) as stowing material in salt caverns. The plaster from the~~ ~~SO_2 scrubber is processed in the building industry.~~

~~Residues~~

~~Quantity of slag: 86 000 t/yr (260 kg/t waste)~~
~~Reprocessing of slag: washing, crushing, metal separation, sifting~~
~~Further use: Utilization, e.g. in road construction~~
~~Quality: (see table below)~~

~~Table 8.62: Slag quality~~

~~Solid matter values:~~	
~~TOC~~	~~<1 %~~
~~Loss on ignition~~	~~<3 %~~
~~PCDD/F~~	~~<10 ng I-TEQ/kg~~
~~Eluate values:~~	
~~Cl^-~~	~~<100 mg/l~~
~~SO_4^{2-}~~	~~<350 mg/l~~
~~As~~	~~<0.006 mg/l~~
~~Cd~~	~~<0.0005 mg/l~~
~~Cr~~	~~<0.05 mg/l~~
~~Cu~~	~~<0.1 mg/l~~
~~Hg~~	~~<0.0002 mg/l~~
~~Ni~~	~~<0.004 mg/l~~
~~Pb~~	~~<0.02 mg/l~~
~~Zn~~	~~<0.01 mg/l~~

~~Energy utilization (reference year 2000)~~

~~Heat generation/output~~
~~Heat generation in total: 3 010 000 GJ/yr~~
~~Internal consumption: 800 900 GJ/yr~~
~~Heat output to thermal power plant: 1 347 000 GJ/yr~~

~~Steam generation/output~~
~~Steam DE1: 493 100 t~~
~~Steam DE2: 488 800 t~~
~~Steam HDE3: 25 460 t~~
~~Steam HDE4: 33 910 t~~
~~Steam output to thermal power plant: 461 800 t~~

~~Electric power generation/output:~~
~~Electric power generation in total: 59 210 MWh~~
~~Internal consumption (incl. additional supplies of approx. 7 398MWh): 36 720 MWh~~
~~Electric power output: 29 900 MWh~~

~~Table 8.63: Energy efficiency ratio (assumed average calorific value ≈ 9 500 kJ/kg)~~

~~Waste quantity combusted: approx. 318 000 t~~		**~~Energy in (MWh)~~**		**~~Energy efficiency ratio in (%)~~**		
		~~El power~~	**~~Heat~~**	**~~El. Power~~**	**~~Heat~~**	**~~Total~~**
	~~generated~~	~~59 210~~	~~526 000~~	~~7/9.3~~[7]	~~66/88~~[1]	~~73/97.3~~[1]

	~~released~~	~~29 900~~	~~344 000~~	~~4/5.3~~^{1}	~~42/56~~^{1}	~~46/61.3~~^{1}

[1] ~~Energy utilization factor, taking into account a combustion efficiency of >75 % of the energy input into the waste.~~

~~Costs~~

- ~~Investment costs (incl. planning and 50 000 000 DM for infrastructure measures): approximately 450*10~~^{6} ~~DM~~
- ~~Specific treatment costs: approximately 250 DM/t (plus VAT)~~

~~8.3.1.5 Grate incinerator with semi-wet FGC, active carbon injection, ash recirculation, bottom ash treatment and (mainly) electricity generation~~

~~GENERAL INFORMATION~~
~~The plant is situated on the Island of Mallorca. The waste treated are municipal solid waste and occasionally sewage sludge. Flexible design to wide range of LCV in urban waste and to adapt to changes is selective collection.~~
~~Of note are:~~

- ~~control of incoming waste (providers, origin and types of waste) and sub-products~~
- ~~water management efficiency - agreement with neighbouring industrial installation to reuse external waste water in the process~~
- ~~contribution to an isolated energy system (island)~~
- ~~measures to avoid/eliminate smell and leaching~~
- ~~certified environmental and quality management system.~~

~~DESIGN/CONSTRUCTION DATA~~
~~Combustion technique: 2 x 18.75 t~~$_{w}$~~/h, Roller type (DBA) 20º Inclination Dusseldorf Grate~~
~~Plant capacity: 300 000 t/yr; LCV range: 6 575 – 8 666 kJ/kg;~~
~~Design thermal input to the grate: 2 x 45.14 MW~~
~~Steam boiler, 42 bar, 400 °C, horizontal design, four superheaters, three economisers.~~
~~Energy valorisation: Electricity for export and internal use, steam for internal use only.~~
~~Turbo-generator: 34.1 MW (design to accept steam from a 3~~rd ~~line which is now under project)~~
~~FGC system (Flue-gas~~ Cleaning ~~Treatment): Semi-wet process, with active carbon injection, ash recirculation.~~
~~Dedusting by Bag Filter. Semi-wet scrubber, atomizer with lime milk injection. De-diox by Active Carbon injection. De-NO~~$_{X}$ ~~(and additional de-diox) by SCR (contracted: installation 2004 – 2005).~~
~~No aqueous effluents are discharged from the plant~~
~~Bottom ash treatment: quenched and directed to a segregation plant in which it is separated into three main fractions: Ferrous Metals, Non-Ferrous Metals and Inerts. Ageing area for the inerts~~
~~FGC solid residues: Fly ash stabilised with special cement and landfilled in a 'safety deposit'~~
~~Material valorisation: Bottom ash used for road construction, cement production and as a substitute for other construction materials when appropriate. Ferrous and non-ferrous metals sold to the local market. Reuse of stabilized APC residues under investigation.~~
~~Start-up: 1996 (test trials), official March 1997.~~
~~Complies with the WID 2000 (Waste Incin. Directive) except de-NO~~$_{X}$~~. SCR de-NO~~$_{X}$ ~~system under contracting, to be in operation in 2005.~~

~~OPERATING DATA~~
~~Year of reference for the following data: 2003~~
~~Waste throughput 300 739 t/yr municipal solid waste.~~
~~Average LHV: 7760 kJ/kg~~
~~Working hours including partial load hours (availability): Line 1: 7 984/8 760 h/Line 2: 7 975/8 760 hr. Main maintenance turn down in November (done every 15 – 18months)~~

~~Reagents consumption: CaO: 684 t/yr // Activ. Carbon: 280 t/yr // Crude Water: 93 980 t/yr.~~
~~Imported electricity: 1 082 MWh/yr (only during yearly shutdown for maintenance). No heat imported.~~
~~Electricity consumption: 22 810 MWh/yr.~~
~~Energy output: 154 GWh/yr~~
~~Material residues: Cemented Fly Ash: 21 020 t/yr~~
~~Annual average of continuous concentrations measurement in clean gas:~~
~~Total dust: 1.2 mg/Nm^3 // HCl: 5.3 mg/Nm^3 // HF <0.1 mg/Nm^3 // SO_X as SO_2 (data 2004): 6.5 mg/Nm^3 // TOC: 1.8 mg/Nm^3 // CO: 1.9 mg/Nm^3 // NO_X:280 mg/Nm^3.~~
~~Average value of concentration samplings in clean gas (periodic measurement of substances listed in the WID 2000), 8 samplings:~~
~~Cd: <0.008 mg/Nm^3 // Tl: <0.008 mg/Nm^3 // Cd + Tl: <0.016 mg/Nm^3 // Hg: <0.0005 mg/Nm^3 // Sb: <0.01 mg/Nm^3 // As: <0.025 mg/Nm^3 // Pb: <0.02 mg/Nm^3 // Cr: <0.009 mg/Nm^3 // Co: <0.01 mg/Nm^3 // Cu: <0.015 mg/Nm^3 // Mn: <0.05 mg/Nm^3 // Ni: <0.009 mg/Nm^3 // V: <0.009 mg/Nm^3~~
~~Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V: <0.16 mg/Nm^3~~
~~PCDD/F (4 samplings):<0.005 ng_{iteq}/m^3~~

~~ECONOMICS~~
~~Investment cost 90 million Euros financed by the European Investment Bank~~
~~Gate fee: 75 Euros/tonne. This fee is the fee per tonne entering in the integrated waste management scheme which includes management of transfer stations, separation of packaging residues, composting and anaerobic digestion for organic fraction, bottom ash recycling, stabilization/solidification of ashes and APC residues and safety landfill for stabilized residues. It is the result of the local decision to favour recycling schemes and therefore all the costs of the integrated management are supported by the incineration fee. Municipalities do pay ZERO euros for composting and recycling options.~~

~~8.3.1.6 Grate incinerator with SNCR de-NO_X, semi-wet FGC, active carbon injection and high steam parameters (60 bar/380 °C) electricity generation~~

~~GENERAL information~~
~~Municipal authority (Final customer) and the Owner of the plant: Consorci per al Tractament de residus solids urbans del Maresme~~
~~Operator: Tractament i Revaloritzacio de Residus del Maresme, S.A.~~
~~The plant treats Municipal Solid Waste~~
~~On this plant, it is worth noting the high steam characteristics (60 bar)~~

~~DESIGN/CONSTRUCTION DATA~~
~~Combustion technique: Reverse-acting reciprocating grates, 2 x 10 t/h~~
~~Plant capacity: 165 000 t/yr; LCV range: 5 440 – 12 560 kJ/kg; nominal: 8 375 kJ/kg.~~
~~Design thermal input to the grate: 2 x 23.2 MW~~
~~Steam boiler, 60 bar, 380 °C; vertical design, 5 passes.~~
~~Energy valorisation: Electricity for export and internal use, steam for internal use only.~~
~~Turbo-generator: 11.25 MW~~
~~FGC system (Flue-gas Cleaning Treatment): Semi-wet process, with active carbon injection, and SNCR.~~
~~SNCR de-NO_X (urea). Dedusting by Bag Filter. Semi-wet scrubber, with upstream injection of lime milk and active carbon (separately) + (added) Contact (Dry) Reactor (Ca(OH)2) with recirculation of ashes from the BHF. De-diox by Active Carbon injection after the Semi-wet scrubber.~~
~~No aqueous effluent from the FGC. Other waste water treatment (by precipitation) and release to the sewer.~~
~~Bottom ash treatment: quenched scrap ferrous metals removal, recovered for road construction~~
~~FGC solid residues: Fly ash stabilisation and landfilling.~~

~~Material valorisation: Bottom ash used for road construction. Ferrous metals recovered.~~
~~Start-up: 1994 (grates, boilers, semi wet FGC), 2000 (Active carbon), 2004 (SNCR + Dry (Contact reactor) $Ca(OH)_2$.~~

~~OPERATING DATA~~
~~Year of reference (for the following data): 2003~~
~~Waste throughput: 163 400 t/yr. Municipal solid waste 96 %, Industrial waste 4 %~~
~~Average LHV: 8 820 kJ/kg~~
~~Working hours including partial load hours (availability): L1: 8 319/8 760 h, L2: 8 424/8 760 h.~~
~~Reagents consumption: $Ca(OH)_2$: 1 844 t/yr // NaOH: 54.2 t/yr // HCl: 20.3 t/yr // Activated carbon: 148 t/yr // Urea N_2H_4: 720 kg/yr // Fresh water: 62 144 m^3/yr.~~
~~Imported electricity: 1 547 MWh/yr (only during yearly shutdown for maintenance).~~
~~Energy consumption: Electricity 10 930 MWh, Natural gas: 68 370 Nm^3/yr~~
~~Energy output: Electricity: 61 690 MWh.~~
~~Material recovery: Bottom ash for road construction: 40 390 t/yr. Ferrous metals: 833 t/yr~~
~~Material residues: Fly Ash: 6 261 t/yr~~
~~Annual average of continuous concentrations measurement in clean gas:~~
~~// HCl: 26 mg/Nm^3 // PST: 9 mg/Nm^3 // CO: 13 mg/Nm^3~~
~~Average value of concentration samplings in clean gas (periodic measurement):~~
~~TOC: 11.66 mg/Nm^3 // HF: 0.071 mg/Nm^3 // SO_2: 22.06 mg/Nm^3 // Cd+Hg: 0.0178 mg/Nm^3 // Ni+As: 0.0385 mg/Nm^3 // Pb+Cr+Cu+Mn: 0.2499 mg/Nm^3 // NO_X: 237.59 ppm~~
~~PCDD/F: 0.0462 ng_{iteq}/m^3~~
~~Concentrations in cleaned waste water: Total suspended solids: 33 mg/l // Cd: <0.05 mg/l // Pb: <0.5 mg/l // Zn: <0.5 mg/l // pH value: 8 // P: 8 mg/l.~~

~~8.3.1.7 Grate incinerator with SNCR (NH_3), semi-wet lime, active carbon and electricity generation~~

~~GENERAL information~~
~~The plant is in South East London, UK. Owned by SELCHP Ltd and operated by Onyx SELCHP Ltd~~
~~It's worthy noting of: ISO 9001 and ISO 14001. Investors in People (IIP). Project financing. High electricity generation. Big plant.~~
~~The waste is municipal solid waste~~

~~DESIGN/CONSTRUCTION DATA~~
~~Combustion technique: 2 x 29 t_w/h, Reverse-acting Reciprocating grate.~~
~~Plant capacity: 420 000 t/yr; LCV range: 7 500 to 10 000 kJ/kg;~~
~~Design thermal input to the grate: 2 x 68.5 MW~~
~~Steam boiler, 45 bar, 395 °C; Vertical design, 4 passes.~~
~~Energy valorisation: Electricity for export and internal use, steam for internal use only.~~
~~Turbo-generator: 35 MW~~
~~FGC system (Flue-gas Treatment): SNCR Semi-wet process with active carbon injection.~~
Dedusting by Bag Filter. ~~Semi-wet scrubber with lime milk from quick lime. De-diox by Active Carbon injection before the semi-wet scrubber. SNCR de-NO_X (ammonia water).~~
~~No aqueous effluent discharged from the plant~~
~~Bottom ash treatment: quenched, scrap ferrous metals removal, ash stored for ageing, scrap non-ferrous removal. Max 110 000 tonnes per year.~~
~~FGC solid residues: APC Residues: 12 500 t/yr mixed with water and landfilled.~~
~~Material valorisation: Bottom ash used for road construction. Ferrous and non-ferrous metals.~~
~~Start-up: 1994.~~
~~Complies with the WID 2000 emission limits except for NO_X and HCl. Enlarged baghouse and some work to SNCR to comply by 12/2005~~

~~OPERATING DATA~~
~~Reference year (for the following data): 2003~~

~~Waste throughput: 404 000 t/yr, 100 % municipal waste.~~
~~Average LHV: 9 250 kJ/kg~~
~~Working hours (availability) including partial load hours: line 1: 8 403 h/yr; line 2: 7 812 h/yr~~
~~Reagents consumption: Quick lime: 3 876 t/yr // Caustic Soda: 45.75 t/yr // Activ. Carbon: 79 t/yr // Hydroc. Acid: 57 t/yr // Ammonia: 997 t/yr.~~
~~Energy input: Imported electricity: 274 MWh // Fuel: 457 427 litres~~
~~Energy consumption: Electricity: 66 kWh/t of waste~~
~~Electricity output: 243 GWh generated, 216 GWh exported~~
~~Material recovery: Bottom ash: 111 000 t/yr // Ferrous metals: 9 300 t/yr~~
~~Material residues: FGC residues: 12 500 t/yr~~
~~Concentrations in clean gas (continuous measurement). Annual average, plus maximum 1/2 hour average and max daily average:~~

~~SO$_2$: 8.2/<30/<60 mg/Nm^3~~
~~HCl: 13.4/11.5/<40 mg/Nm^3~~
~~CO: 6.2/<12/<65 mg/Nm^3~~
~~Dust: 1.2/<10/<20 mg/Nm^3~~
~~NO$_X$: 282/<320/<380 mg/Nm^3~~
~~TOC: 1.2/<2/<15 mg/Nm^3~~

~~Concentrations in clean gas (periodic measurement). Average value:~~
~~Hg + Cd: 0.003 mg/Nm^3 // Dioxins: 0.004 ng/Nm^3 // Total other metals: 0.019 mg/Nm^3~~

~~ECONOMICS~~
~~Investment costs: GBP 100 million, including GBP 15 million construction finance.~~
~~Gate fee: Average GBP 35 per tonne. Electricity selling price all up around GBP 27 per MW hour.~~

~~8.3.1.8 Grate incinerator with SNCR (NH$_3$), semi-wet lime, active carbon and electricity generation~~

~~GENERAL information~~
~~The plant is owned by Hampshire Waste Services Ltd and operated by Onyx Hampshire Ltd. The municipal authority (final customer) is Hampshire County Council, UK.~~
~~Waste type: Municipal solid waste only.~~

~~Of particular note:~~
- ~~Award-winning architecture~~
- ~~Part of a major integrated municipal waste contract, with enhanced recycling & composting~~
- ~~Project financing~~

~~DESIGN/CONSTRUCTION DATA~~
~~Combustion technique: Reverse-acting Reciprocating grate, 1 x 12 t/h~~
~~Plant capacity: 90 000 t/yr; LCV range: 6 990 – 12 500 kJ/kg; nominal: 9 200 kJ/kg~~
~~Design thermal input to the grate: 1 x 30.67 MW~~
~~Steam boiler, 45 bar, 395 °C; vertical design, 4.5 passes.~~
~~Energy valorisation: Electricity for export and internal use, steam for internal use only.~~
~~Turbo-generator: 8 MW~~
~~FGC system (Flue-gas Cleaning Treatment): Semi-wet process with active carbon injection, SNCR.~~
~~SNCR de-NO$_X$ (urea). Dedusting by 1 BHF (Bag Filter). Semi-wet scrubber with lime milk from quick lime. De-diox by Active Carbon injection before the BHF.~~
~~No aqueous effluent from the plant under steady state conditions.~~
~~Bottom ash treatment: quenched, scrap ferrous metals removal.~~
~~FGC solid residues: Dampened & landfilled as special waste. Mid 2005: secondary processing planned using waste acids to give non-hazardous filter cake~~

~~Material valorisation: Bottom ash – mid 2005 plant planned for non-ferrous extraction & secondary aggregate production.~~
~~Start-up: 2003.~~
~~reported to comply with the WID-2000 since start up, but some procedural issues to be resolved with Regulator~~

~~OPERATING DATA~~
~~Reference year (for the following data): Design/2004/2005 forecast~~
~~Waste throughput: 90 000 t/yr; 100 % municipal waste~~
~~Average LHV: 9 100 kJ/kg est.~~
~~Working hours (availability) including partial load hours: 87.80 %~~
~~Reagents consumption: Quick lime: 10 kg/t$_w$ // Urea: 1.25 kg/t$_w$ // Activated carbon: 0.25 kg/t$_w$ // Fresh water: 0.25 t/t$_w$.~~
~~Energy input: Imported electricity: 340 MWh electricity// Fuel oil: 80 000 l~~
~~Energy consumption: Elec: 70 kWh/t of waste~~
~~Electricity output: 0.5 MWh/t~~
~~Material recovery: Bottom ash: 25 % // Ferrous metal: 2 %~~
~~Material residues: FGC residues: 35 kg/t~~
~~Average concentrations in clean gas (continuous measurement):~~
~~CO: 4.7 mg/Nm^3 // HCl: 8.1 mg/Nm^3 // VOCs: 0.4 mg/Nm^3 // NO$_X$: 177 mg/Nm^3 // SO$_2$: 7.5 mg/Nm^3 // TPM: 4.2 mg/Nm^3.~~
~~Concentrations in clean gas (periodic measurement of substances listed in the WID-2000)~~
~~Cd+Tl: 0.0002 mg/Nm^3 // Hg: 0.009mg/Nm^3 // Total other heavy metals: 0.02 mg/Nm^3 // Dioxins: 0.00882 ng/Nm^3.~~
~~Concentrations in clean gas (periodic measurement of substances not listed in the WID-2000): NH$_3$: 0.7 mg/Nm^3.~~

~~ECONOMICS~~
~~Investment costs: GBP 30 – 35 million, depending on assumptions~~
~~Gate fee: Internal cost centre - no gate fee~~

~~8.3.2 Examples of the hazardous wastes installations~~

~~8.3.2.1 Rotary kiln with heat recovery, SNCR, EP, wet scrubber and static fixed-bed coke filter~~

~~Two rotary kilns of the Plant Simmeringer Haide are operated for incineration of hazardous wastes. In the year 2000, 89 960 tonnes of wastes were combusted. A detailed list of treated types of waste and quantities is given in Table 8.64.~~

~~Table 8.64: Types of waste and waste quantities incinerated in the rotary kilns of Plant Simmeringer Haide (reference year: 2000)~~

~~Types of waste~~	~~Waste quantity (t yr^{-1})~~
~~Waste oil~~	~~9 521~~
~~Oil-water mixture, oil content 85 – 100 %~~	~~28~~
~~Oil-water mixture, oil content 50 – 85 %~~	~~1 655~~
~~Oil-water mixture, oil content <50 %~~	~~6 384~~
~~Oil-water mixture, oil content <10 % which can be separated~~	~~759~~
~~Separator content~~	~~1 216~~
~~Other waste, internal waste~~	~~1 902~~
~~MA 48; collection of hazardous waste~~	~~1 059~~
~~Liquid organic waste~~	~~10 703~~
~~Solid or pasty organic waste~~	~~11 100~~
~~Liquid inorganic waste~~	~~10 005~~
~~Solid or pasty inorganic waste~~	~~328~~
~~Oil contaminated soil~~	~~115~~
~~Trade and industrial waste~~	~~16 308~~

~~Types of waste~~	~~Waste quantity (t yr^{-1})~~
~~Hospital waste~~	~~2 360~~
~~Old medicines~~	~~768~~
~~Herbicides~~	~~802~~
~~Hazardous household waste~~	~~2~~
~~Chemically contaminated soil~~	~~56~~
~~Laboratory waste~~	~~344~~
~~Biofilter from the main WWTP Vienna, residual waste~~	~~3 256~~
~~Screening DRO~~	~~5 008~~
~~Sand and crushed stone, canal waste~~	~~4 829~~

~~General data of the two rotary kilns of the Plant Simmeringer Haide are shown in Table 8.65.~~

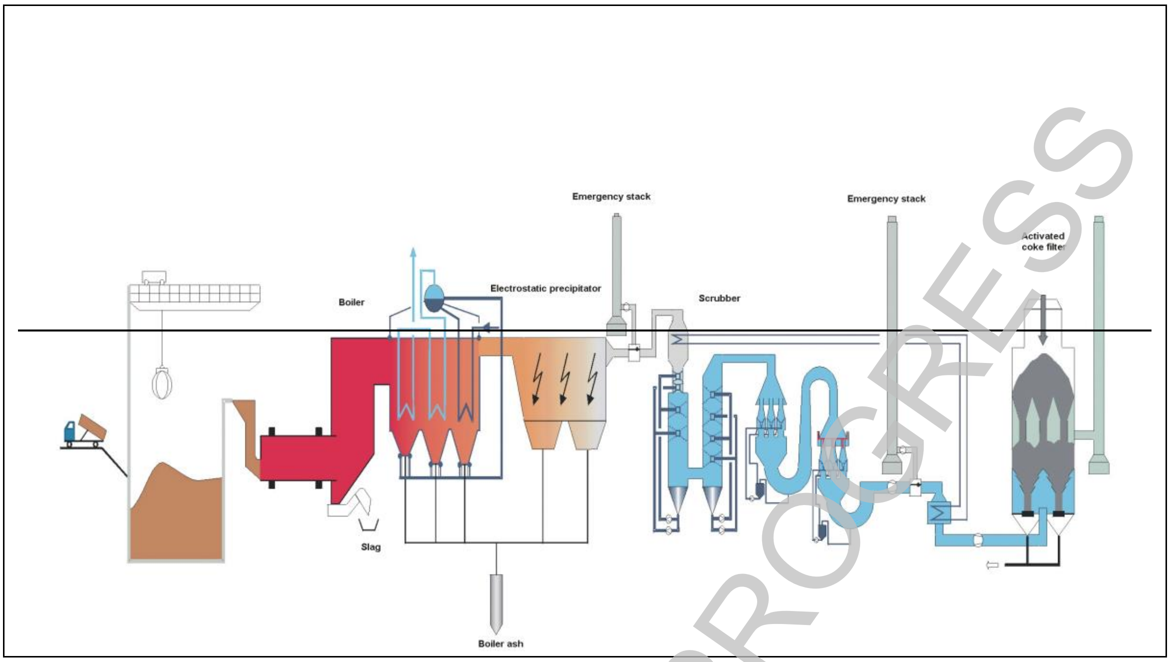
~~Table 8.65: General data of the rotary kilns of the Plant Simmeringer Haide (reference year: 2000)~~

~~Rotary kilns of the Plant Simmeringer Haide~~	
~~Operator~~	~~Fernwärme Vienna GmbH~~
~~Years of commissioning~~	~~1980~~
~~Firing technology~~	~~rotary kiln~~
~~Waste throughput~~	~~89 960 t~~
~~Theoretical rated thermal input~~	~~50 MW~~
~~Working hours line 1~~	~~6 782~~
~~Working hours line 2~~	~~7 423~~

~~Plant concept~~

~~A process flow diagram of one of the rotary kilns is shown in Figure 8.10. Each combustion line basically consists of the following units:~~

- ~~delivery and acceptance zone~~
- ~~firing system: Rotary kiln (length: 12 m, outer diameter 4.5 m, rotations per minute: 0.1–0.6)~~
- ~~waste heat boiler~~
- ~~flue-gas cleaning devices: SNCR process, electrostatic precipitator, four-stage wet scrubber, activated coke filter~~
- ~~multistage waste water treatment plant~~
- ~~steam distribution system.~~



~~**Figure 8.10: Process flow scheme of the rotary kilns of the Plant Simmeringer Haide**~~

~~Table 8.66 presents an input/output balance of the rotary kilns of the Plant Simmeringer Haide related to one tonne of waste.~~

~~**Table 8.66: Input and output flows of the rotary kilns of the Plant Simmeringer Haide (reference year: 2000)**~~

~~**Input related to 1 t waste**~~		~~**Output related to 1 t waste**~~	
~~Electricity~~	~~234 kWh~~	~~Heat~~	~~1 459 kWh~~
~~Fresh water~~	~~6 158 l~~	~~Electricity~~	~~269 kWh~~
~~Heavy fuel oil, 1 % S~~	~~0.033 m^3~~	~~Steam (p = 52 bar; T = 350 °C)~~	~~3.7 t~~
~~Lime~~	~~23.2 kg~~	~~Slag~~	~~190 kg~~
~~Coke~~	~~5.0 kg~~	~~Metal scrap~~	~~13.4 kg~~
~~Sodium hydroxide, 50 %~~	~~5.2 kg~~	~~Fly ash~~	~~14.6 kg~~
~~Ammonia, 25 %~~	~~3.0 kg~~	~~Filter cake (54.7 % H_2O)~~	~~17 kg~~
~~Precipitating agents, 15 %~~	~~0.32 kg~~	~~Cleaned waste water~~	~~1657 l~~
~~$FeCl_3$, 40 %~~	~~1.53 kg~~	~~Cleaned flue-gas (dry)~~	~~7 900 Nm^3~~
~~Hydrochloric acid, 30 %~~	~~1.0 kg~~		
~~Sand~~	~~35.6 kg~~		
~~Liquid nitrogen, 98.5 %~~	~~3.6 kg~~		

~~**Acceptance, treatment, storage and introduction of waste**~~

~~After delivery hazardous wastes are visually examined whereby the accordance with accompanying documents is verified. Afterwards chemical and physical parameters according to ÖNORM S2110 (1991) are determined. On the basis of analysis results waste fractions are evaluated, intermediately stored, mixed according to existing 'recipes' and fed into the rotary kiln.~~

~~*Solid Waste:* Solid waste is delivered in containers and vats by trucks and dumped into the waste bunker. Waste from the waste bunker is directly supplied either to the combustion process over a feeding chute or is homogenised first.~~

~~*Liquid Waste:* Liquid waste is delivered in tank lorries and stored depending on their properties. Combustible liquids are either directly supplied to the combustion process or after previous mixing using combustion lances.~~

~~*Container:* Containers are intermediately stored, sorted and directly supplied to the combustion process or to the homogenization process using roller conveyors and lifts~~

~~*Infectious clinical waste:* This waste fraction is delivered in sealed plastic containers, intermediately stored and supplied to the combustion chamber by a fully automatic conveyor.~~

~~Supply of combustion air~~

~~Combustion air is sucked off from the bunker and supplied to the rotary kiln over the front wall as primary air and over the afterburning chamber as secondary air.~~

~~Rotary kilns with afterburning chamber~~

~~The steel tubes are refractory-lined and have a length of 12 meters and an outer diameter of 4.5 m. Waste is mixed by slow rotation (0.1 - 0.6 rotations per minute), transported through the rotary kiln and combusted at a temperature of about 1 200 °C.~~

~~Flue-gases of the rotary kiln are fully combusted in the afterburning chamber. If the combustion temperature in the afterburning chamber falls below 1 200 °C two side wall burners using extra light and heavy fuel oil can be additionally switched on. In the middle respective upper end of the afterburning chamber secondary and tertiary air is injected.~~

~~Utilisation of energy~~

~~Electricity is produced to cover the own needs of the Plant Simmeringer Haide. Additionally heat is fed into the remote district heating system of Vienna.~~

~~Flue-gas cleaning system and emissions to the air~~

~~*Electrostatic precipitator:* In this first flue-gas cleaning step dust emissions are reduced to 10 - 30 mg/Nm^{-3}.~~

~~*Wet flue-gas cleaning:* The wet flue-gas cleaning system consists of two cross flow scrubbers for separation of acid, water soluble gases as well as dust and heavy metals. The subsequent venturi scrubber is operated for separation of fine dust and for preconditioning of flue-gases for the electrodynamic venturi scrubber.~~

~~*SNCR:* Nitrogen Oxides are reduced by injection of an aqueous solution of ammonia into the flue-gas.~~

~~*Activated coke filter:* Post-treatment takes place in a countercurrent plant using activated coke separately for each combustion line. This unit consists of two parallel arranged adsorbers that are filled with lignite-furnace coke. The adsorbers for the rotary kilns consist of 8 modules each, whereby each module is filled with 15 t adsorbent. Flue-gas flows through the layer from the bottom up while the coke slowly moves downwards.~~

~~Using these flue-gas cleaning system emission levels shown below are achieved:~~

~~Table 8.67: Emissions to air from the rotary kilns of the Plant Simmeringer Haide (reference year: 2000)~~

~~Parameter~~	~~Emission (mg Nm^{-3})~~ [a]	~~Total mass (kg yr^{-1})~~ [b, d]	~~Specific emissions (g t^{-1})~~ [c,d]
~~Dust~~ [*]	~~<0.05~~	~~35.54~~	~~0.395~~
~~HCl~~ [*]	~~0.42~~	~~298.5~~	~~3.318~~
~~HF~~	~~<0.05~~	~~35.54~~	~~0.395~~

~~Parameter~~	~~Emission (mg Nm^{-3})~~ [a]	~~Total mass (kg yr^{-1})~~ [b, d]	~~Specific emissions (g t^{-1})~~ [c,d]
~~SO_2~~ [*]	~~1.2~~	~~853~~	~~9.48~~
~~CO~~ [*]	~~33~~	~~23 450~~	~~261~~
~~NO_X as NO_2~~ [*]	~~104~~	~~73 910~~	~~822~~
~~Cr~~	~~0.0005~~	~~0.35~~	~~0.004~~
~~As~~	~~<0.0001~~	~~0.071~~	~~0.00079~~
~~Ni~~	~~0.0003~~	~~0.21~~	~~0.0024~~
~~Cd~~	~~0.0003~~	~~0.21~~	~~0.0024~~
~~Hg~~	~~0.0014~~	~~0.995~~	~~0.011~~
~~Cu~~	~~0.0005~~	~~0.35~~	~~0.004~~
~~C_{org}~~ [*]	~~2.2~~	~~1 564~~	~~17.4~~
~~NH_3~~	~~1.9~~	~~1 350~~	~~15.0~~
~~PCDD+PCDF~~	~~0.00154 ng Nm^{-3}~~	~~1.1 mg yr^{-1}~~	~~0.012 µg t^{-1}~~
~~PAH~~	~~0.0133~~	~~9.45~~	~~0.11~~

[*] ~~Continuous measurement~~

[a] ~~Half hourly average values in mg Nm^{-3}; dioxin emissions are given in ng Nm^{-3} (11 % O_2; dry flue-gas; standard conditions)~~

[b] ~~In kg yr^{-1}, dioxin loads in mg yr^{-1}~~

[c] ~~Emissions related to one tonne used waste in g t^{-1}; dioxin emissions in µg t^{-1}~~

[d] ~~Total mass and specific emissions are calculated based on average half hourly mean values, using the quantity of dry flue-gas (7 900 Nm^3 t^{-1} $_{waste}$) and the waste quantity (89 964 t yr^{-1}).~~

~~Waste water treatment and emissions to water~~

~~Waste water from both rotary kilns is pre-cleaned together with those of the three fluidised bed reactors. Afterwards it is conducted into the main sewage treatment plant of Vienna. Waste water cleaning is performed using gravity separation, neutralisation, flocculation, filtration and precipitation processes.~~

~~Using these cleaning steps emission levels shown below are achieved:~~

~~Table 8.68: Waste water parameters of the rotary kilns of the Plant Simmeringer Haide after waste water treatment (reference year: 2000)~~

~~Parameter~~	~~Measured value (mg l^{-1})~~
~~Temperature~~	~~<30 °C~~
~~Electric conductivity~~	~~24.6 mS cm^{-1}~~
~~pH value~~	~~9.2~~
~~Undissolved compounds~~	~~10~~
~~As~~	~~<0.02~~
~~Ca~~	~~3.86 g l^{-1}~~
~~Cd~~	~~0.019~~
~~Chlorides (Cl)~~	~~8.86 g l^{-1}~~
~~Cyanides~~	~~<0.1~~
~~Cr~~	~~0.01~~
~~Cu~~	~~0.01~~
~~Fluorides (F)~~	~~5.2~~
~~Hg~~	~~0.001~~
~~NH_4—N~~	~~63~~
~~Nitrate (NO_3)~~	~~50~~
~~Ni~~	~~0.01~~
~~Pb~~	~~<0.02~~
~~Sulphate (SO_4)~~	~~912~~
~~Sulphides~~	~~<0.01~~
~~Sulphites~~	~~<5~~
~~Zn~~	~~0.05~~
~~AOX/EOX~~	~~0.01~~
~~Phenol~~	~~0.11~~
~~Sb~~	~~0.047~~
~~Tl~~	~~0.02~~
~~V~~	~~0.01~~

~~Wastes~~

~~*Slag and filter ash:* Slag and filter ashes are landfilled.~~

~~*Filter cake:* The filter cake from the waste water cleaning plant is filled into 'big bags' and landfilled.~~

~~*Ferrous scrap:* Separated ferrous metals are delivered to a scrap dealer.~~

~~*Activated coke:* Loaded activated coke is removed into a silo by conveying installations and combusted internally.~~

~~Chemical data of waste fractions from the rotary kilns are shown in Table 8.69~~

~~Table 8.69: Chemical data of wastes from the rotary kilns (reference year: 2000)~~

~~Parameter~~	~~Measured value~~		
	~~Slag~~	~~Fly ash~~	~~Filter cake~~
~~TOC (%) (air dried basis - ad)~~	~~2.22~~	~~2.19~~	
~~Cl (%) (ad)~~		~~3.4~~	
~~SO_3 (%) (ad)~~		~~21.4~~	
~~Main components (mg kg^{-1}) (dry basis)~~			
~~SiO_2~~	~~40.9 %~~	~~12.2 %~~	~~2.9 %~~
~~Al~~	~~22 220~~	~~13 580~~	~~3 308~~
~~MgO~~	~~3.1 %~~	~~1.4 %~~	~~0.5 %~~
~~Fe~~	~~97 820~~	~~46 930~~	~~26 620~~
~~CaO~~	~~12.1 %~~	~~8.2 %~~	~~31.4 %~~
~~Na_2O~~		~~17.9 %~~	
~~K_2O~~	~~1.1~~	~~5.3~~	~~<0.4~~
~~Heavy Metals (mg kg^{-1}) (dry basis)~~			
~~Zn~~	~~1 868~~	~~52 920~~	~~9 399~~
~~Pb~~	~~802~~	~~25 162~~	~~1 062~~
~~Mn~~	~~826~~	~~1 046~~	~~467~~
~~Cr~~	~~643~~	~~494~~	~~37~~
~~Cd~~	~~4.4~~	~~360~~	~~162~~
~~As~~	~~7.6~~	~~142~~	~~12~~
~~Hg~~	~~0.29~~	~~0.42~~	~~1 088~~
~~Ni~~	~~375~~	~~995~~	~~83~~

~~Results from leaching tests are presented in Table 8.70.~~

~~Table 8.70: Leaching tests (according to ÖNORM S 2115) rotary kilns of the Plant Simmeringer Haide (reference year: 2000)~~

~~Leached concentrations (mg kg^{-1})~~	~~Slag~~	~~Fly ash~~	~~Gypsum~~
~~pH value~~	~~11.0~~	~~6.6~~	~~8.5~~
~~SO_4~~	~~90~~	~~18 720~~	~~1 441~~
~~Cl~~	~~30~~	~~5 260~~	~~624~~
~~NH_3 as N~~	~~0.29~~	~~0.65~~	~~1.73~~
~~NO_3~~	4	~~4.6~~	~~5~~
~~NO_2~~	~~0.1~~	~~0.1~~	~~0.8~~
~~Fe~~	~~0.02~~	~~0.02~~	~~0.01~~
~~Mn~~	~~0.02~~	~~20~~	~~0.19~~
~~Ni~~	~~<0.1~~	~~5.47~~	~~<0.1~~
~~Cd~~	~~0.02~~	~~31~~	~~0.01~~
~~Cr~~	~~0.01~~	~~0.01~~	~~0.01~~
~~Cu~~	~~0.01~~	~~19.2~~	~~<0.01~~
~~Pb~~	~~0.13~~	~~9.3~~	~~0.1~~
~~Zn~~	~~0.99~~	~~2 178~~	~~0.18~~

~~Leached concentrations (mg kg^{-1})~~	~~Slag~~	~~Fly ash~~	~~Gypsum~~
~~Hg~~	~~<0.001~~	~~0.003~~	~~<0.001~~

~~8.3.2.2 Rotary kiln with SCR, EP, wet scrubber and static fixed-bed carbon filter~~

~~Total capacity 110 000 t/yr~~
~~Drum-type Rotary kiln with secondary reaction chamber~~
~~2 incineration lines of 6.3 t/h each~~
~~Start-up: 1997~~

~~Reduction of emissions into the air~~

~~The waste gas cleaning system consists of the following components:~~

- ~~Electrostatic filter~~
- ~~Quench~~
- ~~HCl absorber (2-step scrubbing)~~
- ~~SO$_2$ scrubber (2-step neutralization with lime milk)~~
- ~~Activated carbon filter~~
- ~~DeNO$_X$ SCR catalyser.~~

~~Waste gas per line: 61 800 m^3/h~~
~~Manufacturer:~~

~~The average values measured in clean gas (operating values) of the plant are listed in the following Table 8.71.~~

~~Table 8.71: Average values measured in clean gas (operating values)~~

~~Parameter~~	~~Measure~~	~~Half-hour average value~~	~~Daily average value~~	~~Annual average value~~
~~Continuous measurement~~				
~~Total dust~~	~~mg/m^3~~			~~0.2~~
~~HCl~~	~~mg/m^3~~			~~0.7~~
~~SO$_X$~~	~~mg/m^3~~			~~0.08~~
~~NO$_X$~~	~~g/m^3~~			~~0.075~~
~~Total C~~	~~mg/m^3~~			~~0.3~~
~~CO~~	~~mg/m^3~~			~~8.9~~
~~Hg~~	~~mg/m^3~~			~~0.002~~
~~Periodic measurement (average value over sample taking period)~~				
~~HF~~	~~mg/m^3~~			~~<0.2~~
~~Cd, Tl~~	~~mg/m^3~~			~~0.0004~~
~~Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn~~	~~mg/m^3~~			~~0.009~~
~~PCDD/F, I-TEQ~~	~~ng/m^3~~			~~0.005~~

~~Reduction of emissions into the water~~

~~The incineration plant is operated with a zero waste water discharge. The raw acid from the hydrochloric acid scrubber is upgraded to 18 % hydrochloric acid in a chemical-physical reprocessing plant. The plaster from the SO$_2$ scrubber is reprocessed.~~

~~Energy utilization~~

~~With a waste quantity of 69 000 t combusted in the year 2000, a heat quantity of 192 000 was fed into the existing district heating system.~~

~~Noise emissions/immissions~~

~~Distance of plant to site of immission/impact: 500 m~~

~~Sound assess level:~~
~~L_{aeq} = 44.3 dB(A) - short-term (1 minute) events~~
~~L_{AF} = 56.5 dB(A)~~
~~Costs~~

~~- Investment costs (including modernization of the plant): approximately 400m DM~~
~~- Specific treatment costs: 400 to 800 DM~~

~~8.3.2.3 Rotary kiln with SNCR (urea), dry lime FGC, double bag filtration and dioxin absorption~~

~~Installation operated by SARP Industries, Limay~~

~~GENERAL Information~~
~~Hazardous wastes incinerators (2 lines + 1 under construction) owned and operated by SARP Industries.~~
~~Waste treated: hazardous wastes, solid, pasty, liquid. Outstanding issues: Cyanide solid and liquids/Organic acid special lines/Odorous wastes injection. High Chlorine input (close to 2 % in weight)~~

~~DESIGN/CONSTRUCTION DATA~~

- ~~rotary Kilns (Diameter 2.5m, 3.0m, 3.5m/Length 11m, 11m, 12m)~~
- ~~secondary Combustion Chamber (200 to 300 m^3)~~
- ~~LHV range: -600 to 10 000 kcal/kg (average at 2 500 kcal/kg)~~
- ~~design thermal input: 17 to 20 MW/7 - 8 T/h per line~~
- ~~permit: 3 x 50 000 T/y~~
- ~~steam boiler: 6 pass, vertical, 30bar saturated steam~~
- ~~energy valorisation: steam sold to power plant (heating of fuel tanks)~~
- ~~FGC system: Conditioning tower (water), Double dry = Reactor 1 + BHF 1 + Reactor 2 + BHF 2, spongiacal lime and dioxorb injection in stage 2 and recycling~~
- ~~SNCR deNO_X with solid urea~~
- ~~consumption: lime 50 kg/tonne HW (stoichiometric ratio 1.5)~~
- ~~bottom ash: to HW landfill~~
- ~~FGC residues: BHF dust to stabilisation unit and the HW landfill~~
- ~~start up dates: line 1: 1985, line 2: 1989, line 3: 2005~~
- ~~complies with the WID 2000 directive since 2000 (because of HWID).~~

~~OPERATING DATA~~

- ~~year of reference 2001~~
- ~~waste throughput: 105 000 tonnes~~
- ~~average LHV: 2 200 to 2 500 kcal/kg~~
- ~~working hours: line 1: 7 259/8 760 h/line 2: 8208/8 760 h~~
- ~~reagent consumption: $Ca(OH)_2$ 5 000 tonnes/Dioxorb (dediox clay) 540 tonnes~~

- ~~electricity consumption: 24 330 000 kWh (for the all plant, including, Physico Chemical treatment, Evapo-oxydation unit, Shredding, Stabilisation plant)~~
- ~~material residues: bottom ash 12 600 tonnes/BHF dust 7 800 tonnes~~
- ~~annual average of continuous concentration measurement in clean gas (dry 11 % O_2):~~
- ~~dust 1.42/1.33 mg/Nm^3 // HCl 0.75/0.60 mg/Nm^3 // SO2 5.2/22.7 mg/Nm^3 // TOC 2/0.8 mg/Nm^3 // CO 13.5/15.2 mg/Nm^3 // NO_X 117/73 mg/Nm^3~~
- ~~average values of concentration sampling in clean gas (periodic measurements), 2 samplings:~~
- ~~sum Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V 0.05/0.34 mg/Nm^3 // Hg 0.002/0.002 mg/Nm^3 // Cd+Tl 0.006/0.004 mg/Nm^3 // PCDD-F 0.022/0.013 ng I-TEQ/Nm^3.~~

~~ECONOMICS~~

~~Investment costs: line 3 around EUR 27 million~~

~~Gate fee: varying from EUR 80 to 1 000/T (average around EUR 300/tonne)~~

~~8.3.3 Examples of sewage sludge installations~~

~~8.3.3.1 Bubbling fluidised bed with heat recovery, SNCR, EP, wet scrubbing and static fixed-bed coke filter~~

~~In the year 2000 54390 tonnes of sewage sludge and 3378 tonnes of waste oils as well as about 1 000 tonnes of feeding stuff and solvents each were combusted in three fluidised bed reactors. General data of the fluidised bed reactors are shown in Table 8.72.~~

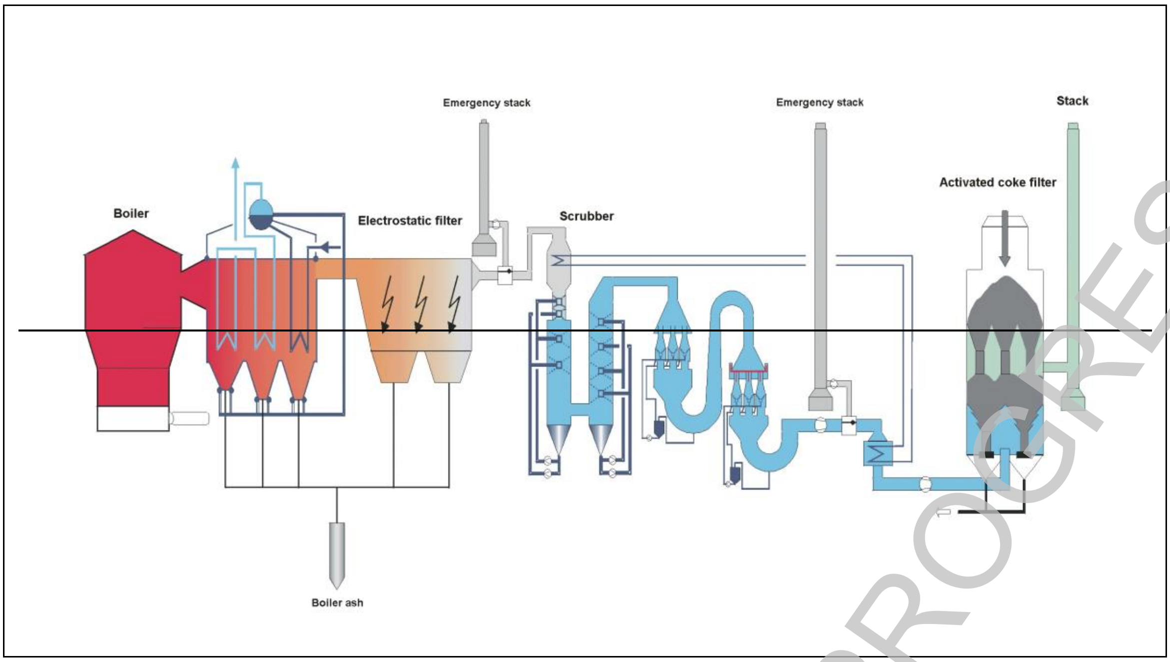
~~Table 8.72: General data of the fluidised bed reactors of the Plant Simmeringer Haide (2000)~~

~~Fluidised bed reactors in the plant Simmeringer Haide~~	
~~Operator~~	~~Fernwärme Vienna GmbH~~
~~Start-up~~	~~1980/1992~~
~~Firing technology~~	~~Stationary fluidised bed reactors System Copeland~~
~~Sludge throughput~~	~~54 390 t dry substance, corresponding to 1 656 000 m^3 thin slurry~~
~~Average net calorific value~~	~~15.7 MJ kg^{-1}dry substance~~
~~Average gross calorific value~~	~~17.1 MJ kg^{-1}dry substance~~
~~Theoretical rated thermal input~~	~~50 MW~~
~~Working hours line 1~~	~~2 484~~
~~Working hours line 2~~	~~5 603~~
~~Working hours line 3~~	~~8 784~~

~~Plant concept~~

~~A process flow scheme of one fluidised bed reactor is shown in Figure 8.11. One incineration line basically consists of the following units:~~

- ~~fluidised bed reactor~~
- ~~waste heat boiler~~
- ~~flue gas cleaning devices: SNCR process, electrostatic precipitator, acid and alkaline scrubber, activated coke filter~~
- ~~multistage waste water treatment plant~~
- ~~steam distribution system~~



~~**Figure 8.11: Process flow scheme of the fluidised bed reactors of the Plant Simmeringer Haide**~~

~~Table 8.73 presents an input/output balance of the three fluidised bed reactors of the Plant Simmeringer Haide related to one tonne of waste.~~

~~**Table 8.73: Input and output flows of the fluidised bed reactors (reference year: 2000)**~~

~~**Input related to 1 t waste**~~		~~**Output related to 1 t waste**~~	
~~Electricity~~	~~590 kWh~~	~~Hydrochloric acid, 30 %~~	~~1.4 kg~~
~~Heavy fuel oil (1 % S)~~	~~0.059~~ m^3	~~Quartz sand~~	~~13.7 kg~~
~~Fresh water~~	~~15 530 l~~	~~Liquid nitrogen, 98.5 %~~	~~2.5 kg~~
~~Lime~~	~~4.7 kg~~	~~Heat~~	~~1.98 MWh~~
~~Sodium hydroxide, 50 %~~	~~16.5 kg~~	~~Electricity~~	~~0.363 kWh~~
~~Ammonia, 25 %~~	~~4.1 kg~~	~~Steam (p = 52 bar; T = 350 °C)~~	~~5.22 t~~
~~Precipitating agents, 15 %~~	~~0.05 kg~~	~~Fly and bed ash~~	~~264 kg~~
~~$FeCl_3$, 40 %~~	~~2.1 kg~~	~~Filter cake (54.7 % H_2O)~~	~~23 kg~~
~~Coke~~	~~3.4 kg~~	~~Cleaned waste water~~	~~1 104 l~~
~~Polyelectrolyte~~	~~4.45 kg~~	~~Cleaned flue-gas (dry)~~	~~13 110~~ Nm^3

~~**Acceptance, treatment, storage and introduction of waste**~~

~~The three fluidised bed reactors are constructed for the incineration of sewage sludge from the main waste water treatment plant of Vienna. Supplied thin sludge is dewatered by means of centrifuges. The resulting thick sludge has a dry substance content between 30 and 36 % and is supplied to the fluidised bed reactors.~~

~~**Supply of combustion air**~~

~~Combustion air is preheated by means of an air preheater.~~

~~**Fluidised bed reactors**~~

~~The three fluidised bed reactors of the plant Simmeringer Haide are constructed according to the principle of the stationary fluidised bed technology. The temperature of the fluidised bed is 750 °C. The combustion chamber is equipped with an oil burner.~~

~~**Utilisation of energy**~~

~~Energy from the flue-gas is used for the production of steam (53 bar). Steam produced by the rotary kilns and the fluidised bed reactors is combined and converted to electricity by two turbines. Electricity is used for covering the own needs of the installation of the Plant Simmeringer Haide. Additionally the oven lines are equipped with a cogeneration (CHP) system which decouples heat for the district heating system of Vienna.~~

~~Flue-gas cleaning system and emissions to the air~~

~~*Electrostatic precipitator:* In the first flue-gas cleaning step dust emissions are reduced to 10 – 30 mg Nm^{-3}.~~

~~*Flue-gas scrubbing:* The wet flue-gas cleaning system consists of two cross-flow scrubbers for separation of acid, water soluble gases as well as dust and heavy metals. The subsequent venturi scrubber is used for separation of fine dust and for preconditioning of flue-gases for a electrodynamic venturi scrubber.~~

~~*SNCR:* Nitrogen oxides are reduced by injection of an aqueous solution of ammonia into the flue-gas.~~

~~*Activated coke filter:* Post-treatment takes place in a countercurrent plant using activated coke separately for each combustion line. This unit consists of two parallel arranged adsorbers that are filled with lignite-furnace coke. The adsorbers for the fluidised bed reactors consist of 4 modules each, whereby each module is filled with 15 t adsorbent. Flue-gas flows through the layer from the bottom up while the coke slowly moves downwards.~~
~~Using these flue-gas cleaning measures emission levels shown in Table 8.74 are achieved:~~

~~Table 8.74: Emissions to air from the fluidised bed reactors (reference year: 2000)~~

~~Parameter~~	~~Emission (mg Nm^{-3})~~ [a]	~~Total mass (kg yr^{-1})~~ [b,d]	~~Specific emissions (g t^{-1})~~ [c,d]
~~Dust~~ [*]	~~0.6~~	~~498.6~~	~~7.8~~
~~HCl~~ [*]	~~0.11~~	~~91.41~~	~~1.45~~
~~HF~~	~~<0.05~~	~~41.55~~	~~0.65~~
~~SO_2~~ [*]	[e]		
~~CO~~ [*]	~~4~~	~~3 324~~	~~52.44~~
~~NO_X as NO_2~~ [*]	~~100~~	~~83 100~~	~~1311~~
~~Cr~~	~~0.0004~~	~~0.33~~	~~0.0052~~
~~As~~	~~<0.0001~~	~~0.083~~	~~0.0013~~
~~Ni~~	~~0.0006~~	~~0.499~~	~~0.0079~~
~~Cd~~	~~0.0006~~	~~0.499~~	~~0.0079~~
~~Hg~~	~~0.0015~~	~~1.25~~	~~0.02~~
~~Cu~~	~~0.0009~~	~~0.75~~	~~0.012~~
~~PAH~~	~~0.0069~~	~~5.73~~	~~0.09~~
~~NH_3~~	~~3.55~~	~~2950~~	~~46.54~~
~~PCDD+PCDF~~	~~0.00079 ng TE Nm^{-3}~~	~~0.66 mg yr^{-1}~~	~~0.01 µg t^{-1}~~

[*] ~~*Continuous measurement*~~
[a] ~~*Half hourly average values in mg Nm^{-3}; dioxin emissions are given in ng Nm^{-3} (11 % O_2; dry flue-gas; standard conditions)*~~
[b] ~~*In kg yr^{-1}, dioxin loads in mg yr^{-1}*~~
[c] ~~*Emissions related to one tonne used waste in g t^{-1}; dioxin emissions in µg t^{-1}*~~
[d] ~~*Total mass and specific emissions are calculated based on average half hourly mean values, using the quantity of dry flue-gas (13 110 Nm^3 t^{-1} $_{waste}$) and the waste quantity (63 390 t yr^{-1}).*~~
[e] ~~*below detection limit (0.3 mg Nm^{-3})*~~

~~Waste water treatment and emissions to water~~

~~The waste water from the three fluidised bed reactors is precleaned together with those of the two rotary kilns. Afterwards it is conducted into the main waste water treatment plant of Vienna. Waste water cleaning is performed using gravity separation, neutralisation, flocculation,~~

~~filtration and precipitation processes. Neutralisation is performed in order to separate HCl and HF.~~

~~Waste~~

~~*Bed- and filter ash:* Bed- and filter ashes are landfilled.~~

~~*Filter cake:* The filter cake from the waste water cleaning plant is filled into 'big bags' and landfilled.~~

~~Chemical data of wastes from the fluidised bed reactors are shown in Table 8.75. Results from leaching tests are presented in Table 8.76.~~

~~Table 8.75: Chemical data of wastes from the fluidised bed reactors (reference year: 2000)~~

~~Parameter~~	~~Fly ash~~
~~TOC (%) (air dried basis - ad)~~	~~0.97~~
~~Cl (%) (ad)~~	~~0.18~~
~~SO_3 (%) (ad)~~	~~3.3~~
~~Main components (mg kg^{-1}) (dry basis)~~	
~~SiO_2~~	~~225~~
~~Al~~	~~41 950~~
~~MgO~~	~~25~~
~~Fe~~	~~179 100~~
~~CaO~~	~~164~~
~~K_2O~~	~~1.3~~
~~Heavy metals (mg kg^{-1})~~	
~~Zn~~	~~2 738~~
~~Pb~~	~~378~~
~~Mn~~	~~414~~
~~Cr~~	~~108~~
~~Cd~~	~~10.4~~
~~As~~	~~11.6~~
~~Hg~~	~~0.76~~
~~Ni~~	~~87~~

~~Table 8.76: Leaching tests according to ÖNORM S 2115 – fluidised bed reactors (reference year: 2000)~~

~~Parameter~~	~~Concentration (mg kg^{-1})~~
~~pH value~~	~~9.5~~
~~SO_4~~	~~1 284~~
~~Cl~~	~~58~~
~~NH_3 as N~~	~~0.75~~
~~NO_3~~	~~5~~
~~NO_2~~	~~0.1~~
~~Fe~~	~~0.01~~
~~Mn~~	~~<0.01~~
~~Ni~~	~~<0.1~~
~~Cd~~	~~<0.01~~
~~Cr~~	~~0.03~~
~~Cu~~	~~<0.01~~
~~Pb~~	~~0.1~~
~~Zn~~	~~0.04~~
~~Hg~~	~~0.001~~

~~8.3.3.2 Bubbling FB with CHP, SNCR, flue-gas recirculation, EP, wet scrubbing and bag filters with coke/calcium carbonate injection~~

~~Total capacity 78 840 t m$_T$/yr, currently 42 000 t of sewage sludge and 7 000 t of rakings~~
~~Stationary fluidized bed furnaces~~
~~3 incineration lines with 26 280 t m$_T$/yr each~~
~~Start-up: 1997~~

~~Sewage sludge and rakings as incineration materials may be described as follows:~~

~~Table 8.77: Characterization of the incineration materials~~

~~Parameter~~	~~Measure~~	~~Sewage sludge~~	~~Rakings~~
~~Calorific value~~	~~kJ/kg~~	~~3 190 – 5 300~~	~~2 900 – 7 000~~
~~Solid contents~~	~~% m$_T$~~	~~39 – 46~~	~~22 – 34~~
~~Loss on ignition~~	~~% by weight~~	~~48 – 56~~	

~~Reduction of emissions into the air~~
~~The waste gas cleaning system consists of the following components:~~

- ~~SNCR nitrogen removal~~
- ~~Flue-gas recirculation~~
- ~~Electrostatic filter (2-stage)~~
- ~~HCl scrubber (pH value 2.3)~~
- ~~SO$_2$ scrubber (1-stage neutralization with lime milk)~~
- ~~Tissue filter with coke/calcium hydrate/calcium carbonate dosing~~

~~Waste gas quantity per line: 15 000 m^3/h~~

~~Table 8.78: Average values measured in clean gas (operating values) – BAT5~~

~~Parameter~~	~~Measure~~	~~Half-hour average values~~	~~Daily average values~~	~~Annual average values~~
~~Continuous measurement~~				
~~Total dust~~	~~mg/m^3~~	~~<5~~	~~<2.5~~	~~0.2~~
~~HCl~~	~~mg/m^3~~	~~<10~~	~~<5~~	~~0.2~~
~~SO$_X$~~	~~mg/m^3~~	~~<50~~	~~<20~~	~~3.3~~
~~NO$_X$~~	~~g/m^3~~	~~<0.220~~	~~<0.12~~	~~43~~
~~Total C~~	~~mg/m^3~~	~~<10~~	~~<7~~	~~0.7~~
~~CO~~	~~mg/m^3~~	~~<100~~	~~<20~~	~~2.4~~
~~Periodical measurement~~				
~~HF~~	~~mg/m^3~~	~~<0.06~~	-	
~~Cd, Tl~~	~~mg/m^3~~	~~<0.001~~	-	~~0.0002~~
~~Hg~~	~~mg/m^3~~	~~<1~~	-	~~0.0008~~
~~Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V,Sn~~	~~mg/m^3~~	~~<0.013~~	-	~~0.007~~
~~PCDD/F, I-TEQ~~	~~ng/m^3~~	~~<0.011~~	-	~~0.0012~~

~~Reduction of emissions into the water~~
~~The waste gas cleaning system operates with zero waste water discharge.~~
~~Energy utilization~~

~~With a combusted sewage sludge total of 102 100 t (m_T content approximately 42 %), there was an output of 48 000 MWh electric power and 62 630 MWh process steam.~~

~~Noise emissions/immissions~~
~~No information.~~

~~Costs~~
~~- Investment costs: approximately 180*10^6 DM~~
~~- Specific treatment costs: no information~~

~~8.3.3.3 Bubbling FB Plant with CHP, EP and wet scrubbing~~

- ~~Total capacity 100 000 t m_T/yr~~
- ~~Stationary fluidized bed furnaces~~
- ~~2 incineration lines with 30 t m_T/h each~~

~~Reduction of emissions into the air~~
~~The waste gas cleaning system consists of the following components:~~

~~- Electrostatic filters~~
~~- 4-stage waste gas washing~~

~~Waste gas per line: 62 540 m^3/h~~

~~The incineration material sewage sludge can be described as follows:~~

~~Table 8.79: Characterization of the incineration material~~

~~**Parameter**~~	~~**Measure**~~	~~**Filter cake**~~
~~Calorific value~~	~~kJ/kg~~	~~13 000~~
~~Solid content~~	~~% m_T~~	~~45~~
~~Loss on ignition~~	~~% by weight~~	

~~Table 8.80: Average values measured in clean gas (operating values) – BAT6~~

~~**Parameter**~~	~~**Measure**~~	~~**Half-hour average values**~~	~~**Daily average values**~~	~~**Annual average values**~~
~~Continuous Measurement~~				
~~Total dust~~	~~mg/m^3~~	~~<30~~	~~<10~~	
~~HCl~~	~~mg/m^3~~	~~<60~~	~~<10~~	
~~SO_X~~	~~mg/m^3~~	~~<200~~	~~<50~~	
~~NO_X~~	~~g/m^3~~	~~<0.4~~	~~<0.2~~	
~~Total C~~	~~mg/m^3~~	~~<20~~	~~<10~~	
~~CO~~	~~mg/m^3~~	~~<100~~	~~<50~~	
~~Hg~~	~~mg/m^3~~	~~<0.05~~	~~<0.03~~	
~~Periodic measurement (Average values over sample taking period)~~				
~~HF~~	~~mg/m^3~~		~~<1~~	
~~Cd, Tl~~	~~mg/m^3~~		~~<0.05~~	

~~Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V,Sn~~	~~mg/m^3~~		~~<0.5~~	
~~PCDD/F, I-TEQ~~	~~ng/m^3~~		~~<0.1~~	

~~Reduction of emissions to water~~

~~The waste water cleaning system consists of a chemical (heavy metal precipitation) and a biological phase.~~

~~Table 8.81: Emission values of the waste water from the waste gas cleaning system before mixing (BAT6)~~

~~Parameter~~	~~2-hour composite sample (mg/l)~~
~~Suspended solid matter~~	
~~Hg~~	~~0.05~~
~~Cd~~	~~0.05~~
~~Tl~~	-
~~As~~	-
~~Pb~~	~~0.1~~
~~Cr~~	~~0.5~~
~~Cu~~	~~0.5~~
~~Ni~~	~~0.5~~
~~Zn~~	~~1.0~~
~~PCDD/F (ng I-TEQ/l)~~	
~~pH value~~	
~~Temperature~~	

~~Energy utilization~~

~~Heat generation/output~~
~~Total heat generation: 70 000 MWh~~
~~Internal consumption:~~

~~Power generation/output~~
~~Total power generation: 80 000 MWh~~
~~Internal use (additional supplies included): 20 000 MWh~~
~~Power output: 60 000 MWh~~

~~Noise emissions/immissions~~

~~Distance of plant to immision site: 1 200 m~~

~~The immission values admissible according to Item 2.321 TA Noise are observed at the prominent immission sites.~~

~~Costs~~

~~No information.~~

~~8.3.4 Examples of combined incineration of various wastes~~

~~8.3.4.1 Circulating FB for selected/pretreated wastes with heat recovery, dry and wet FGC, SCR and ash treatment~~

~~Following types of waste are combusted at AVE - Reststoffverwertung Lenzing:~~

- ~~packaging materials from the separated collection~~
- ~~rejects~~
- ~~light fractions/sieve overflow from mechanical-biological plants~~
- ~~waste wood, particularly contaminated~~
- ~~sewage sludge.~~

~~In 2000 134715 tonnes of waste were treated in total.~~

~~Table 8.82: Types of waste and waste quantities treated at AVE - Reststoffverwertung Lenzing (reference year: 2000)~~

~~Types of waste~~	~~Waste quantity (t yr^{-1})~~
~~Plastic wastes~~	~~34 450~~
~~Rejects~~	~~19 460~~
~~Sewage sludge~~	~~31 990~~
~~Mixed plastic fractions~~	~~41 910~~
~~Old wood~~	~~6 898~~

~~General data of the fluidised bed reactor of AVE-RVL Lenzing are presented in Table 8.83~~

~~Table 8.83: General data of the fluidised bed reactor of AVE-RVL Lenzing~~

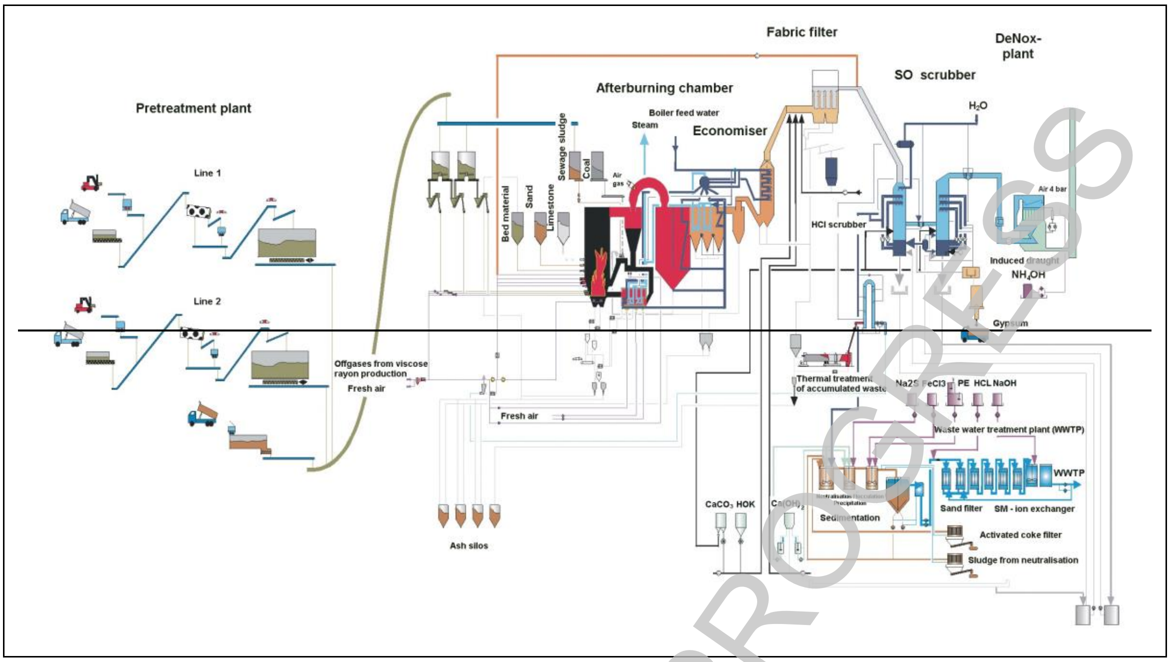
~~AVE - Reststoffverwertung Lenzing~~	
~~Operator~~	~~RVL GmbH~~
~~Start up~~	~~September 1998~~
~~Technology~~	~~Circulating fluidised bed reactor~~
~~Waste throughput (2001)~~	~~134 700 t~~
~~Calorific value of the waste~~	~~6.5 - 29 MJ kg^{-1}~~
~~Rated thermal input~~	~~110 MW$_{th}$~~
~~Operating hours (2000)~~	~~About 6 100~~

~~Fuel oil, natural gas and coil are used as additional fuels for start up and shut down if necessary. The maximum rated thermal input of the plant is about 110 MW as continuous load. The plant is constructed for the treatment of wastes with a mixed calorific value of 6.5 - 29 MJ kg^{-1}. The required waste quantity is defined by the thermal output and is about 7 - 60 tonnes per hour.~~

~~Plant concept~~

~~A process flow diagram of AVE – Reststoffverwertung Lenzing is shown in two following figure. The plant basically consists of the following units:~~

- ~~delivery~~
- ~~treatment and storage of waste~~
- ~~fluidised bed combustion with fluidised bed cooler and afterburning chamber~~
- ~~waste heat boiler~~
- ~~dry, wet and catalytic flue-gas cleaning devices~~
- ~~waste water treatment.~~



~~**Figure 8.12: Process flow scheme of AVE-Reststoffverwertung Lenzing**~~

~~Acceptance, treatment and storage of waste~~

~~Delivered wastes such as packaging materials, rejects, light fraction and waste wood are declared by the deliverer and randomly tested by the operator, crushed and ground up and interim stored in two daily bunkers that are situated directly near the boiler. Feeding of waste into the pulveriser, distribution in the daily bunker and discharge from the daily bunker is carried out in view of good homogenization.~~

~~Sewage sludge is directly dumped into two charging hoppers with discharge floor and interim stored in a silo. Sewage sludge is usually stabilized and combusted a few hours after delivery. In all cases transport from the pretreatment site to the boiler house is performed periodically with a pipe belt conveyor.~~

~~Waste introduction and supply of combustion air~~

~~Ground up wastes such as plastics, rejects, sieve overflow and waste wood can be fed from the charging hopper into the firing zone using 3 pneumatic conveyors. For sewage sludge, a separate conveyor line with a plug screw as dosing device is provided. For oil and natural gas, burners and oil lances are installed. Coal can be fed with a separate dosing plant.~~

~~Exhaust gas from the neighbouring viscose rayon production containing H_2S (hydrogen sulphide) and CS_2 (carbon disulphide) is used as combustion air. Exhaust gas from waste treatment and storage is dedusted with fabric filters and discharged into the atmosphere.~~
~~Combustion air is injected into the combustion chamber through the valve tray, two secondary air levels and several process-related places such as pneumatic conveyors and fluidising plates in the ash circle.~~

~~Dosing of particular wastes, co-fired fuels and combustion air is regulated by a firing performance control system. The demand for air and fuel is calculated online. The most important parameters such as calorific value and demand on combustion air are calculated automatically from process data and adapted to the combusted wastes.~~

~~Fluidised bed combustion with afterburning chamber~~

~~The firing system mainly consists of:~~

- ~~uncooled combustion chamber with slightly conical shape at the bottom and cylindrical form at the top~~
- ~~cyclone~~
- ~~afterburning chamber~~
- ~~recirculation system for bed material with a siphon and a fluidised bed cooler.~~

~~Wastes are mixed homogeneously into the lower part of the combustion chamber and transported through the firing chamber with combustion air. In order to pre-separate SO_2 limestone is continuously added to the fluidised bed reactor of AVE - Reststoffverwertung Lenzing. This is a necessary procedure, because the exhaust air of the viscose rayon production that is used as combustion air contains high amounts of sulphurous compounds.~~

~~Bed material is separated from the flue-gas by a cyclone and fed into the siphon and fluidised bed cooler. A regulated quantity of bed material is passed over the fluidised bed cooler in order to extract heat from bed material either for steam production and superheating of steam or temperature regulation of the combustion chamber.~~

~~Flue-gases leaving the cyclone are fully combusted in the afterburning chamber at sufficient temperature and residence time.~~

~~Waste heat boiler~~

~~Flue-gases leaving the afterburning chamber are passing two vertical void zones with heating surfaces for evaporation, a horizontal zone with hanging heating surfaces for evaporation and superheating, a cyclone battery system and a preheater for feed water.~~

~~The steam system is connected to that of the adjacent Lenzing AG. Feed-water is pumped from the existing feed-water system into the boiler drum through the feed-water preheater. The water passes in the so-called natural circulation the evaporator surfaces in the fluidised bed cooler and the waste heat boiler and evaporates to some extent. Steam is separated from water in the steam drum and conducted into the steam network of Lenzing AG via the superheater. The first superheaters are arranged in the waste heat boiler, the last superheaters are arranged in the fluidised bed cooler.~~

~~Utilisation of energy~~

~~The steam parameters of the produced fresh steam are 78 bar and 500 °C. Electricity is produced by the turbines of Lenzing AG. The major part of the steam is withdrawn at 4 bar from the turbines and introduced into the process steam system of Lenzing AG. The overall demand for process steam is several times higher than the produced amount, exists all over the year and is covered by another fluidised bed reactor, two waste liquor boilers and an oil and gas fired reserve boiler.~~

~~Flue-gas cleaning and emissions into the air~~

~~*Dry flue-gas:* The dry flue-gas cleaning system is constructed as transport reactor with downstream fabric filter. The flue-gas temperature is regulated by the boiler to a constant value of about 160 °C.~~

~~The dry flue gas cleaning system is used for dedusting, heavy metal precipitation and pre-separation of acid components such as HCl, HF and SO_3. Lime, limestone and activated coke can be dosed into the ducts before the fabric filter. Separated dust is recirculated to some part.~~

~~*Wet flue-gas cleaning:* The wet flue-gas cleaning system consists of a co-current scrubber with acid circulating water, a countercurrent scrubber with gypsum suspension, droplet separators after each scrubber and a downstream steam heated gas preheater. The first step is used for the separation of acid components such as HCl, HF, SO_3 and for separation of volatile components. The second step is used for the separation of SO_2. The gypsum suspension of a partial flow is dewatered. Waste water from both scrubbers is treated by the waste water treatment plant.~~

~~Cleaned waste water is partly returned to the first step. Limestone is injected in dry form as neutralizing agent.~~

~~*Catalytic flue gas cleaning:* The catalytic flue-gas cleaning system is arranged in clean gas application with preheating by a gas/gas heat exchanger and a high pressure steam preheater. It is used for reduction of NO$_X$ and oxidation of organic pollutants such as dioxins and furans.~~

~~The whole plant is designed in terms of precautionary environmental protection what means that the particular plant elements are dimensioned and arranged in such a way that the prescribed emission limit values can be observed even in cases of highest possible pollutant loads of combusted wastes.~~

~~Achieved emission values of the fluidised bed reactor are shown in Table 8.84.~~

~~**Table 8.84: Emissions to air from the fluidised bed reactor of AVE - Reststoffverwertung Lenzing**~~

~~**Parameter**~~	~~**Emission ^{a} (mg Nm^{-3})**~~
~~Dust~~	~~0.6~~
~~HCl~~	~~0.8~~
~~HF~~	~~0.02~~
~~SO$_2$~~	~~4.1~~
~~C$_{org}$~~	~~0.6~~
~~CO~~	~~2.3~~
~~NO$_X$ as NO$_2$~~	~~14.6~~
~~Σ Pb, Cr, Zn~~	~~0.003~~
~~Σ As, Co, Ni, Sb, Cu, Mn, V, Sn~~	~~0.00075~~
~~Cd+Tl~~	~~0.001~~
~~Hg~~	~~0.003~~
~~NH$_3$~~	~~1.8~~
~~PCDD+PCDF~~	~~0.05 ng Nm^{-3}~~
~~^{a} Half hourly average values in mg Nm^{-3}; dioxin emissions are given in ng Nm^{-3} (11 % O$_2$; dry flue gas, standard conditions)~~	

~~**Waste water treatment**~~

~~The waste water treatment plant consists of following units: Neutralisation, precipitation, flocculation and sedimentation and post treatment with gravel filters, ion exchanger and activated coke filter. For neutralisation lime milk is added.~~

~~**Waste**~~

~~As far as waste from combustion is concerned a process concept was chosen by AVE-RVL Lenzing with the following goals:~~

- ~~minimizing the amount of waste~~
- ~~concentration of pollutants in small amounts of waste~~
- ~~low concentration of volatile heavy metals in the main part of the ash~~
- ~~minimization of the PCDD/F content in the predominant part of the ash~~
- ~~reduction of the metallic Al content in the ash.~~

~~For that purpose the major part of the ash is separated in a cyclone battery at the end of the superheater zone. A part of this fine ash is recirculated into the combustion chamber again, in order to reduce volatile components and oxidise the major part of metallic Al.~~

~~Following wastes accumulate:~~

~~*Bed ash:* Coarse ash and interfering materials such as ferrous fragments and stones, that are separated by a coarse sieve and a magnetic separator.~~
~~*Coarse ash:* Overflow of the coarse sieve of the bed ash.~~

~~*Ferrous scrap:* Separated with magnetic separators from bed ash.~~
~~*Ash from pre-dedusting:* Fine ash with a grain size between 40 and 100 µm, that is separated in the cyclone battery in the temperature range of 900 to 400 °C. Additionally fine ash can be withdrawn by the air separator in the ash cycle of the firing system.~~

~~*Eco- and fabric filter ash:* Very fine ash (<40 µm) that arises in the flue-gas zone after pre-dedusting in the temperature range between 400 and 160 °C and in the dry flue-gas cleaning system. The mass fraction of very fine ash is less than 30 % of the overall ash but contains the main part of the volatile heavy metal and PCDD/F load. Very fine ash can be thermally post-treated in a rotary kiln. As this ash is disposed of underground anyway and already has the required properties without treatment, the rotary kiln was in operation only at the beginning of the test operation.~~

~~*Neutralisation sludge from the waste water treatment plant:* Inorganic sludge dewatered in chamber filter presses.~~

~~*Gypsum:* Arising in the suspension scrubber and dewatered in the centrifuge.~~

~~Bed ash, coarse ash and pre-dedusting ash are exempted and disposed of at landfills.~~
~~Eco- and fabric filter ash and neutralisation sludge are exported as hazardous wastes and disposed of underground.~~

~~8.3.4.2 Fluidized bed plant for selected hazardous and non-hazardous wastes with heat recovery, EP, fabric filter, wet scrubber and SCR~~

~~Fluidised bed reactors of the waste incineration plant Arnoldstein~~

~~The fluidised bed reactor of the waste incineration plant Arnoldstein was upgraded in 2000 and is continuously operated since January 2001. In 2001 26 000 tonnes of hazardous and non-hazardous wastes (oily waste, solvent-water mixtures, treated and untreated wood waste, wood packaging, plastic waste, sludge and waste water) were combusted. The catalogue of key numbers of wastes permitted for thermal treatment can be found on the homepage of the waste incineration plant (www.abrg.at). General data of the fluidised bed reactor of the waste incineration plant Arnoldstein are given in Table 8.85.~~

~~Table 8.85: General data of the fluidised bed reactor of the waste incineration plant Arnoldstein (reference year: 2001)~~

~~Fluidised bed reactor Arnoldstein~~	
~~Operator~~	~~Asamer Becker Recycling Gesellschaft mbH~~
~~Start-up~~	~~1994~~
~~Start-up after overhaul~~	~~31.12.2000~~
~~Firing technology~~	~~Fluidised bed reactor~~
~~Waste throughput~~	~~26 000 t~~
~~Average calorific value of the waste~~	~~5 000 – 30 000 kJ kg^{-1}~~
~~Thermal output~~	~~8 MW~~
~~Operating hours (test operation)~~	~~7 300~~

~~Plant concept~~
~~A process flow diagram is shown in Figure 8.13. The plant basically consists of the following units:~~

- ~~treatment hall for crushing and grinding and mixing of wastes~~
- ~~hall for intermediate storage of wastes~~
- ~~firing system: Stationary fluidised bed reactor with waste heat boiler~~

- ~~flue-gas cleaning devices: Electrostatic precipitator, two-stage wet scrubbing with NaOH scrubber, flow injection process and catalytic flue-gas cleaning system (clean gas application)~~
- ~~central waste water treatment plant.~~

~~If necessary oil is used as additional fuel for start up and shut down.~~

~~Figure 8.13: Process flow scheme of the Fluidised bed reactors at Arnoldstein~~

~~In Table 8.86 output flows of the fluidised bed reactors of the waste incineration plant Arnoldstein are shown.~~

~~Table 8.86: Output flows of the fluidised bed reactors of the waste incineration plant Arnoldstein (reference year: 2001)~~

~~Outputs~~	
~~Steam (25 bar; 180 °C)~~	~~4.5 t h^{-1}~~
~~Ash~~	~~9 000 t yr^{-1}~~
~~Ferrous scrap~~	~~170 t yr^{-1}~~
~~Filter cake~~	~~200 t yr^{-1}~~
~~Waste water~~	~~13 000 $m^3 yr^{-1}$~~
~~Flue-gas~~	~~15 500 $Nm^3 h^{-1}$~~

~~Acceptance, treatment and storage of waste~~

~~Incoming wastes are declared by the deliverer and always controlled optically by the operator of the waste incineration plant. Depending on the waste and on the deliverer singular or mixed samples are taken regularly in order to determine various parameters such as pH, calorific value, ignition loss, halogens, heavy metals, density and others. Waste is intermediately stored in boxes. Immediately before combustion they are transported to the waste bunker using a crane. Liquid waste fractions are intermediately stored in tanks.~~

~~Waste introduction and supply of combustion air~~

~~Mixed, crushed and grinded solid wastes are fed into the bunker by means of a crane. The bottom of this bunker is constructed as slowly moving conveyer belt. Waste discharged from the bunker falls onto another conveyor belt and is conveyed into a charging hopper for a dosing screw. Using the dosing screw solid wastes are charged regularly onto a so-called throw feeder, which distributes the waste uniformly across the fluidised bed. Liquid wastes are injected by means of a lance. For start up of the plant two burners firing fuel oil are installed. Exhaust air from the waste storage facilities and the tanks are used as combustion air.~~

~~The combustion air is introduced into the combustion chamber as secondary air through nozzles and as conveying air for recirculated bed ash. In order to regulate the dosage of waste, fuel oil and combustion air, a control system for the regulation of the firing performance is installed.~~

~~Combustion chamber~~

~~The combustion chamber is constructed as an uncooled, brick-lined stationary fluidised bed system. Immediately above the stationary fluidised bed reactor the afterburning zone with secondary air injection is arranged. Hydrated lime and limestone from the flow injection process are pneumatically conveyed into the combustion chamber for pre-separation of SO_2.~~

~~Waste heat boiler~~

~~The waste heat boiler is constructed as a horizontal boiler with radiation heating surfaces in the first and convection surfaces in the second part. These heating surfaces are pure evaporating heating surfaces. The horizontal waste heat boiler is followed by a feed-water preheater. In the~~

~~energy system saturated steam is produced which is fed into the local steam network using a pressure reducing valve.~~

~~**Flue-gas cleaning system and emissions into the air**~~

~~*Dedusting:* Dedusting of flue-gases leaving the boiler is performed by means of an electrostatic precipitator. The temperature of flue-gases entering the electrostatic precipitator depends on the boiler load and the travel time.~~

~~*Wet flue-gas cleaning:* The wet flue-gas cleaning system consists of a co-current scrubber with acid circulation water and a countercurrent scrubber with NaOH as neutralizing agent. Each scrubber is followed by a droplet separator. Heat from the flue-gases entering the scrubber is transferred to the flue-gases leaving the scrubber by means of a gas/gas heat exchanger. The outlet temperature can be regulated by a downstream steam heated gas preheater.~~

~~*Flow injection process:* The flow injection unit consists of a flue-gas channel with injection of furnace coke, limestone and hydrated lime and a fabric filter. The operating temperature is about 120 °C.~~

~~Added chemicals are recirculated several times and then injected into the combustion chamber.~~

~~*Catalytic flue-gas cleaning:* The catalytic flue-gas cleaning system is constructed as clean gas application with heat transfer system (gas/gas heat exchanger). It exclusively serves the function of NO_X reduction An aqueous solution of ammonia (25 %) is used as reducing agent. After the catalytic flue-gas cleaning system flue-gases are cooled in a heat exchanger. The heat is used for preheating water for the feed-water tank.~~

~~Using these cleaning steps emission levels shown in Table 8.87 are achieved.~~

~~**Table 8.87: Emissions to air from the waste incineration plant Arnoldstein (reference year: 2001)**~~

~~Parameter~~	~~Emission (mg Nm^{-3})~~ [a]	~~Total mass (kg yr^{-1})~~ [b, d]	~~Specific emissions (g t^{-1})~~ [c,d]
~~Dust~~ *	~~1.5~~	~~169.7~~	~~6.53~~
~~HCl~~	~~0.14~~	~~15.84~~	~~0.61~~
~~HF~~	~~0.038~~	~~4.3~~	~~0.16~~
~~SO_2~~ *	~~<5~~	~~566~~	~~21.8~~
~~C_{org}~~ *	~~<1~~	~~113~~	~~4.35~~
~~CO~~ *	~~<5~~	~~566~~	~~21.8~~
~~NO_X as NO_2~~ *	~~<150~~	~~16 970~~	~~653~~
~~Cd~~	~~0.003~~	~~0.34~~	~~0.013~~
~~Hg~~	~~0.003~~	~~0.34~~	~~0.013~~
~~PCDD+PCDF~~	~~0.022 ng Nm^{-3}~~	~~2.489 mg yr^{-1}~~	~~0.096 µg t^{-1}~~

~~* *Continuous measurement*~~

~~[a] *Half hourly average values in mg Nm^{-3}; dioxin emissions are given in ng Nm^{-3} (11 % O_2; dry flue-gas; standard conditions)*~~

~~[b] *In kg yr^{-1}, dioxin loads in mg yr^{-1}*~~

~~[c] *Emissions related to one tonne used waste in g t^{-1}; dioxin emissions in µg t^{-1}*~~

~~[d] *Total mass and specific emissions are calculated based on average half hourly mean values, using the quantity of dry flue-gas (5 388 Nm^3 t^{-1} waste; calculated from the hourly flue-gas volume of 15 500 Nm^3, the operating hours and the waste input) and the waste quantity (26 000 t yr^{-1}).*~~

~~**Waste water treatment and emissions to water**~~

~~Waste water from the fluidised bed reactors (13 000 m^3 yr^{-1} or 36 m^3 h^{-1}) and landfill leachate are cleaned in the waste water treatment plant. After cleaning using heavy metal precipitation, neutralisation and gypsum precipitation the waste water is released into the receiving water.~~

~~Using these cleaning steps emission levels shown in Table 8.88 are achieved.~~

~~Table 8.88: aste water parameters (composite sample) of the waste incineration plant Arnoldstein after waste water treatment (reference year: 2001)~~

~~Parameter~~	~~Measured value (mg l^{-1})~~
~~pH value~~	~~7.2~~
~~Filterable substances~~	~~7~~
~~As~~	~~<0.01~~
~~Cd~~	~~<0.05~~
~~Total Cr~~	~~<0.05~~
~~Cu~~	~~<0.05~~
~~Fluoride~~	~~8~~
~~Ni~~	~~0.06~~
~~Hg~~	~~<0.005~~
~~Pb~~	~~<0.1~~
~~Sb~~	~~<0.1~~
~~Sulphate (SO_4)~~	~~8 000~~
~~Zn~~	~~<0.5~~
~~Cyanides (easy releasable)~~	~~<0.1~~
~~NH_4 — N~~	~~127~~
~~TOC~~	~~25~~
~~Phenol~~	~~<0.1~~
~~EOX~~	~~<0.1~~

~~Waste~~

~~Wastes arising from the whole process (bed ash, fly ash, gypsum and filter cake) are mixed, exempted and disposed of on a landfill for residual waste. Occurring metal scrap is recycled.~~

~~Table 8.89: Chemical data of ash from the fluidised bed combustion of the waste incineration plant Arnoldstein (reference year: 2001)~~

~~Parameter~~	~~Measured value (mg kg^{-1}) (dry basis)~~	~~Limit value~~
~~Hg~~	~~<1~~	~~20/3 000~~
~~As~~	~~55~~	~~5 000~~
~~Pb~~	~~2550~~	~~10 000~~
~~Cd~~	~~20~~	~~5 000~~

~~Table 8.90: Concentration of pollutants in the eluate of ash from the waste incineration plant Arnoldstein (reference year: 2001)~~

~~Parameter~~	~~concentration~~		
	~~Limit value eluate (mg kg^{-1}) (dry basis)~~	~~Limit value concentrate (mg l^{-1}) (dry basis)~~	~~Measured value (mg kg^{-1}) (dry basis)~~
~~Residue on evaporation~~	~~100 000~~	~~30 000~~	~~46 000~~
~~pH value~~	~~6 - 13~~	~~2 - 11.5~~	~~10.2~~
~~Sb~~	~~50~~	~~5~~	~~1~~
~~As~~	~~50~~	~~5~~	~~<1~~
~~Pb~~	~~100~~	~~10~~	~~<1~~
~~Total Cr~~	~~300~~	~~30~~	~~<0.5~~
~~Cr (VI) as Cr~~	~~20~~	~~2~~	~~<0.2~~
~~Co~~	~~100~~	~~10~~	~~<0.5~~
~~Cu~~	~~100~~	~~10~~	~~<0.5~~
~~Ni~~	~~500~~	~~50~~	~~<0.5~~
~~Hg~~	~~0.5~~	~~0.05~~	~~<0.05~~
~~Tl~~	~~20~~	~~2~~	~~<0.5~~

~~Parameter~~	~~concentration~~		
	~~Limit value eluate (mg kg^{-1}) (dry basis)~~	~~Limit value concentrate (mg l^{-1}) (dry basis)~~	~~Measured value (mg kg^{-1}) (dry basis)~~
~~V~~	~~200~~	~~20~~	~~<1~~
~~Zn~~	~~1 000~~	~~100~~	~~<0.5~~
~~Sn~~	~~1 000~~	~~100~~	~~<1~~
~~F~~	~~500~~	~~50~~	~~55~~
~~Ammonia as N~~	~~10 000~~	~~1 000~~	~~825~~

~~8.3.4.3 Watercooled grate furnace with CHP, cyclone dedusting, SNCR and high dust SCR de-NO$_X$, and dry fabric filter~~

~~Capacity 175 000 t/yr~~
~~3 incineration lines, 2 with 12.5 t/h each and 1 with 15.5 t/h~~
~~reverse current furnace with reverse grate or with water-cooled feed grate~~
~~Incineration temperature 850 °C at a residence time of >2 seconds~~
~~Start-up: 1984, expansion: 1998 (line 3), modernization: 2000 (grate with water enclosure)~~

~~Reduction of emissions into the air~~

~~The waste gas cleaning system consists of the following components:~~

~~Line 1+2:~~
~~- Cyclone~~
~~- Evaporation cooler~~
~~- Current flow system with tissue filter~~
~~- DeNO$_X$ catalyser~~

~~Line 3: - SNCR~~
~~- Cyclone~~
~~- DeNO$_X$ catalyser (high dust)~~
~~- Evaporation cooler~~
~~- Current flow system with tissue filter~~

~~Waste gas quantity per line: 2 x 70 000 m^3/h~~
~~1 x 88 000 m^3/h~~
~~Manufacturer: Noell KRC GmbH~~

~~Special features: Waste gas recirculation behind multi-cyclone (branch current approximately 20 25 % of the waste gas quantity at 300 400 °C, economizer at 190 °C, injection into constriction between secondary incineration chamber and incineration chamber)~~

~~**Table 8.91: Average values measured in clean gas (operating values)**~~

~~Parameter~~	~~Measure~~	~~Daily average value~~ ~~Minimum~~	~~Daily average value~~ ~~Maximum~~	~~Annual average value~~ ~~(reference year 2000)~~	~~Portion in % (over the annual operation time)~~ ~~hav^1>lv^3~~	~~dav^2>lv~~
~~Continuous measurement~~						
~~Total dust~~	~~mg/m^3~~	~~0.04~~	~~15.15~~	~~0.45~~	~~0.0~~	~~0.0~~
~~HCl~~	~~mg/m^3~~	~~0.24~~	~~15.15~~	~~3.27~~	~~0.0~~	~~0.5~~
~~SO$_X$~~	~~mg/m^3~~	~~0.56~~	~~42.56~~	~~11.41~~	~~0.0~~	~~0.0~~
~~NO$_X$~~	~~g/m^3~~	~~15.42~~	~~249~~	~~166~~	~~0.0~~	~~2.2~~
~~Total C~~	~~mg/m^3~~	~~0.02~~	~~0.41~~	~~0.41~~	~~0.0~~	~~0.5~~

~~CO~~	~~mg/m^3~~	~~1.29~~	~~70.67~~	~~6.39~~	~~0.2~~	~~0.5~~
~~Hg^2~~	~~mg/m^3~~	~~0.00014~~	~~0.01717~~	~~0.00413~~	~~0.04~~	~~0.0~~
~~Periodical measurement (average value over sample taking period)~~						
~~HF~~	~~mg/m^3~~			~~<0.1~~		
~~Cd, Tl~~	~~mg/m^3~~			~~0.0017~~		
~~Σ Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn~~	~~mg/m^3~~			~~<0.01~~		
~~PCDD/F, I-TEQ~~	~~ng/m^3~~			~~0.0053~~		
~~^{1} hav – half-hour average value~~ ~~^{2} dav – daily average value~~ ~~^{3} lv – limit value~~						

~~**Table 8.92: Measuring devices used for continuous measuring**~~

~~**Toxic agent**~~	~~**Measuring device**~~
~~Dust~~	~~Sick RM 210~~
~~HCl~~	~~Perkin Elmer MCS 100 E~~
~~C_{total}~~	~~M&A Thermo FID~~
~~SO_2~~	~~Perkin Elmer MCS 100 E~~
~~NO_X~~	~~Perkin Elmer MCS 100 E~~
~~CO~~	~~Perkin Elmer MCS 100 E~~
~~Hg~~	~~Perkin Elmer ACE 100 Mercem~~
~~O_2 (secondary incineration)~~	~~Perkin Elmer MCS 100 E~~
~~Temperature (secondary incineration)~~	~~NiCr-Ni~~
~~Temperature (waste gas)~~	~~Sensycon PT 100~~

~~**Table 8.93: Deposition degrees in waste gas cleaning**~~

~~**Toxic agent**~~	~~**Concentration in (mg/m^3)**~~		~~**Deposition degree in %**~~
	~~**before cleaning**~~	~~**after cleaning**~~	
~~HCl~~	~~1 700~~	~~10~~	~~99.4~~
~~HF~~	~~10~~	~~1~~	~~90~~
~~SO_X~~	~~400~~	~~50~~	~~87.5~~
~~NO_X~~	~~400~~	~~200~~	~~50~~
~~Dust~~	~~800~~	~~10~~	~~98.7~~
~~Cd/Tl~~	~~5~~	~~0.05~~	~~99~~
~~Hg~~	~~1~~	~~0.05~~	~~95~~
~~Other heavy metals~~	~~100~~	~~0.5~~	~~99.5~~
~~PCDD/F (ng I-TEQ/m^3)~~	~~10~~	~~0.1~~	~~99~~

~~**Reduction of emissions into the water**~~

~~There is no waste water resulting from waste gas cleaning, as the plant uses the conditioned dry process.~~

~~**Energy utilization (reference year 1999)**~~
~~Heat generation/output~~
~~Heat generation in total: 115 000 MWh~~
~~Internal consumption: 50 000 MWh~~
~~Heat output, external: 65 000 MWh~~

~~Steam generation/output~~
~~Fresh steam production: 580 000 t/yr~~

~~Electric power generation/output~~
~~Electric power generation in total: 95 000 MWh~~

~~Internal consumption (additional supplies incl.): 23 100 MWh~~
~~Electric power output: 71 900 MWh~~

~~Table 8.94: Energy efficiency ratio (supposed average calorific value Hu ≈ 11500 kJ/kg)~~

		~~Energy in (MWh)~~		**~~Energy efficiency ratio in (%)~~**		
		~~El. power~~	**~~Heat~~**	**~~El. Power~~**	**~~Heat~~**	**~~Total~~**
~~Waste quantity combusted: approx. 174.100 t~~	**~~generated~~**	~~95 000~~	~~115 000~~	~~17~~ ~~22.7~~[1]	~~20.6~~ ~~27.5~~[1]	~~37.6~~ ~~50.2~~[1]
	~~released~~	~~71 900~~	~~65 000~~	~~12.9~~ ~~17.2~~[1]	~~11.7~~ ~~15.6~~[1]	~~24.6~~ ~~32.8~~[1]

[1] ~~Energy efficiency ratio taking into account a combustion efficiency ratio of 75 % of the energy input~~

~~Residues – slag~~

~~The contents of toxic agents are in the following ranges:~~

~~Table 8.95: Slag quality – BAT2~~

~~TOC~~	~~0.1 - 2 %~~
~~Loss on ignition~~	~~<3 %~~
~~PCDD/F~~	~~15 ng I-TEQ/kg~~
~~Cl^-~~	~~4 100 mg/kg~~
~~SO_4^{2-}~~	~~21 000 mg/kg~~
~~Fluoride~~	~~600 mg/kg~~
~~As~~	~~1 - 20 mg/kg~~
~~Cd~~	~~1 - 25 mg/kg~~
~~Cr~~	~~100 – 1 000 mg/kg~~
~~Cu~~	~~500 – 5 000 mg/kg~~
~~Hg~~	~~0.01 - 0.5 mg/kg~~
~~Ni~~	~~30 - 600 mg/kg~~
~~Pb~~	~~300 – 6 000 mg/kg~~
~~Zn~~	~~300 – 10 000 mg/kg~~

~~Noise emissions/immissions~~

~~Allowable immission values according to Item 2.321 TI Noise are observed on the prominent immission sites.~~

~~Costs~~

- ~~Investment costs incl. planning: 130 x10^6 DM~~
- ~~Specific treatment costs: 120 to 339 DM/t~~

~~8.3.4.4 Grate incinerator treating MSW, SS & CW with SNCR (urea), dry Na bicarbonate FGC, activated C injection and electricity generation~~

~~GENERAL information~~

~~The plant is owned and operated by Tecnoborgo S.p.A.: 51 % Tesa S.p.A. which is the district for Waste and water treatment - City of Piacenza and 49 % private company.~~

~~Notable are: High electricity selling price (CIP6 contract), Project financing~~

~~The waste treated are: municipal solid waste; sewage sludge - delivered as liquid (3 % solids) and dried on site; clinical waste - received in plastic and cardboard hard boxes~~

~~DESIGN/CONSTRUCTION DATA~~

- ~~combustion technique: Reverse-acting reciprocating grates, 2 x 8.5 t/h~~
- ~~plant capacity: design 136 000 t/yr; permit 105 000 t/yr; LCV range: 7 540 – 13 400 kJ/kg; nominal: 9 600 kJ/kg~~

- ~~design thermal input to the grate: 2 x 22.7 MW~~
- ~~steam boiler, 39 bar, 390 °C; horizontal design, 3 free vertical passes and 1 horizontal~~
- ~~energy valorisation: Electricity for export and internal use, steam for internal use only~~
- ~~turbo-generator: 11.5 MW~~
- ~~FGC system (Flue-gas Treatment): Dry process, with active carbon injection and SNCR.~~
- ~~SNCR de-NO_X (solid urea). Dedusting by 1 ESP 2 fields (Electrostatic Precipitator) + 1 BHF (Bag Filter). Dry scrubber with separate upstream injection of bicarb. De-diox by Active Carbon injection before the BHF~~
- ~~no waste water from the FGC. Waste water treatment (precipitation) and release to the sewer~~
- ~~bottom ash treatment: quenched scrap ferrous metals removal, landfilled~~
- ~~FGC solid residues: Fly ash and Reaction products (salts): landfilled~~
- ~~material valorisation: Ferrous metals recovered~~
- ~~start-up: 2002~~
- ~~complies fully with the WID 2000 (Waste Incin. Directive).~~

~~OPERATING DATA~~

- ~~year of reference (for the following data): 2003~~
- ~~waste throughput: 105 000 t/yr. Municipal solid waste 90.5 %, Industrial waste 8 %, Clinical waste 0.5 %, Sewage sludge 1 %~~
- ~~average LHV: 9 630kJ/kg~~
- ~~working hours including partial load hours (availability): 7530 h/yr~~
- ~~reagents consumption: Bicarb.: 15 kg/t // Urea: 2.2 kg/t // Activated carbon: 0.2 kg/t // Polyelectrolyte: 13.5 kg/tds~~
- ~~imported electricity: 203 300 kWh~~
- ~~electricity consumption: 8 775 000 kWh~~
- ~~electricity produced kWh, exported: 56 680 000 kWh~~
- ~~material recovery:. Ferrous metals: 2 %~~
- ~~material residues: Bottom ash to landfill: 21 % // Fly ash + Reaction Products: 2.9 %.~~

~~Continuous concentrations measurement in clean gas. Annual average/Max 24h/Max 1/2h (over the year), in mg/Nm^3:~~
~~Total dust: 1.2/1.3/0.8~~
~~HCl: 7.8/8.7/9.8~~
~~HF: 1.3/1.7~~
~~SO_X as SO_2: 3.2/5.3/48~~
~~TOC: 1.5/3.2/5.7~~
~~CO: 10/15/60~~
~~NO_X: 180/199/400~~

~~Average value of concentration samplings in clean gas (periodic measurement of substances listed in the WID 2000):~~
~~Cd + Tl: 0.000007 mg/Nm^3~~
~~Hg: 0.000026 mg/Nm^3~~
~~Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V+Sn: 0.0041 mg/Nm^3~~
~~PCDD/F: 0.004 ng_{iteq}/m^3~~

~~Concentration samplings in clean gas: (substances not listed in the WID 2000)~~
~~NH_3: 8.9 mg/Nm^3~~

~~Concentrations in clean waste water~~
~~Total suspended solids: 42 mg/l~~
~~Cd: <limit~~
~~Pb: 0.01 mg/l~~
~~Cr: 0.01 mg/l~~
~~Cu: 0.03 mg/l~~
~~Ni: 0.01 mg/l~~

~~Zn: 0.14 mg/l~~
~~pH value: 7.8~~

~~**ECONOMICS**~~

~~Investment costs: EUR 60 million (VAT excluded, value 2001)~~
~~Gate fee:EUR 92.1/t (includes Investment cost, operating cost, residue disposal, energy and materials revenue, VAT excluded, value 2004); EUR 276.4/t for clinical waste residues.~~

~~8.3.4.5 Grate incinerator treating MSW and industrial waste with EP, wet scrubbing, effluent evaporation, SCR and high pressure steam electricity generation~~

~~**GENERAL information**~~

~~The plant is owned by a private company, Azalys, and operated by Novergie for the Municipality of Carrierres sous Poissy, Yvelines, Ile-de-France.~~
~~Municipal solid waste & Industrial waste are treated~~

~~Of particular note are:~~

- ~~high steam characteristics~~
- ~~high energy efficiency~~
- ~~evaporation and crystallization of aqueous effluents~~
- ~~SCR de-NO_X and de-diox~~
- ~~project financing.~~

~~**DESIGN/CONSTRUCTION DATA**~~

- ~~combustion technique: Reciprocating grates, 2 x 7.5 t/h~~
- ~~plant capacity: 115 000 t/yr; nominal LCV: 10 260 kJ/kg~~
- ~~design thermal input to the grate: 2 x 21.4 MW~~
- ~~steam boiler, 46 bar, 365 °C; vertical design, 4 passes~~
- ~~energy valorisation: Electricity for export and internal use, steam for internal use only~~
- ~~turbo-generator: 9.3 MW~~
- ~~FGC system (Flue gas treatment): ESP, Wet scrubbers, Wet ESP, SCR, Evapo-Crystallisation.~~
- ~~dedusting by ESP. Wet scrubbers, 3 stages: lime milk/HCl, lime milk/ SO_X, venturi scrubber. De-diox and de-NO_X by SCR (low dust, 280 °C)~~
- ~~no aqueous effluents:~~
- ~~FGC effluents: waste water treatment (precipitation, flocculation, filtration) + onsite offline evaporation & crystallization (salt recovery),~~
- ~~other aqueous effluents are reused in the plant (FGC)~~
- ~~bottom ash: quenched, scrap ferrous metals removal, stored for ageing, recovered for road construction~~
- ~~FGC solid residues. Fly ash: mixed with cement and landfilled (Hazardous waste landfill). filter cake: mixed with fly ash and cement and landfilled (Haz. landfill). Reaction products (salts)~~
- ~~material valorisation: Bottom ash for road construction, Ferrous metals~~
- ~~start-up: 1998~~
- ~~complies with the emissions requirements of the WID-2000 since 7/1998, (Waste Incin. Directive).~~

~~**OPERATING DATA**~~

- ~~reference year (for the following data): 2003~~
- ~~waste throughput: 106 200 t/yr, 69 % municipal waste, 31 % industrial~~
- ~~average LHV: 11 390 kJ/kg~~
- ~~working hours (availability) including partial load hours: line 1: 8 102/8 760 hr; line 2: 6 500/8 760 (Stopped 3 month for works; availability: 8 000 hr)~~

- ~~reagents consumption: Lime: 3.8 kg/tw~~
- ~~energy input: Elec.: 9 500 MWh, i.e. 80 kWh/t of waste (the TG set was stopped too during the works) // steam for incineration process (de-aerator, soot blowing, …)~~
- ~~energy consumption: Elec.: 16 320 MWh, i.e. 153 kWh/tw of waste (including the imported 80 kWh/tw)~~
- ~~electricity output: generated: 501 kWh/tw/exported 353 kWh/tw~~
- ~~material recovery: Bottom ash for road construction: 23 600 t/yr // Ferrous metals: 289 t/yr~~
- ~~material residues: Fly ash: 2345 t/yr // Filter cake: 476 t/yr // Salts:1528 t/yr~~
- ~~max 24h Concentrations in clean gas (continuous measurement): HCl: <8 mg/Nm^3 // SO_X <15 mg/Nm^3 // TOC: <2 mg/Nm^3 // CO: <25 mg/Nm^3 // NO_X: <60 mg/Nm^3~~
- ~~average concentrations in clean gas (periodic measurement), 4 samplings: Cd: <0.009 mg/Nm^3 // Hg: <0.045 mg/Nm^3 // Sb: <0.009 mg/Nm^3 // As: <0.0015 mg/Nm^3 // Pb: <0.016 mg/Nm^3 // Cr: <0.09 mg/Nm^3 // Co: <0.0017 mg/Nm^3 // Cu: <0.0045 mg/Nm^3 // Mn: <0.012 mg/Nm^3 // Ni: <0.05 mg/Nm^3 // V: <0.0023 mg/Nm^3~~
- ~~PCDD/F (1 sampling)::0.07 ngiteq/ Nm^3.~~

~~8.3.4.6 Grate incinerator treating MW, IW, SS and waste sorting refuse with SNCR, EP, wet scrubbing (on-line evaporation of effluent), bag filters and CHP~~

~~GENERAL information~~

~~The plant is owned by a Municipal authority, Sidompe (122 municipalities, Ile-de-France, West of Paris), and operated by CNIM.~~

~~It treats Municipal waste, Industrial waste, Sorting refuse, Fresh (22 % dry) Sewage sludge~~

~~Of particular note are:~~

- ~~FGC without aqueous effluent~~
- ~~co-combustion of fresh sewage sludge with the waste~~
- ~~hot water boiler for feeding a DH network and a steam boiler for electricity generation.~~
- ~~the long history of the plant with successive upgrading~~
- ~~ISO 14001 since 1999~~
- ~~OHSAS 18001 (Safety & Hygiene, 2003).~~

~~DESIGN/CONSTRUCTION DATA~~

- ~~combustion technique: Reverse-acting Reciprocating grates, 2 x 10t/h + 1 x 14.7t/h~~
- ~~plant capacity: 240 000 t/yr; nominal LCV: 7 955 kJ/kg; range 1st & 2nd lines: 5 025 – 10 050 kJ/kg; range 3rd line: 5 025 – 10 470 kJ/kg~~
- ~~design thermal input to the grate: 2 x 22 MW + 1 x 32.6 MW~~
- ~~steam/hot water & Boiler design:~~
- ~~lines 1 & 2: hot water 37 bar, 220 °C; hot water boilers, vertical design, 2 passes~~
- ~~line 3: steam 42 bar 380 °C; steam boiler, vertical design, 4 passes~~
- ~~energy valorisation:~~
- ~~hot water (from lines 1 & 2) to D.H. network. Satisfy heat demand of 5 000 equivalent inhabitants~~
- ~~steam (from line 3) to TG set for export and internal use~~
- ~~turbo-generator: 7 MW (steam from line 3 only)~~
- ~~FGC system (Flue-gas Treatment): ESP, Wet scrubbers and upstream online evaporation, with active carbon injection in the upstream evaporator and in the wet scrubbers.~~
- ~~dedusting by 2 ESP 3 fields (lines 1 & 2) or 1 BHF (line 3). Wet scrubbers 2 stages: lime & NaOH. Double active carbon injection: before the 1st BHF and in the wet scrubber. SNCR, urea (in 2005)~~
- ~~no waste water from the FGC: (online evaporation of the aqueous effluents).~~
- ~~other aqueous effluents: Reuse in the plant + Waste water treatment (precipitation) and release to the sewer. In 2005 no reject at all~~

- ~~bottom ash: quenched, first removal of scrap ferrous metals on site. Offsite: second scrap ferrous metals removal, scrap non-ferrous removal, stored for ageing, recovered for road construction~~
- ~~FGC solid residues: Fly ash to landfill~~
- ~~material valorisation: Bottom ash for road construction, Ferrous and non-ferrous metals (offsite)~~
- ~~start-up (main phases): 1974 two grates, 1986 two hot water boilers, 1993 third line with its boiler + 3 FGC (wet without effluent), 2003 sewage sludge injection, 2004 de-diox, 2005 de-NO_X~~
- ~~complies with the WID 2000 (Waste Incin. Directive) emissions requirements since April 2004 except de-NO_X SCR to be started in 9/2005.~~

~~OPERATING DATA~~

- ~~reference year (for the following data): 2003~~
- ~~waste throughput 194 964 t/yr; 67 % municipal waste, 30 % industrial, 3 % s. sludge~~
- ~~average LHV: 9 610 kJ/kg~~
- ~~working hours (availability) including partial load hours L1: 7 854 h/yr, L2: 7 624 h/yr, L3: 7 662 h/yr~~
- ~~reagents consumption: Lime 508 t/yr, NaOH 71 t/yr, urea, active carbon, Fresh water: 162 000 m^3/yr~~
- ~~energy input: Electricity: 2 688 MWh (when line nr 3 is off)~~
- ~~electricity consumption: 19 GWh, including imported elec.~~
- ~~energy output: Electricity exported: 28 290 MWh // Heat exported: 66 710 MWh~~
- ~~material recovery: Bottom ash for road construction: 37 480 t/yr // Ferrous metals: 3 079 t/yr~~
- ~~material residues: Fly ash: 5 123 t/yr~~
- ~~concentrations in clean gas (continuous measurement) 'Annual average, plus maximum 1/2 hour average and max daily average:~~
- ~~HCl in mg/Nm^3: 0.4/<2.5/<5~~
- ~~CO in mg/Nm^3: 12.3/<30/<80~~
- ~~average Concentrations in clean gas (periodic measurement); 2 samplings:~~
- ~~Cd: <0.012 mg/Nm^3 // // Tl: <0.004 mg/Nm^3 // Cd + Tl: <0.016 mg/Nm^3 // Hg: <0.026 mg/Nm^3 // Sb: <0.014 mg/Nm^3 // As: <0.005 mg/Nm^3 // Pb: <0.061 mg/Nm^3 // Cr: <0.006 mg/Nm^3 // Co: <0.005 mg/Nm^3 // Cu: <0.021 mg/Nm^3 // Mn: <0.006 mg/Nm^3 // Ni: <0.006 mg/Nm^3 // V: <0.005 mg/Nm^3~~
- ~~Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V: 0.127 mg/Nm^3~~
- ~~PCDD/F (1 sampling): 0.036 ng iteq/Nm^3~~
- ~~concentrations in clean waste water (substances listed in the WID-2000):~~
- ~~total suspended solids: 9.4 mg/l // Hg: <0.002 mg/l // Cd: <0.01mg/l // As: <0.01mg/l// Pb: 0.09 mg/l// Cr: <0.05 mg/l // Cu: 0.14 mg/l // Ni: <0.05 mg/l // Zn: 0.16 mg/l~~
- ~~PCDD/F: 0.005 ng i-TEQ/l~~

~~8.3.4.7 Grate incinerator treating MSW, industrial and commercial waste with SNCR and semi-wet FGC and 20 bar 260 °C to district heating network~~

~~GENERAL information~~

~~The owner of the plant is the Sitdce (Syndicat Intercommunal de Traitement des Dechets de Colmar et Environ) Municipal authority (Final customer). The operator is SCCU (Societe Colmarienne de Chauffage Urbain)~~
~~Waste type: Municipal solid waste & Industrial and commercial waste~~
~~Of note for: Recovered energy sent entirely to the Colmar D.H. network (4 km piping)~~

~~DESIGN/CONSTRUCTION DATA~~

- ~~Combustion technique: Reverse-acting Reciprocating grate, 2 x 6 t/h~~

- ~~Plant Capacity: Nominal 78 000 t/yr. Effective: 80 to 82 000 t/yr. Design LCV range: 5 440 – 9 210 kJ/kg~~
- ~~Design thermal input to the grate: 2 x 14.5 MW~~
- ~~Steam Boiler: 20 bar, 260 °C, vertical design, with superheater & economiser~~
- ~~Energy valorisation: Heat only; steam sent to the heating plant, itself connected to the District Heating network~~
- ~~FGC system (Flue gas~~ Cleaning ~~Treatment): SNCR + semi-wet process + active carbon injection~~
- ~~Dedusting by BHF. Semi-wet scrubber with lime milk from hydrated lime. Active carbon injection before the scrubber. SNCR (solid urea)~~
- ~~Aqueous effluents: No aqueous effluent from FGC. Other aqueous effluents (bottom ash releases, boilers blowdown, ground and road cleaning): Waste water treatment (precipitation) and release to the sewer~~
- ~~Bottom ash: quenched, scrap ferrous and non-ferrous metals removal, recovered for road construction.~~
- ~~FGCsolid residues: Fly ash and Reaction products (salts) in hazardous waste landfill~~
- ~~Material valorisation: Bottom ash for road construction. Ferrous and non-ferrous metals recovered. Screening residue 0.4 % to landfill.~~
- ~~Start-up (main phases): 1988; FGC upgrading in 2002 (de-NO$_X$ + de-diox)~~
- ~~Complies with the WID-2000 emissions requirements since October 2002.~~

~~OPERATING DATA~~

- ~~reference year (for the following data) 2003~~
- ~~waste throughput: 80 400 t/yr; 70 % municipal waste, 10 % public direct supply, 18 % industrial and commercial waste~~
- ~~average LCV: 10 050 to 11 700 kJ/kg~~
- ~~working hours (availability) including partial load hours: line 1: 8 500 h/yr, line 2: 8 350 h/yr.~~
- ~~energy output: Exported heat:124 000 MWh~~
- ~~reagents consumption: Hydrated lime: 1 420 t/yr; Urea: 235 t/yr; Active carbon: 45 t/yr; Water: 59 000 m^3/yr~~
- ~~material recovery: Bottom ash for road construction: 14 800 t/yr; Ferrous metals: 2 450 t/yr; Non-Ferrous metals: 100 t/yr~~
- ~~material residues: Bottom ash to landfill: 200 t/yr; FGC residues: 3 350 t/yr~~
- ~~annual average concentrations in clean gas (continuous measurement):~~
- ~~Dust: 1.7 mg/Nm^3 // HCl: 6.8 mg/Nm^3 // HF: 0.1 mg/Nm^3 // SO$_X$: 9.5 mg/Nm^3 // COT: 1.9 mg/Nm^3 // CO: 15.4 mg/Nm^3 // NO$_X$: 178 mg/Nm^3~~
- ~~concentrations in clean gas (periodic measurement of substances listed in the WID-2000):~~
- ~~Cd: 0.0054 mg/Nm^3 // Tl: 0.0128 mg/Nm^3 // Cd+Tl: <0.019 mg/Nm^3 // Hg: 0.0014 mg/Nm^3 // Sb: 0.039 mg/Nm^3 // As: 0.029 mg/Nm^3 // Pb: 0.017 mg/Nm^3 // Cr: 0.016 mg/Nm^3 // Co: 0.005 mg/Nm^3 // Cu: 0.056 mg/Nm^3 // Mn: 0.01 mg/Nm^3 // Ni: 0.139 mg/Nm^3 // V: 0.009 mg/Nm^3~~
- ~~Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V: <0.28 mg/Nm^3~~
- ~~PCDD/F: 0.006 ngiteq/Nm^3~~
- ~~concentrations in clean gas (substances not listed in the WID-2000): NH$_3$: 7.3 mg/Nm^3~~
- ~~concentrations in clean waste water (substances listed in the WID-2000):~~
- ~~M.E.S.: 90 mg/l // Hg: <0.0001 mg/l // Cd: 0.012 mg/l // As: 0.003 mg/l // Pb: 0.137 mg/l // Cr: 0.044 mg/l // Cu: 0.41 mg/l // Ni: 0.05 mg/l // Zn: 0.46 mg/l~~
- ~~PCDD/F: <0.010 ngiteq/l.~~
- ~~clean waste water (not listed in the WID-2000): 5.5<pH<8.5~~

~~ECONOMICS~~

~~Investment costs: Plant 92 million French Francs, Connection to the heating plant 24 MFF (VAT excluded, 1986 value // In 2002, when euro replaced French Franc, EUR 1 = 6.55957 FRF) + Conformity with WID2000: EUR 6.3 million (VAT excluded, 2002 value).~~

~~8.3.4.8 Grate incinerator treating MSW, IW and clinical waste with SNCR, dry FGC and electricity generation~~

~~GENERAL information~~

~~The plant is owned by the Syndicat Inter Arrondissement de Valorisation et d'Elimination des Déchets (Siaved) for the Arrondissements de Denain et de Saint Amand~~
~~The Waste treated are Municipal solid waste, Sorting refuse, Industrial waste water and Clinical waste received in metal containers.~~

~~Notable for the co-combustion of the Clinical waste and the long history of the plant with successive upgrading, no material residues.~~

~~DESIGN/CONSTRUCTION DATA~~

- ~~combustion technique: Reverse-acting Reciprocating grates, 2 x 5.5 t/h~~
- ~~nominal capacity (permit): 88 000 t/yr~~
- ~~design LCV: nominal: 8 375 kJ/kg; range: 4 600 – 9 210 kJ/kg~~
- ~~thermal input to the grate: 2 x 12.8 MW~~
- ~~steam Boiler: 40 bar, 360 °C, vertical design, 3 passes~~
- ~~energy valorisation: Electricity for export and internal use, steam for internal use only.~~
- ~~turbo-generator: 6 MW~~
- ~~FGC system (Flue-gas Treatment): SNCR + Dry scrubbers+ Active carbon injection~~
- ~~dedusting by 1 ESP (1 field) and 1 BHF. Active carbon injection and bicarb. injection before the 2nd deduster (BHF). De-NO_X by SNCR (NH_3), 900 °C.~~
- ~~aqueous effluents: No waste water from the FGC. Internal industrial waste water evaporated in the furnace, sanitary water evacuated to the municipal waste water treatment, rainwater released to the river.~~
- ~~bottom ash: quenched, scrap ferrous metals removal, recovered for road construction.~~
- ~~material valorisation: Bottom ash: for road construction // Fly ash and Reaction products: recovery by underground storage // Ferrous metals // Non-ferrous metals.~~
- ~~start-up (main phases): 1976 Furnace building, 2000 Active carbon + bicarb., 2004 boiler + SNCR.~~
- ~~complies fully with the WID-2000 since 10/2004~~

~~OPERATING DATA~~

- ~~reference year (for the following data) Design/2004/2005 forecast~~
- ~~waste throughput: 88 000 t/yr, 80 % municipal waste, 15 % sorting refuse, 5 % clinical waste.~~
- ~~average LHV: 8 370 kJ/kg~~
- ~~working hours (availability) including partial load hours: 8 000 h/yr.~~
- ~~reagents consumption: Bicarb.: 28 kg/t, Ammonia NH_3: 3.1 kg/t, Activated carbon: 0.5 kg/t, Fresh water: 0.2 m^3/t~~
- ~~energy input: Petrol gas.~~
- ~~electricity consumption: 80 kWh/t~~
- ~~electricity generated: 530 kWh/t~~
- ~~material recovery:~~
- ~~bottom ash. Ratio 24 %. Recovered for road construction~~
- ~~fly ash, reaction products. Ratio: 28 kg/tw. Recovery by underground storage '~~
- ~~ferrous metals~~
- ~~non ferrous metals~~
- ~~material residues: none~~
- ~~concentrations in clean gas (continuous measurement)~~
- ~~Total dust: 3.27 mg/Nm^3 // HCl: 4.16 mg/Nm^3 // HF: 0.15 mg/Nm^3 // SO_X: 1.94 mg/Nm^3 // TOC: 1.10 mg/Nm^3 // CO: 18.81 mg/Nm^3 // NO_X: 137.54 mg/Nm^3 // NH_3: 30.28 mg/Nm^3~~
- ~~concentrations in clean gas (periodic measurement of substances listed in the WID-2000)~~

- ~~Cd: 0.0003 mg/Nm^3 // Tl: <0.0128 mg/Nm^3 // Hg: 0.0044 mg/Nm^3 // Sb: 0.0013 mg/Nm^3 // As: <0.0128 mg/Nm^3 // Pb: 0.0264 mg/Nm^3 // Cr: 0.0079 mg/Nm^3 // Co: <0.0128 mg/Nm^3 // Cu: 0.0025 mg/Nm^3 // Mn: 0.0232 mg/Nm^3 // Ni: <0.0130 mg/Nm^3 // V: <0.0128 mg/Nm^3 PCDD/F: 0.013 ngiteq/Nm^3.~~
- ~~Concentrations in clean gas (periodic measurement of substances not listed in the WID-2000): NH_3: 30.28 mg/Nm^3~~

~~**ECONOMICS**~~
~~Investment costs: EUR 20 million (for the boilers and SNCR upgrading phase).~~

~~8.3.4.9 Grate incinerator treating MSW, waste sorting residues and sludges with SNCR, dry FGC and heat supply to DH and local electricity plant~~

~~**GENERAL information**~~
~~The plant is owned by the Sivom of Metz for the City of Metz and operated by Haganis~~
~~Waste type: Municipal solid waste & sorting refuse + Sludges (65 % by gravity in the waste hoppers).~~
~~**DESIGN/CONSTRUCTION DATA**~~

- ~~combustion technique: Reciprocating grate, 2 x 8 t/h~~
- ~~capacity: 90 000 t/yr of waste & 18 000 t/yr of sludge~~
- ~~design LHV: 9 210 kJ/kg~~
- ~~design thermal input to the grate: 2 x 20.5 MW~~
- ~~steam Boiler: 24 bar, 325 °C, horizontal design, 3 vertical passes, 1 horizontal pass~~
- ~~energy valorisation: Steam exported to a District heating network and to the Electricity Plant of Metz~~
- ~~FGC system (Flue-gas Treatment): Dry process with active carbon injection~~
- ~~de-NO_X by Urea SNCR in the first pass of the boiler. Dry scrubbers before BHF. Dedusting by 2 BHF(Bag Filter). De-diox by active carbon injection~~
- ~~aqueous effluents: No aqueous effluents from the FGC. Continuous blow-down recycled towards the bottom ash extractor~~
- ~~bottom ash: quenched, scrap ferrous metals removal, scrap non-ferrous removal (eddy current machine), stored for ageing~~
- ~~FGC solid residues: Fly ash landfilled. Filter cake landfilled separately~~
- ~~material valorisation:~~
- ~~bottom ash for road construction~~
- ~~ferrous metals~~
- ~~non ferrous metals~~
- ~~residual sodium salts recycled~~
- ~~start-up whole plant: 2001~~
- ~~complies fully with the WID-2000 since 2001 (Waste Incin. Directive).~~

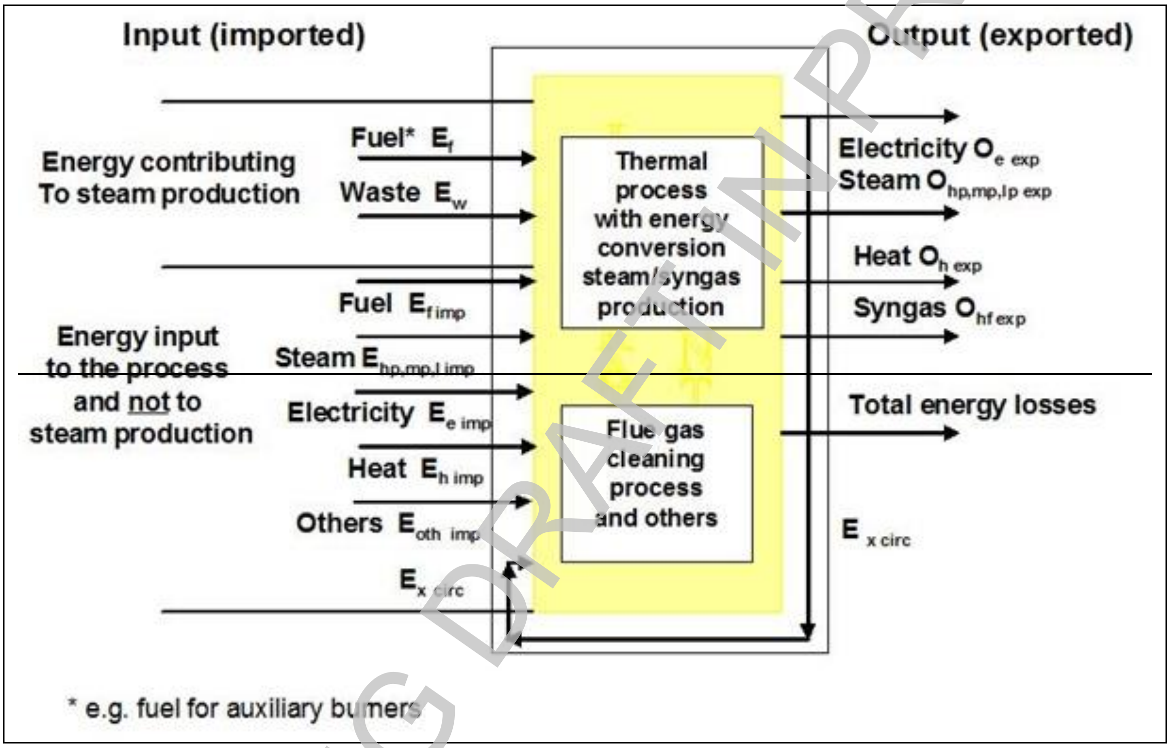
~~**OPERATING DATA**~~
~~Reagents: Bicarbonate of soda, active carbon, liquid urea (32 %).~~

~~8.4 Energy calculation methodology and example calculation~~

~~Data appear in this document that was calculated and compiled by members of the *Energy sub-group of the TWG (ESG)*. This annexe provides the calculation method that was developed and used by some of the members of this sub-group when compiling the data shown. It should be noted that there exist various methods for the calculation of energy efficiency, however it is anticipated that the provision of the method developed and used by the TWG sub-group may help reader to understand the basis for the figures derived by energy sub-group work.~~

~~8.4.1 General explanations of terms and system boundary of the energy calculation~~

~~For the purposes of the BREF the calculation was restricted to the waste 'incineration site'. The diagram below summarises the system inputs and outputs used by the BREF ESG:~~



~~**Figure 8.14: Summary of the energy system inputs and outputs used by BREF ESG**~~

~~The main energy flows in waste incinerators can be summarised as:~~

~~**a) Energy inputs (imported)**~~

- ~~only the energy input that is imported for the incineration process itself is included (see also d below). This will include, for example, the energy required for operation of a bulky waste shredder~~
- ~~energy required to operate, for example, a full RDF plant (whether on site or not) is (for the purposes of this calculation) outside the system boundary and should not be included in the calculation (however it should be noted that this may be very significant if a wider life cycle boundary calculation is attempted)~~
- ~~do not include energy required for waste collection, transportation and external pretreatment that is not necessary for the incineration process~~

- ~~other energy imported to the site is included as an input e.g. electricity, natural gas for flue-gas reheating and/or oil for auxiliary burners, as long as they are partly or totally used to cover the energy needed in the incineration process.~~

~~**b) Energy conversion**~~

~~This is the energy from wastes/fuels that is converted in the incinerator to another form (e.g. steam or syngas) for export or circulation.~~

~~**c) Energy outputs (exported)**~~

- ~~only the actual amount of energy exported is included (i.e. the gross production minus the energy circulated and consumed as losses to run the process itself)~~
- ~~auxiliary on-site energy usage such as lighting and heating for offices should only be taken into account in the efficiency calculation if these figures are available and if a very precise balance is wanted. Otherwise this influence is considered small and can be neglected~~
- ~~where energy is used on-site for another process (e.g. drying of sewage sludge or for running a district heating) this is counted as an output (export).~~

~~**d) Circulated energy as energy losses** (for explanation see figure above)~~

~~This is the energy that is generated by the process (e.g. steam/heat/electricity) that is then used in the process itself. This energy is not considered to count as a system input because it has not been imported from outside the system boundary. However, it is considered important that such circulation (if it is providing for energy losses) should be identified (as they substitute for imported energy) and should therefore be included in the check-list.~~

~~8.4.2 Example of LHV calculation used by energy sub-group~~

~~The data required for the calculation are generally available to incineration plant and are either measured or calculated from dimensioning figures such as steam parameters.~~

~~Method to calculate LHV of incinerated mono- and mixed waste~~

~~**c = (1.133 x ($m_{st\ w}$/m) x $c_{st\ x}$ + 0.008 x T_b)/1.085 (GJ/tonne)**~~

~~**c = lower (net) calorific value (LHV) of the incinerated waste with mst w /m ≥ 1 (GJ/tonne)**~~

~~**$m_{st\ w}$ = $m_{st\ x}$ - (m_f x(c_f/$c_{st\ x}$)x η_b)**~~

~~$m_{st\ w}$ = amount of the produced steam out of waste in the corresponding time period to $m_{st\ x}$ e.g. per year (tonne/y)~~
~~$m_{st\ x}$ =total amount of the produced steam in a defined time period e.g. per year (tonne/y)~~
~~m_f =amount of fuel with steam production (see E_f in checklist) in the corresponding time period to $m_{st\ x}$ e.g. per year (tonne/y)~~
~~m =amount of incinerated waste (see E_w in checklist) in a defined time period to $m_{st\ x}$ e.g. per year (tonne/y)~~
~~$c_{st\ x}$ = net enthalpy of steam (enthalpy of steam minus enthalpy of boiler water) (GJ/tonne) see e.g. VDI Steam Tables in general constant for every single plant~~
~~c_f = net calorific value of fuel with steam production see Table 1 (GJ/tonne)~~
~~T_b = temperature of flue-gas after boiler (at 4 – 12 % O_2 in flue-gas) (°C)~~
~~0.008 = spec. energy content in flue-gas (GJ/tonne x °C)~~
~~1.133 and 1.085 = constant figures by regression equation~~
~~ηb = efficiency of heat exchange (as approach 0.80)~~
~~Reference:~~
~~The basic equation for the calculation of LHV is taken from:~~
~~"Technology of Waste Incineration in Theory and Practice (Verbrennungstechnik von Abfällen in Theorie und Praxis)", 1995 ed. by Reimann, D.O.; Hämmerli, H;. and~~
~~VDI "Steam Tables", 1968 ed. by Schmidt,E.~~

~~**Example LHV calculation for an average MSW:**~~

~~Steam parameters 40 bar, 400 °C, $C_{st\ hp}$ = 3.217 GJ/tonne~~

~~boiler water 3.2 bar, 135 °C $C_{st\ bw}$ = 0.565 GJ/tonne~~

~~(constant for this W-t-E plant) $C_{st\ x}$ = 2.652 GJ/tonne~~

~~$m_{st\ hp}$ = 404 623 (tonne of HP steam)~~
~~m_f = 95.875 (tonne of fuel) (light oil)~~
~~C_f = 42.73 GJ/tonne~~
~~η_b = efficiency of heat exchange (as approach 0.80)~~

~~$m_{st\ w}$ = $m_{st\ hp}$ - (m_f x (c_f/$c_{st\ x}$) x 0.80)~~
~~= 404 623 - (95.875 (tonne)x (42.73/ 2.652) x 0.80) = 404 623 - 1236 = 403 387 (tonne)~~
~~m = 126 692 tonne of mixed municipal solid waste (MSW)~~
~~T_b = 220 °C (at 6 – 11 % O_2 in flue-gas)~~
~~C = (1.133 x ($m_{st\ w}$/m x $c_{st\ x}$) + 0.008 x T_b)/1.085~~
~~C = (1.133 x (403387/126692) x 2.652) + 0.008 x 220)/ 1.085 = (9.567 +1.760)/1.085~~

~~**LHV = C = 10440 GJ/ tonne = 2900 MWh/tonne as average of mixed MSW**~~

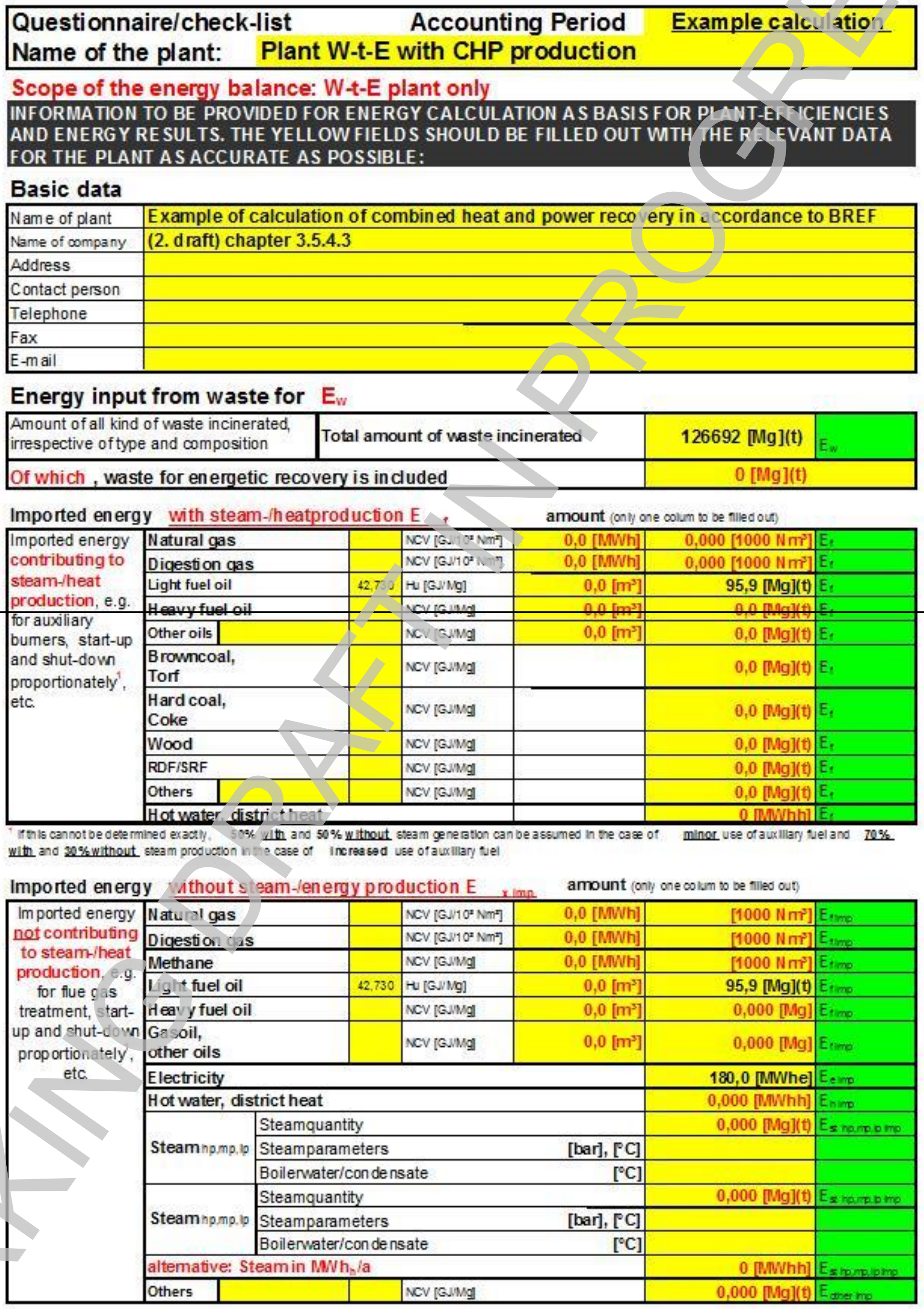
~~8.4.3 Basic operational data for three examples of the energy calculation~~

~~Annual basic operational data and figures may be collected using check-list shown below.~~

~~The check-list shown includes the data for the example of CHP production and export. Instead of generating an individual list for operational basic data of a plant the use of a standard~~

~~checklist will deliver higher accuracy and reduce the risk of forgetting data to be taken into account for the energy calculation method.~~

~~**Table 8.96: Energy efficiency calculation data checklist 1**~~



Questionnaire/check-list		Accounting Period	Example calculation
Name of the plant:	Plant W-t-E with CHP production		

Scope of the energy balance: W-t-E plant only

INFORMATION TO BE PROVIDED FOR ENERGY CALCULATION AS BASIS FOR PLANT-EFFICIENCIES AND ENERGY RESULTS. THE YELLOW FIELDS SHOULD BE FILLED OUT WITH THE RELEVANT DATA FOR THE PLANT AS ACCURATE AS POSSIBLE:

Basic data

Name of plant	Example of calculation of combined heat and power recovery in accordance to BREF
Name of company	(2. draft) chapter 3.5.4.3
Address	
Contact person	
Telephone	
Fax	
E-mail	

Energy input from waste for E_w

Amount of all kind of waste incinerated, irrespective of type and composition	Total amount of waste incinerated	126692 [Mg](t)	E_w
Of which , waste for energetic recovery is included		0 [Mg](t)	

Imported energy with steam-/heatproduction E_f amount (only one colum to be filled out)

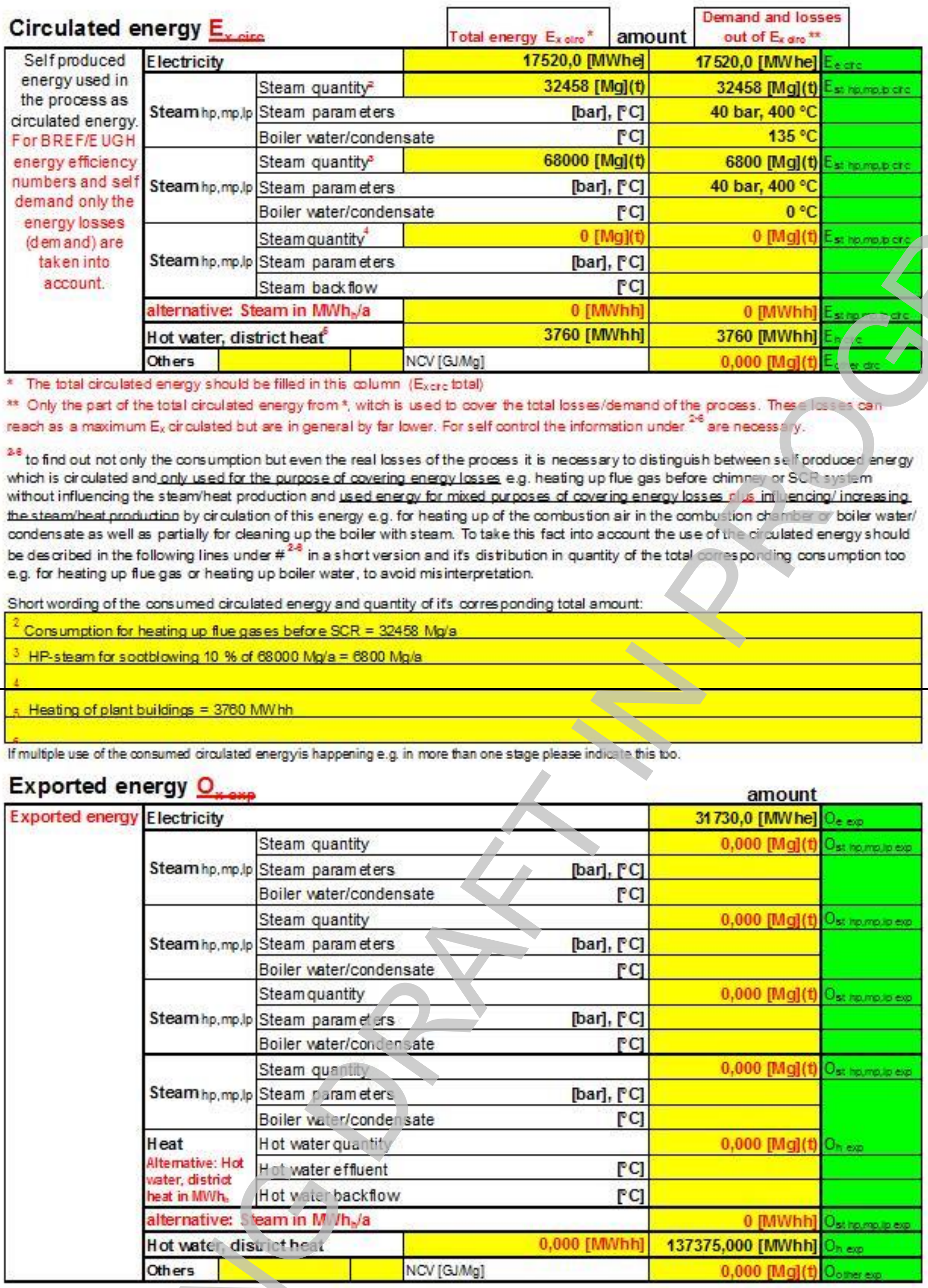
Imported energy contributing to steam-/heat production, e.g. for auxiliary burners, start-up and shut-down proportionately[1], etc.	Natural gas		NCV [GJ/10³ Nm³]	0,0 [MWh]	0,000 [1000 Nm³]	E_f
	Digestion gas		NCV [GJ/10³ Nm³]	0,0 [MWh]	0,000 [1000 Nm³]	E_f
	Light fuel oil	42,730	Hu [GJ/Mg]	0,0 [m³]	95,9 [Mg](t)	E_f
	Heavy fuel oil		NCV [GJ/Mg]	0,0 [m³]	0,0 [Mg](t)	E_f
	Other oils		NCV [GJ/Mg]	0,0 [m³]	0,0 [Mg](t)	E_f
	Browncoal, Torf		NCV [GJ/Mg]		0,0 [Mg](t)	E_f
	Hard coal, Coke		NCV [GJ/Mg]		0,0 [Mg](t)	E_f
	Wood		NCV [GJ/Mg]		0,0 [Mg](t)	E_f
	RDF/SRF		NCV [GJ/Mg]		0,0 [Mg](t)	E_f
	Others		NCV [GJ/Mg]		0,0 [Mg](t)	E_f
	Hot water, district heat				0 [MWhh]	E_f

[1] If this cannot be determined exactly, 50% with and 50% without steam generation can be assumed in the case of minor use of auxiliary fuel and 70% with and 30% without steam production in the case of increased use of auxiliary fuel

Imported energy without steam-/energy production $E_{x\ imp}$ amount (only one colum to be filled out)

Imported energy not contributing to steam-/heat production, e.g. for flue gas treatment, start-up and shut-down proportionately[1], etc.	Natural gas		NCV [GJ/10³ Nm³]	0,0 [MWh]	[1000 Nm³]	$E_{f\ imp}$
	Digestion gas		NCV [GJ/10³ Nm³]	0,0 [MWh]	[1000 Nm³]	$E_{f\ imp}$
	Methane		NCV [GJ/Mg]	0,0 [MWh]	[1000 Nm³]	$E_{f\ imp}$
	Light fuel oil	42,730	Hu [GJ/Mg]	0,0 [m³]	95,9 [Mg](t)	$E_{f\ imp}$
	Heavy fuel oil		NCV [GJ/Mg]	0,0 [m³]	0,000 [Mg]	$E_{f\ imp}$
	Gasoil, other oils		NCV [GJ/Mg]	0,0 [m³]	0,000 [Mg]	$E_{f\ imp}$
	Electricity				180,0 [MWhe]	$E_{e\ imp}$
	Hot water, district heat				0,000 [MWhh]	$E_{h\ imp}$
	$Steam_{hp,mp,lp}$	Steamquantity			0,000 [Mg](t)	$E_{st\ hp,mp,lp\ imp}$
		Steamparameters	[bar], [°C]			
		Boilerwater/condensate	[°C]			
	$Steam_{hp,mp,lp}$	Steamquantity			0,000 [Mg](t)	$E_{st\ hp,mp,lp\ imp}$
		Steamparameters	[bar], [°C]			
		Boilerwater/condensate	[°C]			
	alternative: Steam in MWh_h/a				0 [MWhh]	$E_{st\ hp,mp,lp\ imp}$
	Others		NCV [GJ/Mg]		0,000 [Mg](t)	$E_{other\ imp}$

~~**Table 8.97: Energy efficiency calculation data checklist 2**~~



Circulated energy $E_{x\ circ}$

			Total energy $E_{x\ circ}$ *	amount Demand and losses out of $E_{x\ circ}$ **	
Self produced energy used in the process as circulated energy. For BREF/EUGH energy efficiency numbers and self demand only the energy losses (demand) are taken into account.	Electricity		17520,0 [MWhe]	17 520,0 [MWhe]	$E_{e\ circ}$
	Steam hp,mp,lp	Steam quantity^{2}	32458 [Mg](t)	32458 [Mg](t)	$E_{st\ hp,mp,lp\ circ}$
		Steam parameters	[bar], [°C]	40 bar, 400 °C	
		Boiler water/condensate	[°C]	135 °C	
	Steam hp,mp,lp	Steam quantity^{3}	68000 [Mg](t)	6800 [Mg](t)	$E_{st\ hp,mp,lp\ circ}$
		Steam parameters	[bar], [°C]	40 bar, 400 °C	
		Boiler water/condensate	[°C]	0 °C	
	Steam hp,mp,lp	Steam quantity^{4}	0 [Mg](t)	0 [Mg](t)	$E_{st\ hp,mp,lp\ circ}$
		Steam parameters	[bar], [°C]		
		Steam backflow	[°C]		
	alternative: Steam in MWh_h/a		0 [MWhh]	0 [MWhh]	$E_{st\ hp,mp,lp\ circ}$
	Hot water, district heat^{5}		3760 [MWhh]	3760 [MWhh]	$E_{h\ circ}$
	Others		NCV [GJ/Mg]	0,000 [Mg](t)	$E_{other\ circ}$

* The total circulated energy should be filled in this column ($E_{x\ circ}$ total)

** Only the part of the total circulated energy from *, witch is used to cover the total losses/demand of the process. These losses can reach as a maximum E_x circulated but are in general by far lower. For self control the information under $^{2-6}$ are necessary.

$^{2-6}$ to find out not only the consumption but even the real losses of the process it is necessary to distinguish between self produced energy which is circulated and only used for the purpose of covering energy losses e.g. heating up flue gas before chimney or SCR system without influencing the steam/heat production and used energy for mixed purposes of covering energy losses plus influencing/ increasing the steam/heat production by circulation of this energy e.g. for heating up of the combustion air in the combustion chamber or boiler water/ condensate as well as partially for cleaning up the boiler with steam. To take this fact into account the use of the circulated energy should be described in the following lines under # $^{2-6}$ in a short version and it's distribution in quantity of the total corresponding consumption too e.g. for heating up flue gas or heating up boiler water, to avoid misinterpretation.

Short wording of the consumed circulated energy and quantity of it's corresponding total amount:

^{2} Consumption for heating up flue gases before SCR = 32458 Mg/a

^{3} HP-steam for sootblowing 10 % of 68000 Mg/a = 6800 Mg/a

^{4}

^{5} Heating of plant buildings = 3760 MWhh

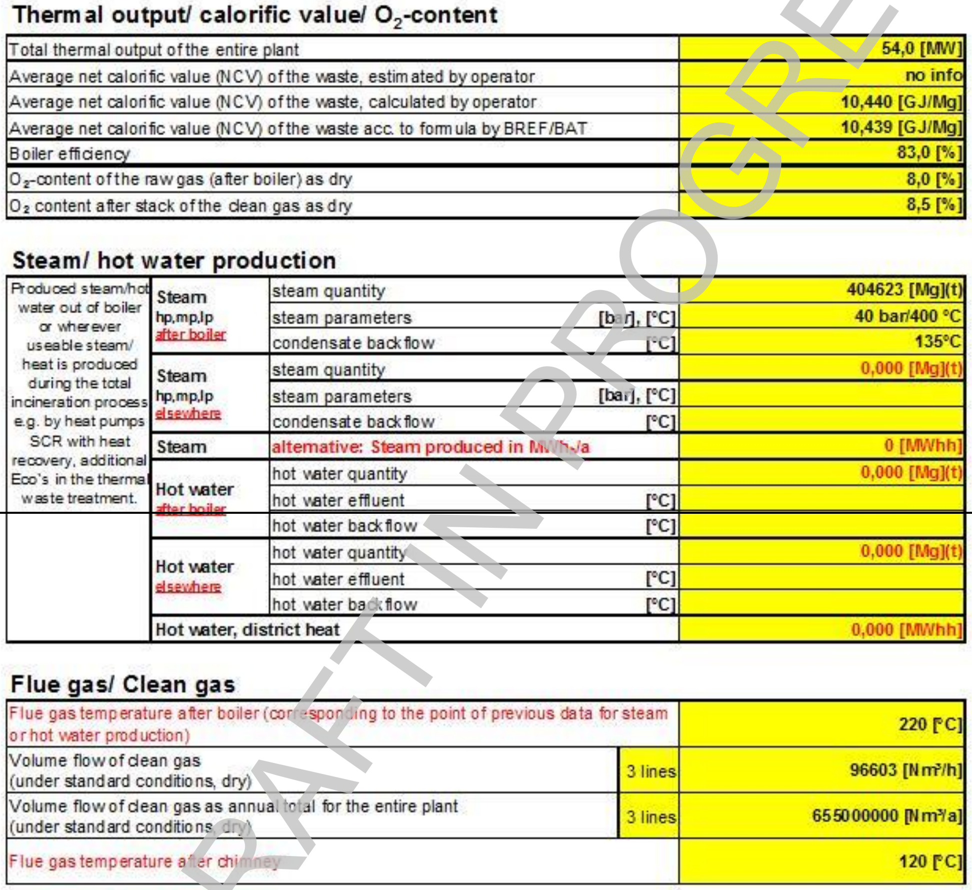
^{6}

If multiple use of the consumed circulated energyis happening e.g. in more than one stage please indicate this too.

Exported energy $O_{x\ exp}$

				amount	
Exported energy	Electricity			31 730,0 [MWhe]	$O_{e\ exp}$
	Steam hp,mp,lp	Steam quantity		0,000 [Mg](t)	$O_{st\ hp,mp,lp\ exp}$
		Steam parameters	[bar], [°C]		
		Boiler water/condensate	[°C]		
	Steam hp,mp,lp	Steam quantity		0,000 [Mg](t)	$O_{st\ hp,mp,lp\ exp}$
		Steam parameters	[bar], [°C]		
		Boiler water/condensate	[°C]		
	Steam hp,mp,lp	Steam quantity		0,000 [Mg](t)	$O_{st\ hp,mp,lp\ exp}$
		Steam parameters	[bar], [°C]		
		Boiler water/condensate	[°C]		
	Steam hp,mp,lp	Steam quantity		0,000 [Mg](t)	$O_{st\ hp,mp,lp\ exp}$
		Steam parameters	[bar], [°C]		
		Boiler water/condensate	[°C]		
	Heat Alternative: Hot water, district heat in MWh_h	Hot water quantity		0,000 [Mg](t)	$O_{h\ exp}$
		Hot water effluent	[°C]		
		Hot water backflow	[°C]		
	alternative: Steam in MWh_h/a			0 [MWhh]	$O_{st\ hp,mp,lp\ exp}$
	Hot water, district heat		0,000 [MWhh]	137375,000 [MWhh]	$O_{h\ exp}$
	Others		NCV [GJ/Mg]	0,000 [Mg](t)	$O_{other\ exp}$

~~Table 8.98: Energy efficiency calculation data checklist 3~~



Thermal output/ calorific value/ O_2-content

Total thermal output of the entire plant	54,0 [MW]
Average net calorific value (NCV) of the waste, estimated by operator	no info
Average net calorific value (NCV) of the waste, calculated by operator	10,440 [GJ/Mg]
Average net calorific value (NCV) of the waste acc. to formula by BREF/BAT	10,439 [GJ/Mg]
Boiler efficiency	83,0 [%]
O_2-content of the raw gas (after boiler) as dry	8,0 [%]
O_2 content after stack of the clean gas as dry	8,5 [%]

Steam/ hot water production

Produced steam/hot water out of boiler or wherever useable steam/ heat is produced during the total incineration process e.g. by heat pumps SCR with heat recovery, additional Eco's in the thermal waste treatment.	Steam hp,mp,lp after boiler	steam quantity		404623 [Mg](t)
		steam parameters	[bar], [°C]	40 bar/400 °C
		condensate back flow	[°C]	135°C
	Steam hp,mp,lp elsewhere	steam quantity		0,000 [Mg](t)
		steam parameters	[bar], [°C]	
		condensate back flow	[°C]	
	Steam	alternative: Steam produced in MWh/a		0 [MWhh]
	Hot water after boiler	hot water quantity		0,000 [Mg](t)
		hot water effluent	[°C]	
		hot water back flow	[°C]	
	Hot water elsewhere	hot water quantity		0,000 [Mg](t)
		hot water effluent	[°C]	
		hot water back flow	[°C]	
	Hot water, district heat			0,000 [MWhh]

Flue gas/ Clean gas

Flue gas temperature after boiler (corresponding to the point of previous data for steam or hot water production)		220 [°C]
Volume flow of clean gas (under standard conditions, dry)	3 lines	96603 [Nm³/h]
Volume flow of clean gas as annual total for the entire plant (under standard conditions, dry)	3 lines	655000000 [Nm³/a]
Flue gas temperature after chimney		120 [°C]

~~8.4.4 Energy calculation formulas with basic operational data for three examples of the energy calculation~~

~~The annual basic operational figures and data are the basis for the calculation of specific energy results and percentage efficiencies.~~

~~For the purpose of aggregation of data relating to the consumption/production/export of different sources of energy, reference has been made to GJ. However, more commonly electrical~~

~~energy is reported as MWh_e, and steam, heat and hot water as $MWh_{h/st}$, therefore the examples are calculated with this unit.~~

~~To enable the comparison between different incineration plants in an easy and reliable way, simple formulas are adopted, all based on annual balances. Where used, international equivalency factors have been considered for energy conversions to obtain energy balances.~~

~~**Method 1:** Net annual specific (i.e. per tonne of waste treated) energy needed for and recovered by the installation, expressed as absolute and equivalent energy figures (N), in correlation to the quantity of incinerated waste (investigation period one year)~~

~~The specific value for the amount of energy produced, exported or needed per tonne of waste input is obtained simply by dividing the annual data by the waste throughput. The result delivers specific information for the considered plant because the LHV of waste itself is not taken into account.~~
~~This technique uses annual totals to calculate separate figures for:~~

- ~~total specific energy demand of the entire plant per tonne of waste input Nop sp~~
- ~~total specific electrical energy production/export per tonne of waste input Ne sp prod/exp~~
- ~~total specific heat and steam production/export per tonne of waste input Nh/st sp prod/exp~~
- ~~total specific electrical energy and heat/steam production/export of the entire plant~~
- ~~per tonne of waste input Ne+h/st sp prod/exp~~

~~**Method 2:** Percentage yield (η)~~
~~This method calculates the overall percentage of energy needed for and recovered by the installation in relation to the steam producing energy inputs from the waste, as well as other energy inputs (e.g. support fuels) i.e. in relation to the total energy input into the plant.~~

~~Because the energy content of the waste input is included, an advantage of this method is that comparison is possible between incineration plants, independent of the waste type. This calculation method is widespread and the results are generally well understood. If the LHV of the waste is not known, it can be obtained from knowledge of the produced steam.~~

~~In this method, separate efficiency values are calculated for electricity and heat production/consumption using absolute figures as well as energy equivalents. These figures may be added together to give a total efficiency figure.~~

~~This technique uses annual totals for the entire plant to calculate separate figures for:~~

- ~~percentage of energy demand of the entire plant in relation to the total energy input~~ $\eta_{op\ sp}$
- ~~percentage of electrical energy production/export in relation to the total energy input~~ $\eta_{e\ sp\ prod/exp}$
- ~~percentage of heat and steam production/export in relation to the total energy input~~ $\eta_{h/st\ sp\ prod/exp}$
- ~~percentage of electrical energy and heat/steam production/export of in relation to the total energy input~~ $\eta_{e+h/st\ sp\ prod/exp}$

~~The basic equations are:~~

~~**a) in absolute figures**~~
~~In this case all data even for electricity and heat must be counted not as equivalents but as measured figures e.g.~~ MWh_e ~~and~~ MWH_h ~~or in~~ GJ_e ~~and~~ GJ_h ~~all others with their energy content~~

~~**b) in equivalent figures**~~
~~Here all data for electricity and heat must be counted as equivalents e.g.~~ $MWh_{e\ equ}$ ~~and~~ $MWH_{h\ equ}$ ~~all others with their energy content~~

~~Specific energy demand of the entire plant in correlation to the quantity of waste incinerated:~~

~~$N_{op\ sp}$ = (E_f + $E_{x\ imp}$ + $E_{x\ circ}$)/ m~~

~~a) as $MWh_{op\ abs}$/t (of waste) or $GJ_{op\ abs}$/t (of waste)~~
~~b) as $MWh_{op\ equ}$/t (of waste) or $GJ_{op\ equ}$/t (of waste)~~

~~Examples for specific energy demand in relation to the basis data of Table 1 in section 3 and Chapter 3.5.5 of the BREF~~

~~a) plant with only electricity production (in absolute) $N_{op\ sp}$= (1 138+ 1 318 + 51 269)/ 126 692 = 0.424MWh abs/t~~
~~b) plant with only electricity production (in equivalent) $N_{op\ sp}$ = (1 138+ 1 612 + 80 226)/ 126 692 =0.655MWh equ/t~~

~~a) plant with only heat/steam production (in absolute) $N_{op\ sp}$= (1 138+18 838 +33 749)/ 126 692 = 0.424 MWh abs/t~~
~~b) plant with only heat/steam production (in equivalent) $N_{op\ sp}$ = (1 138+47 717 +34 121)/ 126 692 = 0.655 MWh equ/t~~

~~a) plant with CHP (in absolute) $N_{op\ sp}$ = (1 138+ 1 318 + 51 269)/ 126 692 = 0.424 MWh abs/t~~
~~b) plant with CHP (in equivalent) $N_{op\ sp}$ = (1 138+ 1 612 + 80 226)/ 126 692 = 0.655 MWh equ/t~~

~~Percentage of total specific energy demand of the entire plant in correlation to the total energy input~~

~~$\eta_{op\ abs}$ = ((E_f + $E_{x\ imp}$ + $E_{x\ circ}$)/(E_f + $E_{x\ imp}$ + E_w)) x 100 {%}~~

~~Examples for percentages of energy demand in connection with the basis data of Table 1 in section 3.~~

~~a) plant with only electricity production (in absolute) $\eta_{op\ abs}$ = ((1 138+ 1 318 + 51 269)/ (1 138+ 1 318+367 406))*100 = 14.5 (%)~~
~~b) plant with only electricity production (in equivalent) $\eta_{op\ equ}$ = (1 138+ 1 612 + 80 226)/ (1 138+ 1 612+367 406))*100 = 22.4 (%)~~

~~a) plant with only heat/steam production (in absolute) $\eta_{op\ abs}$ = (1 138+18 838 +33 749)/ (1 138+ 1 318+367 406))*100 = 13.9 (%)~~
~~b) plant with only heat/steam production (in equivalent) $\eta_{op\ equ}$ = (1 138+47 717 +34 121)/ (1 138+ 1 612+367 406))*100 = 19.9(%)~~

~~a) plant with CHP (in absolute) $\eta_{op\ abs}$ = (1 138+ 1 318 + 51 269)/ (1 138+ 1 318+367 406))*100 = 14.5 (%)~~
~~b) plant with CHP (in equivalent) $\eta_{op\ equ}$ = (1 138+ 1 612 + 80 226)/ (1 138+ 1 612+367 406))*100 = 22.4 (%)~~

~~Total specific electricity produced in correlation to the quantity of waste incinerated:~~

~~$N_{e\ sp\ prod}$ = ($O_{e\ exp}$ + $E_{e\ circ}$)/ m~~

~~Total specific electricity exported in correlation to the quantity of waste incinerated:~~

~~$N_{e\ sp\ exp}$ = ($O_{e\ exp}$)/ m~~

~~a) as $MWh_{op\ abs}$/t (of waste) or $GJ_{op\ abs}$/t (of waste)~~
~~b) as $MWh_{op\ equ}$/t (of waste) or $GJ_{op\ equ}$/t (of waste)~~

~~Examples for specific electricity produced and exported:~~

~~a) plant with only electricity production (in absolute) $N_{e\ sp\ prod}$ = (17 520+50 800)/ 126 692= 0.539 MWh_e abs/t~~
~~$N_{e\ exp}$ = (50 800)/ 126 692 = 0.401 MWh_e abs/t~~
~~b) plant with only electricity production (in equivalent) $N_{e\ sp\ prod}$ = ((17 520 +50 800)*2.6316)/ 126 692 =1.419 MWh_e equ/t~~
~~$N_{e\ exp}$ = (50 800*2.6316)/ 126 692 = 1.055 MWh_e equ /t~~

~~a) plant with only heat/steam production (in absolute) $N_{e\ sp\ prod}$ = (0)/ 126 692 =0.0 MWh_e abs/t~~
~~$N_{e\ exp}$ = (0)/ 126 692 =0.0 MWh_e abs/t~~
~~b) plant with only heat/steam production (in equivalent) $N_{e\ sp\ prod}$ = (0)/ 126 692 =0.0 MWh_e equ /t~~
~~$N_{e\ exp}$ = (0)/ 126 692 =0.0 MWh_e equ /t~~

~~a) plant with CHP (in absolute) $N_{e\ sp\ prod}$ = (17 520+31 730)/ 126 692 =0.389 MWh_e abs/t~~
~~$N_{e\ exp}$ = (31 730)/ 126 692 =0.250 MWh_e abs/t~~
~~b) plant with CHP (in equivalent) $N_{e\ sp\ prod}$ = ((17 520 +31 730)*2.6316)/ 126692=1.023 MWh_e equ /t~~
~~$N_{e\ exp}$ = (31 730*2.6316)/ 126 692 =0.659 MWh_e equ /t~~

~~Percentage of total electricity produced and exported in correlation to the total energy input:~~

~~$\eta_{e\ abs} = ((O_e + E_{e\ circ})/(E_f + E_{x\ imp} + E_w)) \times 100$ {%}~~

~~Examples for percentages of electricity produced and exported:~~

~~a) plant with only electricity production (in absolute) $\eta_{e\ abs\ prod}$ = (17 520+50 800)/ (1 138+ 1 318+367 406))*100 =18.5 (%)~~
~~$\eta_{e\ abs\ exp}$ = (50 800)/ (1 138+ 1 318+367 406)*100 =13.7 (%)~~
~~b) plant with only electricity production (in equivalent) $\eta_{e\ equ\ prod}$ = ((17 520 +50 800)*2.6316)/ (1 138+ 1 612+367 406))*100 =48.6 (%)~~
~~$\eta_{e\ equ\ exp}$ = (50 800*2.6316)/ (1 138+ 1 612+367 406))*100 =36.1 (%)~~

~~a) plant with only heat/steam production (in absolute) $\eta_{e\ abs\ prod}$ = (0)/ (1 138+ 1 318+367 406))*100 =0 (%)~~
~~$\eta_{e\ abs\ exp}$ = (0)/ (1 138+ 1 318+367 406))*100 = (%)~~
~~b) plant with only heat/steam production (in equivalent) $\eta_{e\ equ\ prod}$ = (0)/ (1 138+ 1 612+367 406))*100 =0 (%)~~
~~$\eta_{e\ equ\ exp}$ = (0)/ (1 138+ 1 612+367 406))*100 =0 (%)~~

~~a) plant with CHP (in absolute) $\eta_{e\ abs\ prod}$ = (17 520+31 730)/ (1 138+ 1 318+367 406))*100 =13.3 (%)~~
~~$\eta_{e\ abs\ exp}$ = (31 730)/ (1 138+ 1 318+367 406))*100 =8.8 (%)~~

~~b) plant with CHP (in equivalent) $\eta_{e\ equ\ prod}$ = ((17 520 +31 730)*2.6316)/ (1 138+ 1 612+367 406))*100 = 35.0 (%)~~
~~$\eta_{e\ equ\ exp}$ = (31 730*2.6316)/ (1 138+ 1 612+367 406))*100 = 22.6 (%)~~

~~Total specific heat/steam produced in correlation to the quantity of waste incinerated:~~

~~$N_{h/st\ sp\ prod} = (O_{h/st\ exp} + E_{h/st\ circ})/ m$~~

~~Total specific heat/steam exported in correlation to the quantity of waste incinerated:~~

~~$N_{h/st\ sp\ exp} = (O_{h/st\ exp})/ m$~~

~~a) as $MWh_{op\ abs}$/t (of waste) or $GJ_{op\ abs}$/t (of waste)~~
~~b) as $MWh_{op\ equ}$/t (of waste) or $GJ_{op\ equ}$/t (of waste))~~

~~Examples for specific heat/steam produced and exported:~~

~~a) plant with only electricity production (in absolute) Nh/st sp prod = (33 749+0)/ 12 669 =0.266 MWhh/st abs/t~~
~~Nh/st exp = (0)/ 126 692 =0.0 MWhh/st abs/t~~
~~b) plant with only electricity production (in equivalent) Nh/st sp prod = (34 121+0)/ 126 692 =0.269 MWhh/st equ/t~~
~~Nh/st exp = (0)/ 126 692 =0.0 MWhh/st equ /t~~

~~a) plant with only heat/steam production (in absolute) Nh/st sp prod = (33 749+242 443)/ 126 692 =2.180 MWhh/st abs/t~~
~~Nh/st exp = (242 443)/ 126 692 =1.914 MWhh/st abs/t~~
~~b) plant with only heat/steam production(in equivalent) Nh/st sp prod = (34 121+242 443)/ 126 692 =2.183 MWhh/st equ /t~~
~~Nh/st exp = (242 443)/ 126 692 =1.914 MWhh/st equ /t~~

~~a) plant with CHP (in absolute) Nh/st sp prod = (33 749+137 375)/ 126 692 =1.351 MWhh/st abs/t~~
~~Nh/st exp = (137 375)/ 126 692 =1.084 MWhh/st abs/t~~
~~b) plant with CHP (in equivalent) Nh/st sp prod = (34 121+150 961)/ 126 692 =1.461 MWhh/st equ /t~~
~~Nh/st e exp = (150 961)/ 126 692 =1.192 MWhh/st equ /t~~

~~Percentage of total heat/steam produced and exported in correlation to the total energy input:~~

~~$\eta_{h/st\ abs} = ((O_{h/st} + E_{h/st\ circ})/(E_f + E_{x\ imp} + E_w)) \times 100$ {%}~~

~~Examples for percentages of heat/steam produced and exported:~~

~~a) plant with only electricity production (in absolute) ηh/st abs prod = (33 749+0)/ (1 138+ 1 318+367 406))*100 =18.5 (%)~~
~~ηh/st abs exp= (0)/ (1 138+ 1 318+367 406)*100 =13.7 (%)~~
~~b) plant with only electricity production (in equivalent) ηh/st equ prod = (34 121+0)/ (1 138+ 1 612+367 406))*100 = 48.6 (%)~~
~~ηh/st equ exp = (0)/ (1 138+ 1 612+367 406))*100 = 36.1 (%)~~

~~a) plant with only heat/steam production (in absolute) ηh/st abs prod = (33 749+242 443)/ (1 138+ 1 318+367 406))*100 =71.3 (%)~~
~~ηh/st abs exp = (242 443)/ (1 138+ 1 318+367 406))*100 =62.6 (%)~~
~~b) plant with only heat/steam production (in equivalent) ηh/st equ prod = (34 121+242 443)/ (1 138+ 1 612+367 406))*100 =66.4(%)~~
~~ηh/st equ exp = (242 443)/ (1 138+ 1 612+367 406))*100 =58.2 (%)~~

~~a) plant with CHP (in absolute) ηh/st abs prod = (33 749+137 375)/ (1 138+ 1 318+367 406))*100 =9.1 (%)~~
~~ηh/st abs exp = (131 730)/ (1 138+ 1 318+367 406))*100 =0.0 (%)~~
~~b) plant with CHP (in equivalent) ηh/st equ prod = (34 121+150 961)/ (1 138+ 1 612+367 406))*100 =9.2 (%)~~
~~ηh/st equ exp = (150 961)/ (1 138+ 1 612+367 406))*100 =0.0 (%)~~

~~Total specific electricity and heat/steam produced in correlation to the quantity of waste incinerated:~~

~~$$N_{e+h/st\ sp\ prod} = N_{e\ sp\ prod} + N_{h/st\ sp\ prod}$$~~

~~Total specific electricity and heat/steam exported in correlation to the quantity of waste incinerated:~~

~~$$N_{e+h/st\ sp\ exp} = N_{e\ sp\ exp} + N_{h/st\ sp\ exp}$$~~

~~a) as $MWh_{op\ abs}$/t (of waste) or $GJ_{op\ abs}$/t (of waste)~~
~~b) as $MWh_{op\ equ}$/t (of waste) or $GJ_{op\ equ}$/t (of waste)~~

~~Examples for specific heat/steam produced and exported:~~

~~a) plant with only electricity production (in absolute)~~	~~Ne+h/st sp prod = 0.539 + 0.266~~	~~=0.805MWhe+h/st abs/t~~
	~~Ne+h /st exp = 0.401 + 0~~	~~=0.401MWhe+h /st abs/t~~
~~b) plant with only electricity production (in equivalent)~~	~~Ne+h /st sp prod = 1.419 + 0.269~~	~~=1.688 MWhe+h /st equ/t~~
	~~Ne+h /st exp = 1.055 + 0~~	~~=1.055 MWhe+h /st equ /t~~
~~a) plant with only heat/steam production (in absolute)~~	~~Ne+h /st sp prod = 0 + 2.180~~	~~=2.180 MWhe+h /st abs/t~~
	~~Ne+h /st exp = 0 + 1.914~~	~~=1.914 MWhe+h /st abs/t~~
~~b) plant with only heat/steam production (in equivalent)~~	~~Ne+h /st sp prod = 0 + 2.183~~	~~=2.183 MWhe+h /st equ /t~~
	~~Ne+h /st exp = 0 + 1.914~~	~~=1.914 MWhe+h /st equ /t~~
~~a) plant with CHP (in absolute)~~	~~Ne+h /st sp prod = 0.389 + 1.351~~	~~=1.740 MWhe+h /st abs/t~~
	~~Ne+h /st exp = 0.250 + 1.084~~	~~=1.334 MWhe+h /st abs/t~~
~~b) plant with CHP(in equivalent~~	~~Ne+h /st sp prod = 1.023 + 1.461~~	~~=2.484 MWhe+h /st equ /t~~
	~~Ne+h /st e exp = 0.659 + 1.192~~	~~=1.851 MWhe+h /st equ /t~~

~~Percentage of total electricity and heat/steam produced and exported in correlation to the total energy input:~~

~~$$\eta_{e+h/st\ abs} = \eta_{e\ abs} + \eta_{h/st\ abs}\ \{\%\}$$~~

~~$$\eta_{e+h/st\ equ} = \eta_{e\ equ} + \eta_{h/st\ equ}\ \{\%\}$$~~

~~Examples for percentages of heat/steam produced and exported:~~

~~a) plant with only electricity production (in absolute)~~	~~ηe+h/st abs prod = 18.5 + 9.1~~	~~= 27.6 (%)~~
	~~ηe+h/st abs exp = 13.7 + 0~~	~~=13.7 (%)~~
~~b) plant with only electricity production (in equivalent)~~	~~ηe+h/st equ prod = 48.6 + 9.2~~	~~= 57.8 (%)~~
	~~ηe+h/st equ = 36.1 + 0~~	~~= 36.1 (%)~~
~~a) plant with only heat/steam production (in absolute)~~	~~ηe+h/st abs prod = 0 + 71.3~~	~~= 71.3 (%)~~
	~~ηe+h/st abs exp = 0 + 62.6~~	~~= 62.6 (%)~~
~~b) plant with only heat/steam production (in equivalent)~~	~~ηe+h/st equ prod = 0 + 66.4~~	~~= 66.4(%)~~
	~~ηe+h/st equ exp = 0 + 58.2~~	~~= 58.2 (%)~~
~~a) plant with CHP (in absolute)~~	~~ηe+h/st abs prod = 13.3 + 46.3~~	~~= 59.6 (%)~~
	~~ηe+h/st abs exp = 8.6 + 37.1~~	~~= 5.7 (%)~~
~~b) plant with CHP (in equivalent)~~	~~ηe+h/st equ prod = 35.0 + 50.0~~	~~= 85.0 (%)~~
	~~ηe+h/st equ exp = 22.6 +40.8~~	~~= 63.3 (%)~~

~~Boiler efficiency by heat/steam production in absolute figures in correlation to the total heat/steam producing energy input:~~

~~**ηb = (Eh/st boiler/(Ef + Ew))x 100 {%}**~~

~~or because by losses of energy in the bottom ash, boiler dewatering and radiation estimated only 97 % released heat out of the furnace into the boiler~~

~~$$\eta_{b\ (97\ \%)} = (E_{h/st\ boiler}/0.97x(E_f + E_w))x\ 100\ \{\%\}$$~~

~~Examples for boiler efficiency by heat/steam production in absolute figures in correlation to the total heat/steam producing energy input:~~

~~$\eta_b = (E_{h/st\ boiler}/(Ef + Ew))x\ 100$ = (289 207/(1 138 + 367 407))*100 = 80.9 (%)~~

~~ηb (97 %) = (Eh/st boiler/0.97x(Ef + Ew))x 100 = (289 207/(0.97*(1 138 + 367 407)))*100 = 83.4 (%)~~

~~8.4.5 Equations to calculate the plant efficiency (Pl ef)~~

~~Annual basic operational figures and data are the basis for the calculation of the plant efficiency figures for the 3 examples given here. Both calculations provide a figure for the total efficiency of a plant (Pl ef) but with different correlation.~~

~~The exported (sold) energy minus the net part of imported energy is divided by the total energy demand for the waste incineration process, including flue-gas cleaning, generation of heat and electricity etc.~~

~~Because the calculation does nearly not take into account the energy content in the waste, it only allows efficiency comparison of incinerators processing similar wastes.~~

~~$$Pl_{ef} = (O_{exp} - (E_f + E_{imp}))/(E_f + E_{imp} + E_{circ})$$~~

~~all figures as equivalents in accordance to BREF, Chapter 3.5.6~~

~~E_f = *annual energy input to the system by fuels with steam production (GJ/y)*~~
~~E_{imp} = *annual imported energy (Note: energy from the treated waste (E_w) is not included)*~~
~~E_{circ} = *annual energy circulated*~~
~~O_{exp} = *annual exported energy (combined total of heat plus electricity as equivalents)*~~

~~For the calculation of Pl_{ef} the figures of section 3, enclosure 2 and 3 are used:~~

~~**plant with only electricity (13.7 % abs) export** (in equivalent)~~
~~**Pl_{ef} = (133 685 - (1 138+1 612))/(1 138+1 612+80 226) = 1.58**~~

~~**plant with only heat/steam (steam 62.6 % abs) export** (in equivalent)~~
~~**Pl_{ef} = (242 443 - (1 138+47 717))/(1 138+47 717+34 121) = 2.33**~~

~~**plant with CHP (H= 37.1 % abs and P = 8.6 % abs) export** (in equivalent)~~
~~**Pl_{ef} = (234 462 - (1 138+1 612))/(1 138+1 612+80 226) = 2.79**~~

~~**If the resulting figure is 0 or <0:**~~

~~*This means that no energy is exported (BREF) or produced(ECJ) but some imported energy is needed. This could be because no energy is recovered or because the energy that is recovered is consumed by the waste incineration process itself and not available for export and further more some imported energy is necessary.*~~

~~**If the result is higher than 1:**~~

~~*This shows that the plant minus imported energy with steam production is exporting (BREF) or producing (ECJ) more energy than that which is required to operate the total waste incineration process.*~~

~~This calculation does not require knowledge of the energy content of the waste. However, the result will be influenced by the waste energy content, and it can be expected that wastes with a higher energy content can result in greater energy exports, and hence higher values of Pl_{ef}.~~

8.5 Example of a multi-criteria assessment used for the selection of FGC systems

The tables below provides an example of how, in an actual project, the assessment and selection of FGC system was carried out:

Table 8.99: Example of a multi-criteria assessment of FGC system selection

Criteria				
Process		**Semi-wet**	**Dry double filtration**	**Dry simple filtration**
1- NATURAL RESOURCES CONSERVATION a- raw material & EFFICIENCY (IPPC dir. Criterion nr. 9) water reagents type quantity type 2 (ammonia) type 3 (activated carbon) energy consumption auxiliary fuel electricity b- recovery & recycling (IPPC dir. Criterion nr.3) energy recovery metal recovery construction material recovery **salts recovery**	m^3/t_W kg/t_W kg/t_W kg/t_W kg/t_W kg/t_W	0.2 lime 18 5 0.6 - 25 -	- bicarb 26 5 0.6 - 30 possible	- bicarb 26 5 0.6 - 20 -
2- EMISSIONS a- low waste techniques (IPPC dir. Criterion nr.1) liquid effluents solid residues FGC residues quantity Flying ashes Salts FGC/salts residues quality b- emissions and impact (criteria nr 6 and 10 of the IPPC directive) emissions to atmosphere pollutants noise odours emissions to waters emissions via residues	kg/t_W	- 54 - - calcic	- - 25 20 sodic	- 45 - - sodic
3- RISKS (IPPC dir. Criteria nr. 2, 10, 11) risks from hazardous substances chemicals risks from emissions risks from accidents		Little negligible	None negligible	None negligible
4- ECONOMICS costs and benefits (IPPC dir annex 4 introduction) annuity (corresp. to the invest. principal and interests) operation costs availability construction duration		2.8 20.3 23.1	3.5 20.4 23.9	2.7 20.9 23.6

Table 8.100: Example of a multi-criteria cost assessment used for comparing FGC system options

200 000 t_W/yr								
Process Reagent(s)			**Semi-wet** Lime		**Dry** double filtration Bicarb		**Dry** simple filtration Bicarb	
I) Variables costs:								
Reagents:	Unit (u)	Cost (€/u)	Quant. (u/t_W)	Cost (€/t_W)	Quant. (u/t_W)	Cost (€/t_W)	Quant. (u/t_W)	Cost (€/t_W)
Lime	Kg	0.1	18	1.8				
sodium bicarbonate	Kg	0.2			26	5.2	26	5.2
ammonia	Kg	0.15	5	0.8	5	0.8	5	0.8
activated carbon	Kg	1.5	0.6	0.9	0.6	0.9	0.6	0.9
Utilities:								
water	m^3	0.5	0.2	0.1				
electricity	kWh	0.04	25	1.0	30	1.2	20	0.8
1- Total reagents and utilities		**€/t_W**		**3.8**		**7.3**		**6.9**
Residues and effluents:								
flying ashes	Kg	0.27			25	6.8		
FGC Residues	Kg	0.27	54	14.6			45	12.2
salts	Kg	0.20			20	4.0		
2- Total residues and effluents		**€/t_W**		**14.6**		**10.8**		**12.2**
TOTAL 1+2		**€/t_W**		**18.4**		**10.8**		**19.0**
3- Total workforce		**€/t_W**		**0.2**		**0.2**		**0.2**
4- Total daily maintenance		**€/t_W**		**0.5**		**0.6**		**0.5**
II) Fixed costs:								
5- Provision for mainten. & renewal		**€/t_W**		**1.3**		**1.6**		**1.2**
6 Annuity (corresp. to the invest. principal + interest)*		**€/t_W**		**2.8**		**3.5**		**2.7**
Total variable costs 1+2+3+4		**€/t_W**		**19.1**		**18.8**		**19.7**
Total variable costs 5+6		**€/t_W**		**4.1**		**5.0**		**3.9**
GLOBAL COST		**€/t_W**		**23.1**		**23.9**		**23.6**
*Fixed rate 6 % - duration 20 years								

8.6 List of European Waste Incineration Plants that participated in the 2016 data collection.

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
AT02R	MVA Spittelau	Vienna	AT	5.2. (a)	32 t/h	M	SCR BF WS2s
AT03R	MVA Pfaffenau	Vienna	AT	5.2. (a)	32 t/h	M	SCR ESPd WS2s Bed
AT04.1R	WAV Wels	Wels	AT	5.2. (a)	8 t/h	O	SCR ESPd WS2s Bed
AT04.2R	WAV Wels	Wels	AT	5.2. (a)	28.9 t/h	O	Prim SCR ESPd BF WS2s DSI
AT05.1R	MVA Duernrohr	Zwentendorf	AT	5.2. (a)	150000 t/yr	M	Prim SCR BF WS2s DS_rcy DSI
AT05.2R	MVA Duernrohr	Zwentendorf	AT	5.2. (a)	150000 t/yr	M	Prim SCR BF WS2s DS_rcy DSI
AT05.3R	MVA Duernrohr	Zwentendorf	AT	5.2. (a)	225000 t/yr	M	Prim SCR BF WS2s DS_rcy DSI
AT06R	TBA Arnoldstein	Arnoldstein	AT	5.2. (a)	96000 t/yr	M	SCR BF Bed Other
AT07R	MVA Zistersdorf	Zistersdorf	AT	5.2. (a)	19.8 t/h	M	SCR BF DS_rea
AT08.1R	Simmeringer Haide	Vienna	AT	5.2. (a)	30 t/h	S	SCR ESPd WS2s Bed
AT08.2R	Simmeringer Haide	Vienna	AT	5.2. (a)	16.2 t/h	M	SCR ESPd WS2s Bed
AT09R	RVL Lenzing	Lenzing	AT	5.2. (a)	37 t/h	O	SCR BF Cyc WS2s DSI
AT11R	RHKW Linz-Mitte	Linz	AT	5.2. (a)	28 t/h	M	SCR BF Cyc WS2s DSI
BE01R	BIONERGA VERBRANDING	Houthalen-Helchteren	BE	5.2. (a)	6.1 t/h	M	SCR ESPd Cyc sWS DS_rea DSI

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
BE02R	Brussel-Energie	Brussel	BE	5.2. (a)	75 t/h	M	SCR ESPd ESPw WS2s
BE03R	IMOG	Harelbeke	BE	5.2. (a)	8 t/h	M	SCR ESPd BF WS2s DSI
BE04.1	Intradel-Uvelia	Herstal	BE	5.2. (a)	67.08 MW	M	SCR ESPd BF sWS DSI
BE04.2	Intradel-Uvelia	Herstal	BE	5.2. (a)	67.08 MW	M	SCR ESPd BF sWS DSI
BE05R	Ipalle	Beloeil	BE	5.2. (a)	51.94 t/h	O	SNCR ESPd BF WS2s sWS DSI Qch
BE06R	Biostoom Oostende nv	Oostende	BE	5.2. (a)	31.25 t/h	O	SNCR BF Qch
BE07R	Grate furnace Indaver	Beveren	BE	5.2. (a)	50 t/h	M	SNCR BF WS2s DS_rea DSI
BE08.1R	Sleco	Beveren	BE	5.2. (a)	71 t/h	O	SNCR ESPd BF WS1s DS_rcy DSI
BE08.2R	Sleco	Beveren	BE	5.2. (a)	71 t/h	O	SNCR ESPd BF WS1s DS_rcy DSI
BE08.3R	Sleco	Beveren	BE	5.2. (a)	71 t/h	O	SNCR ESPd BF WS1s DS_rcy DSI
BE09.1R	Rotary Kiln Indaver	Antwerp	BE	5.2. (a)	16.67 t/h	H	SNCR ESPd WS2s Bed
BE09.2R	Rotary Kiln Indaver	Antwerp	BE	5.2. (a)	16.67 t/h	H	SNCR ESPd WS2s Bed
BE09.3R	Rotary Kiln Indaver	Antwerp	BE	5.2. (a)	16.67 t/h	H	SNCR ESPd WS2s Bed
BE10R	ISVAG	Antwerp	BE	5.2. (a)	8.5 t/h	M	Prim SNCR ESPd BF WS1s WS2s sWS Bed Qch
BE12	MIROM	Roeselare	BE	5.2. (a)	4 t/h	M	SCR ESPd DSI

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
BE13	IVBO	Brugge	BE	5.2. (a)	200000 t/yr	M	Prim SCR WS2s DSI Qch
BE14	IVM	Eeklo	BE	5.2. (b)	95152 t	M	SCR ESPd sWS DS_rcy
CZ01.1R	Waste to Energy Plant SAKO Brno, a.s.	Brno	CZ	5.2. (a)	32	M	SNCR sWS DSI
CZ01.2R	Waste to Energy Plant SAKO Brno, a.s.	Brno	CZ	5.2. (a)	32	M	SNCR sWS DSI
DE01	Danpower Biomassekraftwerk	Delitzsch	DE	5.2. (a)	NA	O	SNCR BF Cyc
DE02	Heizkraftwerk Altenstadt	Altenstadt	DE	5.2. (a)	NA	O	Prim BF DSI
DE03	biotherm Hagenow GmbH	Hagenow	DE	5.2. (a)	67765.18 t/yr	O	BF Cyc
DE04	Biomasseheizkraftwerk Zolling GmbH	Zolling	DE	5.2. (b)	210240 t	H	SNCR BF Cyc DS_rea
DE05	BHZ Zapfendorf	Zapfendorf	DE	5.2. (a)	60000 t/yr	H	SCR BF DSI
DE15.1R	Sewage Sludge Incineration BASF SE	Ludwigshafen	DE	5.2. (b)	200000 t/yr	S	ESPd BF WS3s DSI
DE15.2R	Sewage Sludge Incineration BASF SE	Ludwigshafen	DE	5.2. (b)	200000 t/yr	S	ESPd BF WS3s DSI
DE16R	INNOVATHERM GmbH	Lünen	DE	5.2. (a)	265000 t/yr	S	ESPd BF WS2s DSI Qch
DE17R	Currenta	Dormagen	DE	5.2. (a)	NA	H	Prim SCR ESPw WS3s
DE18.1	GSB Ebenhausen	Baar-Ebenhausen bei Ingolstadt	DE	5.2. (a)	NA	H	SNCR ESPd BF WS3s DSI Bed
DE18.2	GSB Ebenhausen	Baar-Ebenhausen bei Ingolstadt	DE	5.2. (a)	NA	H	SNCR ESPd BF WS3s DSI Bed
DE19R	AGV	Trostberg	DE	5.2. (a)	30 t/d	H	SCR WS2s Qch
DE20.1R	Wacker Chemie AG, Burghausen	Burghausen	DE	4	NA	H	SCR ESPw WS1s WS2s PC Qch

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
DE20.2R	Wacker Chemie AG, Burghausen	Burghausen	DE	4	NA	H	SCR ESPw WS1s WS2s PC Qch
DE21.1R	Wacker Chemie AG, Nünchritz	Nünchritz	DE	4	NA	H	ESPw WS3s Bed Qch
DE21.2R	Wacker Chemie AG, Nünchritz	Nünchritz	DE	4	NA	H	ESPw Cyc WS3s Bed Qch
DE22R	Drehrohrofenanlage Schkopau	Schkopau	DE	5.2. (a)	124 t/d	H	ESPw WS1s Bed Qch
DE23R	Reststoffverwertungsanlage (RVA)	Stade	DE	5.2. (b)	150 t/d	H	Prim ESPw WS2s Bed Qch
DE24	Chemiepark Marl	Marl	DE	5.2. (a)	NA	H	SNCR BF WS2s Bed
DE25R	TRV Thermische Rückstandsverwertung GmbH & Co KG	Wesseling	DE	5.2. (b)	41 MWth	H	SCR ESPd WS2s Bed
DE26.1R	BASF Ludwigshafen	Ludwigshafen	DE	5.2. (b)	23 t/h	H	SCR ESPd WS3s Qch
DE26.2R	BASF Ludwigshafen	Ludwigshafen	DE	5.2. (b)	23 t/h	H	SCR ESPd WS3s Qch
DE26.3R	BASF Ludwigshafen	Ludwigshafen	DE	5.2. (b)	23 t/h	H	SCR ESPd WS3s Qch
DE27.1	InfraServ Höchst	Frankfurt	DE	5.2. (a)	NA	#N/A	
DE27.2	InfraServ Höchst	Frankfurt	DE	5.2. (a)	NA	#N/A	
DE28	Sonderabfallverbrennungsanlage Brunsbüttel	Brunsbüttel	DE	5.2. (a)	NA	H	SCR ESPd BF WS3s DSI PC
DE29.1R	SAV Biebesheim	Biebesheim	DE	5.2. (b)	35 MW	H	SNCR ESPd BF WS3s DSI PC Qch
DE29.2R	SAV Biebesheim	Biebesheim	DE	5.2. (b)	35 MW	H	SNCR ESPd BF WS3s DSI PC Qch

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
DE30.1R	SAV Hamburg	Hamburg	DE	5.2. (b)	NA	H	SCR ESPd WS2s Bed PC Qch
DE30.2R	SAV Hamburg	Hamburg	DE	5.2. (b)	69.4 MW	H	SCR ESPd WS2s Bed PC Qch
DE31R	BMHKW Flohr	Neuwied	DE	5.2. (b)	30.2 MW th (rated thermal input)	H	Prim SNCR BF Cyc sWS
DE32R	BMK Biomassekraftwerk Lünen GmbH	Lünen	DE	5.2. (b)	68.4 MW th (rated thermal input)	H	Prim SNCR BF Cyc sWS
DE33R	BMHKW Buchen	Buchen / Odenwald	DE	5.2. (b)	29.7 MW th (rated thermal input)	H	Prim SNCR BF Cyc sWS
DE34	AVA	Augsburg	DE	5.2. (a)	240000 3	M	SCR ESPd WS2s DSI
DE35R	MHKW	Berlin	DE	5.2. (a)	88.2 5	M	SCR BF DSI
DE36.1R	PD energy GmbH	Bitterfeld-Wolfen	DE	5.3. (a)	134400 t/yr	O	SNCR BF DS_rcy
DE36.2R	PD energy GmbH	Bitterfeld-Wolfen	DE	5.3. (a)	134400 t/yr	O	SNCR BF DS_rcy
DE37R	TREA Breisgau	Eschbach	DE	5.2. (a)	22 t/h	M	SCR ESPd WS2s DSI Bed
DE38	Müllheizkraftwerk Bremen	Bremen	DE	5.2. (a)	NA	M	SNCR ESPd BF sWS DS_rcy DSI
DE39.1	MHKW Bremerhaven	Bremerhaven	DE	5.2. (a)	401500 t/yr	M	SNCR ESPd BF WS2s DSI
DE39.2	MHKW Bremerhaven	Bremerhaven	DE	5.2. (a)	401500 t/yr	M	SNCR ESPd BF WS2s DSI
DE39.3	MHKW Bremerhaven	Bremerhaven	DE	5.2. (a)	401500 t/yr	M	SNCR ESPd BF WS2s DSI
DE40.1	Müllheizkraftwerk Burgkirchen	Burgkirchen	DE	5.2. (a)	230000 t/yr	M	SCR ESPd BF WS3s DSI

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
DE40.2	Müllheizkraftwerk Burgkirchen	Burgkirchen	DE	5.2. (a)	230000 t/yr	M	SCR ESPd BF WS3s DSI
DE41.1R	Müllheizkraftwerk Darmstadt	Darmstadt	DE	5.2. (a)	217000 t/yr	M	SCR ESPd WS3s
DE41.2R	Müllheizkraftwerk Darmstadt	Darmstadt	DE	5.2. (a)	217000 t/yr	M	SCR ESPd WS3s
DE41.3R	Müllheizkraftwerk Darmstadt	Darmstadt	DE	5.2. (a)	217000 t/yr	M	SCR ESPd WS3s
DE42R	Müllverbrennungsanlage Düsseldorf	Düsseldorf	DE	5.2. (a)	75 t/h	M	SCR ESPd sWS DSI Bed
DE43R	Waste incineration plant Karnap	Essen	DE	5.2. (a)	180237 t/yr	M	SCR ESPd WS1s Bed
DE44R	MHKW - Frankfurt	Frankfurt Main	DE	5.2. (a)	525600 t/yr	M	SNCR BF DSI
DE45R	Müllheizkraftwerk Göppingen	Göppingen	DE	5.2. (a)	19.8 t/h	M	SCR BF WS1s WS2s DSI Qch
DE46R	EEW Energy from Waste Großräschen GmbH	Großräschen	DE	5.2. (a)	28.6 t/h	O	SNCR BF DSI
DE47.1R	MVB Müllverwertung Borsigstraße GmbH	Hamburg	DE	5.2. (a)	320000 t/yr	M	SNCR BF WS3s DSI
DE47.2R	MVB Müllverwertung Borsigstraße GmbH	Hamburg	DE	5.2. (a)	320000 t/yr	M	SNCR BF WS3s DSI
DE48.1	MVR Müllverwertung Rugenberger Damm GmbH & Co. KG	Hamburg	DE	5.2. (a)	320000 t/yr	M	SNCR BF WS3s
DE48.2	MVR Müllverwertung Rugenberger Damm GmbH & Co. KG	Hamburg	DE	5.2. (a)	320000 t/yr	M	SNCR BF WS3s
DE49.1R	NA	Hannover	DE	5.2. (a)	28 t/h	M	SNCR BF sWS DSI
DE49.2R	NA	Hannover	DE	5.2. (a)	28 t/h	M	SNCR BF sWS DSI
DE50.1R	ETN Heringen	Heringen / Werra	DE	5.2. (a)	35 t/h	O	SNCR BF sWS DS_rea

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
DE50.2R	ETN Heringen	Heringen / Werra	DE	5.2. (a)	35 t/h	O	SNCR BF sWS DS_rea
DE51R	Abfallentsorgungszentrum (AEZ) Asdonkshof	Kamp-Lintfort	DE	5.2. (a)	260000 t/yr	O	SCR ESPd WS1s WS2s Bed Qch
DE52.1	MHKW Kassel	Kassel	DE	5.2. (a)	200000 t/yr	M	SCR BF DSI Bed
DE52.2	MHKW Kassel	Kassel	DE	5.2. (a)	200000 t/yr	M	
DE53.1	Müllverbrennung Kiel	Kiel	DE	5.2. (a)	140000 t/yr	M	SCR ESPd WS2s WS3s Bed Qch
DE53.2	Müllverbrennung Kiel	Kiel	DE	5.2. (a)	140000 t/yr	M	SCR ESPd WS2s WS3s Bed Qch
DE54.1	AVG Köln mbH	Köln	DE	5.2. (a)	780000 t/yr	O	SCR BF WS1s WS2s Bed
DE54.2	AVG Köln mbH	Köln	DE	5.2. (a)	780000 t/yr	O	SCR BF WS1s WS2s Bed
DE54.3	AVG Köln mbH	Köln	DE	5.2. (a)	780000 t/yr	O	SCR BF WS1s WS2s Bed
DE54.4	AVG Köln mbH	Köln	DE	5.2. (a)	780000 t/yr	O	SCR BF WS1s WS2s Bed
DE55.1R	MKVA Krefeld	Krefeld	DE	5.2. (a)	80.29 t/h	M	SNCR BF WS2s WS3s DSI Qch
DE55.2R	MKVA Krefeld	Krefeld	DE	5.2. (a)	80.29 t/h	M	SNCR BF DSI
DE55.3R	MKVA Krefeld	Krefeld	DE	5.2. (a)	80.29 t/h	M	SCR BF WS2s WS3s DSI Qch
DE56R	Waste incineration plant	Lauta	DE	5.2. (a)	225000 t/yr	M	SCR BF DS_rcy DSI Bed Qch
DE57	MVV TREA Leuna	Leuna	DE	5.2. (a)	400000 t/yr	O	SNCR BF sWS DS_rcy DS_rea DSI Qch

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
DE58.1R	MHKW Leverkusen	Leverkusen	DE	5.2. (a)	680 t/d	M	SCR ESPd WS2s Bed
DE58.2R	MHKW Leverkusen	Leverkusen	DE	5.2. (a)	680 t/d	M	SCR ESPd WS2s Bed
DE58.3R	MHKW Leverkusen	Leverkusen	DE	5.2. (a)	680 t/d	M	SCR ESPd WS2s Bed
DE59	MHKW Ludwigshafen	Ludwigshafen	DE	5.2. (a)	200 t	M	SCR BF DS_rcy Qch
DE60	MHKW Mainz	Mainz	DE	5.2. (a)	NA	O	SNCR BF WS2s DSI
DE61R	Abfallheizkraftwerk Neunkirchen	Neunkirchen	DE	5.2. (a)	17 t/h	O	SCR ESPd ESPw BF WS3s Bed
DE62	Müllverbrennungsanlage Nürnberg	Nürnberg	DE	5.2. (a)	105 MWth	M	SCR ESPd WS1s DS_rea
DE63R	GMVA Gemeinschafts-Müll-Verbrennungsanlage Niederrhein GmbH	Oberhausen	DE	5.2. (a)	96 t/h	M	SNCR ESPd BF WS2s DSI
DE64.1R	Müllheizkraftwerk Pirmasens	Pirmasens	DE	5.2. (a)	24 t/h	O	SNCR ESPd BF WS3s
DE64.2R	Müllheizkraftwerk Pirmasens	Pirmasens	DE	5.2. (a)	24 t/h	O	SNCR ESPd BF WS3s
DE65.1	Müllheizkraftwerk Solingen	Solingen	DE	5.2. (a)	53123 t/yr	O	SNCR ESPd BF sWS DSI
DE65.2	Müllheizkraftwerk Solingen	Solingen	DE	5.2. (a)	53123 t/yr	O	SNCR ESPd BF sWS DSI
DE66.1	EEW Energy from Waste Stapelfeld GmbH	Stapelfeld	DE	5.2. (a)	350000 t/yr	M	SCR ESPd WS2s
DE66.2	EEW Energy from Waste Stapelfeld GmbH	Stapelfeld	DE	5.2. (a)	350000 t/yr	M	SCR ESPd WS2s
DE67.1	REMONDIS Thermische Abfallverwertung GmbH	Staßfurt	DE	5.2. (a)	380000 t	M	SNCR BF sWS
DE67.2R	REMONDIS Thermische Abfallverwertung GmbH	Staßfurt	DE	5.2. (a)	380000 t	M	SNCR BF sWS

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
DE68R	EBS-Kraftwerk Witzenhausen - DSS Paper	Witzenhausen	DE	5.2. (a)	326000	O	SNCR ESPd BF Cyc DS_rcy DSI Qch
DE69	Abfallwirtschaftsgesellschaft mbH Wuppertal	Wuppertal	DE	5.2. (a)	406933 t/yr	M	SCR ESPd BF DS_rcy DS_rea DSI Bed Qch
DE70	MHKW Würzburg	Würzburg	DE	5.2. (a)	NA	M	SCR BF DS_rcy DSI Qch
DE71.1	Abfallverwertung Zorbau	Lützen	DE	5.2. (a)	107.2 MWth	M	SNCR BF DS_rcy DSI
DE71.2	Abfallverwertung Zorbau	Lützen	DE	5.2. (a)	107.2 MWth	M	SNCR BF DS_rcy DSI
DE72R	IHKW Andernach GmbH	Andernach	DE	5.2. (a)	17.5 t/h	M	SNCR BF DS_rcy
DE73R	EEW Stavenhagen GmbH & Co. KG	Stavenhagen	DE	5.2. (a)	11.5 t/h	M	Prim SNCR BF sWS DS_rcy
DE74.1R	MVA Bielefeld-Herford	Bielefeld	DE	5.2. (a)	56.4 t/h	O	SCR ESPd WS2s DSI
DE74.2R	MVA Bielefeld-Herford	Bielefeld	DE	5.2. (a)	56.4 t/h	O	SCR ESPd WS2s DSI
DE74.3R	MVA Bielefeld-Herford	Bielefeld	DE	5.2. (a)	56.4 t/h	O	SCR ESPd WS2s DSI
DE76.1R	MVA Hameln	Hameln	DE	5.2. (a)	50.2 t/h	O	SNCR SCR ESPd DS_rcy Bed Qch
DE76.2R	MVA Hameln	Hameln	DE	5.2. (a)	50.2 t/h	#N/A	SNCR SCR ESPd DS_rcy Bed
DE76.3R	MVA Hameln	Hameln	DE	5.2. (a)	50.2 t/h	O	SNCR SCR ESPd DS_rcy Bed Qch
DE76.4R	MVA Hameln	Hameln	DE	5.2. (a)	50.2 t/h	O	SCR BF DS_rea
DE78R	Siedlungsmüllverbrennungsanlage (Linien 1 bis 4)	Herten	DE	5.2. (a)	600000 t/yr	O	SCR ESPd BF WS2s Bed
DE80.1R	Zweckverband MVA Ingolstadt Ersatzverbrennungslinie I	Ingolstadt	DE	5.2. (a)	34 t/h	M	Prim SCR BF WS3s DSI
DE80.2R	Zweckverband MVA Ingolstadt Ersatzverbrennungslinie I	Ingolstadt	DE	5.2. (a)	34 t/h	M	Prim SCR BF WS3s DSI

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
DE80.3R	Zweckverband MVA Ingolstadt Ersatzverbrennungslinie I	Ingolstadt	DE	5.2. (a)	34 t/h	M	Prim SCR ESPd BF WS3s DSI
DE84R	NA	Rüdersdorf	DE	5.2. (a)	36.8 t/h	M	SNCR BF sWS DSI Bed
DE86R	4.BimSchV Anhang 1 unter 8.1 Müllverbrenungsanlage	Iserlohn	DE	5.2. (a)	295000 t/yr	M	SCR ESPd BF WS2s DS_rea
DE87.1R	Klärwerk Ruhleben - Klärschlammverbrennungsanlage	Berlin	DE	5.1. (a)	43 t/h	S	ESPd WS1s
DE87.2R	Klärwerk Ruhleben - Klärschlammverbrennungsanlage	Berlin	DE	5.1. (a)	43 t/h	S	ESPd WS1s
DE87.3R	Klärwerk Ruhleben - Klärschlammverbrennungsanlage	Berlin	DE	5.1. (a)	43 t/h	S	ESPd WS1s
DE89R	Restmüllheizkraftwerk Stuttgart Münster	Stuttgart	DE	5.2. (a)	420000 t/yr	M	SCR ESPd WS3s Qch
DK01R	I/S Reno-Nord WTE plant	Aalborg	DK	5.2. (a)	161500 t/yr	M	SNCR Cyc WS3s
DK02.1R	Incineration of household and industrial waste	Glostrup	DK	5.2. (a)	32 t/h	O	SNCR ESPd BF WS2s DSI Other
DK02.2R	Incineration of household and industrial waste	Glostrup	DK	5.2. (a)	37.4 t/h	M	SNCR BF WS2s DSI
DK03R	Slagelse Forbrændings Anlæg	Slagelse	DK	5.2. (a)	50000 t/yr	M	SNCR BF Cyc DS_rcy DSI
DK04R	I/S REFA	Nykøbing Falster	DK	5.2. (a)	22000 t/yr	O	SNCR BF DS_rcy DSI
DK05R	EKOKEM	DK - 5800 Nyborg	DK	5.2. (a)	NA	H	SNCR ESPd BF WS3s DSI Qch
DK06R	BIOFOS Lynetten	Refshalevej 250, 1432 København K	DK	5.2. (a)	18800 t	S	SNCR ESPd BF WS3s DS_rcy DS_rea DSI Qch
ES01.1	TIRMADRID	MADRID	ES	5.2. (a)	300000 t/yr	M	SCR BF Cyc sWS DSI
ES01.2	TIRMADRID	MADRID	ES	5.2. (a)	300000 t/yr	M	SCR BF Cyc sWS DSI
ES01.3	TIRMADRID	MADRID	ES	5.2. (a)	300000 t/yr	M	SCR BF Cyc sWS DSI

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
ES02.1R	TIRME	Palma de Mallorca	ES	5.2. (a)	91.5 t/h	M	SCR BF sWS DS_rcy DSI
ES02.2R	TIRME	Palma de Mallorca	ES	5.2. (a)	91.5 t/h	M	SCR BF sWS DS_rcy DSI
ES02.3R	TIRME	Palma de Mallorca	ES	5.2. (a)	91.5 t/h	M	SCR BF DS_rcy DS_rea
ES02.4R	TIRME	Palma de Mallorca	ES	5.2. (a)	91.5 t/h	M	SCR BF DS_rcy DS_rea
ES03.1R	SIRUSA	TARRAGONA	ES	5.2. (a)	9.6 t/h	M	SNCR BF sWS DS_rcy
ES03.2R	SIRUSA	TARRAGONA	ES	5.2. (a)	9.6 t/h	M	SNCR BF sWS DS_rcy
ES04.1	UTE-TEM	Mataró	ES	5.2. (a)	160000 t	O	SCR BF sWS DSI
ES04.2	UTE-TEM	Mataró	ES	5.2. (a)	160000 t	O	SCR BF sWS DSI
ES05R	TERSA	SANT ADRIÀ DE BESÒS (BAECELONA)	ES	5.2. (a)	45 t/h	M	SNCR ESPd BF sWS DSI
ES06	TIRCANTABRIA, S.L.U.	Meruelo	ES	5.2. (a)	115351 t/yr	M	SNCR BF DS_rcy
ES07.1	SOGAMA	Cerceda	ES	5.2. (a)	360000 t/yr	M	SNCR BF FSI sWS Bed
ES07.2	SOGAMA	Cerceda	ES	5.2. (a)	360000 t/yr	M	SNCR BF FSI sWS Bed
ES08R	ZABALGARBI	Bilbao	ES	5.2. (a)	30 t/h	M	SNCR BF sWS Bed
ES10R	SAICA PVE	El Burgo de Ebro (Zaragoza)	ES	5.2. (a)	57 t/h	O	Prim SNCR BF Cyc DSI
ES11	SARPI CONSTANTÍ S.L.U.	CONSTANTI-TARRAGONA	ES	5.2. (a)	8 t/h	H	SCR ESPd WS3s Qch
FI01.1R	Ekokem Oyj	Riihimäki	FI	5.2. (a)	33 t/h	M	Prim SNCR ESPd BF WS2s DSI
FI01.2R	Ekokem Oyj	Riiihimäki	FI	5.2. (a)	33 t/h	M	Prim SNCR ESPd BF WS2s DSI

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
FI01.3R	Ekokem Oyj	Riihimäki	FI	5.2. (a)	33 t/h	M	Prim SNCR BF DS_rea DSI
FI02	Kotka Wte	Kotka	FI	5.2. (a)	285.7 GWh	M	Prim SNCR BF sWS
FI03	Kymijärvi II	Lahti	FI	5.2. (a)	249056 t	M	SCR BF DSI
FI04R	Laanila WtE Plant	Oulu	FI	5.2. (a)	150000 t/yr	M	SNCR BF WS1s DS_rcy DS_rea Qch
FI05	Vantaan Jätevoimala	Vantaa	FI	5.2. (a)	116 MWth	M	SNCR ESPd BF WS1s DS_rea
FI06R	Westenergy Oy Ab	Mustasaari	FI	5.2. (a)	20 t/h	M	SNCR BF DS_rea
FR002R	VITRE	VITRE	FR	5.2. (a)	4 t/h	M	BF DSI
FR003R	Meuse Energie	Tronville En Barrois	FR	5.2. (a)	4 t/h	M	ESPd BF WS2s DSI PC
FR010R	Cluses	Marignier	FR	5.2. (a)	5 t/h	M	SNCR ESPd BF DSI
FR012R	Egletons	Rosiers d'Egletons	FR	5.2. (a)	5.3 t/h	M	BF DSI
FR015	Fourchambault	Fourchambault	FR	5.2. (a)	6 t/h	M	SCR BF DSI
FR017	UVE PLUZUNET	PLUZUNET	FR	5.2. (a)	7 t/h	O	SCR ESPd WS2s
FR018.1R	SMECO	PONTMAIN	FR	5.2. (a)	7 t/h	M	SNCR BF DSI Qch
FR018.2R	SMECO	PONTMAIN	FR	5.2. (a)	7 t/h	M	Prim BF DSI Qch
FR019R	SET Mont Blanc (Passy)	Passy	FR	5.2. (a)	7.5 t/h	M	SNCR BF DSI Qch
FR023R	La Rochelle	La Rochelle	FR	5.2. (a)	8 t/h	M	SNCR BF DSI
FR027R	BAYET	BAYET	FR	5.2. (a)	9 t/h	M	SCR ESPd BF WS1s sWS

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
FR028R	Montereau-Fault-Yonne	Montereau-Fault-Yonne	FR	5.2. (a)	9 t/h	M	SCR BF DSI
FR029.1R	HAGUENAU	SCHWEIGHOUSE SUR MODER	FR	5.2. (a)	10 t/h	M	SNCR BF sWS DSI
FR029.2R	HAGUENAU	SCHWEIGHOUSE SUR MODER	FR	5.2. (a)	10 t/h	M	SNCR BF sWS DSI
FR033.1R	ARCANTE	BLOIS	FR	5.2. (a)	11 t/h	M	SNCR BF WS3s sWS DSI
FR033.2R	ARCANTE	BLOIS	FR	5.2. (a)	11 t/h	M	SNCR BF WS3s sWS DSI
FR034R	VILLEJUST	VILLEJUST	FR	5.2. (a)	12.9 t/h	M	SCR BF DSI
FR040R	ARQUES	ARQUES	FR	5.2. (a)	12.5 t/h	M	SCR ESPd BF DSI
FR046.1R	Usine de Fort-De-France	Fort de France	FR	5.2. (a)	14 t/h	M	SNCR BF WS1s WS2s sWS Other
FR046.2R	Usine de Fort-De-France	Fort de France	FR	5.2. (a)	14 t/h	M	SNCR BF WS1s WS2s sWS Other
FR052.1R	Limoges	Limoges	FR	5.2. (a)	15 t/h	M	SNCR BF WS1s DSI Qch
FR052.2R	Limoges	Limoges	FR	5.2. (a)	15 t/h	M	SNCR BF WS1s DSI Qch
FR052.3R	Limoges	Limoges	FR	5.2. (a)	15 t/h	M	SNCR BF DSI Qch
FR053R	Ludres	Ludres	FR	5.2. (a)	15 t/h	M	SCR ESPd BF DSI
FR054.1R	ORISANE	MAINVILLIERS	FR	5.2. (a)	15 t/h	M	SNCR BF sWS DSI
FR054.2R	ORISANE	MAINVILLIERS	FR	5.2. (a)	15 t/h	M	SNCR BF sWS DSI
FR056.1R	AZALYS	Carrieres sous Poissy	FR	5.2. (a)	15 t/h	M	SCR ESPd Cyc WS2s Qch

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
FR056.2R	AZALYS	Carrieres sous Poissy	FR	5.2. (a)	15 t/h	M	SCR ESPd Cyc WS2s Qch
FR057.1R	UVE (unité de valorisation énergétique des déchets)	Metz	FR	5.2. (a)	8 t/h	M	SNCR BF DSI
FR057.2R	UVE (unité de valorisation énergétique des déchets)	Metz	FR	5.2. (a)	8 t/h	M	SNCR BF DSI
FR059.1R	OCREAL	LUNEL-VIEL	FR	5.2. (a)	16 t/h	M	SCR ESPd BF DSI
FR059.2R	OCREAL	LUNEL-VIEL	FR	5.2. (a)	16 t/h	M	SCR ESPd BF DSI
FR062.1R	VALORYELE	OUARVILLE	FR	5.2. (a)	16 t/h	M	SNCR BF WS3s sWS DSI Qch
FR062.2R	VALORYELE	OUARVILLE	FR	5.2. (a)	16 t/h	M	SNCR BF WS3s sWS DSI Qch
FR064R	RUNGIS	RUNGIS	FR	5.2. (a)	17 t/h	M	SCR ESPd BF DSI
FR070	ALCEA - Nantes	Nantes	FR	5.2. (a)	19 t/h	M	SCR BF DS_rea
FR071.1R	Carrières Sur Seine	Carrières Sur Seine	FR	5.2. (a)	20 t/h	M	SCR BF DSI
FR071.2R	Carrières Sur Seine	Carrières Sur Seine	FR	5.2. (a)	20 t/h	M	SCR BF DSI
FR072.1R	Lagny	Saint thibault des vignes	FR	5.2. (a)	20 t/h	M	SNCR ESPd BF DSI
FR072.2R	Lagny	Saint thibault des vignes	FR	5.2. (a)	20 t/h	M	SNCR ESPd BF DSI
FR073.1R	ESIANE	Villers St Paul	FR	5.2. (a)	20 t/h	M	SNCR ESPd BF DSI
FR073.2R	ESIANE	Villers St Paul	FR	5.2. (a)	20 t/h	M	SNCR ESPd BF DSI
FR075R	Cergy	Saint Ouen L'aumone	FR	5.2. (a)	21 t/h	M	SCR BF WS1s WS2s
FR076.1R	MULHOUSE	Sausheim	FR	5.2. (a)	21 t/h	M	SCR ESPd ESPw Cyc WS2s

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
FR076.2R	MULHOUSE	Sausheim	FR	5.2. (a)	21 t/h	M	SCR ESPd ESPw Cyc WS2s
FR077R	SARCELLES	SARCELLES	FR	5.2. (a)	20 t/h	M	SCR BF DSI
FR078R	Bourgoin-Jallieu	Bourgoin-Jallieu	FR	5.2. (a)	22 t/h	M	SCR BF sWS
FR080.1R	W-T-E Plant Thiverval-Grignon	THIVERVAL GRIGNON	FR	5.2. (a)	27.8 t/h	M	SNCR ESPd WS2s DSI Qch
FR080.2R	W-T-E Plant Thiverval-Grignon	THIVERVAL GRIGNON	FR	5.2. (a)	27.8 t/h	M	SNCR ESPd WS2s DSI Qch
FR080.3	W-T-E Plant Thiverval-Grignon	THIVERVAL GRIGNON	FR	5.2. (a)	243000 t/yr	M	SNCR BF WS1s WS2s DSI Qch
FR082.1R	NOVALIE	VEDENE	FR	5.2. (a)	26.8 t/h	M	SNCR BF sWS DSI
FR082.2R	NOVALIE	VEDENE	FR	5.2. (a)	26.8 t/h	M	SNCR BF sWS DSI
FR082.3R	NOVALIE	VEDENE	FR	5.2. (a)	26.8 t/h	M	SNCR BF sWS DSI
FR082.4R	NOVALIE	VEDENE	FR	5.2. (a)	26.8 t/h	M	SNCR BF sWS DSI
FR083.1R	OREADE	SAINT JEAN DE FOLLEVILLE	FR	5.2. (a)	24 t/h	M	SCR ESPd BF DSI
FR083.2R	OREADE	SAINT JEAN DE FOLLEVILLE	FR	5.2. (a)	24 t/h	M	SCR ESPd BF DSI
FR084.1R	ARGENTEUIL	ARGENTEUIL	FR	5.2. (a)	24 t/h	M	SCR ESPd WS3s
FR084.2R	ARGENTEUIL	ARGENTEUIL	FR	5.2. (a)	24 t/h	M	SCR ESPd WS3s
FR087.1R	CIE (CRETEIL)	CRETEIL	FR	5.2. (a)	30 t/h	M	SCR ESPd WS2s
FR087.2R	CIE (CRETEIL)	CRETEIL	FR	5.2. (a)	30 t/h	M	SCR ESPd WS2s

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
FR087.3R	CIE (CRETEIL)	CRETEIL	FR	5.2. (a)	30 t/h	M	SNCR ESPd BF WS2s PC Other
FR091R	GRAND QUEVILLY	GRAND QUEVILLY	FR	5.2. (a)	43.5 t/h	M	Prim SCR ESPd BF sWS
FR092R	HALLUIN	HALLUIN	FR	5.2. (a)	43.5 t/h	M	Prim SCR BF WS2s sWS
FR096.1R	IVRY	Paris	FR	5.2. (a)	100 t/h	M	SCR ESPd WS3s Qch
FR096.2R	IVRY	Paris	FR	5.2. (a)	100 t/h	M	SCR ESPd WS3s Qch
FR098R	Saint-Thibault des Vignes	Saint-Thibault des Vignes	FR	5.2. (a)	3.75 t/h	S	SNCR ESPd BF DS_rea DSI
FR104R	incinerateur fos sur mer kem one	Fos/MER	FR	4.1. (f)	400000 t/yr	H	WS3s Qch
FR106R	Four d'incinération John Zink	Chalampé	FR	5.2. (b)	325 t/d	H	Prim BF WS3s DSI Qch
FR107R	Four John ZINK	Chalampé	FR	5.2. (b)	744 t/d	H	ESPd
FR108	TREDI Saint-Vulbas	Saint-Vulbas (F-01155 Lagnieu)	FR	5.1. (b)	12000 t/yr	H	ESPw WS1s WS2s WS3s Bed PC Qch
FR109	Trédi Salaise	Salaise-sur-Sanne (F-38150)	FR	5.2. (b)	74000 t/yr	H	SNCR ESPd Cyc WS1s WS2s WS3s DSI PC
FR110	Sotrenor	Courrières	FR	5.2. (a)	140000 t/yr	H	BF DSI
FR111.1	SEDIBEX	Sandouville	FR	5.2. (a)	33 t/d	H	ESPd WS2s
FR111.2	SEDIBEX	Sandouville	FR	5.2. (a)	33 t/d	H	ESPd WS2s
FR111.3	SEDIBEX	Sandouville	FR	5.2. (a)	33 t/d	H	ESPd WS2s
HU01	FKF nonprfit Zrt.	Budapest	HU	1.1.	NA	M	SNCR BF Cyc sWS
HU02R	FKF nonprfit Zrt.	Budapest	HU	5.2. (a)	60 t/h	M	SNCR BF Cyc sWS

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
IT01.1R	WTE ACCAM BUSTO ARSIZIO	BUSTO ARSIZIO (VA)	IT	5.2. (a)	30.5 MWht	M	SNCR BF WS1s WS2s
IT01.2R	WTE ACCAM BUSTO ARSIZIO	BUSTO ARSIZIO (VA)	IT	5.2. (a)	30.5 MWth	M	SNCR BF WS1s WS2s
IT02R	ACSM-AGAM.S.p.A.	como	IT	5.2. (a)	39.01 MWth	M	Prim SCR ESPd BF FSI DS_rea DSI
IT03	Brianza Energia Ambiente SpA	DESIO	IT	5.2. (a)	149260 MJ/h	M	SNCR ESPd BF Cyc DS_rcy DS_rea PC
IT05.1R	Termovalorizzatore Silla2	Milano	IT	5.2. (a)	24.17 t/h	M	SNCR SCR ESPd BF DS_rea PC
IT05.2R	Termovalorizzatore Silla2	Milano	IT	5.2. (a)	24.17 t/h	M	SNCR SCR ESPd BF DS_rea PC
IT05.3R	Termovalorizzatore Silla2	Milano	IT	5.2. (a)	24.17 t/h	M	SNCR SCR ESPd BF DS_rea PC
IT06.1R	Termoutilizzatore di Brescia	Brescia	IT	5.2. (a)	43,6 max 21,8 min t/h	O	Prim SNCR SCR BF DSI
IT06.2R	Termoutilizzatore di Brescia	Brescia	IT	5.2. (a)	43,6 max 21,8 min t/h	O	Prim SNCR SCR BF DSI
IT06.3R	Termoutilizzatore di Brescia	Brescia	IT	5.2. (a)	43,6 max 21,8 min t/h	O	Prim SNCR SCR BF DSI
IT07R	Area Impianti Bergamo	Bergamo	IT	5.2. (a)	10.5 t/h	O	SCR BF FSI DS_rea
IT09.1R	Lomellina Energia	Parona (PV)	IT	5.2. (a)	43.4 T/h	O	SNCR BF FSI DS_rea
IT09.2R	Lomellina Energia	Parona (PV)	IT	5.2. (a)	43.4 T/h	O	SNCR BF FSI DSI
IT10.1R	Rea Dalmine	Dalmine	IT	5.2. (a)	9.2 t/h	O	SCR ESPd BF DS_rea Bed PC
IT10.2R	Rea Dalmine	Dalmine	IT	5.2. (a)	9.2 t/h	O	SCR ESPd BF DS_rea Bed PC

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
IT11.1R	SILEA S.p.A.	Valmadrera	IT	5.2. (a)	15.6 t/h	M	SCR BF WS1s DS_rea PC
IT11.2R	SILEA S.p.A.	Valmadrera	IT	5.2. (a)	15.6 t/h	M	SCR BF WS1s WS2s DS_rea PC
IT12.1R	Tecnoborgo	Piacenza	IT	5.2. (a)	15 t/h	M	SNCR SCR ESPd BF DSI Other
IT12.2R	Tecnoborgo	Piacenza	IT	5.2. (a)	15 t/h	M	SNCR SCR ESPd BF DSI Other
IT13.1	PAIP- Polo Ambientale Integrato Provinciale	Parma	IT	5.2. (a)	130000 t/yr	O	SNCR SCR BF DSI
IT13.2	PAIP- Polo Ambientale Integrato Provinciale	Parma	IT	5.2. (a)	130000 t/yr	O	SNCR SCR BF DSI
IT14R	WTE MODENA	Modena	IT	5.2. (a)	27.08 t/h	M	SNCR SCR ESPd BF DS_rea DSI
IT15R	wte rimini	Coriano (RN)	IT	5.2. (a)	20 t/h	M	SNCR SCR BF DS_rea DSI
IT16R	WTE IRE Ravenna	Ravenna	IT	5.2. (a)	6 t/h	O	SNCR BF Cyc WS2s DSI PC Qch
IT17.1R	WTE FEA	Granarolo dell' Emilia , Bologna	IT	5.2. (a)	218500 t/yr	O	Prim SCR BF WS2s DS_rcy DSI Qch
IT17.2R	WTE FEA	Granarolo dell' Emilia , Bologna	IT	5.2. (a)	218500 t/yr	O	Prim SCR BF WS2s DS_rcy DSI Qch
IT18R	WTE Padova S. Lazzaro	Padova	IT	5.2. (a)	600 t/d	M	Prim SNCR SCR BF DSI
IT19	Waste to Energy San Zeno	Arezzo	IT	5.3. (b)	86000 t/yr	M	SNCR BF DS_rea Bed PC
IT21.1R	TRM - IMPIANTO TERMOVALORIZZAZIONE DI TORINO	TORINO	IT	5.2. (a)	421000 t/yr	M	SCR ESPd BF DS_rea

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
IT21.2R	TRM - IMPIANTO TERMOVALORIZZAZIONE DI TORINO	TORINO	IT	5.2. (a)	421000 t/yr	M	SCR ESPd BF DS_rea
IT21.3R	TRM - IMPIANTO TERMOVALORIZZAZIONE DI TORINO	TORINO	IT	5.2. (a)	421000 t/yr	M	SCR ESPd BF DS_rea
IT22R	wte isernia	Pozzilli (IS)	IT	5.2. (a)	13.4 t/h	O	SNCR BF DS_rea DSI
IT23	WTE TRIESTE	TRIESTE	IT	5.2. (a)	223000 t/yr	M	SNCR BF DS_rea DSI Qch
NL01R	EEW Energy from Waste Delfzijl BV	Farmsum	NL	5.2. (a)	46.4 t/h	O	SCR BF DS_rcy DSI
NL02R	Twence Holding B.V.	Hengelo	NL	5.2. (a)	99.5833333333333 t/h	O	SCR ESPd BF WS2s DSI Qch
NL03R	Waste to Energy Plant HVC Dordrecht	Dordrecht	NL	5.2. (a)	38.3 t/h	M	SCR ESPd ESPw WS2s Qch
NL04R	ZAVIN C.V.	Dordrecht	NL	5.2. (b)	30 t/d	C	SCR BF WS2s DSI
NL05R	Sewage Sludge Incineration Plant HVC Dordrecht	Dordrecht	NL	5.2. (a)	45.8333333333333 t/h	S	SNCR ESPd BF WS3s Bed PC
NL06R	SNB	Moerdijk	NL	5.2. (a)	56 t/h	S	Prim SNCR ESPd BF FSI WS2s DSI
NO01.1R	BIR Avfallsenergi AS	Bergen	NO	5.2. (a)	28.7 t/h	M	SNCR ESPd BF WS2s DSI
NO01.2R	BIR Avfallsenergi AS	Bergen	NO	5.2. (a)	28.7 t/h	M	SNCR BF WS3s DS_rea
NO02R	Returkraft AS	Kristiansand S	NO	5.2. (a)	408 t/d	M	SCR BF WS1s DS_rcy DS_rea DSI Qch
NO03.1R	Heimdal Varmesentral	Trondheim	NO	5.2. (a)	6 t/h	M	Prim SNCR ESPd WS1s WS2s WS3s DSI Qch

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
NO03.2R	Heimdal Varmesentral	Trondheim	NO	5.2. (a)	6 t/h	M	Prim SNCR ESPd WS1s WS2s WS3s DSI Qch
NO03.3R	Heimdal Varmesentral	Trondheim	NO	5.2. (a)	18 t/h	M	Prim SNCR BF WS1s WS2s WS3s DSI Qch
PL01.1R	Incineration plant of non-hazardous waste (STUOŚ)	WARSAW	PL	5.2. (a)	671 t/d	S	Prim SNCR SCR Cyc DSI
PL01.2R	Incineration plant of non-hazardous waste (STUOŚ)	WARSAW	PL	5.2. (a)	671 t/d	S	Prim SNCR SCR Cyc DSI
PL02R	Incineration plant of non-hazardous waste (STUO)	Cracow	PL	5.2. (a)	2267 t/h	S	SNCR ESPd BF Cyc DS_rea
PL03R	WASTE INCINERATION PLANT SARPI DABROWA GORNICZA	DĄBROWA GÓRNICZA	PL	5.2. (b)	6.25 t/h	H	Prim SNCR SCR ESPd BF FSI WS1s WS2s DS_rcy DSI Bed Qch
PL04	Incineration plant for waste other than hazardous and inert	Warsaw	PL	5.2. (a)	60000 t/yr	M	Prim SNCR BF DS_rcy DSI Bed
PL05	Incineration plant for waste other than hazardous and inert	Nowiny, com. Sitkówka - Nowiny	PL	5.2. (a)	28780 t/yr	S	SNCR BF Cyc DS_rcy
PL06	Instalacja odzysku chlorowodoru z odpadowych związków chloroorganicznych	Włocławek	PL	4.3.	900000 t/yr	H	ESPd ESPw WS3s
PL07.1R	Instalacja Termicznego Przekształcania Osadów i Skratek (ITPOS)	Łódź	PL	6.11.	1026260 PE	S	SNCR BF DSI
PL07.2R	Instalacja Termicznego Przekształcania Osadów i Skratek (ITPOS)	Łódź	PL	6.11.	1026260 PE	S	SNCR BF DSI
PT01.1	Central de Tratamento de Resíduos Sólidos Urbanos	Loures - S. João Talha	PT	5.2. (a)	84 t/h	M	SNCR BF sWS
PT01.2	Central de Tratamento de Resíduos Sólidos Urbanos	Loures - S. João Talha	PT	5.2. (a)	84 t/h	M	SNCR BF sWS

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
PT01.3	Central de Tratamento de Resíduos Sólidos Urbanos	Loures - S. João Talha	PT	5.2. (a)	84 t/h	M	SNCR BF sWS
PT02.1	Lipor	Maia	PT	5.2. (a)	380000 t/yr	M	SNCR BF sWS DSI
PT02.2	Lipor	Maia	PT	5.2. (a)	380000 t/yr	M	SNCR BF sWS DSI
PT03.1	Estação de Tratamento de Resíduos Sólidos da Meia Serra	Santa Cruz	PT	5.2. (a)	8 t/h	M	SNCR BF sWS
PT03.2	Estação de Tratamento de Resíduos Sólidos da Meia Serra	Santa Cruz	PT	5.2. (a)	8 t/h	M	SNCR BF sWS
SE02R	Umeå Energi AB	Umeå	SE	5.2. (a)	20 t/h	M	Prim SNCR BF WS2s DSI Other
SE03R	Gärstadverket	Linköping	SE	5.2. (a)	26.4 t/h	O	SNCR BF WS2s DSI Qch Other
SE06R	Avfallskraftvärmeverket Renova	Göteborg	SE	5.2. (a)	73 t/h	O	Prim SCR ESPd ESPw WS3s Qch
SE09R	Filbornaverket	Helsingborg	SE	5.2. (a)	25 t/h	O	SNCR BF WS1s
SE15	NA	NA	SE	NA	NA	#N/A	#REF!
SE20R	Bristaverket	Märsta	SE	5.2. (a)	36 t/h	M	SNCR BF WS1s WS2s DSI Qch
SE21R	Ekokem Sweden	Kumla	SE	5.2. (b)	200000 t/yr	H	SNCR BF WS2s DSI Other
UK01R	Veolia High Temperature Icineration Plant	Ellesmere Port	UK	5.2. (b)	276.98 t/d	H	SNCR BF WS2s Qch
UK02R	Tradebe Fawley Limited	Southampton	UK	5.2. (a)	124 t	H	ESPw WS1s Bed Qch
UK03R	Kirklees Energy from Waste plant	Huddersfield	UK	5.2. (a)	17 t/h	M	SNCR BF WS1s

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
UK04R	Bolton Thermal Recovery Facility	Bolton	UK	5.2. (a)	13 t/h	M	SNCR BF DS_rcy
UK05.1R	Stoke EfW	Stoke on Trent	UK	5.2. (a)	12 t	M	SNCR BF WS1s DSI
UK05.2R	Stoke EfW	Stoke on Trent	UK	5.2. (a)	12 t	M	SNCR BF WS1s DSI
UK06.1R	Integra South East ERF Portsmouth	Portsmouth	UK	5.3. (b)	12 t/h	M	SNCR BF sWS
UK06.2R	Integra South East ERF Portsmouth	Portsmouth	UK	5.3. (b)	12 t/h	M	SNCR BF sWS
UK07.1R	ALLINGTON INCINERATOR	Allington, Maidstone	UK	5.2. (a)	3 t/h	M	Prim SNCR ESPd BF DS_rea
UK07.2R	ALLINGTON INCINERATOR	Allington, Maidstone	UK	5.2. (a)	3 t/h	M	Prim SNCR ESPd BF DS_rea
UK07.3R	ALLINGTON INCINERATOR	Allington, Maidstone	UK	5.2. (a)	3 t/h	M	Prim SNCR ESPd BF DS_rea
UK08.1R	CSWDC Ltd	Coventry	UK	5.2. (a)	36 t/h	M	SNCR BF DS_rcy
UK08.2R	CSWDC Ltd	Coventry	UK	5.2. (a)	36 t/h	M	SNCR BF DS_rcy
UK08.3R	CSWDC Ltd	Coventry	UK	5.2. (a)	36 t/h	M	SNCR BF DS_rcy
UK09.1R	NA	London	UK	5.2. (a)	90 t/h	M	SNCR BF sWS DSI
UK09.2R	NA	London	UK	5.2. (a)	90 t/h	M	SNCR BF sWS DSI
UK09.3R	NA	London	UK	5.2. (a)	90 t/h	M	SNCR BF sWS DSI
UK10.1R	MES Environmental Ltd Wolverhampton	Wolverhampton	UK	5.2. (a)	7 per stream per hour	M	SNCR BF WS1s DSI
UK10.2R	MES Environmental Ltd Wolverhampton	Wolverhampton	UK	5.2. (a)	7 per stream per hour	M	SNCR BF WS1s DSI
UK11.1R	Dudley EfW	Dudley	UK	5.2. (a)	6 per hour	M	SNCR BF WS1s DSI Other

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D. 2010/75/EU)	Capacity	Pred. Waste Burnt	Techniques to reduce air emissions
AT01R	MVA Floetzersteig	Vienna	AT	5.2. (a)	27.9 t/h	M	SCR BF WS2s DSI
UK11.2R	Dudley EfW	Dudley	UK	5.2. (a)	6 per hour	M	SNCR BF WS1s DSI Other
UK12R	NA	Lincoln	UK	5.2. (a)	19.24 t/h	M	SNCR BF DS_rea PC
UK13.1R	NA	Nottingham	UK	5.2. (a)	11.3 t/h	M	SNCR BF DSI
UK13.2R	NA	Nottingham	UK	5.2. (a)	11.3 t/h	M	SNCR BF DSI
UK14.1R	Knostrop Clinical Waste Incinerator	Leeds	UK	5.2. (b)	2 t/h	C	BF DS_rea DSI
UK14.2R	Knostrop Clinical Waste Incinerator	Leeds	UK	5.2. (b)	2 t/h	C	BF DS_rea DSI
UK15R	Thames Water Utilities Ltd	Barking , Essex , IG11 0AD	UK	5.2. (a)	13.5 t/h	S	Prim ESPd BF WS2s Other
UK17R	Blackburn Meadows Renewable Energy Plant	Sheffield	UK	5.2. (a)	25 t/h	O	SNCR BF DSI
UK18	Kemsley CHP Plant K2 Incinerator	Kemsley, Sittingbourne, Kent	UK	5.2. (a)	29 MW thermal input	O	SNCR BF DSI

Notes:
Main Activity: 1.1 Energy – Combustion // 4 Chemical industry // 4.1(f) Chemical – Production of organic chemicals – Halogenic hydrocarbons // 4.3 Chemical – Production of phosphorous-, nitrogen- or potassium-based fertilisers // 5.1 (a) Waste – Disposal or recovery of hazardous waste – Biological treatment // 5.1 (b) Waste – Disposal or recovery of hazardous waste – Physico-chemical treatment // 5.2 (a) Waste – Disposal or recovery of waste in waste (co-)incineration plants – Non-hazardous waste // 5.2 (b) Waste – Disposal or recovery of waste in waste (co-)incineration plants – Hazardous waste // 5.3 (a) Waste – Disposal of non-hazardous waste // 5.3 (b) Waste – Recovery, or a mix of recovery and disposal, of non-hazardous waste // 6.11 Other – Independently operated treatment of waste water.

Pred. Waste Burnt: Prevalent waste burnt: M= municipal solid waste; S= sewage sludge; O= other non-hazardous waste; C= clinical waste; H= hazardous waste

Techniques to reduce air emissions: Bed = Adsorption bed // BF = Bag Filter // Cyc = Multicyclone // DS_rcy = Dry scrubber Recirculation system // DS_rea = Dry scrubber Mixing unitreactor // DSI = Dry sorbent injection // ESPd = Dry Electrostatic precipitator // ESPw = Wet Electrostatic precipitator // FSI = In-furnace desulphurisation // PC = post combustion // Prim = Primary techniques // Qch = Quench system // SCR = Selective Catalytic Reduction // SNCR = Selective Non-Catalytic Reduction // sWS = Semi-wet scrubber // WS1s = 1-stage wet scrubber // WS2s = 2-stage wet scrubber // WS3s = 3-stage wet scrubber
NA = Data not available

8.7 List of European Bottom Ash Treatment Plants that participated in the 2016 data collection.

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D 2010/75/EU)	IBA Treatment Capacity (t/yr)	Type of sorting	Are the bottom ash treatment plant and Waste Incineration Plant within the same installation?
AT.B-01	NUA-Abfallwirtschaft Anlage Hohenruppersdorf	Hohenruppersdorf	AT	5.3. (b)	40	M,F,E,Dw,SS	Out
BE.B-01	Ipalle	Beloeil	BE	5.2. (a)	100	F,E,A,B,SS	In
BE.B-02	Indaver Doel	Beveren	BE	5.2. (a)	NA	M,F,E,S,Dw,SS	In
CZ.B-01R	WtE Plant -SAKO Brno, a.s.	Brno	CZ	5.2. (a)	120000	M,F,E,	In
DE.B-01	Schlackenaufbereitungsanlage Würzburg	Würzburg	DE	NA	180	M,F,E,A,SS	Out
DE.B-02	MDSU Reesen	Burg OT Reesen	DE	5.3. (a)	400	M,F,E,A,Dw,SS	NA
DE.B-03	Slagtreatment Facility Kochendorf	Bad Friedrichshall-Kochendorf	DE	5.1. (f)	300000	M,F,E,SS	Out
DE.B-04	STORK Umweltdienste GmbH	Magdeburg	DE	5.3. (b)	600000	M,F,E,I,N,O,A, SS	Out
DE.B-05	RAA Sandersdorf-Brehna	Sandersdorf-Brehna	DE	5.3. (b)	340	M,F,E,A,SS	Out
DE.B-06	Schlackenaufbereitungsanlage Krefeld	Krefeld	DE	NA	216	M,F,E,A,SS	Out
DE.B-07	MAV Lünen GmbH, Buchenberg 70	Lünen	DE	5.3. (b)	450	M,F,E,A,SS	Out
DE.B-08	Heidemann Bremen	Bremen	DE	5.3. (b)	250000	M,F,E,I,A,SS	Out
DE.B-09	AVA Augsburg GmbH	Augsburg	DE	5.2. (a)	70000	M,F,E,SS	In
DE.B-10	Müllverwertung Borsigstrasse GmbH	Hamburg	DE	5.3. (b)	90000	M,F,E,	In
DE.B-11	Müllverwertung Rugenberger Damm GmbH & Co. KG	Hamburg	DE	5.3. (b)	90000	M,F,E,A	In
DE.B-12	AEZ Asdonkshof	Kamp-Lintfort	DE	5.3. (b)	79000	F,E,A,SS	In

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D 2010/75/EU)	IBA Treatment Capacity (t/yr)	Type of sorting	Are the bottom ash treatment plant and Waste Incineration Plant within the same installation?
AT.B-01	NUA-Abfallwirtschaft Anlage Hohenruppersdorf	Hohenruppersdorf	AT	5.3. (b)	40	M,F,E,Dw,SS	Out
BE.B-01	Ipalle	Beloeil	BE	5.2. (a)	100	F,E,A,B,SS	In
BE.B-02	Indaver Doel	Beveren	BE	5.2. (a)	NA	M,F,E,S,Dw,SS	In
CZ.B-01R	WtE Plant -SAKO Brno, a.s.	Brno	CZ	5.2. (a)	120000	M,F,E,	In
DE.B-01	Schlackenaufbereitungsanlage Würzburg	Würzburg	DE	NA	180	M,F,E,A,SS	Out
DE.B-13	WVW Wertstoffverwertung Wuppertal GmbH	Wuppertal	DE	5.2. (a)	140.000,00	M,F,E,I,A,B,SS	In
DE.B-14	ZV MVA Ingolstadt	Ingolstadt	DE	5.2. (a)	NA	M,F,E,B,SS	In
DK.B-01	Bottom ash treatment plant	Copenhagen	DK	5.3. (b)	125000	M,F,E,I,A,SS	Out
DK.B-02	Meldgaard Recycling A/S	NA	DK	5.3. (b)	750000	M,F,E,I,A,SS	Out
DK.B-03	Jørgen Rasmussen Gruppen A/S Restproduktplads	Aalborg	DK	5.3. (b)	180	M,F,E,A,SS	Out
ES.B-01R	TIRME	Palma de Mallorca	ES	5.2. (a)	200000	M,F,E,A,SS	In
FR.B-01	SMECO	PONTMAIN	FR	5.3. (b)	5500	F,E,SS	In
FR.B-02	SET Mont Blanc (Passy)	Passy	FR	5.3. (b)	12000	F,E,SS	In
FR.B-03	SCOREL	Ouarville	FR	5.3. (b)	90000	F,E,A,SS	In
FR.B-04	NA	VEDENE	FR	5.3. (b)	87000	M,F,E,SS	In
FR.B-05	ARGENTEUIL	ARGENTEUIL	FR	5.2. (a)	54250	F,E,A,SS	In
FR.B-06	Routière de l'Est Parisien (REP) IME Clayes - Souilly	Claye Souilly	FR	5.3. (b)	200 000	M,F,E,A,SS	Out

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D 2010/75/EU)	IBA Treatment Capacity (t/yr)	Type of sorting	Are the bottom ash treatment plant and Waste Incineration Plant within the same installation?
AT.B-01	NUA-Abfallwirtschaft Anlage Hohenruppersdorf	Hohenruppersdorf	AT	5.3. (b)	40	M,F,E,Dw,SS	Out
BE.B-01	Ipalle	Beloeil	BE	5.2. (a)	100	F,E,A,B,SS	In
BE.B-02	Indaver Doel	Beveren	BE	5.2. (a)	NA	M,F,E,S,Dw,SS	In
CZ.B-01R	WtE Plant -SAKO Brno, a.s.	Brno	CZ	5.2. (a)	120000	M,F,E,	In
DE.B-01	Schlackenaufbereitungsanlage Würzburg	Würzburg	DE	NA	180	M,F,E,A,SS	Out
FR.B-07	BEDEMAT	BEDENAC	FR	5.3. (b)	120000	M,F,E,A,SS	Out
FR.B-08	RECYDEM	LOURCHES	FR	5.3. (b)	100000	M,F,E,SS	Out
FR.B-09	PLANGUENOUAL	PLANGUENOUAL	FR	5.3. (b)	7000	F,SS	In
FR.B-10	PAU	LESCAR	FR	5.3. (b)	20000	F,E,SS	Out
IT.B-01	Officina dell'Ambiente S.p.A.	Lomello (PV)	IT	5.3. (b)	250	M,F,E,A,SS	Out
IT.B-02	RMB S.p.A.	Polpenazze del Garda (BS)	IT	5.3. (b)	620	M,F,E,I,A,S,Dw,Dd,SS	Out
NL.B-01	Twence bv SOI	Hengelo	NL	5.3. (b)	180	F,E,A,B,SS	In
NL.B-02	waste to energy plant HVC Dordrecht	Alkmaar	NL	5.3. (b)	320000	F,E,A,B,SS	Out
NL.B-03	Centrale Bodemas Opwerk Installatie (CBOI)	Sluiskil	NL	5.3. (b)	700000	M,F,E,A,B,SS	Out
PT.B-01	Instalação de Tratamento e Valorização de Escórias	Vila Franca de Xira	PT	5.3. (b)	200000	M,F,E,A,SS	Out
PT.B-02	Estação de Tratamento de Resíduos Sólidos da Meia Serra	Santa Cruz	PT	NA	NA	F	In
SE.B-01	Gärstad waste treatment plant	Linköping	SE	5.3. (b)	87000	F,E,SS	In

Ref. Line	Name installation	City	Country	Main Activity (Annex I-D 2010/75/EU)	IBA Treatment Capacity (t/yr)	Type of sorting	Are the bottom ash treatment plant and Waste Incineration Plant within the same installation?
AT.B-01	NUA-Abfallwirtschaft Anlage Hohenruppersdorf	Hohenruppersdorf	AT	5.3. (b)	40	M,F,E,Dw,SS	Out
BE.B-01	Ipalle	Beloeil	BE	5.2. (a)	100	F,E,A,B,SS	In
BE.B-02	Indaver Doel	Beveren	BE	5.2. (a)	NA	M,F,E,S,Dw,SS	In
CZ.B-01R	WtE Plant -SAKO Brno, a.s.	Brno	CZ	5.2. (a)	120000	M,F,E,	In
DE.B-01	Schlackenaufbereitungsanlage Würzburg	Würzburg	DE	NA	180	M,F,E,A,SS	Out
SE.B-02	Spillepeng Waste treament site	Malmö	SE	5.3. (b)	129905	F,E,A,SS	Out
SE.B-03	Sävenäs waste incineration plant	Gothenburg	SE	5.3. (b)	100 000	M,F,E,I,SS	Out
UK.B-01	Riverside Resource Recovery Limited	Tilbury	UK	5.3. (b)	200000	F,E,A,B,SS	Out

Notes:

Main Activity: 5.1. (f) Waste – Disposal or recovery of hazardous waste – Recycling/reclamation of inorganic materials other than metals or metal compound // 5.2 (a) Waste – Disposal or recovery of waste in waste (co-)incineration plants – Non-hazardous waste // 5.3 (a) Waste – Disposal of non-hazardous waste // 5.3 (b) Waste – Recovery, or a mix of recovery and disposal, of non-hazardous waste.

Type of sorting: A = Wind shifter / air/ -aeraulic separation // B = Ballistic separation // Dd = Density separation (dry) // Dw = Density separation (wet) // E = Eddy current separation // F = Ferromagnetic separation // I = Induction all-metal separation // M = Manual sorting // N = Near-Infrared Separation // O = Optical separation other than NIS // S = Sink-float separation // SS = Screening / Sieving.

Are the bottom ash treatment plant and Waste Incineration Plant within the same installation? Out = Not in the same installation // In = Same installation

NA = Data not available

9 GLOSSARY

This glossary is meant to facilitate the understanding of the information contained in this document. The definitions of terms in this glossary are not legal definitions (even if some of them may coincide with definitions given in European legislation), they are meant to help the reader understand some key terms in the context of their use in the specific sector covered by this document.

This glossary is divided into the following sections:

I. ISO country codes
II. Monetary units
III. Unit prefixes, number separators and notations
IV. Units and measures
V. Chemical elements
VI. Chemical formulae commonly used in this document
VII. Acronyms
VIII. Definitions

I. ISO country codes

ISO code	Country
***Member States* ([*])**	
AT	Austria
BE	Belgium
BG	Bulgaria
CZ	Czech Republic
CY	Cyprus
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom
Non-member countries	
NO	Norway
([*]) The protocol order of the Member States is based on the alphabetical order of their geographical names in the original language(s).	

II. Monetary units

Code([1])	**Country/territory**	**Currency**
Member State currencies		
EUR	Euro area ([2])	euro (pl. euros)
DKK	Denmark	Danish krone (pl. kroner)
GBP	United Kingdom	pound sterling (inv.)
Other currencies		
USD	United States	US dollar

[1] ISO 4217 codes.

[2] Includes Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, the Netherlands, Portugal, Slovakia, Slovenia and Spain.

III. Unit prefixes, number separators and notations

Numbers in this document are written using the '.' character as the decimal separator and the space as the separator for thousands.

The symbol ~ (around; about) is the notation used to indicate approximation.

The symbol Δ (delta) is the notation used to indicate a difference.

The following table contains the frequently used prefixes:

Symbol	**Prefix**	**10^n**	**Word**	**Decimal Number**
M	mega	10^6	Million	1 000 000
k	kilo	10^3	Thousand	1 000
-------	-------	1	One	1
m	milli	10^{-3}	Thousandth	0.001
µ	micro	10^{-6}	Millionth	0.000 001
n	nano	10^{-9}	Billionth	0.000 000 001

IV. Units and measures

Unit Symbol	Unit Name	Measure name (measure symbol)	Conversion and comment
atm	normal atmosphere	Pressure (P)	1 atm = 101 325 N/m^2
bar	bar	Pressure (P)	1.013 bar = 100 kPa = 1 atm
°C	degree Celsius	Temperature (T) temperature difference (ΔT)	
d	day	Time	
g	gram	Weight	
h	hour	Time	
J	joule	Energy	
K	Kelvin	Temperature (T) temperature difference (ΔT)	0 °C = 273.15 K
kcal	kilocalorie	Energy	1 kcal = 4.1868 kJ
kg	kilogram	Weight	
kJ	kilojoule	Energy	
kPa	kilopascal	Pressure	
kWh	kilowatt-hour	Energy	1 kWh = 3 600 kJ
l	litre	Volume	
m	metre	Length	
m^2	square metre	Area	
m^3	cubic metre	Volume	
mg	milligram	Weight	1 mg = 10^{-3} g
mm	millimetre		1 mm = 10^{-3} m
min	minute		
MW$_e$	megawatts electric (energy)	Electric energy	
MW$_{th}$	megawatts thermal (energy)	Thermal energy Heat	
nm	nanometre		1 nm = 10^{-9} m
Nm^3	normal cubic metre	Volume	at 101.325 kPa, 273.15 K
OU$_E$	European odour unit	Odour	
Pa	pascal		1 Pa = 1 N/m^2
ppb	parts per billion	Composition of mixtures	1 ppb = 10^{-9}
ppm	parts per million	Composition of mixtures	1 ppm = 10^{-6}
ppmv	parts per million by volume	Composition of mixtures	
rpm RPM	Revolutions per minute	Rotational speed, frequency	
s	second	Time	
St	stokes	Kinematic viscosity	1 St = 10^{-4} m^2/s; old, cgs unit
t	metric tonne	Weight	1 t = 1 000 kg or 10^6 g
t/d	tonnes per day	Mass flow Materials consumption	
t/yr	tonnes per year	Mass flow Materials consumption	
vol-% % v/v	percentage by volume	Composition of mixtures	
wt-% % w/w	percentage by weight	Composition of mixtures	
W	watt	Power	1 W = 1 J/s
yr	year	Time	
µm	micrometre	Length	1 µm = 10^{-6} m

V. Chemical elements

Symbol	Name	Symbol	Name
Ac	Actinium	Mn	Manganese
Ag	Silver	Mo	Molybdenum
Al	Aluminium	N	Nitrogen
Am	Americium	Na	Sodium
Ar	Argon	Nb	Niobium
As	Arsenic	Nd	Neodymium
At	Astatine	Ne	Neon
Au	Gold	Ni	Nickel
B	Boron	No	Nobelium
Ba	Barium	Np	Neptunium
Be	Beryllium	O	Oxygen
Bi	Bismuth	Os	Osmium
Bk	Berkelium	P	Phosphorus
Br	Bromine	Pa	Protactinium
C	Carbon	Pb	Lead
Ca	Calcium	Pd	Palladium
Cd	Cadmium	Pm	Promethium
Ce	Cerium	Po	Polonium
Cf	Californium	Pr	Praseodymium
Cl	Chlorine	Pt	Platinum
Cm	Curium	Pu	Plutonium
Co	Cobalt	Ra	Radium
Cr	Chromium	Rb	Rubidium
Cs	Caesium	Re	Rhenium
Cu	Copper	Rf	Rutherfordium
Dy	Dysprosium	Rh	Rhodium
Er	Erbium	Rn	Radon
Es	Einsteinium	Ru	Ruthenium
Eu	Europium	S	Sulphur
F	Fluorine	Sb	Antimony
Fe	Iron	Sc	Scandium
Fm	Fermium	Se	Selenium
Fr	Francium	Si	Silicon
Ga	Gallium	Sm	Samarium
Gd	Gadolinium	Sn	Tin
Ge	Germanium	Sr	Strontium
H	Hydrogen	Ta	Tantalum
He	Helium	Tb	Terbium
Hf	Hafnium	Tc	Technetium
Hg	Mercury	Te	Tellurium
Ho	Holmium	Th	Thorium
I	Iodine	Ti	Titanium
In	Indium	Tl	Thallium
Ir	Iridium	Tm	Thulium
K	Potassium	U	Uranium
Kr	Krypton	V	Vanadium
La	Lanthanum	W	Tungsten
Li	Lithium	Xe	Xenon
Lr	Lawrencium	Y	Yttrium
Lu	Lutetium	Yb	Ytterbium
Md	Mendelevium	Zn	Zinc
Mg	Magnesium	Zr	Zirconium

VI. Chemical formulae commonly used in this document

Chemical formula	Name (explanation)
CH_4	Methane
Cl^-	Chloride ion
CN^-	Cyanide ion
CO	Carbon monoxide
F^-	Fluoride ion
HCl	Hydrogen chloride
HF	Hydrogen fluoride
H_2S	Hydrogen sulphide
H_2SO_4	Sulphuric acid
NaOH	Sodium hydroxide. Also called caustic soda
NH_3	Ammonia
N_2O	Nitrous oxide
NO^{2-}	Nitrite ion
NO^{3-}	Nitrate ion
NO_X	Nitrogen oxides (mixture of NO and NO_2)
SO_3^{2-}	Suphite ion
SO_X	Sulphur oxides (mixture of SO_2 and SO_3)

VII. Acronyms

Acronym	Full phrase
ACC	Air-cooled condenser
AMS	Automated measuring system
APC	Air pollution control, term used elsewhere for Flue-gas Cleaning (FGC)
BAT	Best Available Techniques, as defined in Article 3(10) of the IED
BAT-AEL	Best Available Techniques - associated emission level, , as defined in Article 3(13) of the IED
BAT-AEPL	Best Available Techniques - associated performance emission level, as described in section 3.3.2 of Commission Implementing Decision 2012/119/EU
BF	Bag Filter
BFB	Bubbling Fluidised Bed – a type of fluidised bed (see also CFB)
BOD	Biochemical oxygen demand
BREF	Best available techniques (BAT) reference document
BTEX	Benzene, toluene, ethylbenzene, xylene
CAPEX	Capital expenditure
CAS	Chemical abstracts service (chemicals registry number)
CEFIC	Conseil Européen de l’Industrie Chimique (European Chemical Industry Council)
CEN	Comité Européen de Normalisation (European Committee for standardisation)
CFB	Circulating Fluidised Bed – a type of fluidised bed (see also BFB)
CFC	Chlorofluorocarbon
CFD	Computerised fluid dynamics - a modelling technique used to predict gas flow and temperature in incinerators and other systems
CHP	Combined heat and power (cogeneration).
COD	Chemical oxygen demand
CV	Calorific value, e.g. in MJ/kg or MJ/m^3
DIN	Deutsches Institut für Normung (German national organisation for standardisation)
DE	Destruction Efficiency - the overall percentage of the substance that is fed to an incineration process that is destroyed and not then emitted to all combined environmental media
DRE	Destruction and Removal Efficiency - the percentage of a substance fed to an incineration process that is not then emitted from the stack
DH	District heating – a network supplying heat via hot water or steam
DS	Dry solids (content)
EA	Environment Agency (England and Wales)
EDTA	Ethylenediaminetetraacetic acid
EDTMA	Ethylenediaminetetra (methylenephosphonic) acid
EEA	European Environment Agency
EFTA	European Free Trade Association
ELV	Emission limit value
EMAS	Eco-Management and Audit Scheme (Council Regulation (EC) No 1221/2009)
EMS	Environmental management system.
EN	European Norming (EN standards)
EPA	Environmental Protection Agency (US)
ESP	Electrostatic precipitator
EQS	Environmental quality standard
EU	European Union
EU+	European Union + EFTA (European Free Trade Association) countries + Candidate countries
EWC	European waste code
FB	Fluidised bed
FBC	Fluidised bed combustion

Acronym	Full phrase
FD	Forced draught – often used in the context of forced draught fans which use positive pressure to activate (typically) down stream FGC equipment (see also ID)
FGC	Flue-gas cleaning
FGR	Flue-gas recirculation
FGT	Flue-gas treatment, term used elsewhere for Flue-gas Cleaning (FGC)
FID	Flame ionisation detector
GHG	Greenhouse Gases (e.g. CO_2)
HCB	Hexachlorobenzene
HCFC	Hydrogen chloro fluoro carbons
HFC	Hydrofluoro carbon
HFO	Heavy fuel oil
HP	High pressure
HW	Hazardous waste
HWI	Hazardous waste incinerator
IBA	Incinerator bottom ash
ID	Induced draught – often used in the context of induced draught fans that are used to draw incineration gases through the incineration plant
IED	Industrial Emission Directive (2010/75/EU)
IPPC	Integrated pollution prevention and control
IR	Infrared
ISO	International Organisation for Standardisation
JRC	Joint Research Centre
L/S	Liquid/solid ratio
LCA	Life cycle assessment.
LCP	Large combustion plant
LCV	Lower Calorific Value, e.g. in kJ/kg - the calorific value of a substance including its moisture content (which will consume a part of the total energy by transforming into vapour during the combustion process). (See also UCV).
LDAR	Leak detection and repair
LDL	Analytical lower determination level is the practical level for which a concentration can be accurately determined over a longer period. It is clear that this value is higher than the theoretical level of determination (LOD). The former is used in this text and is based on practical experience (e.g. drift), the latter is more theoretically correct. It is known that all installations comply with LOD.
LFO	Light fuel oil
LHV	Lower heating value
LOI	Loss on ignition – often referred to in the context of a test used for assessing organic content of materials.
LoW	List of Waste (from COM Decision 2000/532/EC)
LPG	Liquefied petroleum gas
LOQ	Limit of quantification
MP	Medium pressure
MS	(European Union) Member State
MSW	Municipal solid waste
MSWI	Municipal solid waste incinerator
N	Normal – refers to volume of gases under normal operating conditions with a temperature of 273.15 K and pressure of 101.325 kPa
NA	Not applicable
ND	Not determined / Not detectable
NGO	non-Governmental organisation
NI	No information
NIRS	Near-infrared spectroscopy
NMVOC	non-Methane Volatile Organic Compound
NOC	Normal Operating Conditions
ODS	Ozone depletion substances – as defined by the Montreal Protocol
OJ	Official journal (of the EU)
OPEX	Operating expenditure/costs

Acronym	Full phrase
OTNOC	Other Than Normal Operating Conditions
PAC	Powdered activated carbon
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PCC	Post combustion chamber - a term applied to the zone after the initial combustion zone where gas burnout occurs (also referred to as the secondary combustion chamber or SCC)
PCDD/F	Polychlorinated dibenzodioxins/dibenzofurans
PEMS	Predictive emissions monitoring system
PIC(s)	Products of incomplete combustion
PM	Particulate matter
POPs	Persistent organic pollutants
PRTR	European Pollutant Release and Transfer Register
PSA	Pressure swing adsorption
QMS	Quality management system
RDF	Refuse derived fuel
SCR	Selective catalytic reduction
SD	Shut down
SNCR	Selective non-catalytic reduction
SRF	Solid recovered fuel, see RDF
SS	Sewage sludge
SSI	Sewage sludge incinerator
SU	startup
TDS	Total dissolved solids
TEQ	Toxicity equivalents (iTEQ: international toxicity equivalents)
TG	Urbo generator
TOC	Total organic carbon
TMT	2,4,6-Trimercapto-1,3,5-triazine - A sulphide reagent used for heavy metal capture in WWT plants
TSS	Total suspended solids
TWG	Technical Working Group
UV	Ultraviolet
VOC	Volatile organic compound
WDF	see RDF
WEP	Wet Electrostatic Precipitator
WI	Waste incinerator/incineration
WFD	Waste Framework Directive (2008/98/EC), now superseded by the IED
WT	Waste treatment
WWT(P)	Waste water treatment (plant)

VIII. Definitions

Activated sludge process	A biological process for treating municipal and industrial waste waters by the use of microorganisms under aerobic conditions.
Aerobic processes	Biological processes that occur in the presence of oxygen.
Anaerobic processes	Biological processes that occur in the absence of oxygen and other electron accepting substances except carbon dioxide/carbonate.
Biofuel	Biofuel as defined in Article 2(i) of Directive 2009/28/EC.
Biological nutrient removal	The removal of nitrogen and/or phosphorus from aqueous effluents in biological treatment processes.
Biomass	Biomass as defined in Article 2(e) of Directive 2009/28/EC.
Biowaste	Biowaste as defined in Article 3(4) of Directive 2008/98/EC.
Bottom ash	Solid residues from a combustion process, see "Slags and/or bottom ashes".
Bottom ash treatment plant	Plant treating slags and/or bottom ashes from the incineration of waste in order to separate and recover the valuable fraction and to allow the beneficial use of the remaining fraction.
By-product	A substance or object, resulting from a production process, the primary aim of which is not the production of that item and which is not regarded as being waste, and which meets the requirements of Article 5 of Directive 2008/98/EC on waste.
Cake	Solid or semisolid material remaining on a filter after pressure filtration.
CAS	Chemical abstracts service (registry number). A division of the American Chemical Society holds registries of chemical substances; providing a unique numerical identifier for chemical compounds, polymers, biological sequences, mixtures and alloys which designates only one substance.
Certification	Procedure by which a third party gives written assurance that a product, process or service conforms to specified requirements. Certification can apply to instruments, equipment and/or personnel.
Channelled emissions	Emissions of pollutants into the environment through any kind of pipe, regardless of the shape of its cross-section.
Clinical waste	Infectious or otherwise hazardous waste arising from healthcare institutions (e.g. hospitals)
Composite sample	A composite sample refers to a water sample which is taken continuously over a given period, or a sample consisting of several samples taken either continuously or discontinuously over a given period (e.g. during 24 hours) and blended.
Continuous measurement	Measurement with an automated measuring system (AMS) permanently installed on site for continuous monitoring of emissions, according to EN 14181:2004.
Cooling water	Water used for energy transfer (heat removal from components and industrial equipment), which is kept in a network separated from industrial water and which can be released back to receiving waters without further treatment.
Co-product	Any of two or more products coming from the same unit process or product system.
Decommissioning	The shutdown of an installation including decontamination and/or dismantling.
Diffuse emissions	Emissions of pollutants into the environment arising from a direct (non-channelled) contact of volatile or dusty substances with the environment under normal operating conditions. Diffuse emission sources can be point, linear, surface or volume sources. Multiple emissions inside a building are normally considered as diffuse emissions. Other examples of diffuse emissions include venting from storage facilities during loading and unloading, the storage of solid matter in the open air, separation pools in oil refineries, vents, doors in coke plants, mercury emission from electrolysis cells, etc.
Diffuse emissions sources	Multiple sources of similar diffuse or direct emissions distributed inside a defined area; they can be point, linear, surface or volume sources.
Digestate	The solid residue remaining after anaerobic digestion.

Dioxins	Polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs).
Direct measurements	Specific quantitative determination of the emitted compounds at source.
Discharge	Physical release of a pollutant through a defined outlet, (i.e. channelled), system, (e.g. sewer, stack, vent, curbing area, outfall).
Discrete	Not continuous, i.e. having gaps between all possible values.
Drainage	Natural or artificial removal of surface and sub-surface water from an area, including surface streams and groundwater pathways.
Draining	Emptying the liquid contents of a system to a collection system or other storage system, creating a possible liquid waste stream.
Emission	The direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources in the installation into the air, water or land (from Directive 2010/75/EU).
Emissions factors	Numbers that can be multiplied by known data such as plant/process activity data or throughput data to estimate emissions.
Exhaust gas (or exhaust air)	Gas/air stream coming off a combustion or extraction process; it may contain gaseous or particulate components. There is no link with exhausting through a stack.
Existing plant	A plant that is not a new plant.
Flue-gas	A mixture of combustion products and air leaving a combustion chamber and that is directed up a stack to be emitted.
Fly ash	Particles from the incineration chamber or formed within the flue-gas stream that are transported in the flue-gas.
Fouling	A process of becoming dusty or clogged, e.g. by undesirable foreign matter, such as dirt and other material, accumulating and clogging pores and coating surfaces.
Fugitive emissions	Emissions of pollutants into the environment resulting from a gradual loss of tightness of a piece of equipment designed to contain an enclosed fluid (gaseous or liquid). Fugitive emissions are a subset of diffuse emissions.
Flaring	High-temperature oxidation to burn combustible compounds of waste gases from industrial operations with an open flame. Flaring is primarily used for burning off flammable gas for safety reasons or during non-routine operating conditions.
Gross electrical efficiency	Ratio between the gross electrical output of the turbine and the waste/fuel energy input expressed as the lower heating value.
Gross heat efficiency	Ratio between the gross heat output and the waste/fuel energy input. The energy input is expressed as the lower heating value; the gross heat output is expressed as the sum of: • the generated electricity output of the turbine • for direct export of steam and/or hot water, the exported thermal power less the thermal power of the return flow • the thermal power to primary heat exchangers.
Hazardous waste	Hazardous waste as defined in Article 3(2) of Directive 2008/98/EC.
IED	Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).
Incineration plant	Either a waste incineration plant as defined in Article 3(40) of Directive 2010/75/EU, or a waste co-incineration plant as defined in Article 3(41) of Directive 2010/75/EU, covered by the scope of this BREF.
IPPC Directive	Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control (IPPC Directive) that has been replaced by Directive 2010/75/EU on industrial emissions (see IED).
Laboratory smalls	Laboratory chemicals in containers of a small capacity.
Leachate	Solution obtained by leaching. The solution consists of liquid that, in passing through matter, extracts solutes, suspended solids or any other component of the material through which it has passed.
Leakage	Gaseous or liquid spills out of system/equipment due to system/equipment failure.

Limestone	Mineral rock consisting merely of $CaCO_3$ used as $CaCO_3$ or as raw material for producing quicklime (calcium oxide) by decarburisation and hydrated lime (calcium hydroxide) by the hydration of quicklime.
Major plant upgrade	A major change in the design or technology of a plant with major adjustments or replacements of the process and/or abatement technique(s) and associated equipment.
Make-up water	Water added to a process or a circuit to replace water that is lost by e.g. leakage or evaporation.
Monitoring	Systematic surveillance of the variations of a certain chemical or physical characteristic of emissions, discharges, consumptions, equivalent parameters or technical measures, etc.
Municipal solid waste	Solid waste from households (mixed or separately collected) as well as solid waste from other sources that is comparable to household waste in nature and composition.
New plant	A plant first operated at the installation following the publication of these BAT conclusions.
Other non-hazardous waste	Non-hazardous waste that is neither municipal solid waste nor sewage sludge.
Output	The treated material coming out of the waste treatment plant.
Pasty waste	Non-pumpable waste (e.g. sludge).
Periodic measurement	Determination of a measure (particular quantity subject to measurement) at specified time intervals using manual or automated methods.
Periodic sampling	Discrete/ individual/ separate/ discontinuous/ grab/ spot sampling - individual samples taken in batches, time or effluent-volume dependent. Three formats can be identified: • periodic time dependent sampling – discrete samples of equal volume are taken at equal time intervals; • periodic flow proportional sampling – discrete samples are taken of variable volumes at equal time intervals; • periodic samples taken at fixed flow intervals – discrete samples of equal volume are taken after the passage of a constant volume.
PLC	Programmable logic controller: digital computer used for the automation of industrial processes.
Plume	Visible or measurable discharge of a contaminant from a given point of origin, usually a channelled emission from the stack at an industrial site.
Pollution source	The emissions source. Pollution sources can be categorised as: • point, or concentrated sources; • dispersed sources; • line sources, including mobile (transport) and stationary sources • area sources.
Precision	Refers to the ability of a measurement to be consistently reproduced.
Primary measure/technique	A measure/technique that changes the way in which the core process operates thereby reducing raw emissions or consumptions (see also the counterpart: end-of-pipe technique).
Purging	Replacement of the gaseous contents of a system by air or inert gases.
Radioactive material	Radioactive material, as defined in the IAEA Safety Glossary, 2016 Revision.
Recovery	Recovery as defined in Article 3(15) of Directive 2008/98/EC.
Recycling	Recycling as defined in Article 3(17) of Directive 2008/98/EC.
Reuse	Reuse as defined in Article 3(13) of Directive 2008/98/EC.
Re-refining	Treatments carried out to waste oil to be transformed to base oil.
Reference conditions	Conditions that are specified, e.g. in connection with operating a process, collecting samples.
Regeneration	Treatments and processes mainly designed to make the treated equipment (e.g. activated carbon) or material (e.g. spent solvent) usable again.
Release	Actual discharge (routine, usual or accidental) of emissions into the environment.

Remediation	The containment and/or decontamination of contaminated environmental media such as soil, groundwater, sediment, or surface water from a contaminated site intended for further use. The area of the site may be larger than the fenced area.
Reporting	A process of periodic transmission of information about environmental performance, including emissions and compliance with permit conditions, to authorities or to the internal management of the installation and other agencies, such as the general public.
Residue	Material generated by the activities covered by the scope of this document, as waste or by-products.
Run-off	Part of the precipitation and snowmelt that does not infiltrate but moves as overland flow.
Sampling, sample	Sampling is the process by which a portion of substance is collected to form a representative part (the sample) of the whole, for the purpose of examination of the substance or material under consideration. (see also continuous sampling, periodic sampling).
Sensitive receptor	Area which needs special protection, such as: - residential areas; - areas where human activities are carried out (e.g. schools, daycare centres, recreational areas, hospitals or nursing homes).
Sewage sludge	Residual sludge from the storage, handling and treatment of domestic, urban or industrial waste water, except if this residual sludge constitutes hazardous waste
Slags and/or bottom ashes	Solid residues removed from the furnace once wastes have been incinerated.
Slurry	A suspension of solid particles in a liquid but at a lower concentration than found in a sludge.
Specific emissions/consumption	Emissions/consumption related to a reference basis, such as production capacity, or actual production.
Spot measurement	A measurement relating to a specific point in time – not a continuous measurement.
Spot sample	A sample related to a single point in time. [to update once new MON REF is published]
Standard conditions	Referring to a temperature of 273.15 K a pressure of 101.325 kPa and a specified oxygen content.
Surrogate parameter	Measurable or calculable quantities which can be closely related, directly or indirectly, to conventional direct measurements of pollutants, and which may therefore be monitored and used instead of the direct pollutant values for some practical purposes. Also called proxy parameter.
Thickening	Liquid-solid separation process to increase the concentration of a suspension by sedimentation, accompanied by the formation of a clear solid.
Unit	A part of the plant in which a specific processing operation is conducted.
Vitrification	The transformation of a substance or a mixture of substances into glass or an amorphous glassy matrix.
Waste	Waste as defined in article 3(1) of Directive 2008/98/EC.
Waste hierarchy	Priority order in waste prevention and management legislation and policy as stipulated in Article 4 of Directive 2008/98/EC.
Waste holder	Waste holder as defined in Article 3(6) of Directive 2008/98/EC.
Waste input	The incoming waste to be treated in the waste treatment plant.
Waste oil	Waste oil as defined in Article 3(3) of Directive 2008/98/EC.
Waste treatment	Treatment as defined in Article 3(14) of Directive 2008/98/EC.
Zeolites	Microporous, aluminosilicate minerals commonly used as commercial adsorbents.

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