Danish Environmental Protection Agency
DANCEE

Detailed Review of Selected Non-Incineration and Incineration POPs Elimination Technologies for the CEE Region

Final

October 2004

Danish Environmental Protection Agency
DANCEE

Detailed Review of Selected Non-Incineration and Incineration POPs Elimination Technologies for the CEE Region

Final

October 2004

Report no.	P-54299
Issue no.	Final Report, version 1
Date of issue	October 2004
Prepared	jss, jql, ehn, aej
Checked	sv
Approved	jss

Table of Contents

Table of Appendices

List of Abbreviation and Acronyms

ACAP	Arctic Council Action Plan
ACWA	US based Assembled Chemical Weapons Assessment Program
AMAP	Arctic Monitoring Assessment Programme
BAT	Best Available Technique
BCD	Base Catalysed Dechlorination
BEP	Best Environmental Practise
BOT	Build, Operate and Transfer
BTU	British Thermal Unit
CB	Chlorobenzene
CEE	Central and Eastern Europe
CIP	Centre for International Projects (Russia)
CIS	Container-based Incineration System
CKI	Cement Kiln
CO	Carbon Oxide
COP	Conference of Parties
CP	Chlorophenols
DANCEE	Danish Co-operation for Environment in Eastern Europe
DDT	Dichloro-Diphenyl-Trichloroethane
DE	Destruction Efficiency
DEPA	Danish Environmental Protection Agency
DG-ENV	Directorate General – Environment
DRE	Destruction and Removal Efficiency
EECCA	Eastern Europe, Caucasus and Central Asia
EHF	Environmental Health Fund
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EU	European Union
FAO	Food and Agriculture Organization

GEF	Global Environment Facility
GJ	Giga Joule
GPCR	Gas-Phased Chemical Reduction
HCB	Hexa-Chloro-Benzene
HCH	Hexachlorohexane
HELCOM	Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area
HW	Hazardous Waste
IERR	Internal Economic Return Rate
IFIs	International Finance Institutions
IFRR	Internal Financial Return Rate
IPEN	International Pesticide Elimination Network
IPPC	Integrated Pollution Prevention Control
IRR	Internal Rate and Return
ISO	International Standard Organisation
ISPA	EU Instrument for Structural Policies for Pre-Accession Reforms
ITD	Indirect Thermal Desorption
LCA	Life Cycle Assessment
LIFE	L'Instrument Financier pour l'Environnement (main focus on development and implementation of Community environment policy and legislation)
LPG	Liquid Purified Gas
MEG	Major Equipment Groups
MJ	Mega Joule
MW	Mega Watt
NEAP	National Environmental Action Plan
NEFCO	Nordic Environment Finance Cooperation
NGO	Non Governmental Organisation
NIP	National Implementation Plan for the Stockholm Convention
NOK	Norwegian Kroner (currency)
NPV	Net Present Value

NSW	New South Wales
ODS	Ozone Depleting Substances
OECD	Organisation for Economic Co-operation and Development
OP	Obsolete Pesticides
PAH	Poly-Aromatic Hydrocarbons
PCB	Poly-Chlorinated-Biphenyls
PCT	Poly-Chlorinated-Terphenyls
PHARE	EU Financial instrument to assist candidate countries in their transition towards EU membership
PIC	Product of Incomplete Combustion
POP	Persistent Organic Pollutants
PPE	Personnel Protection Equipment
PPM	Parts Per Million
PUF	Polyurethane Foam
PVC	Poly Vinyl Chloride
R&D	Research and Development
RF	Russian Federation
SC	Stockholm Convention
SCW	Scheduled Chemical Waste (~Hazardous Waste)
TMT	2,4,6-trimercaptotriazine trisodium salt
TOC	Total Organic Carbon
TRBP	Thermal Reduction Batch Processor
TWG	Technical Working Group
UK	United Kingdom
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organisation
US	United States
USD	US Dollars
US-EPA	United States Environmental Protection Agency

WB	World Bank
WTO	World Trade Organization

1 Foreword

1.1 Executive summary, English

It is estimated that in Central and Eastern Europe more than 100,000 tonnes of obsolete pesticides are stored under uncontrolled conditions. The so-called "persistent organic pollutants" - also known by the name of "POP's" - constitute a considerable part of these. In relation to the estimated amount of obsolete pesticides and POP's, the Central and Eastern European region is characterised as one of the most severely polluted regions. The amount of obsolete pesticides in the region exceeds the equivalent amount in the entire African continent by more than 4 times.

During the mid-1990s, a number of countries entered the EU enlargement process ultimately leading to full EU membership from May 2004. In between, e.g. Bulgaria, Romania and Croatia have been declared new candidate countries with expected accession to the EU by the year 2007. The Stockholm Convention on POPs was formally adopted on 17 May 2004 to further strengthen the need for prioritised and politically sustainable solutions diminishing both environmental and human exposure from extensive stockpiles of obsolete pesticides (OPs) and POPs within the CEE region.

The new EU members will have to manage and adopt the environmental legislation of EU and follow in line with community decisions, e.g. on the Stockholm Convention (SC). Furthermore, the new EU Member States will gain increased access to both structural and cohesion funds supporting national priorities and activities. EU Accession Funds to new applicant countries will also assist in developing targeted elimination activities in these countries. To a still larger extent, non-EU Member States like e.g. Ukraine, Belarus and Albania will also try to affiliate national legislation and regulatory framework with the EU legislation, although their activities related to the Stockholm Convention rely on a combination of national and bilateral and/or international funds.

The review report will contribute to an international clarification of best available technology (BAT) for POPs reduction/elimination and POPs awareness in general within the CEE region. In combination with a detailed screening, selection and review (technical, environmental and economic) of pre-selected non-incineration and incineration-based technologies, the report highlights their applicability, both in the short and long term as BAT for POPs elimination within the CEE region.

In order to facilitate the process leading to the establishment of national elimination capacity to manage OPs and POPs including hazardous waste, the report contains a detailed review of 4 pre-selected incineration and non-incineration elimination technologies. The review criteria consist of:

- Technical criteria (capacity, comprehensiveness, maintenance, transfer of know-how, supply lines, occupational health, operational risks and mobility);

- Environmental criteria (material consumption, emissions and others e.g. residues); and

- Economic criteria (treatment costs, analytical costs, capital investment costs and marginal costs of investment).

The review criteria have been developed in close co-operation with the 4 NGOs affiliated to the project (Greenpeace International, Pesticides Action Network (PAN)-UK, International Pesticides Elimination Network (IPEN) and the International HCH & Pesticides Association).

The pre-selected technologies are all commercially available on the world market and have all been reviewed in operational mode. The pre-selection process involved a global screening of commercially available POPs elimination technologies, and based on meetings with the affiliated NGO's, 4 potential technologies were selected for the independent and comparable detailed review. These were

- Container-based Incineration System (CIS);

- Cement Kiln Incineration (CKI);

- Gas Phased Chemical Reduction (GPCR); and

- Base Catalysed Dechlorination (BCD).

The selected technologies have defined common features such as those dedicated and applicable for OPs and POPs elimination (although the cement kiln option is not defined as a dedicated structure, but of key interest due to extensive distribution and actual operational knowledge related to this technology in the CEE region). Furthermore, experience from on-site elimination of POPs substances in the CKI technology and related detailed mapping of possible point sources for uncontrolled emission (air, waste residues and effluent water) is perceived as a disadvantage for this technology.

In comparison, the other three technologies are small-scale in nature making them more attractive for small-scale investment and organisational settings. Finally, during 2004/2005 the two technologies (CIS and GPCR) are expected to be fully operational on POPs waste within the CEE region (Latvia (CIS) and Slovakia (GPCR)) due to bilateral and international funded projects.

The 4 pre-selected POPs elimination technologies were carefully reviewed on-site by a team of experts covering the technical, environmental and economic aspects. The reviews were performed according to table 1.1.

Table 1.1 Time schedule for performed detailed review of POPs elimination technologies

Technology	Date for evaluation	Place for performed evaluation
Container-based Incineration System (CIS)	1 March 2002	Chemcontrol A/S Kommunekemi, Nyborg, Danmark
Base Catalysed Dechlorination (BCD)	9-10 April 2002	Enterra Pty Ltd. Sydney, Australien
Gas Phased Chemical Reduction (GPCR)	26-27 June 2002	ELI Eco-logic Inc Toronto, Canada
Cement Kiln Incineration (CKI)	27-28 August 2002	NORCEM og Noah, Oslo, Norge

Based on the evaluation performed and considering all the listed review criteria, the review process concludes that:

- The CIS and GPCR POPs elimination technologies are found to be equal in appropriateness, market availability, affordability and operational performances taking into account possible environmental impact, use of supply lines and risk potential;

- The BCD technology is characterised by having a relatively low capacity, high use of supply lines and is thus relatively less affordable;

- The CKI technology is characterised as "a way through" but has several disadvantages. The cement industry is under continuous re-organisation with mergers and acquisitions as day-to-day activities that seriously affect all long-term investment into this kind of technology. This has a serious impact on the sustainability for the selected solutions utilising the CKI technology. Furthermore, the CKI technology is not a dedicated technology, because many resources are used for other purposes than e.g. pure POPs elimination. Extensive investments in pre-treatment are needed. This significantly reduces the economic attractiveness of this technology, although recent test results from stack-emission in e.g. Poland show no or little (below EU admissible levels) emission from a scheduled co-disposal activity (POPs incineration in combination with cement production). Finally, and as a consequence of not being dedicated, documentation of e.g. environmental performance (emission, residual content of substances in e.g. fly ash) is difficult to consolidate; and

- A brief review of promising POPs elimination technologies developed in the CEE region such as the Cyclone technology developed in Russia shows, in line with many other promising Western-based technologies, that a number of promising "merging" technologies are under way. However, most of these will face difficulties developing into commercially market available technologies due to a number of in-built obstacles. These are: increased commercial competition on the free market lowering prices and the need for 3-5 generations to develop a technology that can reach international recognised emission standards and general acceptance in the market.

For a more detailed review result, please refer to chapter 6.9.

The report concludes that, beside mandatory legal planning documents and procedures, a very essential part of the planning work is public participation. The report recommends the development of a Communication Strategy Paper (CSP) which will ensure full integration of the public processes.

Furthermore, the report concludes that selection of a possible POPs elimination technology, based on the listed objective evaluation criteria, is only part of the overall selection process. This will enable countries to deal with their own POPs/OPs waste problems in compliance with national strategies and policies and international environmental binding instruments (like e.g. the Stockholm and Basel Conventions). Experience shows that the final choice of technology often depends on elements like endorsement of donor policies, amount and character of available funds, political tendencies and pressure from private industries and investors encouraging the responsible authorities to implement commercially viable solutions in a broader perspective based on more than just a minor waste fraction, like the POPs and obsolete pesticides.

Nevertheless, as an overall facility, international environmentally binding instruments (protocols, conventions etc.), and their related mandatory actions for Parties, have traditionally been the global modality to move forward significant actions within major environmental problems like e.g. the Montreal Protocol on ODS, biodiversity etc. Taking into account the fact that the expected time span from final decision on the establishment of elimination capacity to day-to-day operation is normally 6-8 years, the political process and constant public awareness are of utmost importance in support of the process all along.

The main part of this review was completed in September 2003. Therefore, the report may include information that is not fully up to date. Among others, the following observations have been recognised: the 17 May 2004 enforcement of the Stockholm Convention, accession of 10 new EU Member States, re-design of the Basel Secretariat working group working paper on the environmentally sound management of POPs as waste and finally significant improvement of the BCD technology proven by the review of an independent UNIDO consultant at S.D. Meyers in Mexico.

1.2 Executive summary, Danish

I Central- og Østeuropa anslås at mere end 100,000 tons forældede pesticider henligger under ukontrollerede forhold, hvoraf de såkaldte "persistente organiske forbindelser" - også kaldet "POPér" udgør en væsentlig del. Den Central- og Østeuropæiske region er, med hensyn til de estimerede mængder af forældede pesticider og POPér, karakteriseret som en af de mest forurenede regioner. Mængden af forældede pesticider i regionen overgår den tilsvarende mængde på det afrikanske kontinent mere end 4 gange.

I midt 1990érne påbegyndte en række Central- og Østeuropæiske lande optagelsesforhandlinger med EU, som 1. maj 2004 ledte til optagelsen af 10 nye EU lande fra regionen. Parallelt hermed har en række nye lande som Rumænien, Bulgarien og Kroatien indledt optagelsesforhandlinger med henblik på EU optagelse i år 2007. Den 17. maj 2004 trådte den internationalt forankrede Stockholmkonvention vedr. POPér ikraft. Konventionens formål er, at styrke den politisk prioriterede indsats mod yderligere anvendelse af POPér gennem forbud, udfasning og mere sikker destruktion af allerede oplagrede mængder. Tiltagene skal medvirke til at nedsætte, og på sigt eliminere stoffernes negative indvirken på mennesker og miljø.

De nye EU lande i den Central- og Østeuropæiske region skal opfylde og sikre fuld implementering af EUs samlede lovgivning, herunder også samlede EU initiativer på områder, som f.eks. Stockholmkonventionen. Landende har i forbindelse med EU optagelsen fået stillet en række finansielle redskaber til rådighed, herunder bl.a. Samhørings- og Strukturfondsmidler. Dele af disse midler vil kunne understøtte den proces og økonomiske byrde til bl.a. etablering af sikre bortskaffelsesmetoder, som Stockholmkonventionens ikrafttræden naturligt pålægger de enkelte lande. Tilgrænsende lande til EU som f.eks. Ukraine, Hviderusland og Albanien vil i stadig stigende omfang tilpasse deres lovgivning til EUs, også selvom aktiviteter forbundet med Stockholmkonventionens ratificering vil skulle finansieres via nationale midler eller i kombination med bilaterale/internationale midler.

Nærværende rapport skal bidrage til en bredere international forståelse af begrebet "best available technology" - bedst tilgængelig teknologi - samt sikre en mere miljømæssig forsvarlig bortskaffelse af POPér indenfor den Central- og Østeuropæiske region. Gennem detaljeret screening, udvælgelse og evaluering af udvalgte POP bortskaffelsesteknologier, opstiller rapporten de enkelte teknologiers egnethed i forhold til deres tekniske, økonomiske og miljømæssige formåen på såvel kort som lang sigt. De udvalgte bortskaffelsesteknologier omfatter forbrændingsbaserede og ikke-forbrændingsbaserede teknologier.

Der er i rapporten udvalgt 4 forskellige teknologier. De anvendte kriterier for den detaljerede evaluering er:

- Tekniske kriterier som kapacitet, kompakthed, vedligeholdelse, overførsel af knowhow, krav til infrastruktur, arbejdsmiljø, operationelle risici samt anlæggets flytbarhed/mobilitet,

- Miljømæssige kriterier som materialeforbrug, emissioner og andre miljømæssige forhold som f.eks. affaldsrester, og
- Økonomiske kriterier som behandlings-, analyse-, investerings- og marginal omkostninger i.f.m. investeringen.

Evalueringskriterierne er udarbejdet i tæt dialog med 4 tilknyttede NGO organisationer - Greenpeace International, Pesticides Action Network (PAN)-UK, International Pesticides Elimination Network (IPEN) og International HCH & Pesticides Association.

De udvalgte bortskaffelsesteknologier er alle kommercielt tilgængelige på verdensmarkedet, hvorfor det har været muligt at evaluerer anlæggene i drift. De er valgt på basis af en global screening af tilgængelige teknologier og efterfølgende accepteret af de tilknyttede NGO organisationer som de umiddelbart mest tilgængelige og udviklede teknologier. De 4 udvalgte teknologier er:

- Container-baseret forbrændingsteknologi (Container-based Incineration System - CIS),
- Cementovnsforbrænding (Cement Kiln Incineration - CKI),
- Gasificeret kemisk reduktionsteknologi (Gas Phased Chemical Reduction - GPCR), og
- Basisk katalytisk afkloreringsteknologi (Base Catalysed Dechlorination - BCD).

De valgte teknologier har en række fælles træk. De er alle kommercielt tilgængelige som affaldsbehandlingsanlæg, herunder til destruktion af bl.a. forældede pesticider og POPér, selvom cementovnsteknologien dog har et andet primært formål (produktion af cement). Cementovnsteknologien er udbredt i den Central- og Østeuropæiske region grundet tidligere tiders planlægning. Dette indebærer endvidere, at de fleste lande i regionen har driftserfaringer med netop denne teknologitype. For de øvrige teknologier gælder, at grundet deres mindre størrelse vil kravene til investeringer og organisation være lavere end for cementovnsteknologien. Afslutningsvis vil 2 af teknologierne indenfor en kortere årrække (2004-2005) formodentlig være opstillet i hhv. Letland (CIS) og Slovakiet (GPCR) som led i bilaterale og international programmer under bl.a. Stockholmkonventionen.

Den gennemførte evaluering af de 4 teknologier er udført på stedet af eksperter indenfor tekniske, miljømæssige og økonomiske parameter. Tidsplan og geografi for den gennemførte evaluering kan ses i tabel 1.1.

Tabel 1.1 Oversigt over gennemførte teknologievalueringer.

Teknologi	Dato for evaluering	Sted for gennemført evaluering
Container-based Incineration System (CIS)	1. marts 2002	Chemcontrol A/S Kommunekemi, Nyborg, Danmark
Base Catalysed Dechlorination (BCD)	9.-10. april 2002	Enterra Pty Ltd. Sydney, Australien
Gas Phased Chemical Reduction (GPCR)	26.-27. juni 2002	ELI Eco-logic Inc Toronto, Canada
Cement Kiln Incineration (CKI)	27.-28. august 2002	NORCEM og Noah, Oslo, Norge

På baggrund af en samlet evaluering af de opstillede evalueringskriterier konkluderer undersøgelsen, at

- CIS og GPCR bortskaffelsesteknologierne vurderes ens med hensyn til deres egnethed til behandling af POPér, markedstilgængelighed, rentabilitet samt driftmæssige- og miljømæssige kvaliteter. Dette konkluderes på baggrund af en samlet vurdering af deres miljømæssige påvirkning af luft, vandmiljø og mennesker, forbrug af hjælpemidler (additiver, vand, elektricitet m.v.) samt samlet risikoprofil ved drift,

- BCD teknologien vurderes at have lavere kapacitet end de ovenstående 2 teknologier. Endvidere har den et højere forbrug af hjælpemidler og fremstår samlet som en dyrere løsning,

- CKI teknologien er vurderet som værende "en mulighed", men der er forbundet en række ulemper ved dette teknologivalg. Cementindustrien undergår internationalt og specielt i den Central- og Østeuropæiske region dramatiske forandringer i ejerstrukturen. Desuden er teknologien ikke udviklet målrettet som affaldsbehandlingsanlæg. Den primære cementproduktion under høje temperaturer åbner dog for dette perspektiv. Disse forhold og grundlæggende stadige forandringer gør målrettede investeringer i forbindelse med f.eks. POP bortskaffelse sårbare og ikke attraktive. Endvidere er der, i.f.m. etablering af affaldsbehandlingsmulighed på en CKI teknologi et behov for nødvendige investeringer i forbehandling. Disse er erfaringsmæssigt af en størrelsesorden, der naturligt begrænser denne teknologis udbredelsesmuligheder indenfor CEE regionen, også selvom nye testresultater for POP bortskaffelse i en cementovn i Polen viser lovende resultater, og

- Supplerende gennemgang af en indenfor CEE regionen udviklet POP bortskaffelsesteknologi, den russisk udviklede cyclon teknologi, viser på linie med mange parallelt udviklede teknologier i f.eks. Vesteuropa, lovende resultater. Den globale screening af mulige POP bortskaffelsesteknologier viste også, at der findes en mængde nye teknologier, som dog for nærværende er på prøvestadiet. Hvorvidt disse får mulighed for at udvikle sig til kommercielle markedstilgængelige teknologier er dog tvivlsomt. Dette begrundes i at eksisterende markedstilgængelige teknologier traditionelt har været gennem flere generationsudgaver. De har for en stor del været støttet af diverse sponsorprogrammer, hvorfor det må forventes, at disse nyligt udviklede teknologier skal modnes over længere tid før de vil være egnede som kommercielt udviklede teknologier.

For detaljerede evalueringsresultater henvises til kapitel 6.9.

Rapporten konkluderer, at i forbindelse med etablering af bortskaffelseskapacitet, hvor planlægning og lovgivningsmæssige forhold ofte er dimensionerende, bør den folkelige inddragen have en særlig fokus. Oplysninger til offentligheden og tilrettelæggelse heraf (såsom møder, høringer, informationsmateriale m.v.). Den skal indgå ligeværdigt som en væsentlig del af hele plangrundlaget og i de tilknyttede forarbejder. Rapporten anbefaler, at der allerede i forbindelse med de indledende tanker omkring etablering af bortskaffelseskapacitet udfærdiges et Strategisk Kommunikations Papir ("Communication Strategy Paper"), der sikrer fuld åbenhed og integration af den folkelige proces i hele arbejdet omkring evt. etablering af bortskaffelseskapacitet.

Rapporten konkluderer også, at den foretagne evaluering af teknologierne kun er en del af hele udvælgelsesprocessen. Det er vigtigt, at de enkelte lande sikrer optimale løsninger på nationalt niveau, således at nationale politikker, love, visioner for f.eks. bortskaffelse af andet farligt affald går hånd i hånd med landets internationale forpligtigelser under f.eks. Stockholm- og Baselkonventionerne. Erfaringen viser dog, at bortskaffelseskapacitet ofte styres af elementer, som f.eks. muligheder for ekstern medfinansiering, politiske strømninger, pres fra NGO organisationer, industri interesser, krav om privatisering til sikring af fremtidig privat affaldsindustri mm.

Erfaringen siger, at fra en politisk beslutning er taget vedrørende etablering af bortskaffelseskapacitet, til et anlæg står drift klart går der typisk 6-8 år. Det kræver altså stor vedholdenhed fra beslutningstagerne og i hele planlægningsprocessen, inklusiv fastholden af den folkelige åbenhed, for at kunne opnå en forventelig succesfuld implementering af et givent anlæg. På trods heraf har internationale protokoller og konventioner gennem deres bindende krav for de deltagende lande traditionelt bidraget positivt til at skubbe udviklingen i den tilsigtede retning som f.eks. Montrealprotokollen om ozon-ødelæggende stoffer, som i dag må betragtes som en ubetinget succes.

Hovedparten af nærværende studie er afsluttet omkring 1. september 2003, hvorfor der kan findes enkelte oplysninger eller passager, der ikke er helt opdaterede. Det kan således konstateres, at Stockholmkonventionen trådte i kraft den 17. maj 2004, og at 10 nye EU lande, hvoraf hovedparten kommer fra den Central- og Østeuropæiske region, blev optaget som fyldgyldige EU medlemslande per 1. maj 2004. Det skal også bemærkes, at der stadig pågår forhandlinger under såvel Stockholm- som Baselkonventionens sekretariat vedrørende udarbejdelsen af en teknisk guideline for miljømæssige håndtering af POP affald.

Afslutningsvis skal det bemærkes, at en nylig UNIDO gennemført evaluering af S.D. Meyers i Mexico, har godtgjort at BCD teknologien til stadighed er under positiv udvikling.

2 Introduction

The present POP elimination technology review project follows in continuation of recommendations outlined in earlier DANCEE report "Review on Obsolete Pesticides in Eastern and Central Europe, May 2001" stating a need for:

- "Provision of input to the international clarification of the applicability of non-incineration technologies in the CEE Region".

Subsequently, the project has the following defined *development objective*:

- "International clarification as to best available technology for POPs reduction/elimination, and POPs awareness in general"

and *immediate objective*:

- "Promising non-incineration and incineration technologies and their applicability in both short and long term perspective as to best available technique for POPs elimination in the CEE Region screened, selected and reviewed".

The development and immediate objectives have been developed in line with the 17 May 2004 enforcement of the Stockholm Convention (SC). The implementation of the SC increases the need for clarification of applicable market available POPs elimination technologies in the CEE region as well as worldwide. On a global scale, a number of in-parallel initiatives are launched to further clarify differences in-between the various market and non-market available elimination technologies. Extensive review of the studies performed either by the various UN institutions (e.g. UNEP Chemicals and UNIDO) as well as national large-scale military de-ammunition programmes (e.g. the US based ACWA programme) significantly contributes to the overall clarification. Nevertheless, many countries in economic transition like the CEE region are in need or more dedicated approach tailoring in regional specific problems.

Furthermore, many of the performed studies have a general lack of economic assessment criteria, why this particular project has developed a separate chapter on likely applicable economic evaluation parameters and considerations to be assessed.

Simultaneously, recognising that final elimination of the POP substances in question is a critical element of national POPs management underlines the importance of such a project focussing on the CEE region.

The report contains detailed environmental, technical and economic review of in total 4 POPs elimination commercial operating technologies into which 2 are characterised as incineration-based and 2 non-incineration based. Each of the reviewed technologies has been visited on-site during operation and key operating companies and license-holders etc. have been interviewed. Each of the interview stakeholders have been peer-reviewing the consultants assessment prior to this publication. Nevertheless, the outlined assessment does not necessarily reflect the full opinion of the vendors.

The project should also be seen in line with the ongoing preparatory process drafting (ongoing process in the open ended working group under the Basel Convention Secretariat) a general technical guideline on the Environmentally Sound Management of POPs as Waste. The guideline is planned to be completed for the 7th Conferences of the Parties to the Basel Convention in October 2004.

2.1 Background

The Report follows in line with the following previous DANCEE financed work within the SC frame and in the CEE region:

- Already Danish DANCEE and Danish consultancy involvement in obsolete pesticides (OP) projects in e.g. the Baltic Republics, Belarus, Poland, Ukraine and Albania (Danish supervisor on year 2002 completed EU-PHARE collection scheme of more than 300 tonnes of OPs in Albania). In Bulgaria, involvement in establishment of a National Centre for Hazardous Waste Management. Finally, various preparatory projects under the Stockholm Convention in the Baltic Republics, Western part of Russia and Poland;

- DANCEE and Danish consultants participation in the latest international (UNEP-FAO-OECD) OPs workshop in Alexandria, USA, September 2000, regional workshops likes the 6th International HCH & Pesticides Forum in Poland, March 2000, UNEP Chemicals regional OP workshop in Russia, September 2001, UNIDO high-level conference in June 2002 in Bratislava, Slovakia, UNEP hosted POPs conference on POPs in Russia, November 2002 and 7th International HCH & Pesticides Forum in Kiev, Ukraine June 2003, all focussing on OPs and POPs and their possible inventorying and elimination in the CEE Region and globally;

- Contemporary projects on POPs elimination techniques including the ongoing UNDP-GEF-UNIDO project "Demonstration of Viability and Removal of Barriers that Impede Adoption and Effective Implementation of Available, Non-combustion Technologies for Destroying Persistent Organic Pollutants (POPs)" in e.g. Slovakia and NEFCO PCB Fast Track

Project “Transformer Cleaning and PCB Incineration” in the Western part of Russia.

Furthermore, at a very early stage of the project implementation, it was decided to involve major NGO organisations like Greenpeace International, Pesticides Action Network (PAN)-UK, International Pesticides Elimination Network (IPEN) and the International HCH & Pesticides Association, all active players in the CEE Region, as external advisors. In total, two Advisory Group meetings have been held (December 2001 and April 2003) between DANCEE, the consultant and the 4 main NGO organisations discussing subjects like project approach, selection of technologies and methodology for review, focussed strategy for the selected region (CEE), accessibility to trustworthy information, key findings as a result of the review performance etc.

The NGOs have contributed with updated information on the selected POPs elimination technologies and in all manners showed serious and professional involvement in the process, making it as objective and updated as possible. **However, it must be underlined that the content of this report not necessarily reflects the opinion of the involved NGO organisations.**

The obsolete pesticides problem in the CEE Region (minimum 100,000 tonnes with reference to the 6th and 7th International HCH & Pesticides Forum conferences in Poland and Ukraine significantly exceeds the similar problem covering the entire African continent (50,000 tonnes based on information from the African Stockpile Project homepage, September 2004 (www.africastockpiles.org/).

With the changed CEE region as per May 2004, the new EU member States must focus their efforts towards full compliance with the EU regulatory framework also covering POPs management activities. The enlargement process has although left behind a group of countries either as accession countries (Bulgaria, Romania and Croatia), potential accession countries (Turkey) and non-accession countries (e.g. Russia, Belarus, Ukraine, Albania and Balkan).

The sub-division of the CEE Region into more or less two sectors will inevitably necessitate the acceptance of a short–term differentiated policy for e.g. chemical elimination, due to different political agendas, but also due to differences in financial access and technical capacities. In the long perspective, chances are that national differences in short-term solutions will merge and the region in seek for sub-regional solutions for chemical fraction such as the POPs. Key features supporting such a process are:

- The Enforcement of the Stockholm Convention as per 17 May 2004;
- Increased international co-operation through various international and bilateral programmes and programming of the EU Cohesion and Structural Funds as well as the EU Regulation no 850 and of the European Parliament and the Council of 29 April 2004 on POPs and Amending Directive 79/117/EEC; and

- Demands from e.g. international organisations like WTO, OECD etc., which could positively influence the long-term prospects of a more uniform attitude to safe chemical management and in particular setting up disposal routings. A parallel initiative from December 2002 (subject: Remove obsolete pesticides - European funding) by 28 members of the EU Parliament highlights the importance of finding sustainable solutions for uncontrolled stored high-risk chemicals and their disposal. Furthermore, NGO initiatives, like the recent 7th International HCH & Pesticides Forum (Kiev, Ukraine, 5-7 June 2003) declared that establishing a fund supporting obsolete pesticides elimination development in non-EU members States in the CEE Region is valuable and facilitating the Stockholm Convention process.

The importance of having a number of in-parallel programmes supporting the environmental sound development within chemicals management was latest recognised by the EU Commissioner on Environment in August 2001. The EU Environmental Commissioner confirmed that the EU-programmes ISPA, LIFE and PHARE could financially contribute to speed up the process of chemicals elimination in the former candidate countries based on national priorities, although, subsequently leaving behind non-candidate countries in a difficult situation with limited access to supportive economic and technical means.

2.1.1 Danish and International support to the Stockholm Convention within the CEE region

Denmark has during more than a decade intensively supported chemicals management and in particular POPs, obsolete pesticides and dioxins etc. within the CEE region. Through involvement in e.g. AMAP, ACAP, HELCOM and related organisations, Denmark has launched a number of “ground activities” enabling co-operative countries to verify the consequences of e.g. SC ratification. Through extensive PCB projects in Western Russia, POPs preparatory projects in the Baltic States and partly Russia (inventorying and preparatory work for the National Implementation Plans under the Stockholm Convention), review of Obsolete Pesticides (OPs) situation in the CEE Region and long lasting direct involvement into OPs projects in Latvia, Belarus and Ukraine, the Danish Assistance Programme for the former CEE countries (DANCEE) has affiliated with the regional situation within chemicals management and in particular OPs/POPs management.

Furthermore, through a Danish EPA grant, the generic Stockholm Convention guidance document “Preparation of a National Implementation Plan for POPs – Guidance Document” has been developed for the WB and is now utilised world-wide as template concept for completion of NIPs under the Stockholm Convention.

Please find in table 2.1 below a list of selected Danish EPA financed activities within the CEE region within POPs management.

Table 2. List of Danish funded POP/OP projects within the CEE Region (1998-2004).

Assistance in implementation of the disposal of PCBs, Estonia
Implementation of the EU requirements for disposal of PCBs/PCT, Lithuania
Phase-out of PCB use and Management of PCB, Russia
Implementation of Collection and Storage of PCB, Russia
Feasibility studies for PCB phase-out in the Russian Federation
Survey of Anthropogenic Sources of Dioxins in the Baltic States
Dioxin measurements in Estonia
Review of obsolete pesticides in Eastern and Central Europe
Reduction of Dioxin emissions from the metallurgical industry, Poland
Disposal of Obsolete Pesticides, Belarus
Incineration Plant for Pesticides and other hazardous substances, Latvia
Consulting services supporting elimination of stock of obsolete pesticides, Latvia
Environmentally sound management of Obsolete pesticides, Russia

Source: DANCEE (www.mst.dk).

In addition, a technical working group under the Basel Secretariat has initiated the work on a global technical guideline for the environmentally sound management of POPs as waste. The draft technical guideline outlines a number of influencing parameters, which must be carefully considered and assessed prior to any national decision of disposal of POPs and/or OPs. These are, but are not limited to:

- Regulatory requirements;
- Inventories of POPs stockpiles;
- Collection, storage and containment;
- Transport; and
- Destruction and irreversible transformation methods.

The international community has furthermore initiated a number of parallel activities like the UNDP-GEF-UNIDO-EHF POPs elimination project in e.g. Slovakia (although primary targeting only PCBs), WB/UNEP POPs initiatives in Russia and Ukraine, EU-PHARE OP collection scheme for Albania and in progress for Romania, DG-Environment Service contract on Obsolete Pesticides in Candidate countries etc. In parallel, various other financial agencies, such as the

Dutch and German governments have launched POPs activities in the CEE Region.

2.1.2 Lessons learned from international projects

The new EU countries have almost completed the process of harmonising their legislation with the EU legislative framework inspiring the new Candidate countries of Bulgaria, Romanian and Croatia to follow. Other countries (e.g. Belarus, Moldova, Russian Federation and Ukraine) are also making some efforts for approximation to the EU legislative framework. Among the latest documents reflecting the modernisation of the national environmental policy and legislation within the non-EU members States are e.g. the Environmental Doctrine of the Russian Federation (2002) and the revised RF Law on the Environmental Protection (2002).

Most of the CEE countries have signed the Stockholm Convention and started preparatory works in accordance with the global generic approach towards the development of National Implementation Plans (NIPs) through GEF POP Enabling Activity Program funded under the Stockholm Convention. The funds are disbursed through the POPs Enabling institutions UNEP, UNDP, WB and UNIDO.

The latest development hosted by the International HCH & Pesticides Association, was the proposal for establishing a fund for the disposal of obsolete stockpiles of POPs within the CEE region. The proposal was initially presented by UNIDO during the International Forum on Strategies and Priorities for Environmental Industries, 12-14 June 2002, Bratislava, Slovak Republic. Subsequently, the declaration from the 7th International HCH & Pesticides Forum in Kiev, Ukraine June 2003 confirmed the establishing of a Working Group to develop a Programme of Action to enable concerted POPs actions in collaboration with governments, appropriate international organisations, international and regional development banks, and other stakeholders, including professional and public interest organisations and the industry. This Programme of Action should include, among others:

- Information on and reference to ongoing activities (such as GEF Enabling Activities, studies related to the EU-Acquis, FAO, UNEP and ACAP), to ensure optimal use of funds and resources and avoid duplication;
- Harmonised methodology for inventories and monitoring;
- Approach for priority setting and assessment of cost effectiveness;
- Ongoing review of existing and emerging technologies for POPs/obsolete pesticides destruction within the framework of existing and future waste management plans;
- Recommendations for the establishment of organisational infrastructure;

- Proposals for the appropriate use of financial mechanisms, such as existing EU and GEF funds;

- Assistance in establishment and implementation of coordination and communication structures; and

- Specific programmes for public education and awareness rising, including measures to secure civil society support.

This Programme of Action should serve as a catalyst for the establishment and implementation of Programmes by the Governments of the Central European and EECCA Countries.

Conclusively, the CEE Region will in the years ahead still find it self in a position where major differences towards POPs management and elimination exist between nations. Moving the EU-border further east (e.g. Belarus has no direct borders with the EU region) will on the one hand impose pressure on nations of instability and decreased focus on chemicals management, and on the other hand make illegal export far more easy. Finally, the overall international focus on e.g. terrorism will encourage nations to corporate on trading, transport and scientific research within hazardous chemical substances in general and highly toxic substances in particular.

2.1.3 Legal framework in the CEE countries

Two legal frameworks are currently developing within the CEE Region. Firstly, the completion of the approximation of national legislation to the EU regulatory framework for the new EU Member States. Secondly, a further development of the ex-USSR legislation in separate CEE countries and NIS States.

The new EU countries in the CEE Region will have to comply with existing EU-legislation, which has substantial regulatory framework e.g. on the incineration of waste, EIA, IPPC, Seveso II etc. Furthermore, the countries will have to comply with international conventions to the extent their obligation requires as signatories and/or Parties.

It is important to have in mind the differences in initiating e.g. collection campaigns and establishment of a national elimination plant. The later is regarded as a polluting industrial activity, which has to undertake e.g. EIA procedures (although depending on the annual treatment capacity), IPPC permission, Seveso II Directive assessment as well as a substantial number of local, regional and national permissions for e.g. construction and civil works, fire safety, effluent (if any) permission, proper addressing of public information and so forth.

The legal framework for the establishment of a POPs elimination facility has although during recent years been uniformed as the new member states have approximated towards the EU legislative framework. Differences most frequently occur within regional and local permissions. Target values for admissible effluent (air, and wastewater) are still normally regulated by the EU directive 2000/76/EC on incineration of waste and its amendment (e.g. Annex 1 on admissible values of dioxins and furans in wastewater).

As an illustration of the differences in e.g. the scheduled planning processes leading to the establishment of a national POPs elimination facility, Annex 1 shows which legal procedures must be completed in e.g. Russia prior to any actual treatment of POPs waste.

In opposition to the described Russian planning context, the EU regulatory framework related to the establishment of national elimination capacity for POPs and alike substances are supported by numerous EU directives among which Regulation no 850 on POPs and amending Directive 79/117/EEC, the EIA, Incineration of Waste and IPPC directives are of main importance. The combined regulatory and legal framework both support mandatory actions involving public participation, facilitate the utilisation of Best Available Technology (BAT) as well as setting of threshold values during operation. Nevertheless, in terms of full adoption of the Stockholm Convention intentions, the European continent with a historical record on e.g. incineration based technologies, further clarification is needed stipulating the dimensioned factor in terms of accepting certain admissible values versus non-acceptance of admissible values of e.g. dioxins and furans through emissions.

Article 6.2 of the Stockholm Convention furthermore requires its "Conference of the Parties to cooperate closely with the appropriate bodies of the Basel Convention to, inter alia, "establish levels of destruction and irreversible transformation necessary to ensure that the characteristics of persistent organic pollutants as specified in paragraph 1 of Annex D are not exhibited; and … work to establish, as appropriate, the concentration levels of the chemicals listed in Annexes A, B and C in order to define the low persistent organic pollutant content referred to in paragraph 1(d)(ii)."

The determination of concentrations to establish low levels of POPs is a highly complex process which existing working groups under the Basel and Stockholm Convention are in progress drafting.

2.2 POPs in the CEE Region

2.2.1 POP amounts and characteristics

The main purpose of this chapter is to give the reader a substantial knowledge of the OPs and POPs problem in the CEE Region as to amounts, characteristics, historical facts and national experiences. Furthermore, more than 10 years of planning, institutional capacity and implementation work in the region have enabled the consultant to perspective the tendencies and identify important key obstacles.

POPs are very stable, carbon-based chemical compounds and mixtures. These pollutants are classified as 'persistent' because they are not degraded easily in the environment by physical, chemical or biological processes. The currently identified POPs are primarily pesticides, industrial products and by-products, of which 12 chemicals and/or groups of chemicals have been identified by the Stockholm Convention for reduction and, where feasible, ultimate elimination. These are aldrin, dieldrin, chlordane, toxaphene, mirex, endrin, heptachlor, hexachlorbenzene (HCB), polychlorinated biphenyls (PCBs), dichloro-diphenyl-trichloroethane (DDT), polychlorinated dibenzo-p-dioxins (PCDDs, 'dioxins') and polychlorinated dibenzo-p-furans (PCDFs, 'furans').

The above mentioned POPs chemicals exist widely spread throughout the entire CEE Region. Most of these are although today covered by the more general nomenclature for obsolete pesticides. This, both due to difficulties in distinguishing the actual POP substances, but also due to the fact that most of these chemicals today are co-stored (stockpiled) with other chemical substances (mainly pesticides). The only POPs substance differentiating from this perception is PCBs due to generic utilisation different from the other POPs.

The Stockholm Convention governing POPs has in accordance with Article 1 the following main objective - "to protect human health and the environment from persistent organic pollutants (POPs)." The Convention obliges Parties to:

- Take measures to eliminate releases from intentional production and use, unintentional production, and stockpiles and wastes of 12 POPs (Articles 3, 5 and 6);

- Eliminate production and use of nine intentionally produced POPs, subject to certain time-limited and general exemptions (Annex A: aldrin, chlordane, dieldrin, endrin, heptachlor, HCB, mirex, toxaphene, and PCBs);

- Take measures to restrict the production and use of one intentionally produced POP (Annex B: DDT);

- Reduce the total releases of unintentionally produced POPs with the goal of their continuing minimisation and where feasible, ultimate elimination (Annex C: polychlorinated dibenzo-p-dioxins, dibenzofurans, HCB, PCBs);

- Take appropriate measures so that waste POPs, including products and articles upon becoming wastes, are handled, collected, transported and stored in an environmentally sound manner, and are disposed of in such a way that the POPs content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of POPs. Alternatively they should be disposed of in an environmentally sound manner when destruction, or irreversible transformation, does not represent the environmentally preferable option or the POPs content is low) (Article 6);

- Prohibit POPs waste to be subject to disposal operations that may lead to recovery, recycling, reclamation, direct reuse or alternative uses of POPs (Article 6.1 (d(iii))); and

- Encourage the implementation of national regulations to prevent development of new chemicals with POPs characteristics by promoting changes in industrial materials, processes, and products that can create POPs.

Furthermore, Article 6 of the Stockholm Convention concerning measures to reduce or eliminate releases from stockpiles and wastes left open a number of definitional issues. It required the COP to cooperate closely with the appropriate bodies of the Basel Convention in addressing these, in particular to establish appropriate levels of destruction and irreversible transformation for POPs wastes; to determine what methods would constitute environmentally sound disposal; and to establish the concentration levels that would define low POPs content. In order to keep the various integrated problems (POPs, other obsolete pesticides and polluted soil) separated in terms of elimination, it has been decided to use the nomenclature obsolete pesticides as descriptive term for POPs substances and other obsolete pesticides. The individual aspect of polluted soil is **NOT** covered by this report and the nomenclature for obsolete pesticides.

Countries in the CEE region have during the last decade used substantial efforts developing national inventories of in particular obsolete pesticides, mainly uncontrolled stored in rural sheds with no or limited control. Nevertheless, the various countries are merely all facing the safe problem - how to have more or less well documented uncontrolled highly toxic chemicals disposed off in an environmentally safe manner. Table 2.2 outlines estimated amounts of obsolete pesticides, POP and hazardous substances in general for selected countries in the CEE Region.

Table 2.2 Estimated amounts (tonnes) of OPs, POPs (inclusive PCBs) and hazardous waste in general based on extrapolation of obsolete pesticide data.

Country	Obsolete Pesticides, t	POPs fraction (inclusive PCBs), t (*1)	Hazardous Waste, in general, t (*2)
Belarus	6,500	1,600 +	Not known (650,000)
Ukraine	15,000	5,000 +	110-115,000,000 (*3), OP = 0.01%
Latvia	1,750 - 2,000	3-800	Not known (150,000)
Lithuania	3,300	500-1,000	Not known (350,000)
Estonia	438 (+100)	250-500	Not known (50,000)
Bulgaria	4,000	1,000 +	Not known (400,000)
Russian Federation	17-20,000	25-30,000	180-185,000,000 (*4), OP = 0.01%
Moldova	3,000	700 +	Not known (300,000)
Poland	18,000 - 90,000	15,000	Not known (6,000,000)
Sum for selected CEE countries	**115,000**	**49-55,600**	**App. 300,000.000**

*1: The POPs fraction is for selected CEE countries positively identified to be between 20-30% of identified obsolete pesticides. A median value of 25% is used for the calculation. Added hereto actual known amount of PCBs generated from various DANCEE financed studies and mass flow calculations.
*2: Based on information from three independent sources of expertise, obsolete pesticides are estimated to provide approx. 0.01% of the anticipated total amount of hazardous waste in selected (Ukraine and Russia) countries. Figures in () are the estimated based on a 0.01% fraction of obsolete pesticides in relation to the total hazardous waste.
*3: The figure is officially announced and is from 1998. The figure includes class 1-3 waste equal to EU classified “toxic waste”.
*4: The figure is officially announced and is from 1999. The figure includes class 1-3 waste equal to EU classified “toxic waste”.

The figures in Table 2.2 is only a estimate due to national inclusion of both mixed POPs substances (e.g. non-POPs mixed with certain POPs) and in a number of cases extensive amounts of polluted soil frequently containing extensive amount of e.g. PCBs. The actual amount of OPs, POPs and in particular hazardous waste will differ, but the table shows an order of magnitude.

The entire CEE Region has an estimated amount of obsolete pesticides (as pure substances not mixed with e.g. soil) in excess of 100,000 tonnes exceeding identified amounts for e.g. the entire African continent. Taking into account that approximately 25% of the identified obsolete pesticides are POPs and that the region has extensive numbers of former large-scale production facilities formerly producing POPs substances, the CEE Region will have more than 100,000 tonnes of POPs substances to be eliminated. Simultaneously, recognising that the POPs fraction only equals less than 1 0/00 of all hazardous waste generated individual or combined elimination solutions must be assessed in this context.

2.2.2 POPs status of the CEE Region

The CEE Region is typically characterised by having relatively large stocks of obsolete pesticides, minor stocks of "pure" POPs and extensive, mostly site specific (hot spot) amounts of polluted soil and industrial produced hazardous waste. Table 2.3 shows for selected new EU countries the progress in terms of POPs inventories and storage characterisation, Stockholm Convention ratification including preparation of NIPs and establishment of national POPs elimination capacities.

Table 2.3 Country specific data on OPs/POPs in selected new EU countries

Country	Poland	Lithuania	Latvia	Estonia
Estimated stocks of OPs (tonnes)	18,000-90,000 (*1)	3,300	1,750-2,000	438 (+ 100?)
Estimated stocks of POPs pesticides + PCBs (tonnes)	Up to 25-30% of OPs	500-1,000	3-800	250-500
Type of storage	Distributed over	Half is stored	Major quanti-	Major quanti-

Country	Poland	Lithuania	Latvia	Estonia
	several provinces, so-called tombs and warehouses	in centrally located warehouses	ties are stored in centrally located warehouse	ties are stored in centrally located warehouse
Presence of "eastern" OPs (*2)	Present - to a large extent	Present - to a large extent	Present - to a large extent	Present - to a large extent
Condition of stores	Mainly unsafe	Varies	Safe	Safe
Condition of stored OPs	10-30 years old, often mixed, missing labels, bunkers	10-30 years old, about 30% identified	10-30 years old, major quantities are identified, repacked and centrally collected to Gardene and Knava central storage facilities	10-30 years old, major quantities are identified
Disposal/ elimination practice	Export for incineration to Western Europe and test incineration as supportive fuel in cement kiln. Ongoing planning work for setting up small purchased incineration units.	Remarketing, export for incineration (planned)	Mobile incinerator for hazardous waste to be put into service September 2003	Most likely awaiting export to Finland for incineration
Position on the Stockholm Convention (SC)	Signed 23.05.2001	Signed 17.05.2002	Signed 23.05.2001.	Not signed per August 2004.
Activities stated by the countries requiring assistance for disposal of OPs/POPs pesticides	Introduction of OP disposal facilities, export for incineration, remediation of OP contaminated sites	Assistance in introduction/ provision of OP disposal facilities; investigation and remediation of OP contaminated sites	Assistance for commissioning of mobile incinerator in joint Latvian/Danish financial package.	Disposal of about 60 tonnes of mercury-containing OP

*1: The official estimate is 18,000 tonnes, while the 6th International HCH and Pesticides Forum, 2001, estimates an amount of 50-60,000 tonnes in bunkers + 160,000 tonnes on industrial industries.
*2: Pesticides produced in the former Soviet Union.

The capacity of facilities currently available that may be used to eliminate the stocks of OP in the countries is far from being sufficient. Arrangements to increase capacity are therefore given high priority. Poland and Estonia have disposed of some quantities of OP in the past by way of export. Latvia is ongoing installing a mobile incinerator, which will run into regular service during 2004. Poland and Lithuania are also looking for opportunities to establish modern OP destruction facilities.

Most of the OP in Estonia and Latvia are stored centrally. Relatively large-scale activities to dispose of or eliminate OP are needed in the four countries of this group in order to solve the problems related to OPs, which will also allow them to meet the obligations under the Stockholm Convention concerning POPs pesticides. Large efforts are being made by the countries to increase national funds for those purposes. However, considerable international funding is required to assist the countries to successfully implement the elimination of OPs.

In Ukraine, the OPs are stored at about 4,000 storage facilities distributed nationwide. The National Action Plan on OP has been prepared, the national inventory of OP is carried out with the technical assistance funded by DANCEE and combined with the practical activities for upgrading selected storage facilities.

According to presentation at the 5th International HCH & Pesticides Forum (1999), the two regions (oblasts) of Ukraine (Dnepropetrivska and Donetska) are responsible for about 80-90% of the total annual generation of hazardous waste in Ukraine and about 90% of the total accumulated hazardous waste amount is located on their territory. Total generation was estimated to 138 million tonnes per year. Certain part of waste is neutralised or recycled. As of January 2000, the total quantity of toxic waste accumulated in Ukraine was about 4.4 billion tonnes, which is about 54 million tonnes more than those accumulated by January 1999 according to source information (reference to "National Report on the State of Environment in Ukraine in 1999").

In the Russian Federation, the problem of PCB is currently prioritised higher than the problem of OPs. The problem is caused by the large quantities of PCBs which were produced in the USSR, exported to other countries and used in industrial equipment of various types. The basic data on PCB balance and distribution are presented in the ongoing AMAP project focussing on phase-out of PCB containing products. As for the POPs/OPs, the main attention in the RF should be paid to DDT and HCB. Other POPs were not so widely used due to long lasting ban or total lack of internal RF production. However, other OPs are present on stocks.

During the 1960s the DDT was sprayed over vast agricultural areas from special aircrafts and with lack of precautions. This resulted in heavy contamination of soil. The formal ban was introduced in 1970, but the agricultural use continued up to 1980 and even later. The use for medical purposes was prohibited in 1989, but some exclusive permits for DDT application were provided later for vector control. There is no current production, import or export of DDT in Russia, but it is present in stores, some of them being in poor conditions.

2.2.3 POPs elimination experiences in the CEE Region

The CEE Region has obtained a number of POPs waste elimination experiences both based on in-house solutions and exporting. The export solutions have turned out to be limited in numbers, but quite successful in the sense that POPs waste are eliminated, although no national capacity is generated beside knowledge on formalised exporting procedures (Basel Convention transhipment documentation).

In a number of countries, national attempts for the establishment of national elimination capacity has been launched, and in particular during latest years. In e.g. Poland, both dedicated semi-mobile based elimination capacity is in preparation, although facing a large number of problems due to restricted funds and public resistance as well as test trails with cement kiln elimination. In Latvia, a semi-mobile elimination facility is under provision enabling the Latvian government to complete final elimination of almost 2,000 tonnes of nationally collected OPs during 2004/05. In Lithuania, strategic considerations are made towards seeking solutions for old stockpiled pesticides and future plans for the establishment of a national system for hazardous waste. In Russia, with assistance from several co-funded programmes, minor breakthroughs are identified for PCB elimination and partly for OP elimination in selected parts of Russia. In the Slovak Republic, a GEF financially supported programme will likely establish the first non-incineration based commercially viable elimination platform in the CEE Region. However, it will take yet a few years to have the entire programme fully implemented and available for possible commercial operations.

3 Public Barriers

The establishment of e.g. an elimination facility includes a number of planning processes independent of technology choice and modality (stationary or mobile). Historically, establishment of treatment facilities for hazardous substances have contributed significantly to the overall change of approach to public participation and awareness rising. A still increasingly number of scheduled elimination projects have either been delayed or actually stopped due to increasingly public resistance basically generated by 2 overall factors;

- increasingly awareness among the general public on possible environmental and human impacts generated from elimination processes due to e.g. local Agenda 21 and general increasing NGO organisations; and
- development of mandatory planning processes involving public hearings (e.g. EIA and IPPC procedures).

During recent years, most authorities, contractors and consultants have recognised the outmost importance in addressing public barriers in advance and all way through the scheduled planning process. Furthermore, the overall development of still more and more internationalised NGO movements/organisations has contributed significantly to the general perception on how to tackle and incorporate public barriers and acceptance.

Within the CEE Region, in parallel to other regions, the following main features of public barriers have been identified:

- general public resistance to "non popular" political decision due to historic reasons;
- increasingly public interest involving society development and priorities (e.g. local Agenda 21);
- still un-mature political systems with relatively large room for political fractions based on "stand alone cases";
- still lack of public information on high-end technologies and their impact on potential and preventive actions;

- non-mature planning process instrumented on e.g. EIA and IPPC, which include public hearings as an integrated part of both the planning and permitting process.

Taking into account the fact that the establishment of local, regional or national elimination capacity is not an "off the shelf commodity", but a highly complex process involving not only economic and technical considerations, but to a still larger extent mandatory obligations for proper public information and involvement, makes the process still more complex in nature and implementation.

Experiences show that from the final political decision on the establishment of elimination capacity to actual operation of the facility in full scale, 5-10 years should normally be scheduled. First of all, time is needed for feasibility and business plan development, local, regional and national political approving processes, preparation of tenders and tender process, planning process with site selection process, EIA, IPPC and Seveso II Directive assessment running in parallel and/or continuously. Furthermore, all preparatory activities related to civil work, infrastructure and supply line support etc have to be designed, planned, contracted and implemented. Finally, decisions on operational responsibility and commissioning conditions must be determined and agreed upon. In addition to the formal planning procedures, supplementary actions devoted to avoid the generating of public barriers must be scheduled, facilitated and constantly updated.

From a planning process point of view, the preparation of a Communication Strategy Paper (CSP) is advisable. The paper takes into account all available nation specific communications means and respond groups and factor in which principles and strategic activities is mandatory for making the process overall public participatory. Based on the CSP - detailed public awareness (brochures, pamphlets etc), media strategies are to be developed linking up with the overall themes and principles of the mandatory planning actions.

All above descriptions refer to pre-installation activities (prior to on-site installation of actual elimination capacity). However, the numerous defined and by experience potential implementing-dealing barriers have also to be considered in the post-installation phase. As soon as the actual erection of a plant facility has merged, the challenge is to perform continued public participation and awareness. Within e.g. existing EU territory, which from May 2004 also covers a large part of the former CEE Region, a number of international and/or EU Community based binding instruments must be compiled into the operational picture. First of all, the Århus Convention on public access to environmental data and mandatory reporting requirements in e.g. obtained IPPC permission is an essential part of the public access avoiding the built up of public resistance.

Lessons learned from e.g. Poland and Latvia on the scheduled activities related to e.g. test incineration of obsolete pesticides in cement kiln (Poland) and establishment of national elimination capacity (Latvia) based on a semi-mobile incineration unit have clearly shown the various difficulties obtaining public acceptance as pre-conditional for a successful planning and ultimately elimination process.

The general perception of public barriers has a significant negative effect on the commercialization of the market sector for establishing treatment facilities. No major commercial investors find the sector attractive for investment projects which, at the same time, are closely related to these objects due to initial needs for large capital cost investments related to the various technologies and built up infrastructure. Subsequently, all major establishments recorded within the CEE Region (Cyclone technology development in Russia, Cement kiln testing in Poland, Semi mobile incineration unit in Latvia and non-incineration facility (GPCR) unit in Slovakia) are all characterized by minor input from private investors thereby almost solely rely on a combination of international and/or bilateral funds and grants supplemented by a minor proportion of national funds. Opposite the commercialized waste sector in general, the sector for elimination of POPs and obsolete pesticides face difficulties securing sufficient investment for actual establishment of objects leading to a still increasing stockpiling of obsolete products.

Attractiveness to private investors into the sector is crucial securing a continuous development of the area related to POPs and obsolete pesticides elimination. There is no doubt that already scheduled activities in e.g. Latvia and Slovakia will prompt further development to the market platform. However, it is of importance that gained experiences with public barriers are disseminated in order to facilitate the process leading to further establishment of eliminating capacities diminishing the environmental and human impacts from the extensive amount of stockpiled products in the CEE Region.

4 Requirements for POPs elimination technologies

4.1 International requirements

For decades hazardous chemicals have either been disposed off in landfills and/or eliminated mainly by incineration based technologies. Increasing awareness of chemical impact on the environment, humans and biota during the 1990ies initiated in mid 1990ies international initiatives for preparation of an international environmental binding convention on selected hazardous substances. In May 2001, the Stockholm Convention (SC) on Persistent Organic Pollutants (POPs) was decided and open for signature, subsequently ratification. The SC is the first step towards an international agreement on successive restricted use, ultimately banning of the most harmful chemical substances.

One of the consequences of the SC is the preparation of National Implementation Plans outlining a number of institutional, technical and financial aspects of POPs waste management. A critical aspect hereof, is the attitude, ability and national/regional perception of what is "environmentally sound elimination of POPs".

The SC processes the issue in a two-fold manner; by making definition in the convention text of the Best Available Technique (BAT) and the principles of Best Environmental Practise (BEP) and by initiating a long pre-conventional discussion amongst key stakeholders to the convention of this critical element recognising the needed time to develop a sustainable foundation for the conventional statement. The SC furthermore clearly distinguishes between reduction/elimination of unintentional releases and reduction/elimination of stockpiles and wastes.

The conclusions from the SC process can be summarised as:

- SC defines the wording BAT as the most effective and accessible technique for providing the basis for release limitations. Both in achieving a high level of protection of the environment in general, but it is also developed to a certain commercial scale that allows implementation under economically and technically viable conditions. However, simultaneously recognising where this achievement is not practicable enforceable, generally to reduce releases and their impact on the environment as a whole;

- SC defines the wording BEP as the optimum result of a process involving the combination of environmental control measures and strategies.

The above conventional wording for BEP can be interpreted as a number of basic principles like use of low-waste technologies, less hazardous substances, promotion of the recovery and recycling of waste and of substances generated and used in the process, replacement of feed materials which are characterised as POPs or where a direct link between the materials and releases of POPs from the source, good housekeeping and preventive maintenance programmes. All, which must be assessed and national imprints made in the preparatory work for the National Implementation Plan under the Stockholm Convention. Interpretation of the SC wording for BAT is of key interest for this project. Initially, the SC wording on BAT need to be further elaborated by both the Conference of Parties and the Interim Secretariat for the Stockholm Convention, although strong perception requirements are highlighted in the SC text. These include:

- A number of general conditions: national POPs characteristics, commissioning of existing and/or new techniques, time for implementation, consumption of raw material, efficiency etc, POPs mass flow characteristic, risks for accidents, humans, environment etc, technology advances, national strategies and abilities (technical, financial etc);

- A number of release reduction measures (preferences to new technology, assessment of existing facilities within areas like retrofitting, residues, open/close systems etc).

Most of the countries in the CEE Region have become Parties to the Basel Convention. One of the main objectives of the Basel Convention is to encourage countries to reduce production of hazardous waste and thereby reduce needs for transboundary transport of such waste. The Basel Convention states "Recognising also the increasing desire for the prohibition of transboundary movements of hazardous wastes and their disposal in other States, especially developing countries" and thereby supporting the principle of handling of own produced waste.

The above requirements related to e.g. the SC and Basel Convention ratification, emphasise the difficulties that many countries in the CEE Region and elsewhere are facing. However, the recognised baseline is the national characteristics of the POPs and other hazardous chemicals. In Section 3.2, an estimate of the amount of stockpiled and waste POPs/OPs is outlined as baseline data considerations related to both BAT and BEP perceptions in the CEE Region.

Focussing on the CEE Region, baseline data from Section 3.1 and outlined international requirements are reflected in the final choice of technology review criteria, which are considered relevant for the CEE Region. Some of these are of more generic character and can eventually find use in other global regions, but many are of generic character for the CEE Region. These are strongly related to both national/regional characteristics within institutional setting, POPs characteristics and financial/structural conditions as well as technical abilities, skill level, occupational health conditions and abilities to operate highly technological facilities.

Chapter 6 outlines the final selected review criteria for the CEE Region in further details. The final review criteria have been selected based upon:

- A wish to create an overview rather than further “confusion” among in-line experts, specialists, vendors, NGOs and policy makers;
- Covering the aspects of technical, economic, environmental and risk related items, which are considered as the main elements of a good, consistent and in-depth review on POPs elimination technologies;
- Drawn-up highlights of CEE Regional specific POPs problem related to cultural, regulatory and institutional differences within the region;
- Liaison with International and Regional recognised POPs problem of the region, outlined in various presentation papers, workshops, conferences and national contacts through existing projects.

4.2 Regional and national requirements

4.2.1 Regional requirements

The EU countries have signed the Stockholm Convention and will therefore be obliged to follow the rules spelled out here (reference to Regulation no. 850/2004 of the European Parliament and the Council of 29 April 2004 on POPs and Amending Directive 79/117/EEC). Concerning the pesticides DDT, Aldrin, Dieldrin, Endrin, Chlordane, Heptachlor, Hexachlorbenzene, Mirex and Toxaphene, EU countries have either already banned the use or will have to do so shortly. This most likely in combination with a general discussion about which pesticides can be accepted in Annex 1 to the EU-Directive 91/414 "Council Directive 91/414/EEC of 15 July 1991 concerning the placing of plant protection products on the market".

Concerning the destruction of POPs, this has already been ruled for in the EU-requirements waste elimination (EU-Directive 2000/76/EC on the Incineration of Waste). Herein are also rules on how to avoid the emission of dioxins and furans.

On the disposal of PXB/PCT, EU has made a special directive, the EU-Directive 96/59 of 16 September 1996 on the disposal of polychlorinated biphenyls and terphenyls (PCB/PCT).

According to the EU Directive 2001/42/EC of 27 June 2001 (assessment of the effect of certain plans and programmes on the environment), the EU member states have to introduce the legal, regulatory and administrative mechanisms for implementation of Strategic Environmental Assessment (SEA) of plans and programmes developed for various sectors including the waste management by 21 July 2004.

The planning process establishing national elimination capacity is supported by the EU-directives on EIA (although only mandatory for larger scale facilities) and IPPC (obtainment of operational permission). Prior to these, a pre-EIA phase will normally include a site selection process into which the EIA procedure and assessment will factor in site specific information. Implementing both the EIA and IPPC procedures requires public hearings allowing public access to key technical and environmental assessment data. Furthermore, the IPPC regulation will stipulate under which mandatory conditions the facility can operate.

Furthermore, the EU Seveso II Directive must be built into the overall planning process. In many countries OPs/POPs are centrally stored evitable posing a high risk for uncontrolled impact in case of e.g. fire. The Seveso II Directive, amended 26 September 2002 highlights possible applicability and further development of e.g. safety reports depending on assessment, characterisation and classification of actual stored chemicals.

All the new EU member states have to incorporate a substantial regulatory framework. With identified restricted capacity in e.g. environmental institutions, the assessed abilities of the competent authorities approving e.g. the establishment of national elimination capacity, could decrease and slow down the development due to extensive new regulations and general transformation of the societies. However, how the impact from signed international environmental legal binding conventions will interact with more immediate needs provided and generated through a soon need for sustainable national systems for hazardous waste stream, is uncertain but must be monitored.

4.2.2 National requirements

The national requirements related to POPs elimination technologies in the CEE countries are determined either by the EU directives (for the new EU members) or by the legislative context historically developed in the CIS in view of obligations under the international conventions (e.g. Convention on Environmental Impact Assessment in a Transboundary Context, Geneva, UN/ECE 1991).

The major set of national requirements for a project on elimination of POPs in CEE countries is covered by the procedure of the National Environmental Expertise, including the EIA (with public hearings) as one of the components. There is also bilateral agreement on the international environmental expertise within the CIS.

Basically, the POPs elimination activities in CEE could be performed in 2 ways: (1) by construction of a new facility, (2) upgrading of an existing facility. In any case, the project documentation has to pass the environmental expertise and an enterprise starting activities for elimination of POPs should apply from the relevant authorities, the permits for use of resources (e.g. land, water, energy) and for emissions (air emissions, discharge of wastewater and management of solid waste) and for other types of impact (e.g. noise, electromagnetic fields) analogue to EU-framework for e.g. IPPC permission.

The legal and administrative framework for the environmental protection provides a background for the compensation of impact resulting from an activity. Several CEE countries are currently introducing environmental insurance, which is seen as one of the mechanism of raising funds for possible damage to the public and the environment.

Nevertheless, looking into e.g. European past history on the establishment of national elimination capacity, the CEE Region will have to promote these historical anchored processes into a one-step process. This is why many CEE countries show obvious reluctance entering in the field of capital investment for national elimination capacity. Resources are restricted, environmental goals many and with the present level of political instability, still limited experiences with democratic ruling, such investment projects have been prioritised, but not on the top list. In the future, the outline picture will change due to increased pressure from the international community, NGO organisations, industries (providence of appropriate infrastructure - e.g. handling of hazardous residuals from production) and public interest (recognition of the fact that systems are needed).

In Chapter 5, the report further elaborates on the "conflict of interest", between the technical wishes, assessed results and the economic incentives to perform capital investment. A combined solution is needed for implementing any new elimination activities in the CEE Region on a commercial scale. Alternatively, the initiate on the establishment of national elimination capacity is highly depending on bilateral aid programmes as seen in Poland, Latvia and Slovakia. However, these bilateral programmes will soon phase out due to EU membership and be replaced by structural funds (cohesion funds) provided for by EU, although one could fear a repetition in a larger context, that the issue will fall in priority due to larger scale problems as for example turnaround of the industrial sector, infrastructure investments etc.

5 Economic review criteria

5.1 Introduction

5.1.1 Background

The economic field of expertise not only deals with the identification and qualification of individual evaluation criteria. It also deals with summarisation of the individual criteria against one another. The present chapter primarily focuses on the former of the two through a systematic analysis of the gross list of criteria outlined below introducing a few of the most commonly used measures for evaluation of generic criteria as well as some of the problems related to this. Finally, Section discusses the issue of environmental financing and argues that the financing available for a specific project in practice is likely to be a decisive factor in the selection of a technology.

The economic review criteria and approach has been focussing on the essence of the technical evaluation of the four selected POP elimination technologies. These are reviewed in detail in Chapter 6.

5.1.2 Gross list of economic criteria

An economic assessment of potentially viable POPs elimination technologies addresses a variety of more or less related areas. These areas include:

- financial criteria, i.e. capital costs, operational costs, unit costs and similar traditional financial evaluation criteria;
- organisational constraints;
- know-how transfer;
- capacity;
- robustness;
- logistics;
- process residues;
- demand; and
- socio-economic costs and benefits.

The aim of the following chapter on economic review criteria is to argue the potential for each of the identified criteria in terms of their appropriateness and applicability on the four selected POP elimination technologies covered by the present review report. Hence, the main objective of this chapter is not to conclude which of the four selected technologies is the favoured option, but rather to establish a set of generic issues to be considered systematically when evaluating the options for a POP elimination solution in a specific context.

5.2 Categorisation of criteria

The term "economic" in this context is very broadly defined so as to concern topics, which one way or the other may have cost implications to the implementation of a specific technology option. Several of these topics are described in the technical, environmental and risk parts of the review, but will be reconsidered in this section with the economic angle.

The nine-item list presented above basically represents a very disparate and complex view on what issues could potentially be relevant in relation to POP elimination technology evaluation. Not all of these issues may prove to be relevant or applicable as technology evaluation criteria, and the approach is to systematically argue why a specific criterion is relevant or not.

The main working hypothesis is that the economic review criteria as outlined above falls into one of three different categories:

- **Category 1:** Criteria which are technology specific, i.e. evaluation criteria that relate solely to the technology option in focus, regardless of the context. A typical example is capital costs;

- **Category 2:** Criteria which are context specific, i.e. evaluation criteria that yield different prioritisation of technology options depending on the actual context, for example region. One such criterion could be treatment capacity of the technology option in focus. If a specific region faces severe problems with certain types of stockpiled pesticides in powder form, the preferred technology may not be the same in another region, where PCB contained in large industrial transformers tends to be the biggest problem. Socio-economic criteria typically fall into this category; and

- **Criteria 3:** Criteria which are generic in terms of technology and context, i.e. evaluation criteria that can be met (or not met) regardless of technology option or context on focus. Typical for this category could be sound implementation and management practices, as for example how to organise the financing of operational activities, how to ensure public acceptability and similar.

5.3 Category 1: Technology specific criteria

5.3.1 General

The category of technology specific criteria covers a number of the technical and performance related attributes that uniquely characterise the technology option in focus. Most of the criteria within this category are being described in the technical, environmental and risk parts of this review. Common to many of these criteria is, however, that they have cost implications either directly for the organisation responsible for running the operations, or for the initial owners of the POPs to be eliminated (or for the society as such, as the ownership issue if for example obsolete pesticides very often is blurred).

A distinction is made between the costs related to the mere elimination process (direct costs) and costs related to some of the supporting activities that inevitably follow from the elimination process, such as transport and temporary storage of POPs and similar. The latter is referred to as indirect costs.

5.3.2 Direct costs

The two main direct cost components involved include treatment costs and capital costs.

- **Treatment costs** - typically formulated in relation to the treatment capacity of the technology - include costs for raw materials, energy consumption, labour input and similar. As prices, however, vary from one region of the world to another, vendors should optimally submit information on required input of raw materials, electricity, labour and similar in natural units, as it will be necessary to assess each of these cost items in the specific context. The cost of labour input will for example often vary substantially from one country to another, whereas many of the raw materials typically must be purchased at prevailing international market prices. Finally, it should be noted that the issue of technology robustness, i.e. the risk of technological breakdown causing temporary cease of operations, has been incorporated indirectly in the treatment costs. The figure is calculated by dividing the annual use of operational costs with the amounts of POPs treated within the same period, adjusted for technological down-time (expected time used for maintenance, service etc.). Treatment costs normally amount to approx. 50% of the total costs pr. unit POP treated.

- **Capital costs** - in principle an objective technology specific evaluation criterion as it is typically to be paid in "hard" exchangeable currency and therefore is comparable in between technologies regardless of the specific context. Nevertheless, the capital cost criterion is not so straight forward. The main reason is that in the CEE Region, collecting and eliminating hazardous chemicals are not likely to become outright profitable in the foreseeable future. This is due to a number of factors, one of which concerns the initial ownership of the POPs as previously mentioned. Another issue concerns the effective (or non-effective) enforcement of environmental regulation put forward by national authorities. In practice, these circumstances in practice often constrain an operator in terms of the revenues that can be gained from the operation. This will change in the new EU member States and new applicant countries. In most of the former Soviet republics, however, activities related to combating the POP problem must be based on substantial subsidising, either from national authorities (state guarantee, for example), or from international donors and other international financing intermediaries (IFI's).

These considerations influence the loan conditions that can be obtained for a particular country or region, which to a certain extent makes capital cost a context specific evaluation criterion.

One should expect a general relation between the capital costs and marginal treatment costs, so that less expensive the plant, the higher the average costs for treating one unit of POP. This is evidenced by the key cost components of the four technologies included in this review (see table 5.1). In practice, the funding options available for the specific project (operational revenues, government subsidies, commercial and development bank loans, grants) will often play a decisive role when prioritising purchase of either an expensive technology with low operational costs or a less expensive technology with relatively higher operational costs.

- **Marginal cost of capital** - in the price comparison table, the costs for capital investment have practically been expressed as the marginal costs of capital. In principle, the marginal costs of capital measure the share of the costs for eliminating one additional kg of POPs, which is incurred by the initial capital investment. In practice, the marginal costs of capital are obtained by expressing the capital investment as an annuity (fixed annual cash flow over the expected lifetime of the elimination plant) divided by the annual elimination capacity of the technology or plant.

- **Direct costs evaluation criteria** - cost estimates have been provided by the individual POPs elimination technology vendors and are based on pricing schemes that prevail in the respective home countries, including the demand for analytical testing and similar. Hence, these estimates cannot be transferred directly to the CEE context, although the figures do give an indication as to the potential for CEE applicability.

Table 5. Criteria in support of main direct cost components

Criterion	Unit	Ecologic	BCD	CIS	Kiln (*2)
Capital investment	mill. USD	15	1	2,6	71
Marginal costs of capital (*1)	USD/kg	0.55	2.44	0.10	0.25
Treatment costs (*3)	USD/kg	0.57	15.10	0.62	2.0
Total costs (*4)	USD/kg	1.12	17.54	0.72	2,25

*1: Assuming full loan financing (annuity at 7% p.a. and 15 years maturity). The loan conditions likely to be obtained from a bank among other things very much depend on the loan amount in question. For the present purpose, however, all four technologies have been tested on the same set of simple loan conditions in order to make the technologies comparable and the comparison thereby transparent.
*2: The cement kiln is a special case in respect of the capital investment, as the facility in its design and purpose is not dedicated to eliminating POPs. Cement production can in principle be maintained parallel with the POPs incineration, and the marginal capital costs should therefore not be included as part of the total costs for POPs elimination, thereby reducing the total costs per eliminated kg POP.
*3: Includes analyses and treatment costs. The estimate is based on cost figures provided for treatment of pesticides.
*4: Assuming average annual treatment capacities of: Ecologic 3,000t/year; BCD 45t/year; CIS 3,000t/year and cement kiln 30,700t/year.

5.3.3 Indirect costs

The term "technology" is typically defined narrowly by vendors as to include the mere destruction process. Costs will in practice, however, accrue to all processes associated with the POPs destruction. Hence, the basic assumption for the technology specific economic criteria is that one should apply a comprehensive and universal view to project costing. A comprehensive list of cost items can be established by applying a kind of cradle-to-grave approach, by which the POPs are followed from the first initial identification all the way to the final elimination and documentation. This will typically include:

- Initial identification and registration of POPs;
- Special repackaging of POPs in order to meet specific requirements posed by the elimination technology;
- Pre-treatment of POPs in order to meet specific requirements posed by the elimination technology;
- Transportation to plant;
- Special requirements for management and storage at plant;
- Destruction of POPs, including analyses etc;
- Destruction/cleaning/safe long-term disposal of temporary storage means (drums etc);
- Safe disposal of residues and rest products (secondary wastes);
- Post-restoration/cleaning up of plant site; and
- Management and administration.

It is likely that all of these items will accrue directly to the organisation operating the elimination process. In terms of what is the most appropriate technology, all costs should, however, be included in the prioritisation process, no matter to which they accrue (government institutions, the operator, private enterprises etc.). Furthermore, some of these items will be common to all technologies and could therefore effectively be excluded as prioritisation criterion.

Those cost items, for which each technology may perform differently (or individually), must be explored, and the vendors should accordingly be urged to submit information on these particular items in addition to information on the mere destruction process.

- **Repackaging costs** - the POPs elimination technologies in focus obviously differ in terms of how the POPs must be handled before and during the mere elimination process. One technology may for example require that the POP is stored in drums with very specific characteristics in order to be practically handled at the elimination facility, whereas another technology may be more rugged in terms of requirements for repackaging of the POPs prior to the treatment. The technologies may thus in this respect have different indirect cost implications, which need to be explored.

- **Pre-treatment costs** - a technology may for instance be able to treat POPs only when these are available in liquid form, thereby implying that POPs appearing in powder form require some kind of pre-treatment. Vendors must specify in details the requirements for the costs related to pre-treatment.

- **Transportation costs for POPs** - transportation costs for POPs to the destruction plant should obviously be weighed against the costs of relocating the plant (if possible at all). Transportation costs are in general in the CEE Region not very high although they are expectedly rising as the full EU membership status approaches. The transportation costs should also include the risk premium that is related to carrying hazardous chemicals over great distances either by road or rail.

- **Safe management of storage means** - safe management of storage means may be an important evaluation criterion, as some technologies offer direct incineration of the entire package, including means of storage and contents, whereas others can work with waste in liquid form only, thus necessitating some kind of post-process handling (cleaning and safe disposal) of the storage means additional costs for the operator.

- **Residues handling** - in most cases will there be residues left from the destruction process, which necessitates post-process handling of some kind, either be in form of land filling or restricted dump site disposal or similar. The main attributes (or cost drivers) to this criterion will be the amount of residues to be disposed of per unit of eliminated POP and hazard potential of the residues.

- **Restoration of the plant site** - cleaning up of contaminated sites can be extremely costly. Although the operators will of course strive to avoid spills and leakages from the operation, there will always be a risk of unforeseen events that require restoration of the plant site after operations have ceased. If the operations are planned to last for many years, the financial impact of this criterion (at the moment of the investment decision) may not be overwhelming simply because of the discounting of future cash flows. But it should be considered, nevertheless, for example, how many cubic metres of contaminated soil that eventually will have to be cleaned in a worst case scenario (i.e. what is the extent of the area needed to erect the plant).

- **Indirect costs evaluation criteria** - actual costs have not been provided by the vendors, as the indirect cost items described above are not normally considered to be an integrated part of the technologies. It is - as described - nevertheless the specific attributes of each technology options that actually make an indirect cost item occur (or not occur). I.e. these attributes can be considered as *cost drivers*, and are therefore also relevant as economic technology evaluation criteria.

Table 5.2 below outlines six criteria, which could support each of the six indirect cost items described above. Each criterion in the table is associated with additional costs, which can be derived relatively easy.

Table 5. Examples of criteria in support of indirect cost indicators

Indirect cost item	Technology attribute or criterion
Repackaging	Repackaging required, and if yes, then what are the restrictions in this respect for the selected technology option
Pre-treatment	Pre-treatment required, and if yes, then what are the restrictions in this respect for the selected technology option
Transport	Costs and options for relocation of facility
Safe management of storage means	Post-process handling of storage means (drums) required
Residues handling	Amounts and hazard potential of residues to be disposed of
Restoration of the plant site	Extent of area potentially exposed to POP contamination

The table may not be exhaustive, but it does give an indication of arguments needed to achieve a comprehensive approach to the costing exercise of the technology evaluation.

5.4 Category 2: Context specific criteria

5.4.1 General

A context specific evaluation criterion is basically a prioritisation scheme that does not yield a direct answer as to what technology option will be preferred universally, as they depend on the context in which they are applied. These criteria may end up ranking the same technology options differently in different contexts, e.g. different countries and regions.

The elements to this category of criteria basically relate to either demand (in terms of amounts and fractions of POPs available for destruction) or the institutional and regulatory framework.

5.4.2 Amounts and fractions of POPs

Meeting the contextual (e.g. local or regional) demand in terms of amounts and fractions available is obviously critical to combating the POP problem of a particular local or regional community. No use in supplying a piece of equipment that cannot actually solve the problems it is supposed to, either because of a mismatching capacity of the acquired treatment facility or because the technology is not technically suited for treating the specific POP fractions that exist in a given region or country.

Whereas this in itself is a fairly simple observation, the argument could in fact be taken a step further. A steady and continuous supply of POPs to be eliminated is needed in order to ensure the full benefit from the acquired treatment facility. Costs will accrue (costs of servicing of loans, maintaining a skilled labour force and similar) even when operations have ceased for lack of POPs to be treated, thus in reality increasing the overall marginal costs. Practical evidence from previous studies (e.g. NEFCO: PCB Fast Track Project, COWI 2002) indicates that reasons for this can be several despite the fact that inventories and other statistics may indicate that plenty of POPs should be available in the region. Some POPs may be tied up in operational equipment, e.g. PCB in industrial capacitors and transformers. This PCB will become available for elimination only to the extent that the electrical equipment can be renewed thus keeping up production lines etc. In some regions and countries it may also be difficult to identify owners of e.g. obsolete pesticides, who are willing to take responsibility (i.e. pay for a safe disposal), as previously mentioned in this section. Some POP owners may also be reluctant to report correctly to environmental authorities, simply because they know that it will impose additional costs to the enterprise or farm collective. Thus, the demand problem also very much involves the question about the regulatory framework, including what options exist for actually enforcing the regulation put forward by public authorities in the regional or local context.

These considerations may not necessarily have a direct and decisive impact on the choice of technology in a specific context. But it is the kind of evidence that will show in pre-investment feasibility studies and businesses plans and therefore potentially constrain the size of loans that can be obtained for the purpose.

5.4.3 Institutional and regulatory framework

Environmental control and monitoring

National environmental legislation and regulation obviously has an impact on the costs of obtaining licenses and permits required for establishing the treatment facility. Furthermore, the market prices for laboratory testing may vary substantially in between regions and countries. Certain particular features in national regulation and enforcement practice may thus render one specific technology more financially attractive than the other. One such example is costs for performing analytical testing to comply with environmental regulation.

Even though a technology may be well tested, environmental authorities require a continuous, rigorous testing of the environmental performance of the treatment technology. Costs for analytical testing and control can amount to as much as 15-40% of the total costs pr unit POP treated. The four technologies included in this review indicate, however, that the relative share of analytical costs to total (direct) costs varies quite a lot. In principle, one would have expected that the need for analytical testing would not depend on the technology option, but rather on the amounts of POP treated. Part of the differences in analytical costs between the technologies of this review may be due to different environmental requirements put forward by the environmental authorities in the countries, from which the individual technologies are sold. Analytical testing will, however, have to comply with the minimum requirements put forward in international conventions, regardless of national regulation.

Furthermore, costs for laboratory testing certified in accordance with international standards may vary substantially from one country to another, and so analytical costs only apply as an evaluation criterion for technology prioritisation in a specific context.

Socio-economic indicators
Furthermore, a number of the socio-economic characteristics of the region or country in question also fall into the category of context specific evaluation criteria. One typical example is the local unemployment rate. If a local community is experiencing high unemployment in the local labour force, a labour intensive technology option may be ranked relatively higher than a technology option that does not yield many new jobs for local people. Such prioritisation can be economically justified by the potential savings on public budgets in form of fewer transferrals of unemployment benefits. More people employed also increases the local tax base, which again can have second order effects in terms of increased private and public spending.

Again, these considerations may not necessarily have a direct impact on the choice of technology in a specific context. But it is the kind of evidence that will show in pre-investment socio-economic cost-benefit analyses. The full socio-economic analysis of project costs and benefits is appropriate when evaluating the individual project in a specific context, as such analysis includes not only financial project costs, but also costs incurred by the relevant local municipality or the entire society as such as a direct or indirect result of the project. These are important tools, not least because public authorities are likely to be involved one way or the other in this kind of activities, either on the financing side or as de-facto operator of the treatment facility.

Political framework and public acceptability
Finally, there may be political or public barriers to overcome locally. Most people do not like the idea of having a hazardous waste treatment plant located nearby - this is well-known from anywhere in the world. Lobbying conducted by NGOs or vendors may make some technology options politically unattractive, as has for example been the case for incineration based technologies some places. A successful POPs elimination project should entail public accept in the local community of the elimination facility as well as the elimination activity

itself. Proper communication between authorities and local communities is in this respect critical, provided of course that the POPs elimination technologies are in fact as environmentally safe as e.g. vendors would argue. One very important aspect of achieving actual local accept, is that the communication between these parties is actively supported by unbiased expert evaluation amended by as early as possible involvement of key interest groups.

5.5 Category 3: Generic criteria

5.5.1 General

A few items in the initial screening list are neither technology nor context specific. In terms of actually reducing stocks of existing POPs, these items play an equally critical role as does the choice of the most appropriate technology. The issues concerned are related to sound implementation and management practices of the specific projects.

5.5.2 Transfer of know-how

Each of the four vendors included in the present review have submitted information on how they envisage conducting the transfer of know-how necessary to run the facility. Typically it involves some kind of initial phase following installation of the technical equipment, in which technicians are operating the facility jointly with the future local operators.

A POPs elimination facility is not a typical off-the-shelf commodity, and it thus seems likely that specific terms for e.g. the extent and type of know-how transfer can be agreed with the vendor during the sales negotiations.

So in practice, transfer of know-how for a specific project is typically an issue that can be arranged at will of the project implementing authorities. Basically, it is about making sure that the people or organisations responsible for the activities also have the necessary means including skills, incentives and authority to conduct the activities efficiently. The vendor of the POPs elimination technology can play an important role in providing local operators with adequate skills.

Commissioning of the chosen technology option may thus be conducted in a way so as to ensure that necessary skills are transferred to the local operators, either through a prolonged commissioning period, in which vendors and future operators work closely together, or by ensuring future involvement from the vendor through leasing contracts, management contracts and similar. These are options that need to be explored in depth regardless of technology type and context.

5.5.3 Organisation

Organisational issues broadly concern financing, ownership responsibilities and instalment of appropriate checks and control procedures. Evidence from other similar sectors of the CEE Region (wastewater treatment, municipal waste facilities etc.) clearly indicates that generic guidelines for sound implementation can be established. The aim of such guidelines is basically to ensure viable and sustainable real-life solutions.

Again, these are topics that the implementing authorities will have to deal with directly when practically designing POP elimination projects, but they are typically not relevant as mere technology evaluation criteria.

5.6 Criteria evaluation measures

5.6.1 The ranking of alternatives

Identifying appropriate technical, risk, environmental and economic review criteria does not in itself enable a unique ranking of the technological alternatives in question. Different people will put emphasis on different criteria, basically because people have different preferences. Furthermore, the ranking process inevitably involves comparison of different criteria that by nature are incomparable. How for example to objectively compare an environmental criteria on emission thresholds with an economic criteria on financial project viability?

Yet, a number of more or less commonly applied methods for formalising the ranking of alternatives do exist. Most of these methods work with measurable indicators rather than evaluation criteria, though, inasmuch as these methods typically are quantitative by nature.

One area, within which a quantitative approach to ranking alternatives is broadly acknowledged, is the evaluation of financial pros and cons (i.e. revenues and costs). There is a range of traditional financial evaluation measures that can summarise and weigh different costs and financial benefits (e.g. revenues for a partly or fully commercial operator) disbursed over time, including for example net present value as well as internal rate of return.

- **Net Present Value:** The basic idea with the net present value (NPV) evaluation measure is that it incorporates the time aspect of investment planning. The principle is that the longer a certain payment can be deferred in time the better in strict financial terms. The rationale for this is that in the meantime until the payment is actually due, the committed but still unspent money will generate interest. If an amount of 105 USD is due in one year from now, the value of this amount today is only 100 USD, because the 100 USD will draw 5 USD interest during the period until the final payment is due (provided a discount rate of 5% p.a.). So, in other words, the investor will need to have only 100 USD in his wallet today in order to be able to commit himself to an investment, which implies a cost of 105 USD in one year from now. This difference is reflected in the NPV measure.

- **Internal Rate of Return:** The internal rate of return (IRR) measure is closely related to the NPV measure, inasmuch as it is the discount rate that satisfies the equation NPV=0. A given investment project represented by an array of net in- and outflows disbursed over time will thus be deemed favourable only if the IRR for the project is at least as high as the IRR that can be obtained from an alternative investment. In practice the alternative investment is typically represented by common market interest rate.

5.6.2 Application of monetarised evaluation measures

The NPV and IRR measures are used for screening of investment opportunities by for example commercial operators. A commercial operator will be searching for profitable business, and the traditional NPV and IRR analysis exactly reveals the expected profitability (or the opposite) of a given investment. As such, this type of analysis is a rather limited tool for ranking of alternatives, as it does not take into consideration any item or criteria that does not have a direct cost or revenue implication.

The NPV approach is, however, often applied on a broader set of criteria or indicators than just the financial (i.e. actual cash flows only), so as to include also for example social, health and environmental costs. The latter is obviously very relevant in the context of a POPs elimination project, as the main objective of such project is to improve the environment in order to impact for example human health. These considerations are not relevant to a potential commercial operator of the POPs elimination technology, but will obviously be in focus for public decision makers, including potential donors (development banks, bilateral donors etc.). Economic cost-benefit analyses take into account not only actual cash flows, but also indirect cost implications related to health, environment and similar so as to prove project viability for a potential commercial operator as well as for the society.

The main drawback of the economic cost benefit analysis is that it requires quantification and monetarisation of a number of criteria or indicators that by nature are very hard to quantify and monetarise. The NPV measure requires all criteria to be expressed in terms of money, and this can be a very problematic or even questionable process for example for environmental benefits. No one in principle doubts the benefits of reducing stocks of hazardous chemicals in a safe manner, but how exactly to measure these benefits in terms of what value this may have for human health and the environment in general? And more, how exactly can one express this value in terms of money, which is a prerequisite for being able to apply the NPV measure? The ultimate question in this respect would be how to measure the value of a human life. These questions are in any case not easily answered.

There exist other approaches to criteria based evaluation of alternatives, which do not necessarily involve direct monetarisation, as for example the various multi criteria planning methods. Common to most of these methods is that they require a more explicit expression of the decision makers' preferences than does the more traditional NPV method. The basic point is that it is necessary to establish some common denominator for all the criteria involved, in order to make them comparable across categories (so that for example technical criteria can be weighed against environmental or financial criteria). Multi criteria planning methods are typically fairly advanced tools, and they are in any case not nearly as commonly acknowledged and accepted as are the NPV and IRR methods.

Despite the methodological hardship related to a full economic cost benefit analysis, this kind of analysis is strongly recommended (and even required) in many western public administrations, including in the US and the EU.

5.7 Summary and discussion

5.7.1 Summary

The aim of this section on economic evaluation criteria has been to identify and argue issues that are likely to have some kind of cost implication in relation to the choice of technology option. The definition of what is an economic criterion has been broad, so as to include in practice most (non-technical) issues that could eventually become a stumbling stone for a successful project.

The list of potential criteria emerging from the dialogue with vendors, NGOs and technical experts have been divided in three categories in order to systematically identify which criteria are in fact relevant at the present stage.

The **first category** of economic criteria includes two major direct cost components - treatment costs and costs of capital. Treatment costs should preferably be identified in terms of natural units (amounts of raw materials, man-days required etc) as prices may vary. Finally, one should apply a comprehensive and universal view to project costing, so as to include all costs related to associate processes (transport, residual products disposal etc.).

The **second category** criteria have basically one thing in common, i.e. that they all require additional analyses into the substantial issues on the ground, be that in the form of feasibility studies, business plans, cost-benefit analyses or similar. These criteria do not apply well at the present stage of mere technology assessment.

Third category criteria mainly deal with sound implementation practices of specific projects. These criteria should rather be used for designing of the specific implementation projects, than for technology evaluation purposes.

So, in essence, most of the initially identified potential economic criteria are in fact not technology-dependent, and must thus be addressed at later stages through further analyses and appropriate designing of the specific projects. Furthermore, it must be recognised that establishing a set of evaluation criteria not in itself automatically yields a unique ranking of the potential candidate technologies. The evaluation process - weighing some criteria before others - is critical in as much as it ultimately involves that the decision makers explicitly reveal their preferences. This can be a complex as well as a troublesome matter.

Finally, the importance of the financing issues involved must be stressed. This is because the available funding sources bear an impact on the choice of technology. This impact runs parallel to the impact any objective criterion set up by an independent expert may have in the same respect. Elaborated financing plans or strategies may enable a project designer to gain control over some of these aspects as well.

5.7.2 Discussion

A note on financing

The present review report represents a bottom-up approach to identifying the most attractive POPs elimination technology from a short-listed selection of likely alternatives. The potential areas of interest (environment, risk, technology, economy) are identified, and within each of the categories a number of relevant measurable criteria are established on the basis of which, the technological alternatives in principle can be ranked.

One might argue, however, that decisions in practice depend also on a number of other factors that are not necessarily entirely grounded in independent and objective expertise. Or at least, that the list of alternative technologies subject to an evaluation in a specific context may be limited by factors that are hard to describe objectively.

The country in which the facility is being installed may for example prefer a facility manufactured in the country or even a technology invented in the country before any internationally recognised 'best available technique', regardless of what an expert's assessment recommends. A potential bilateral donor may have a parallel interest to promote the industry of its own country. This, as well as other more or less politically grounded interests, may distort the choice of a technically, environmentally and economically more justified alternative.

So why even bother making such experts' review of alternatives in the first place, if the choice in the end anyway depends on a number of factors that are political rather than factual?

Firstly, it may not be a major problem at all, provided that appropriate alternatives do exist nationally. Technologies for POPs elimination do exist for example in some of the countries of the CEE Region. These national technologies may not represent international state-of-the-art in terms of for example environmental performance, but as long as they comply with basically agreed standards, it is better that nothing.

Secondly, these considerations very much put the financing aspects in focus. As described, it must be expected that the funding options available for a specific project will impact the choice of a POPs elimination technology alternative, as the political thrust generally tends to follow the money. So, provided that the issue on funding options is important, then the question is what funding sources are available, what is the deciding factors in this respect and can these factors be influenced at all?

For the CEE Region in the long-term perspective it must be expected that economic wealth will increase, so that the countries eventually will be able to finance POPs management by themselves. In a period of time from now, however, the countries of the CEE Region will most likely still are dependent on external assistance of some kind. Environmentally sound elimination of POPs in these countries is not likely to become a business in a foreseeable future, from which one would expect a high financial return on the initial investment, and private capital therefore would be accordingly difficult to attract. So there will most likely still be a role to play for international funding, for example in form of development bank soft loans, EU Structural and Cohesion funds front-runner mechanisms (e.g. ISPA) or bilateral donors.

Almost all of these external funding sources require up-front documentation on a potential project's financial viability (or bankability), and an investment project that does not generate income can by nature never become financially viable. Without prospects of project viability even under very relaxed conditions, funding options are typically very limited, and so this is important to consider when designing the project including the supporting organisation and regulatory framework.

One way for the project designer to cope with these difficulties will be to approach the financing issue actively prior to designing each specific project. A comprehensive financing plan or strategy for future POPs management in the country - maybe as part of an overall national environmental action plan - could thus be an appropriate measure. An overall financing plan could consider total costs for compliance to the Stockholm Convention and compare these with available sources of funding. To the extent that funding proves to be inadequate to meet the objectives of the compliance strategy, the financing plan could then analyse other potential sources of funding as well as what the constraints, in terms of technology choice, may imply to the country. Such a process may very well lead to a reformulation of the requirements to the technologies in question (i.e. a reformulation of evaluation criteria), for example that the technologies should be capable of treating not only POPs but also other specified types of hazardous waste, so as to enlarge the market base for a potential operator.

This could maybe in turn ensure the project's financial viability thus keeping a number of potential sources for funding open.

Environmental financing - brief overview
This section provides a brief overview of possible sources of finance available for a specific POP elimination project as well as of the principal steps that are involved in obtaining external financing e.g. loans and grants from development banks and donor organisations.

Funding sources
Basic funding sources that may in principle be available for financing of POP elimination activities have been listed in *Table 5.* below.

Table 5. Sources of environmental financing (1)

Potential source	Comment
Public funds from both national, regional, and local budgets	In other words, financing is provided by the country's tax payers. Typically in the CEE, environmental issues are not very highly prioritised in view of the challenges these countries face in terms of social, health and infrastructural problems. So it may be politically very demanding to achieve funding from these sources.
National and regional environmental funds	Environmental funds are typically based on revenues from environmental charges imposed on for example industry in various settings. Environmental funds in the CEE typically only have limited financial capacity, and often a large part of these funds have already been committed for rehabilitation of for example water and wastewater infrastructure.
International donor organisations (grants)	In case of the CEE, this source foremost comprises bilateral donor organisations (e.g. DANCEE), but also certain international organisations, such as the EU, specific grant facilities provided by the World Bank, NEFCO and similar. Common for these sources are, however, that they are typically not willing to grant operational subsidies, i.e. they will finance a part of the capital investment, but not support the actual operations. Furthermore, grants are often provided only if the country in question proves its commitment by providing part of the funding itself.

The extent, to which the activities can be organised in order to generate operational revenues, is the key to what kind of financing will be available to support the implementation of a POP elimination technology. Thus the funding options are broader in cases where it can be substantiated that there exists a potential for commercialisation of the operations, i.e. that one can identify customers willing to pay the operator to dispose safely of e.g. obsolete pesticides. The revenue generated under such conditions may be used to cover operational costs, but also to attract lenders willing to finance the initial capital investments. These additional funding sources have been outlined in Table 5. below.

Table 5. Sources of environmental financing (2)

Potential source	Comment
International Financial Intermediaries (IFI's)	This source comprises first of all soft loans and favoured credit facilities provided by development banks such as EBRD, World Bank, EIB, NIB and similar. These institutions typically demand very thorough documentation of the project's technical, economic, financial and environmental viability and sustainability. Providing such documentation can entail an exhaustive and time consuming process. Such lenders furthermore often require some kind of state guarantee.
Private sector participation	A way of financing a capital investment may be for a public authority to engage in some kind of public-private partnership, for example a BOT (build-operate-transfer) relationship. A private operator would normally, however, require a financial return on its initial investment, which is higher than what can be achieved by a treatment facility for POP and hazardous waste.
Domestic finance sector borrowing	Commercial borrowing is in principle an option, but again it should be recognised that these institutions typically demand a much

Potential source	Comment
schemes	higher return on their investments than do e.g. the development banks. Interest rates may be extremely high due to the credit risk faced in many of the countries in the region, in particular in the NIS area.

Project cycle
Obtaining project financing from the various donor organisations and IFI's requires a basic understanding of how these institutions work. The procedures involved may - as mentioned previously - be quite complex. Typically, however, the procedures tend to involve more or less the same steps from the point, where the project is initially conceived until the final agreements are approved and signed. These steps are often referred to as the project cycle.

Identification phase
The identification phase is normally conducted at higher political levels. The major development banks for example prepare dedicated country strategies in close consultation with country officials and thus provide the basis for establishing a policy dialogue and formulating an appropriate development strategy and lending programme for each country. Most of the major bilateral donors do the same. Individual projects typically originate from these studies. Knowledge about these strategies and programmes is essential for the project designer. Documentation required in the identification phase typically involves core elements of a *business plan* as well as a *legal opinion* on the feasibility of the proposed organisation. This phase can take up to two years.

Preparation phase
Preparation of the project proposal begins when there is mutual agreement on project objectives. The process of preparing a project is often time consuming and complex and may require hiring of consultants for preparation of the needed documentation. This documentation can include *technical and financial feasibility studies, elaborated business plans, socio-economic cost-benefit analyses, environmental impact assessments* and similar. In some cases the donor organisation or IFI is capable of conducting/financing the preparation of the required documentation, but it is of course pivotal to all involved parties that the beneficiaries take full ownership to the analyses made and to the project in general. Active participation by the beneficiary throughout this phase is therefore very important. This phase typically lasts somewhere between 1 and 3 years, depending of the extent of the proposed project.

Appraisal phase
After project preparation has been completed, the financial organisation typically needs some time to review the proposal and undertakes a full-scale project appraisal. This is a comprehensive review of the technical, economic, financial, and institutional aspects of the project. This phase may take up till 6 months or so to complete.

Negotiation phase
After the appraisal has been completed, formal loan or grant negotiation begins. The purpose of this phase is to agree on implementation framework and condi-

tions. These agreements, including procurement agreements, are then formalised in loan documents or grant agreements. This phase typically lasts 2-3 months. After the loan is approved, funds are available to implement the project. Implementation is typically the responsibility of the borrower. Following the full disbursement of the allocated funds and subsequent implementation, the project is typically subject for evaluation.

6 Detailed review of selected POPs elimination technologies

Available POPs elimination technologies have been reviewed in detail based on the background information described in previous chapters. Material and listed perceptions (e.g. a future divided CEE Region, environmental and economic "climate" supporting future establishment of POPs elimination initiatives) have been assessed for 4 commercially, in the sense of free market availability, POP elimination technologies.

The review process has followed a number of steps, outlined in further details below, but in short it was selection of technologies and identification of appropriate and CEE Region selective evaluation criteria. Of utmost importance for the detailed review was that all reviews have been performed on technologies in operational mode, although GPCR was reviewed in a down-scale test plant facility. However, the facility was set in operational mode during the actual on-site review.

6.1 Selection of POPs elimination technologies for detailed review

Elimination of POPs differs from region to region. However, in the developing part of the world most elimination is based on various incineration techniques as an integrated part of the overall national approach to treatment of hazardous and/or municipal waste. These facilities furthermore are the basic of a systematic commercial system of treatment capacities for imported waste originating from countries in transition and/or without national treatment capacity. In e.g. Europe, the treatment capacities have increased, although the actual amount of treatable waste has reduced resulting in reduced treatment prices, tempting certain countries to export e.g. hazardous waste instead of initiating precautionary measures for waste reduction and transformation from hazardous to non-hazardous waste.

In many parts of the world, and in particular in regions with economies in transition, like the CEE Region, former treatment habits are either non-competitive in economic sense with external commercial treatment facilities or non existing due to society transformation and economic decline. Considering the CEE Region as a group of countries in economic transition, the countries are facing a situation where national large scaled treatment facilities are almost unattainable due to mainly economic reasons, although recognising the enormous amount of hazardous substances potential for treatment. Alternatively, national priorities must outline which hazardous substances possess the largest risks to environment, human and biota enabling competent authorities to prepare certified actions through e.g. National Environmental Action Plans (NEAP). These could include investment into small-scale treatment capacities, allocation of funds for external treatment and/or various combined solutions allowing each country to gain experiences supporting a long-term sustainable solution.

The key findings of Chapter 2 outlines the necessity of finding solutions for the CEE Region, which on one hand are realistic and originates in the region, but on the other hand have a long-term commitment to the international trend aiming at reducing any impact from chemicals to the environment, human and biota in general. As base for this review study, the requirements defined in chapter 4 must, to the extent possible, be compiled into any assessed solution.

Selection of POPs elimination technologies for review is a difficult process involving a number of selective parameters as highlighted in earlier chapters. The review of previous performed POPs elimination reviews outline a number of alternatives to the existing elimination business mainly based on incineration technology. The project-frame leaves room for review of 4 technologies of which it has been decided that two should have their origin within the existing market platform primarily based on incineration methodologies, while the remaining two consist of alternatives hereto.

The selection of present day available technologies in the CEE Region (e.g. cement kilns) and commercially economic viable technologies like semi-mobile incinerators and non-incineration alternatives hereto, will allow key deciding resources within the national CEE administrations to have a better overview of advantages and/or disadvantages of a given technology. The review and comparison data will in first place be compiled objectively without any interpretation of results in relation to national, regional and/or international requirements. This allows the technical experts to concentrate on performing a consistent review as basic for the later discussion. The reviewed basic data have been presented to the advisory group members of the project involving both main NGO forums and the consultant management experts.

A more detailed review of alternatives to incineration based technology reveal a situation where certain non-incineration alternatives are more commercial developed than others. Among the most recent outlined list of "fully" commercialised alternative non-incineration technologies (reference to UNIDO paper "Available non-combustion POPs destruction technologies, October 2001") are:

- Gas-Phased Chemical Reduction;
- Sodium Reduction Process;
- Base Catalysed Dechlorination; and
- Solvated Electron Process.

Additional, a number of 3-4 other alternatives are classified as “emerging technologies” and finally a few additional are classified as “demonstration technologies”. Finally, a number of CEE based alternative merging technologies are screened including e.g. the Russian developed Cyclone technology.

Of the Russian facilities investigated so far, the cyclone plant appears to be technically and environmentally the most promising. They have minimised the problem with solid waste and made recycling of the sodium chloride possible, and they have operating experience on dioxin treatment. Furthermore, they seem to have documented satisfactory results treating constituents similar to PCB. This will be further evaluated in the ongoing NEFCO Fast Track project.

As basis for the final selection of two non-incineration technologies subject for review, the project has decided only to review technologies, which are characterised as “fully commercial available”. Commercial available technologies mean that the technology has already been successfully operated in a full scale commercial (or other institutional) setting, and that vendor or vendors are available who can provide not only the technology itself, but also can provide the know-how and support needed to successfully set up and operate the technology under circumstances such as those likely to be encountered in the CEE Region.

Furthermore, the project has per default decided only to focuses on “inert” technologies, which are dedicated for the purpose of performing destruction of POPs chemicals. Only deviation is the including of cement plants, which originally are set up as cement production units and where chemical destruction is a side activity utilising the high temperature production methodology. The selective process of only involving dedicated POPs destruction technologies, beside cement kilns, furthermore supports the fact that many countries are looking for economic viable solutions, which partly could be based on a co-financing model involving bilateral as well as regional funding mechanism. The project focuses on accessibility to primary affordable technologies supporting the philosophy of countries gaining their own experiences when initiating the necessary planning process, implement public participation, secure necessary and skilled staff allocation, prepare and carry out educational programming and secure sufficient infrastructure supplies.

The anticipated and partly confirmed magnitude of the problem (amount of obsolete pesticides and POPs) necessitates immediate actions related to the final elimination of these substances. Selection of possible applicable elimination technologies must reflect both the critical conditions and possible impact from these partly uncontrolled stockpiles, but also be instrumented in an accessible form allowing countries to proceed with elimination of hazardous substances on the one hand and instrument precautionary measures towards waste reduction with the other.

After consultation with the Advisory Group, the below two non-incineration technologies were selected for further review. The technologies were found as the optimum technologies complying with the CEE Region's objectives for POPs elimination:

- Gas Phased Chemical Reduction (GPCR). The technology has been commercially used in e.g. Australia and USA for destruction of pesticides, chemical weapons etc; and

- Base Catalysed Dechlorination (BCD). The technology has for several years been commercially utilised for elimination of various POPs substances among others PCBs.

The final choice complies with recommendations put forward in the DANCEE report "Review on Obsolete Pesticides in Eastern and Central Europe", May 2001, recommending the same non-incineration technologies for further review in terms of their applicability for the CEE Region e.g. as BAT for POPs elimination.

Therefore the following non-incineration technologies have been chosen for detailed review in this project:

- Gas Phased Chemical Reduction Technology has in many studies and also in a recent UNIDO review showed promising results and commercial potential. The technology was reviewed in a scaled-down version in Rockwood, Canada during June 2002;

- Base Catalysed Dechlorination, a fully commercialised technology available for potential review activities in Australia, USA, Mexico, Spain and New Zealand. After consultations with e.g. BCD Inc. the project decided to carry out the review on the only operational BCD for organo-chlorinated pesticides in Sydney, Australia during April 2002.

In addition to the two selected non-incineration technologies, two incineration technologies have been selected. Pre-conditional for this selection, the consultant has put forward a number of statements, which have been used during the selection procedure. These are:

- Optimal involvement of relevant experiences within incineration principles already present in the CEE Region;

- Technologies already available in the CEE Region are screened, and optimal efforts are initiated for inclusion of possible commercially developed POPs elimination facilities;

- The financial capacities of the CEE Region countries are limited and still under the influence of strong prioritisation;

- Many CEE countries are getting technical support through various bilateral, regional and/or international aid programmes on dedicated actions within chemical management. The programme policies must comply with regional EU and/or international regulations for the environmentally sound elimination of hazardous substances;

- At present, certain indicators for recovery upon economic recession are in place, supporting the fact that the timing is considered appropriate to implement short-term solutions and start investment in long-term commitments ensuring not only proper POPs elimination, but also support to a broader approach to improved national/regional hazardous waste management activities in general; and

- Finally, the inventoried obsolete pesticides and POPs in most CEE countries are found in stores of various scales, outfit and access conditions etc. including those that are lacking definite owners. This strongly necessitate the involvement of State funds (either directly or through bilateral, regional and/or international grants) as one of the main financial mechanism supporting any further steps towards improved chemical management in these countries.

Analysing the above characteristics of the region, the selection process must also consider the variety of national policies regarding hazardous waste management and willingness to comply with international environmental instrumentation (protocols and conventions) in general, defining potential applicable POPs elimination technologies suitable for the CEE Region.

The DANCEE report "Review on Obsolete Pesticides in Eastern and Central Europe", May 2001 recommended that the following incineration technologies to be subject for further review in terms of their potential for the CEE Region, as e.g. BAT for POPs elimination:

- Dedicated Incineration (small-scale treatment methodology). The technology was reviewed at Kommunekemi A/S in Denmark during March 2002 and can be seen in Latvia during summer 2003 operating in full scale;

- Cement kiln incineration (high level of availability in the CEE Region, mentioned as one of the options in many earlier documents). Reviewing activities could be performed on the Norwegian national facility, although an alternative plant within the CEE Region (Poland) has been considered;

The selected non-incineration technologies follows in line with the result of recent preliminary assessment review of more than approx. 15 different available non-incineration technologies, performed within the frame of the ongoing UNIDO POPs project. The selected incineration based technologies cover technologies, which at present, are seen as the most widespread in the CEE Region (cement kilns) and most trustworthy incineration based alternative (dedicated incinerators) to the established "elimination infrastructure" within the region.

The detailed review of the 4 selected technologies was performed by a team of engineering and environmental experts from COWI A/S. The team managed to oversee all four selected technologies in on-site operational mode, although GPCR and semi-mobile incineration facilities were in testing mode, due to lack of on-time fully operational full-scale units. In Table 6.1 time and contact persons from each of the visited technologies are outlined.

Table 6.1.1 Contact persons and vendor information

POP elimination vendor	Contact person and vendor information
CIS (semi-mobile incinerator) - Visited 1 March 2002	Chemcontrol A/S Lindholmvej 3 5800 Nyborg Denmark Contact person: Ole Møller e-mail: olm@chemcontrol.com
BCD - Visited 9-10 April 2002	The Enterra Pty Limited 12 Forrester Street Kingsgrove NSW 2208 Sidney, Australia. Contact person: Bala Kathiravelu (Principal process engineer). e-mail: bala.k@compuserve.com
GPCR (Eco-logic) - Visited 26-27June 2002	ELI Eco-Logic Inc. 143 Dennis Street Rockwood ON Canada N0B 2K0. Contact person: Elisabeth Kümmling, M. Sc. e-mail: kummlib@eco-logic-intl.com or beth.kummling@ecologic.ca
CKI (Cement kiln incineration) - Visited 27-28 August 2002	NORCEM AS. Lilleakerveien 2B P.O. Box 143 Lilleaker N-0216 Oslo, Norway Contact person: Per Brevik (Manager) e-mail: per.brevik@NORCEM.no NOAH (Norsk Avfallshandtering) Tangenvejen 29 3950 Brevik, Norway Contact person: Harald Gangmark (Operational Manager) e-mail: herald.gangmark@noah.no

6.1.1 Mobile versus stationary plants

It is often discussed if a plant shall be mobile or stationary as optimum POPs waste elimination technology. Stationary plants has several advantages in favour of mobile units, like

- **Only one permit.** Whenever a POPs elimination technology has to be moved, a new permit procedure must be carried out (maybe even a new EIA has to be made);

- **Reduced transport risks.** When transporting heavy destruction technology, it can easy happen that parts of the plant are destroyed (especially if there is brick built elements or painted surfaces etc.) Furthermore, there are the normal risk when transporting heavy goods by road;

- **Mobilisation costs reduced to zero.** In some cases the displacement costs of a destruction plant equals up to 50% of the initial capital costs due to costs of braking down, cleaning up, transport and establishment of new infrastructure support function (electricity, water, sewage systems etc.);

- **Only one infrastructure set-up.** Infrastructure at the destination is often costly, due to installation on the new site of concrete pavement, installation of supply lines (electricity, pressure air, water, nitrogen, hydrogen, etc.) closed sewage system, erection of bunkers etc.;

- **No repetition of the Not-In-My-Back-Yard (NIMBY) effect.** Whenever a hazardous waste elimination facility has to be erected, public concerns are expressed. To avoid repetition of this normal long lasting effect, a proper stationary placement is preferable;

- **Continuation in staff.** When a mobile plant is moved, the staff can not always follow due to family conditions, investment in residential actives (houses) etc. It is time consuming and costly to train new operators. At a stationary plant you optimise the performance by increasing educated staff with little or no substitution. Furthermore, surrounding a potential POPs elimination facility, there could be substantial need of pre-treatment facilities etc. which is crucial for the successful final elimination.

Nevertheless, mobile units are normally more economic accessible due to lower capital costs, they normally have lower capacity enabling countries to work with low-capacity units as a playground for gaining experiences and finally mobile units could be regarded as more accepted by the public due to their "temporary outfit".

We have examined the mobility of all the plants in this report, but we believe that even though a plant is declared mobile, it will have a tendency to become stationary.

6.2 Review criteria

Within the last 5-year period, a number of detailed POP elimination technology studies have been carried out primarily driven by US demand for destruction of stockpiled chemical weapons. In continuation of the negotiation process leading forward to the Stockholm Convention, a number of dedicated studies focussing solely on POPs destruction opportunities and preparatory guidelines have been initiated both through the UN-system as well as on bilateral basis. One of the key documents are the ongoing preparatory process under the Basel Secretariat (Technical Working Group) leading to a guideline on the environmentally sound management of POPs as waste herein included demand for present and prospective future elimination of POP compounds. The technical guideline is expected to be present during COP session under the Basel Convention during October 2004.

Furthermore, Article 6 in the Stockholm Convention outlines:

"Disposed of in such a way that the persistent organic pollutant content is destroyed or irreversibly transformed so that they do not exhibit the characteristics of persistent organic pollutants or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option or the persistent organic pollutant content is low, taking into account international rules, standards, and guidelines, including those that may be developed pursuant to paragraph 2, and relevant global and regional regimes governing the management of hazardous wastes;"

It is clear that the intent of the treaty is to "destroy" POP compounds in an economical favourable way and also at the same time avoid the formation and release of POPs. As such, those technologies which can most effectively deal with the POPs wastes, and minimise or eliminate any further production of POPs wastes or formation or release should be rated highest.

In the overall assessment of the technologies, a rating system has been used where 5 is "Bad", 4 "Below average", 3 "Average", 2 "Above average" and 1 "Best".

6.2.1 Environment

Given a certain amount of substance to be treated, elimination technologies may differ from each other environmentally with respect to:

- Materials used for construction of the elimination plant (actual materials and quantities/lifetime of different parts) – the issue relates to the need for protection of scarce natural resources, but also to the environmental impacts related to extracting and manufacturing such resources;

- Means of operation (materials as well as energy consumption) – the issue is related to natural resources as above and in particular energy resources. Attention should be paid to the fact that the energy resource to be employed, in case extra energy for manufacturing processes is needed (either direct or as electricity) will typically be coal energy (at least in Europe), and that combustion of coal is an important source for release of toxic substances like mercury and dioxins;

- Efficiency of the elimination process;

- Emissions (to air, water and soil – substances /quantities) – the issue relates to toxic substances as well as substances contributing to other environmental impacts like global warming, eutrofication etc;

- Residues (quantities, content of hazardous substances, acceptable options of disposal) – the issue relates to the mere issue of land filling capacity as well as the toxicity of the waste.

The environmental impacts related to the differences may include global warming, depletion of the stratospheric ozone layer, acidification, eutrofication, photochemical ozone creation, ecotoxicity, human toxicity, different types of filling requirements, land use (may include area requirements as well as biodiversity etc. – not yet generally accepted as impact category) and consumption of natural resources and materials (assessed for each resource/material).

The assessment tools are generally characterised as Life Cycle Assessment (LCA) tools, which typically is divided in tools for detailed calculations and tools for screening/hot spot assessments. The choice of tool to be used normally depends on:

- Availability of data;
- Required reliability of the assessment; and
- Manpower to be invested.

In screening assessments, only the most important impact categories are included. Besides that, indicators may be used to simplify some categories. E.g. energy consumption may be used to represent global warming, acidification and to some extent also categories like eutrofication, photochemical ozone creation and toxicity, which partly are influenced by energy production.

Considering that some of the elimination technologies are only available for review at pilot scale level, reliable data may not be available to an extent justifying a full detailed LCA, besides that a full and detailed LCA may require more than one man month of work for each technology, it is proposed to adopt a screening/hot spot assessment. This screening/hot spot assessment has focused on the following characteristics (a reference of 1 kg of POP substance treated is used in all cases):

- **Materials consumption.** Materials consumption generally relates to consumption of means of operation, while consumption related to plant construction typically is insignificant. However, consumption of construction materials may also be important in those cases where large constructions with limited lifetime are used for elimination of small quantities of special chemicals. Attention should be paid to recycling practices, scarcity as well as re-utilisation of the materials consumed. Data is organised as quantity of material consumed divided on the different materials. For materials used for construction the consumption will be divided on the total amount of POP substance previously treated during the useful life of the plant. The criterion is in principle defined as: Less is better. The criterion is used in a qualitative as well as a quantitative way depending on which data are easily available.

- **Energy consumption.** Energy consumption related to the energy consumption of the elimination process itself will normally be the dominating type of consumption, but could be taken to include also the energy consumption for manufacturing of means of operation, while consumption related to construction and material consumption typically is insignificant. Energy consumption will be calculated as consumption of primary energy resources to compensate for loss of conversion and transmission. The criterion is in principle defined as: Less is better. The criterion is used in a qualitative as well as a quantitative way depending on which data are easily available.

- **Chemicals.** Chemicals cover the total quantity of chemicals being released by the process to air, water, soil and residues. The data should be organised as quantity of substance by route of release. Focus is given to toxic substances. The criterion is in principle defined as: Less toxicity as well as less quantity is better. The criterion is used in a semi-qualitative way, a real quantitative assessment is complicated and beyond the scope of this assignment;

- **Other issues.** Other issues focus on the amount and quality of residuals for disposal (less is better). The criterion is used in a qualitative as well as a quantitative way.

6.2.2 Technical

In order to make a detailed technical evaluation of selected POP elimination technologies, a number of different, and to large extent non-comparable criteria, must be assessed. These are as a minimum:

- **Capacity of the technique.** The technical capacity of the different techniques is important for many reasons. First of all, if the capacity is insufficient, the time for taking care of the job will be unsatisfactory and even mean extended danger because POPs are standing untreated for a long time. There is example of techniques which treat 275 kg/day. In one year 100 tonnes might be treated. Also the ability to treat halogenated waste may influence the capacity. If you have 2,000 tonnes of eligible POP waste for elimination, a 20-year period is needed for total elimination. Furthermore, the technical capacity means something to the economy of the process. Too small a capacity might be to expensive; From this point of view e.g. the GPRC has a much bigger capacity for chlorine containing waste such as PCB, where the GPCR capacity may be 3,000 tonnes per year; CIS 400-800 tonnes/year and the cement kiln 13-1,400 tonnes /year.

- **Comprehensiveness of the technique.** An important issue for a proper technique is the ability to treat broad versus narrow spectrum waste fractions, and what the physical constraint of the waste is. The POPs wastes eligible for elimination are by experience stored in various forms of packaging material and sizes. Any needed additional pre-treatment possesses a risk for the occupational health and increase of costs. All pre-treatment activities must be evaluated as part of the whole process with regard to environment, occupational health, economy, risk and complexity. Reviewing a destruction technique must beside assessment of comprehensiveness to take POP-waste, also take into consideration that POPs-waste frequently are mixed with great variety of other kinds of hazardous waste.

- **Robustness and maintenance possibilities and expenses**. The more technically refined and complicated the technology option is, the larger the risk of technical failure resulting in temporary operational breakdown is assumed to be. Can the equipment be mended locally, or will spare parts and similar have to be purchased internationally? Does the elimination process require input materials (chemical catalysts and similar), and if yes, are these input materials to be purchased abroad? There is also the question about currency exchange risks if spare parts or input materials can only be purchased abroad. Most commercial technologies available on the market perform well during continuous operation, however most uncontrolled emission of e.g. dioxins occur during start-up or closure operations, why all precautionary means must be focussing on parameters influencing chances for interruptive operations.

- **Capacity building.** Installation of whatever POP elimination technology of today encompasses a certain degree of high skilled engineering abilities. These must be available and applicable for continuous operation and update. In many CEE countries and the region as such, skilled manpower is available, but there must be focus on intensive update and commitment.

- **Supply lines.** The need for production supplies e.g. electricity, chemicals, fuels, pressure air, light, water, nitrogen, hydrogen, sewage system, raw products must be estimated and their availability evaluated. Furthermore, international demands for products quality must be critically evaluated avoiding negative impact on the operational routines and constancy.

- **Generation.** For every kind of technique, the first versions often suffer from first generation failures. Subsequently, alterations have been made to improve the technique. Therefore the length of experience time, the amount of waste treated or the amount of test results must be evaluated to give an idea of the sturdiness of the technology. Furthermore, the solidity of the company must be evaluated. Has the vendor the financial strength to ensure technical supply and support over the years etc.

- **Residual products.** Every present available technique produces residues of which some can be re-treated others being inert and available for direct deposit. This treatment must be looked upon as part of the total process and evaluated together with the primary technique with regard to secondary release of POP's to environment, occupational health, economy, risk and complexity; For comparison to the SC obligation see Article 6 in the Stockholm Convention outline as discussed above.

- **Occupational health.** Any kind of POPs elimination technology involves a number of potential and/or latent occupational health problems like e.g. noise, light, chemicals, air-pollution, heat, cold, explosion risk etc. Track recording of failure reports from ongoing technologies shows that most operational interruption occurs due to mechanical and/or human failures. This just to underline the importance of having assessed and evaluated all possible scenarios related to human safety.

- **Operational risks.** To operate this kind of technology in Europe, a risk analysis is mandatory. Therefore existing risk analyses of the technology must be evaluated, although recognizing that the quantitative risk analyses is an inexact practice. Comparable analyses must to the extent be performed.

6.2.3 Economy

From an economic point of view, a given POP elimination technology option is not merely a matter of chemical processes and equipment. The long-term objective of the project is to make an impact in the recipient countries in terms of actually eliminating POPs. To achieve this, a number of barriers and pitfalls will have to be closely observed, not only in terms of each technology's technical and environmental performance, but also in terms of the institutional, organisational and financial constraints posed by each individual technology.

From the economist's point of view, the problem can therefore be formulated as follows:

- Identify a technology option, which is practically implementable and which enables sustained operations long enough to actually make an impact in accordance with the project's long-term objective. The constraints to this problem are that the technology should be technically and environmentally satisfactory.

The project covers a wide array of countries and regions, which all have their specific characteristics relevant for dealing with the POPs problem. These characteristics include:

- fractions, compositions and amounts of POPs;
- existing facilities, know-how and culture for handling hazardous waste, including POPs;
- different regulatory set-ups;
- options of law enforcement;
- economical might and political prioritisation; and
- demographics.

The extent, to which the long-term objective can be met, very much depends on the actual circumstances in each country, or even in each region within the country. The present project does not consider location specific solutions, which means that the criteria put forward must be generic to a certain extent.

Economic criteria
The list does not contain traditional criteria for the selective choice of an elimination technology. It is rather a list that highlights potential areas to be scrutinised and further considered when making the technology evaluation.

Organisation
It is important to consider the organisational set-up to be promoted. Should the POP elimination process be run by some government agency, or should the government rather promote incentives (through fees, charges, taxes etc.) in order to encourage private sector involvement? The answer to this question has a number of implications for the choice of technology: How should the operations be financed - equipment transfer; subsidies to sustain operations and in case of the latter, who should be subsidised - POP owners or the organisation running the POP elimination process? The choice of technology may depend very much on e.g. public budgets being available. If equipment is very expensive, the operational costs may be relatively less expensive, thus making operations more viable and attractive to private sector involvement, if the capital investment is made e.g. by some foreign donor.

Transfer of know-how
Do future operators base the technology option on methods and equipment, which are either locally produced or at least well known? In case the option involves import of an entirely new and not locally anchored technology to the country or region in question there will most likely be further obstacles to circumvent in order to actually achieve the long-term objective. How to ensure sustained operations also after the foreign consultants have left the country? In other words, there should be good arguments for choosing e.g. western state-of-the-art technology, or at least the extra costs in terms of know-how transfer and training local operational staff should be explicit.

Capacity
What is the capacity (not just technically, but in real life terms) of the technology option? Amounts of POPs to be treated by unit of time is important, but also what fractions (pesticides, PCB and similar) can be eliminated under the constraint that it should be done technically and environmentally satisfactory. If the fractions change, how difficult/expensive is it then to alter the processes, e.g. change combustion temperatures or change chemical compound in the catalysts applied in the process? Will one facility be dedicated to dealing with one specific fraction of POPs only, thus implying that several facilities are needed in order to cope with the full range of POP related problems faced by the country or region? Information about fractions is important also because economical incentives related to safe disposal may vary substantially from one fraction to the other (e.g. obsolete stockpiled pesticides versus PCB contained in electrical equipment still operational). Questions, which need answers for each technology option.

Robustness
The more technically refined and complicated the technology option is, the larger the risk of technical failure resulting in temporary operational breakdown is assumed to be. Can the equipment be mended locally, or will spare parts and

similar have to be purchased internationally? Does the elimination process require input materials (chemical catalysts and similar), and if yes, are these input materials to be purchased abroad? There is also a question of currency exchange risks, if spare parts or input materials can only be purchased in the US or Canada for example. Again this kind of questions is important because the long-term objective is to keep the operations running. Any technical breakdown will eventually put the ultimate objective at risk.

Logistics

There is an array of logistical questions to be raised concerning the practical handling of the POPs. Is the technology mobile or stationary? Will the facility come to the POPs or must the POPs be transported to the facility site? What are the costs of transportation (including insurance, which is an important issue when dealing with hazardous waste)? What about means of storage of the POPs - if the chemicals arrive at the facility in drums or containers, how then clean and handle these means of storage? See the discussion of mobile versus non-mobile in section 6.1.1. The conclusion is that the so called mobile destruction plants of social reasons have a strong tendency to become stationary.

Process residues

What are the residues of the elimination processes offered by each technology option? How to dispose of the residues? Is it necessary to have specially controlled dumpsites near the facility or maybe additional treatment facilities for lower classes of hazardous waste? What are the costs related to using these additional facilities?

Demand

This question is maybe one of the most critical areas at all, although the answer may not be within the scope of the present project, as context specific solutions are not considered. The long-term objective will not be met if a steady and continuous supply of POPs to be eliminated cannot be secured (POP-elimination services are not in demand). The reasons are several, despite the fact that inventories and other statistics indicate otherwise. Some POPs may be tied up in operational equipment, e.g. PCB in capacitors and transformers at steel mills or similar. This PCB will become available for elimination only to the extent that the electrical equipment can be renewed thus keeping up production lines etc. In some regions and countries it may also be difficult to identify owners of e.g. obsolete pesticides, who are willing to take responsibility (i.e. pay for a safe disposal). Some POP owners may also be reluctant to report correctly to environmental authorities, simply because they know that it will impose additional costs to the enterprise or farm collective. Thus, the demand also very much involves the question about available fractions and treatment capacity. The demand will very much be dictated by the enactment and enforcement of regulations on POPs and hazardous wastes. Also, as nations ratify SC, they must enact/regulate the legally binding provisions at a minimum. Waste treatment must always be law and enforcement driven.

Analytical costs

Experience shows that analytical costs can contribute significantly to the overall operational costs in the range of 20-50%, highly depending on regional/

national authorities demand and development stage of the technology. For merging technologies like e.g. the BCD in Australia, on-site responsible authorities traditionally set forward high demands for chemical analytical documentation related to air emissions, residues and effluent process water. In certain cases even restricted demands are set forward to environmental monitoring in vicinity areas. In a free market environment, such costs are normally regarded as development costs provided for by the vendor. However, in order to re-capture development costs, these will likely increase the capital investment costs of such technologies. The performed review has aimed to give objective information, also on the analytical costs. For comparative reasons, the analytical costs are regarded as equal for all the scheduled and reviewed technologies.

6.3 Destruction technologies

In the last 30 years increasing problems with hazardous waste have been recognised in most countries worldwide. Hazardous waste is the most toxic part of the general waste problem. Often even small amounts of hazardous waste can be more harmful than big amounts of normal organic household waste. As all POPs are hazardous waste, they are also covered in this description.

Hazardous waste stems normally from industry, producing all kinds of normal very useful products. Everybody is today surrounded by products, which in the production phase have resulted in hazardous waste. From the cloth, spectacles, jewellery we use to the floor, wall, ceiling, kitchen elements, water tap, zinc, light bulbs, lamps, windows, pots and pans etc. in our homes. From the bicycles, cars, busses, trains, aeroplanes to the roads, rails for our transport, to our working places. Everywhere you turn there are valuable products, which in the production phase is likely to produce hazardous waste.

This project review has tried to focus on the scenarios of available POP elimination technologies possessing the least secondary problems. POP waste must be treated to the highest degree possible according to the requirements and intents of the Stockholm Convention.

In the following Section, please find a detailed environmental, technical and economical review of the 4 selected POP elimination technologies. Furthermore, in Section 6.8, a brief description and assessment is made for one of the most promising technologies developed within the CEE Region (Russia), the Cyclone Reactor.

6.4 Gas phase chemical reduction (GPCR)

6.4.1 Introduction

Gas phase chemical reduction (GPCR) developed in Canada by Eco-Logic has been heralded as an alternative to incineration. The process involves the gas-phase chemical reduction of organic compounds using hydrogen at temperatures of approx. 850°C and ambient pressure. The organic compounds are reduced by hydrogen to give methane, other light hydrocarbons, and hydrochloric acid gas (chlorinated waste streams). The hydrochloric acid is neutralised by addition of caustic soda during initial cooling of the process gas. Dioxins and furans are not formed due to the reducing conditions prevalent in the reactor.

The process needs tight control to ensure the hydrogen gas and flammable product gases do not form explosive mixtures with air. Destruction efficiencies are high and the system can theoretically operate without an external source of hydrogen, although this does not occur in practise due to the increase in complexity. The process is non-discriminatory, decomposing all organic compounds. With the addition of thermal desorption front-end systems, the process can treat contaminated soil and electrical equipment, and can also evaporate volatile pesticides directly from drums.

Many demonstration tests have been performed using the GPCR process and Eco-Logic has designed, built and delivered portable demonstration plants to both American and Japanese clients. Eco-Logic has operated two full-scale plants, one in North America and one in Australia. From 1995 to 2000, Eco-Logic treated in the excess of 2,000 tonnes of waste at the full-scale plant in Australia with 1,500 tonnes being treated in the last two and a half years of operation alone. During those last two years, Eco-Logic installed a bigger, new Thermal Reduction Batch Processor (TRBP) for the solid waste treatment that had greater capacity, greater reliability, and decreased cycle time. The plant could then operate with two TRBPs and concurrently treat liquid PCB waste resulting in improved process performance.

6.4.2 Description of the technology

The GPCR process is a closed process. The treated solids are analysed before release, the treated flue gas is collected in tanks and analysed before release (by gas chromatographic techniques). The treated scrubber water is collected and analysed before release. The process is based on gas-phase reaction of hydrogen with organic compounds. At 850˚C or higher, hydrogen combines with organic compounds in a reaction known as reduction to form smaller, lighter hydrocarbons, primarily methane. For chlorinated organic compounds, such as PCBs, the reduction products include methane and hydrogen chloride. This reaction is enhanced by the presence of water, which acts as a reducing agent and a hydrogen source.

The process is non-discriminatory; that is organic compounds such as PCBs, PAHs, Chlorophenols, Dioxins, Chlorobenzenes, pesticides, herbicides and insecticides, chemical warfare agents are quantitatively converted to methane. The overall outline of the reaction mechanism is shown in Figure 6.4.1. below:

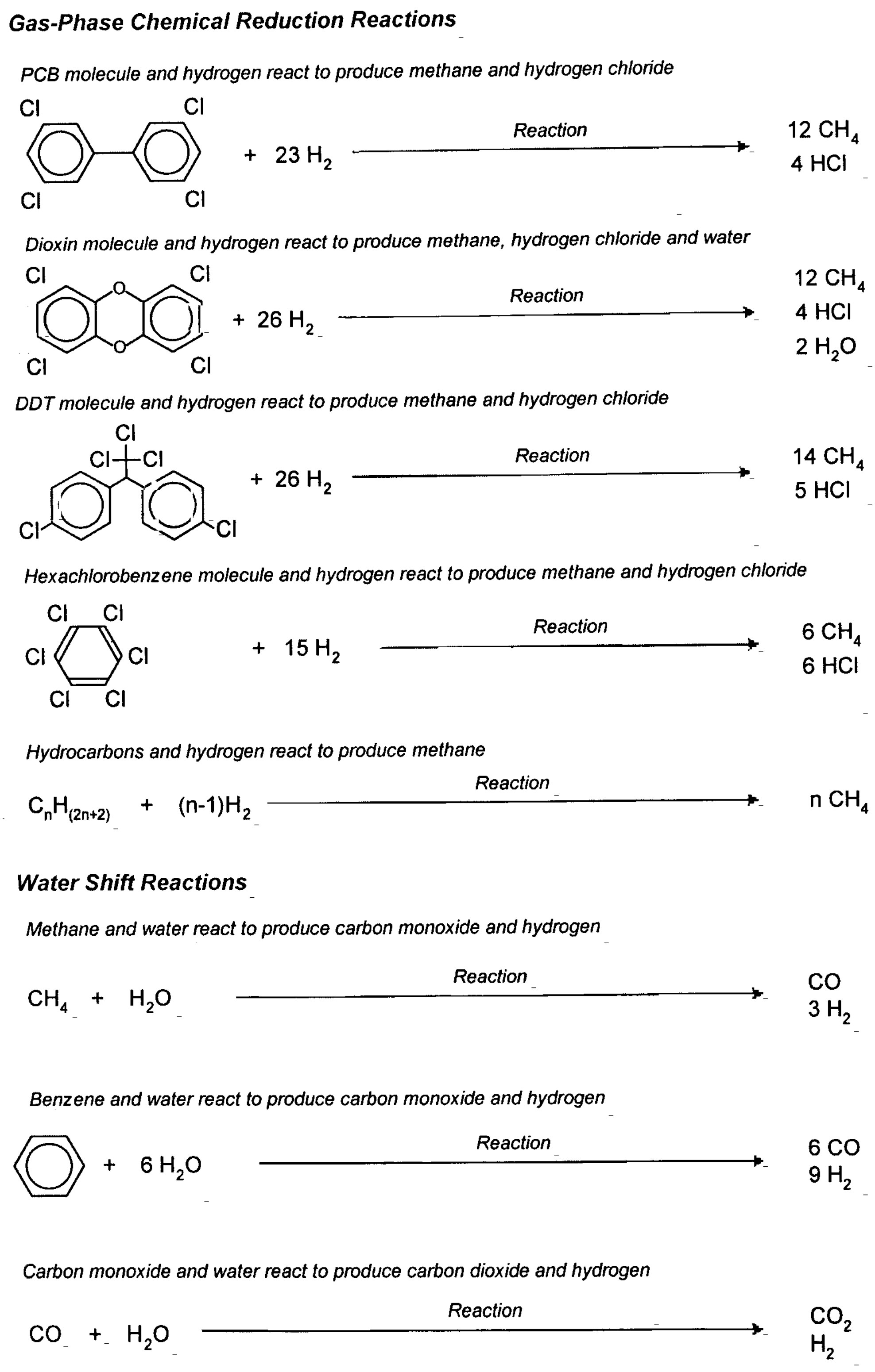

Figure 6.4.1 GPCR reaction scheme.

Hydrogenation
Hydrogen can be used to break down organic contaminants into methane. This reaction can take place in a sealed system which operates at essential ambient pressure in an oxygen free environment. Hydrogen can be explosive only when combined with oxygen or air, and exposed to sparks. If enough measures to ensure tightness of the system, several plants have been developed to use hydrogenation as an industrial process.

Hydrogen has been used in large quantities in the petroleum refining, chemical, petrochemical and synthetic fuel industries for decades. Therefore, the use of hydrogen in industry is fairly routine. The electrical utility industry has also successfully used hydrogen gas for more than forty years, for such operations as cooling rotor and stator coils in large turbine generators. Hydrogen is an accepted fuel in the aerospace industry, and has been safely handed for years in large quantities.

Although hydrogen has been used in industrial processes for decades, it is relative unknown to the public. However, there are strict guidelines for the safe handling and use of hydrogen from the authorities.

Disadvantage
Beside the need for very tight supervision and tight sealing of the hydrogenation process, this process also suffers from the fact that it is a batch process and not a continuous process. This can be partly overcome by erecting several parallel processes, but that might influence the cost per kg treated waste.

Advantage
The Gas Phase Chemical Reduction Process (GPCR) uses hydrogen to break down organic contaminants to methane which then is burned in a conventional process. Toxic material comprising up to 100% pure chlorinated hydrocarbons can be destroyed, which is an advantage of this process compared to incineration that can only treat material containing from 2% to 10% of chlorine.

Furthermore, the hydrogenation process has a very low side production of dioxins and other harmful compounds in comparison to e.g. the incineration process.

6.4.3 Description of the plant

The GPCR process is comprised of a central reactor for the actual destruction of organic waste, with an attached multi-stage scrubbing system to remove inorganic contaminants and light hydrocarbons from the reacted gas stream. Depending on the waste type, various waste preparation and feed mechanisms are used to introduce the contaminants to the reactor.

All of the equipment comprising the GPCR process is broken down into Major Equipment Groups (MEG). Each MEG has an associated equipment list with specifications and a Piping and Instrumentation Diagram (P&ID). The MEGs and their descriptions are presented in Table 6.4.1.

Table 6.4.1 Summary of the GPCR process control MEGs

MEG (Major Equipment Group)		Description	Purpose
03	Pre-heater	Gas heater, mixer and their associated burners	The pre-heater MEG includes all the equipment required to heat any combination of the gas inputs from the hydrogen and steam supply, the off-gases from the TRBP and liquid waste, and the product gas from the MEG 17 hold/test/release vessels. The pre-heater supplies the reactor (MEG 05) and the thermal reduction batch processors (MEG 16) with preheated hydrogen and superheated steam. Three (3) direct fired heat exchangers preheat the hydrogen, steam and waste gases.
04	Compressor	Compressors, heat exchangers and temperature controllers	The compressor MEG includes all equipment required to efficiently remove product gas from the process while maintaining system pressure. The product gas is compressed so that it can be held and tested to verify destruction prior to release as a fuel.
05	Reactor	Reactor and its temperature/heating controls	The Reactor MEG includes all equipment required to efficiently heat and chemically-reduce the organic contaminants from the various input waste streams.
06	Scrubber	Scrubber and associated pumps and heat exchangers	The Scrubber MEG includes all equipment required to efficiently remove heat, particulate, and acid gases from the Product Gas stream from the Reactor (MEG 05).
07	Process water treatment	Decant tanks, filters, and clean water storage tanks	The Water Treatment MEG includes all equipment required to efficiently cool, filter, and neutralize the water from the scrubber system.
10	Nitrogen supply	Cryogenic storage tanks evaporator and associated control valves	This system introduces nitrogen to the system components when such an environment is required. I.e. purging and cooling.
11	Hydrogen supply	Hydrogen storage tanks and associated control valves	This system introduces hydrogen to system components when such an environment is required. Hydrogen is used as a carrier gas and is essential for chemical reduction.
12	Process gas monitoring	Gas analyzers, filters and pumps	The process gas monitoring MEG includes all equipment required to direct process gases through analysers from various locations. Both conditioned and non-conditioned gas streams are analysed for bulk gas components, agent, and trace organic compounds.
13	Boiler	Boiler and ancillary equipment	This boiler system provides steam to the system. Steam is used for heating, cleaning and for water addition to the reduction reactions in the process.
16	Thermal reduction batch processor (TRBP)	TRBP and associated temperature/heating controls	The TRBP MEG includes all the equipment required to efficiently heat and volatilise the organic contaminants from the surfaces of bulk solid materials as well as vaporize organic matrices such as cellulose (wood pallets) and plastics.
17	Product gas storage	Product gas storage tank	The Product Gas Storage MEG includes all the equipment required to hold test and release product gas received from the Compressor MEG. The Product Gas MEG has the ability to recycle product gas to the TRBPs and Pre-heater MEGs. MEG 17 also supplies product gas for fuel gas to the Product Gas Burner and Pre-heater Burner.

MEG (Major Equipment Group)		Description	Purpose
18	Cooling water	Cooling water towers and surge tank	This system provides water for use in the clean/cold side of system heat exchangers.
19 & 20	Instrument air (19) and plant air (20)	Compressors, air and plant accumulators and instrument air piping, plant air piping	This system supplies instrument air and plant air to meet the requirements of the R1 plant.
21	Fuel Supply	Tanks and regulators	This system supplies fuel to meet the requirements of all the burners. LPG/Natural Gas is the fuel used.
22	Blower	Various blowers, silencer/knockout, expansion bellows	This system controls the flow of product gas throughout the system.
23	Product gas burner	Product gas burner, combustion air fan and stack	This system burns the excess product gas generated by the destruction process. It is also designed to mix various combustion exhaust gases prior to exhausting to the atmosphere.
25	Carbon dioxide supply	Tank and evaporator	This system supplies carbon dioxide, which is used as an inert purge gas.
26	Water supply	Piping and backflow preventer	This system provides the necessary water to plant equipment, employee requirements and emergency systems.
27	Caustic supply	Tanks, pumps and piping	This system provides the necessary caustic to the scrubber (06) for pH control of the acids formed in the reduction of wastes.
28	Solid waste pre-processing	Pre-processing unit	This system is a workstation that provides a unit to punch holes in the solid waste equipment to allow the PCB oil to drain out.
29	Liquid waste pre-processing	Tanks associated piping and interconnecting piping	The liquid waste pre-processing MEG includes all equipment required to separate, filter, store, and deliver liquid waste to MEG 03.
31	Electrical distribution	Electrical substation, main power panel, reformer panel, boiler panel, stripper box panel, reactor and cooling tower MCC	This system provides the details of the electrical distribution system for the plant. Specifically this system provides the required electrical power to various electrical drives, heaters and other requirements such as control panels, lighting and process control system.
32	Process Control	I/Os (digital and analogue), control modules and computers	This system provides a robust control system that allows complete control and monitoring of plant operational parameters.

In Figure 6.4.2 please find a process diagram showing the overall process components and their treatment potential (liquids, soil, sediments, bulk etc.) and the process material streams.

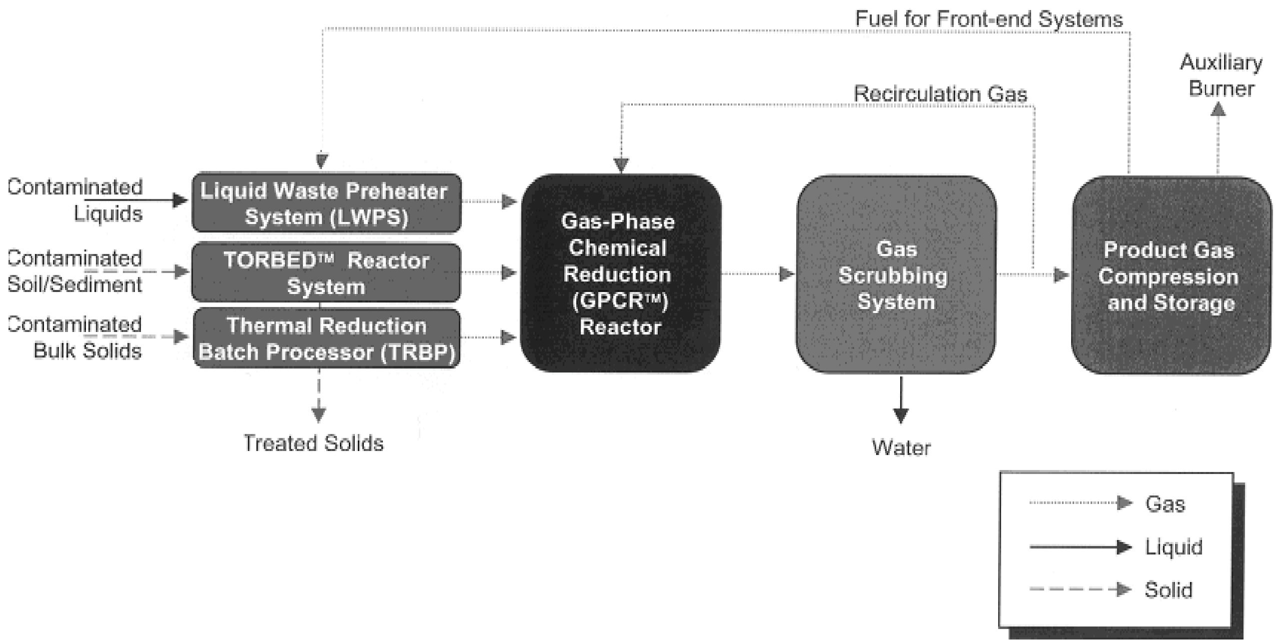

Figure 6.4.2 Process diagram

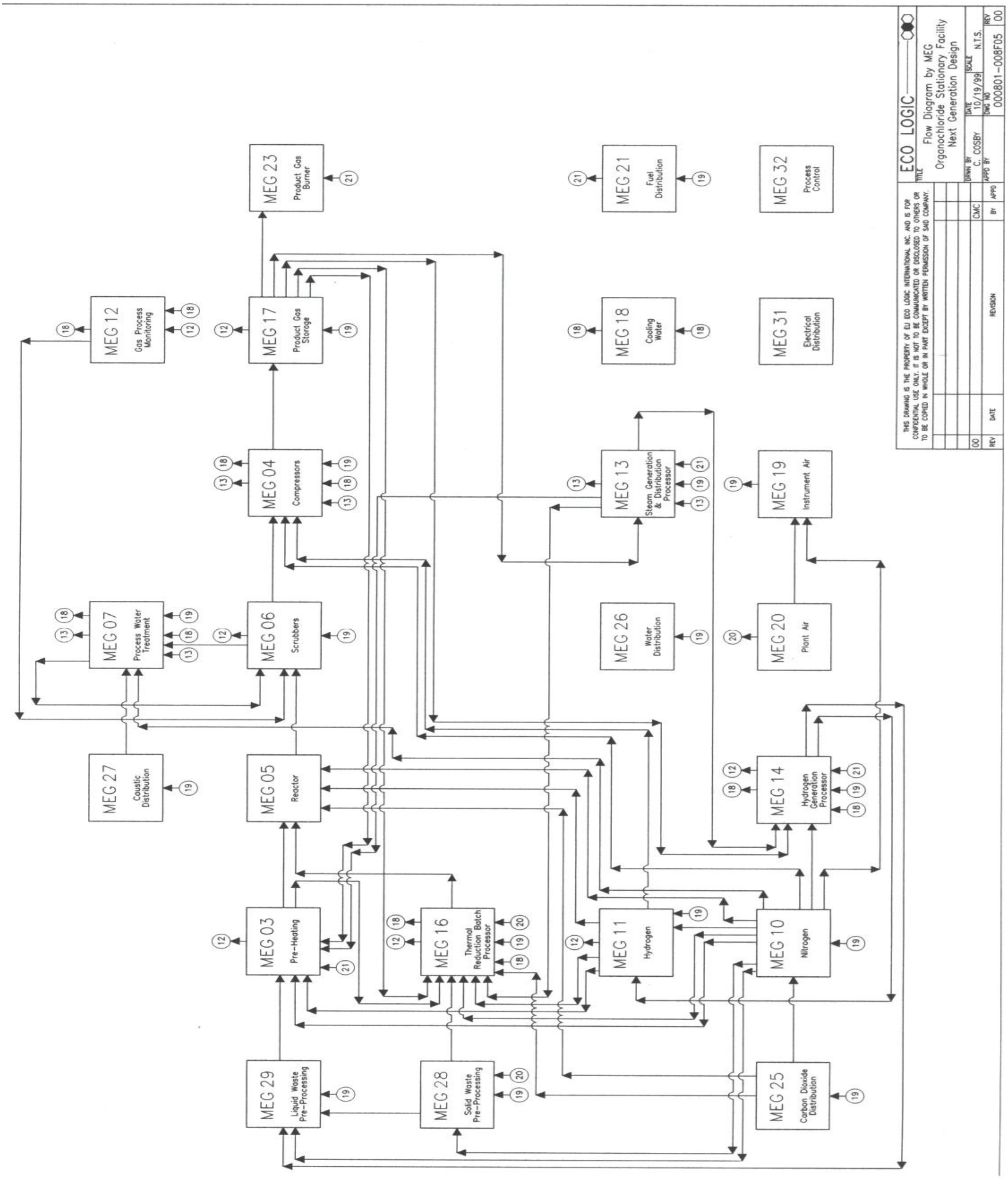

Figure 6.4.3 The process diagram divided into MEG's

6.4.4 Description of the operation

A detailed description of waste preparation and feeding actions needed is outlined in the following.

Bulk solid material

Large bulk solids such as drums, electrical equipment, and process wastes are treated in the Thermal Reduction Batch Processor (TRBP). The TRBP consists of an oven-type chamber where organic contaminants, oil, and any solvents contained in the bulk material are volatilised. The organic vapours are then swept into the reactor by the hydrogen-rich hot re-circulation gas for complete reduction. Batch quantities of soil can also be treated in the TRBP; batch processing meaning that following waste treatment, the TRBP is cooled and the hydrogen purged with nitrogen before the treated residues can be removed and a new batch of waste loaded into the TRBP.

When treating transformers, the PCB oil is drained before the transformer is loaded into the TRBP. The organic contaminants in the waste are thermally desorbed and swept into the reactor by the hydrogen-rich, hot recirculation gas.

During full-scale operations in Australia, the TRBP treated 15 tonnes of waste in open drums. The drums are then sparged with hot hydrogen. Wipe tests following GPCR verified the drums to be free of organic contamination allowing the drums to be disposed of off-site. Contaminated electrical equipment processed in the TRBP constitutes a relatively small organic load to the GPCR reactor. High-strength organic wastes such as Askarel can be processed simultaneously.

The TRBP is also suitable for processing high-strength organic wastes such as obsolete pesticides, which are sufficiently volatile to evaporate directly from drums. One advantage of this approach is reduced waste handling, which minimises fugitive emissions at the site.

Watery wastes and high-strength oily wastes

Experience has shown that fewer undesirable by products are formed when wastes are pre-heated and well mixed. Watery wastes and high-strength oily wastes are injected into a pre-heater that vaporises the liquids in an indirectly fired heat exchanger. The gases are mixed with hydrogen and steam to a temperature of 600°C prior to introduction to the reactor. Another method of preheating liquid wastes is spraying them into the TRBP, which also volatilises the contaminants. This has been used very effectively at Eco-Logic's plant in Australia.

Soil and sediments

A front-end device developed by Torftech Inc. (the TORBED Reactor System) is used to separate contaminants from soil or sediment. The TORBED system heats the soil to 600°C, which desorbs the organic contaminants; these contaminants are then conveyed on a continuous basis to the reactor for complete destruction of the compounds. Treated material exits the TORBED system as a clean, dry, silica-rich material.

Waste treatment
Breakdown of organic contaminants into re-useable or disposable products occurs in the GPCR reactor vessel. The gas mixture from the TRBP enters the reactor, is heated with internal electric heating elements, and then exits through a central vortex tube. By the time it reaches the bottom of the reactor (prior to exiting through the tube), the gas mixture has reached a temperature of approx. 850°C. The optimal process reactions take place from the bottom of the vortex tube onwards, and take less than one second to complete. Gas leaving the reactor is scrubbed to remove acids, water, heat, fine particulates, aromatic compounds and carbon dioxide. The cooled and scrubbed product gas is a mixture of hydrogen, methane, carbon monoxide and other light hydrocarbons.

Some of the gas is reheated and re-circulated back into the pre-heater or through the TRBP as sweep gas. Excess product gas is removed from the system, compressed and stored. The stored product gas is continually analysed and subsequently used as fuel to heat the TRBP, pre-heater, or burned in an auxiliary (excess) gas burner.

Output recovery
System outputs include clean water, treated solids and product gas. Outputs are stored and analysed prior to off-site disposal or reuse. Please find below a detailed description of output recovery detected for the technology.

Water
The scrubber system after the GPCR reactor uses water and NaOH to scrub out acids from the gas. It is important that the scrubber system is effective because HCl in the product gas may cause creation of dioxins when product gas is used as fuel. Water can only be used to wash out small concentrations of H_2S, if a GPCR plant is expected to treat large amounts of sulphur-containing waste. It can be equipped with a specialized H_2S scrubbing system. All water generated from site activities undergoes activated carbon filter treatment. The treated water is stored and chemically tested for waste-specific contaminants. After confirmation that the water is free of contaminants, it is either discharged to a sewer or reused in the system;

Treated bulk solids
Solids remaining in the TRBP following waste treatment are normally free of any hazardous compounds and consist of inorganic compounds, heavy metals or elemental carbon. All material in the TRBP is subjected to chemical testing to verify adequate removal of the contaminants. Following confirmation of complete decontamination, the material can be shipped off-site for recycling;

- **Treated granular solids.** Granular solids generated during operations include treated soil and scrubber particulate. The treated soil is an inert silica-rich, organic-free material that can be replaced on-site, or transported off-site for a variety of uses. Scrubber particulate is reprocessed in the TRBP to eliminate hydrocarbon contamination;

- **Product gas.** Product gas is generated from the breakdown products of the GPCR reactions. Following scrubbing, the product gas, composed primarily of hydrogen and methane, is compressed and chemically tested prior to its use as fuel for various system components. The product gas contains about 60% hydrogen, 20% methane, 10% CO, 10% CO_2, 3-6% moisture (water) and 20-60 mg/m^3 of benzene, and the product gas contains about 12,000 BTU/m^3 corresponding to 13 MJ/m^3, and is roughly similar to coal gas. The product gas can be recycled until the hydrogen concentration reaches a minimum of 60% in the reactor.

The product gases are continuously monitored using a micro-gas chromatograph to detect possible organic pollutants. Before the product gas is sent to the product gas burner, it is analysed to ensure it is free of organic contaminants. This allows for continuous monitoring of product gas (both immediately after processing and in the compressed storage) for specific compounds indicative of incomplete destruction of waste. Product gas outside normal operating maximums is re-routed to the pre-heater for re-processing. Data are stored historically in the process control computer for future analysis and review.

Limitation to the process
If the waste contains compounds like Hg, S, As, or Pb, this could create problems. In the reaction chamber these compounds give rise to AsH_3 and H_2S, which are both very poisonous, and the heavy metals Hg and Pb may evaporate and end up in either the scrubber water or the product gas. Nevertheless, the AsH_3 and the H_2S can be caught in the scrubber water and Eco-logic has also experienced that they may take care of the heavy metals separately by evaporating them before the rest of the waste, but they try to avoid the problems by avoiding these substances in the waste. A disadvantage of the process is that the TRBP front-end device is a batch process, where it is necessary to cool down and empty the TRBP and fill it again. However, liquids and gases can be treated on a continuous basis. It is therefore an advantage to have two TRBPs in combination with liquid input to the reaction chamber, to optimise the operation.

6.4.5 Plant capacity

The throughput capacity of the GPCR process is dictated by the number of TRBP units installed. However, it seem as all capacities have a cost interval close to 1,000 USD/ton of pure chemical treated (e.g. PCB/chlorbenzene mixture with 50% chlorine). If the hazardous chemical fraction of the waste is less, the treatment price per ton will be lower (e.g. if a pesticide is formulated with a lot of talcum (e.g. up to 99%) then the treatment of the active substance will be quicker).

On the head-office location in Toronto, Eco-Logic has in Canada a demonstration facility with a capacity of 5-50 tonnes/year. Furthermore, capacity is established in Japan with a mobile facility of 850 tons/year. Formerly, Eco-Logic operated a full scale facility at 1,800 tons/year in Australia and St. Catharines in Canada.

For the purpose of making possible up-scaling of the technology in order to increase its availability to the CEE market platform with extensive amounts of POP/OP waste, the following additional must be compiled:

- Treatment of e.g. 3,000 tonnes annually: 1 reactor, 2 TRBP and hydrogen plant (from natural gas) are needed;
- Treatment of e.g. 10,000 tonnes annually: 3 reactors, 6 TRBP and hydrogen plant (from natural gas) are needed.

6.4.6 Practical experience

Eco-Logic has considerable practical experience with the GPCR system. The GPCR process was demonstrated in public for the first time in 1991 treating harbour sediment containing coal tar at concentrations up to 300 g/kg. The concentration of PCBs in the air emissions, liquid effluent and processed solids following GPCR treatment were all below the detection limits resulting in a documented PCB Destruction and Removal Efficiency (DRE) of at least 99.9999%.

Over the past 10 years, Eco-Logic has successfully completed a variety of demonstration projects, including the US-EPA SITE demonstration in 1992 and numerous testing programs for the US Army under their chemical demilitarisation program.

The majority of waste treatment activities using GPCR have occurred at Eco-Logic's full-scale commercial plant in Kwinana, Western Australia, which began commissioning operations in 1995 and achieved commercial throughputs by 1998. The plant operated through 2000, and treated in excess of 2,000 tonnes of waste including PCBs, pesticides and other POPs, with most – up to 1,500 tonnes –treated in the final 2.5 years. Another large-scale operation was conducted at General Motors of Canada Limited (GMCL) in St. Catharines, Ontario. This demonstration project, which began in February 1996 and concluded in September 1997, destructed approx. 1,000 tonnes of PCB-contaminated electrical equipment (transformers, capacitors, ballasts), concrete, oil, soil and miscellaneous other solids and liquids.

Recently (2000), the plant participated in the US Assembled Chemical Weapons Assessment (ACWA) program under contract to the US Army, with success. This testing included a thorough risk analysis which addressed important design changes in the full-scale plant designed for the Army.

To date, more than 3,000 tonnes of contaminated waste, including PCBs, dioxin, HCB and chemical warfare agents, have been treated using the GPCR technology, and more than 30,000 commercial operating hours have been recorded.

Demonstration plants continue to operate in North America and Japan.

6.4.7 Maintenance and services requirements

The GPCR process, as mentioned previously, is a closed loop process. Nearly all the processing has been made automatically regulated via an SRM (Steering, Regulating and Monitoring) computer. Most of the streams are fitted with actuator valves, pressure meters, thermometers, and at selected places there are hydrogen measurements.

One of the biggest challenges is to keep the system airtight. For that reason special packing and seals are used. These packing and seals are of Teflon, Viton and synthetic rubber - EPDM (Ethylene Propylene Diene Monomer), which are available off-the-shelf. The GPCR reactor is Hastelloy stainless steel, which is available all over the world. The problem of the availability of packing, seals and actuators may be solved by having the necessary stocks of maintenance material.

Hydrogen, nitrogen, and activated carbon are easily attainable, which means maintenance issues may be easily overcome. The following supply lines and raw materials are required for plant operations.

Supply lines
The following infrastructure support is needed for a full operational mode:

- Electricity, 1,500 kW installed load with maximum load of 1,125 kW supply;
- Water supply (for plant water, decontamination, sanitation, etc.);
- Nitrogen supply;
- Hydrogen supply with a maximum of 600 m^3/hour. A hydrogen generation plant is included in the cost estimates for a plant facility; and
- Compressed air.

Raw materials
The following raw materials are needed in the process:

- Activated carbon;
- Sodium hydroxide; and
- Natural gas.

6.4.8 Occupational health and safety

The most important occupational health problems occur in connection with the handling and loading of the waste before treatment. This concern is mitigated by handling waste in drums, and if necessary to work with appropriate personal protective equipment (PPE).

Any hydrogen that may leak into the working area is detected by hydrogen detectors placed in central places. The working area is ventilated and all electricity is ex-proved to secure against electricity induced ignition. Therefore, explosion risk due to hydrogen seems to be eliminated.

Noise may be a problem when the compressor for the product gas is running. Because of the continuously heating of both the TRBP and the reaction chamber, devices must be well insulated to prevent the working area from getting too hot.

6.4.9 Operational risks

In 1998, Richard W. Prugh from Process Safety Engineering, Inc. conducted an independent review of the safety of the GPCR technology, specifically to examine the use and handling of hydrogen in the process. He identified *potential* hazards associated with the use of hydrogen in the GPCR process at that time and made 19 recommendations to improve the plant. Since then, design changes to the GPCR process have been implemented based on Mr. Prugh's process design recommendations, although his design recommendations were primarily related to the use of GPCR as part of a Total Solution for chemical weapons treatment.

In 2001, as part of the work conducted for the US Army for the Assembled Chemical Weapons Assessment (ACWA) program, the GPCR technology underwent a preliminary hazards analysis, which is reported in the following publication "Engineering Design Package Volume VII, Preliminary Hazards Analysis, 14 December 2001" prepared for the Assembled Chemical Weapons Assessment Program, US Army.

From the independent review and the preliminary hazards analysis, it may be concluded that Eco-Logic's GPCR technology operates to strict risk reduction criteria and is intrinsically safe.

6.4.10 Plant mobilisation/demobilisation

For a 3,000 tonnes/year plant it takes 2-3 months to dismantle - move and re-erect the system somewhere else. The cost of re-locating a plant facility is in the range of 15-25% of the initial capital costs with additional costs required for sampling, analysis, and transportation. It is estimated that the 3,000 tonnes plant facility could be moved for a maximum of 3 to 4 Mill USD incl. decommissioning, transport, crane assistance, re-installation and re-commissioning.

6.4.11 Capacity building

Eco-Logic has twice proved that they can transfer the know-how of running the plant to a new company. An objective of the ACWA demonstration testing program for the US Army was to demonstrate that government operators could be trained to operate the GPCR technology. This objective was successfully completed since Tennessee Valley Authority personnel operated the GPCR process after receiving training from Eco-Logic on technology operation.

Also Eco-Logic's Japanese partners were trained with success. The training is made easier because there are only a few critical process parameters that have to be followed (such as temperature, hydrogen concentration, and the amount of water vapour, etc.).

6.4.12 Environmental impact of the technology

The assessment of the environmental impacts is based on the criteria presented in Section 6.2.

Materials consumption

The total mass of a full-scale plant facility including fundament is estimated by Eco-Logic to around 1,100 tonnes. The main construction parts are construction steel (approx. 400 tonnes), concrete for fundament etc. (approx. 380 tonnes) and specialty alloys/equipment (approx. 265 tonnes).

The annual amount of waste treated in a "normal one reactor facility" is assumed to be in the range of 1,000-1,800 tonnes although depending on the waste type. Assuming an overall life of around 10 years of the plant constructions, the consumption of construction materials will be in the range of 0.06-0.11 kg pr. kg of waste treated. Assuming an overall recycling rate of approx. 90%, which should be considered realistic in most countries, the consumption of construction materials is reduced to ≤ 0.01 kg material pr. kg of waste treated. Compared to the consumption of means of operation indicated below the consumption of construction materials should be regarded as insignificant. It should, however, be noted that no information regarding material composition of special alloys/equipment has been available. Thus, it is not known whether these alloys and equipment contain very scarce and valuable materials.

The main means of operation and consumption related to the selected waste types are listed in *Table 6.*4.2. Among the minor ancillary materials consumed but not listed in *Table 6.*4.2 may be mentioned activated carbon used for cleaning of air and water emissions. The mass of carbon used corresponds to around 6-7% of the waste treated (measured as dry matter on a mass basis). The carbon is after use treated and destructed in the plant parallel to other waste.

Table 6.4.2 Consumption of important means of operation

Means of operation	Unit	Waste Types (*1)		
		Pesticide Mix	DDT	PCBs (oil)
Natural gas	kg gas/kg waste	0.45	0.26	0.29
Electricity	kWh/kg waste	2.6	1.5	1.7
Sodium hydroxide (* 2)	kg NaOH/kg waste	0.175	0.56	0.54

*1: Waste types are characterised as follows:
Pesticide mix contains 10% chlorine, 2.5% sulphur, 86% carbon and 1% hydrogen.
DDT contains 50% chlorine, 0% sulphur, 47.4% carbon and 2.6% hydrogen.
PCBs contain 49% chlorine, 0% sulphur, 49% carbon and 2% hydrogen - in practical tests a mixture of PCBs and chlorobenzenes with 48-54 % PCBs and 26-33% chlorobenzenes
*2: Figures stated as 100% NaOH

Of the means of operation listed in Table 6.4.2, electricity is a energy source and will be considered only as such while natural gas is a non-renewable resource used as energy source, and therefore will be considered in terms of material consumption as well as energy consumption. Finally, sodium hydroxide should be regarded as a renewable resource as well as a source of energy consumption as energy is being used for extraction, preparation and refining.

The material consumption for the GPCR-process related to the selected waste types may thus be presented as in *Table 6.*4.3.

Table 6.4.3 Material consumption related to the GPCR process

Material consumption	Unit	Waste types (*1)		
		Pesticide Mix	DDT	PCBs (oil)
Construction materials	kg/kg waste	≤ 0.01	≤ 0.01	≤ 0.01
Means of operation - non-renewable	kg/kg waste	0.45	0.26	0.29
Means of operation - renewable	kg/kg waste	0.18	0.56	0.54

*1: Waste types are characterised as follows:
Pesticide mix: contains 10% chlorine, 2.5% sulphur, 86% carbon and 1% hydrogen.
DDT: contains 50% chlorine, 0% sulphur, 47.4% carbon and 2.6% hydrogen.
PCBs: contains 49% chlorine, 0% sulphur, 49% carbon and 2% hydrogen - in practical tests a mixture of PCBs and chlorobenzenes with 48-54% PCBs and 26-33% chlorobenzenes.

Energy consumption

The energy consumption related to consumption of electricity, energy materials and significant means of operation is calculated in *Table 6.Table 6.4.4 Energy consumption related to the GPCR-process*

Material	Unit	Waste types		
		Pesticide mix	DDT	PCBs (oil)
Natural gas (*1)	MJ/kg waste	22	12	14
Electricity (*2)	MJ/kg waste	9.4	5.4	6.2
Sodium hydroxide (*3)	MJ/kg waste	3.9	12	12
Total	MJ/kg waste	35	29	32

*1: The energy consumption related to consumption of natural gas is based on a figure of 48 MJ/kg gas, of which 45 MJ is the energy content and 3 MJ is the energy used for extraction and refining of gas.
*2: 1 kWh = 3.63 MJ. The choice is made not to compensate for loss of energy due to conversion and transport as the actual loss depends on the primary energy source combined with local conditions. Often energy efficiency related to electricity may be down to around 35% in case the primary energy source is coal used on central power plants without utilisation of heat.
*3: The energy used for extraction, preparation and refining is assumed to come up to around 22 MJ/kg.

Chemicals, emissions, residues and elimination efficiency

According to information received from Eco-Logic, the emissions and residues related to the selected waste types can be stated as in *Table 6*.4.5.

Table 6.4.5 Generation of emissions and residues

Emissions and residues	Unit	Waste types (*1)		
		Pesticide mix	DDT	PCBs
Emission to air (*2)	Nm^3/ kg waste	201	58	66
Wastewater	Lit. / kg waste	2.5	2.8	2.9
Slag/clinker	kg/kg waste	0.01	0.01	0

*1: Waste types are characterised as follows:
Pesticide mix: contains 10% chlorine, 2.5% sulphur, 86% carbon and 1% hydrogen.
DDT: contains 50% chlorine, 0% sulphur, 47.4% carbon and 2.6% hydrogen.
PCBs: contain 49% chlorine, 0% sulphur, 49% carbon and 2% hydrogen - in practical tests a mixture of PCBs and chlorobenzenes with 48-54 % PCBs and 26-33% chlorobenzenes.
2*: Emission to air of clean flue gas stated by Eco-Logic as 450 Nm^3/min for pesticide mix, 230 Nm^3/min for DDT and 230 Nm^3/min for PCBs. Total air flow per kg waste has been calculated by assuming 7,450 annual working hour and annually treated waste quantities of 1,000 tonnes of pesticide mix, 1,760 tonnes of DDT and 1,560 tonnes of PCBs.

The available data on the content of POPs and similar substances including decomposition substances in emissions and residuals from the GPCR-process have been summarised in Table 6.4.6. It is noted that measurements addressing the substances treated or organic chlorine in general have been available only with respect to PCBs and only with respect to air emissions. Thus, it is only possible to partly assess the elimination efficiency of the GPCR-technology.

Table 6.4.6

Content of substances in emissions and residues by treatment of PCBs by the GPCR process

Substance	Concentration registered			Criteria
	Air emission µg/Nm^3	Wastewater µg/lit	Slag/Clinker mg/kg (*2)	
Total hydrocarbons (*1)	0.3-7.5 x 10^3	?	0?	Air emission: < 10 mg/Nm^3
Total chlorobenzenes	≤ 2.1	NDA	0?	
Total polychlorinated biphenyls	≤ 0.41	NDA	0?	
Other chlorinated organic substances (*3)	≤820	NDA	0?	
Dioxins/furans (as I-TEQ)	≤2 x 10^{-5}	≤6.3 x 10^{-6}	0?	Air emission: < 0.1 ng/Nm^3

NDA: No data available.

*1: Registered concentrations of 0.4-2.3 ppm. Concentrations are transformed into µg/Nm^3 by assuming 760 mbar, 20°C and that THC in this case is composed of methane or benzene only;

*2: Claimed to pure carbon with no residues of the substances treated;

*3: Mainly chloromethane with small quantities of substances like chloroform, dichloromethane, dichlorodifluoromethane, trichloroethane and trichlorofluoromethane.

Using the amount of organic chlorine and the amount of relevant substances as measurement units, DRE (destruction and removal efficiency) can be estimated as shown in Table 6.4.7. However, due to lack of data it is not possible to assess DE (destruction efficiency). The concepts of DE and DRE are defined and discussed in Section 6.6.2.

Table 6.4.7 Assessment of DE and DRE for the GPCR-process

Item	Waste type (*1)		
	Pesticide mix	DDT	PCBs (oil)
Content of organic chlorine in 1 kg untreated waste	100 mg	500 mg	?
Content of chlorobenzenes in 1 kg untreated PCB waste	-	-	300 g
Content of PCBs in 1 kg untreated PCB waste	-	-	500 g
Air emission of organic chlorine from treatment of 1 kg PCB waste (*2)	?	?	≤30 mg
Air emission of chlorobenzenes from treatment of 1 kg PCB waste (*2)	-	-	≤0.11 mg
Air emission of PCBs from treatment of 1 kg PCB waste (*2)	-	-	≤0.027 mg
Wastewater from 1 kg waste (*3)	?	?	?

Slag from 1 kg waste	?	?	0?
DE	?	?	?
DRE related to organic chlorine	?	?	?
DRE related to chlorobenzenes	?	?	≥ 99.9997
DRE related to PCBs	?	?	≥ 99.9998

*1: Waste types are characterised as follows:
Pesticide mix: contains 10% chlorine, 2.5% sulphur, 86% carbon and 1% hydrogen;
DDT: contains 50% chlorine, 0% sulphur, 47.4% carbon and 2.6% hydrogen;
PCBs: contain 49% chlorine, 0% sulphur, 49% carbon and 2% hydrogen - in practical tests a mixture of PCBs and chlorobenzenes with 48-54 % PCBs and 26-33% chlorobenzenes.
*2: All calculations of air emissions are based on air flow stated in Table 6.4.9 and substance concentrations stated in Table 6.4.10. Chloromethane is assumed to contain approx. 69% chlorine.

Other issues
The amounts of residuals for disposal are outlined in Table 6.4.7 under "slag/clinker" and "wastewater". The amount of solid waste - the slag/clinker - should be regarded as extremely low. Assuming that the slag/clinker consist of pure carbon with no traces of POPs and other hazardous substances, the slag/clinker can be disposed of with few - if any - restrictions. The amount of wastewater is on the other hand relatively high.

6.4.13 Economy

Based on information from Eco-Logic, the following general pricing can be outlined for the establishment of annually POP elimination treatment capacity of 3,000 and 10,000 tonnes, respectively.

Annual treatment capacity - 3,000 tonnes
One reactor, two TRBP and a hydrogen plant (from natural gas) is needed at an estimated cost of 15 million USD. Subdividing of the capital costs on interest and repayment, operation and labour costs are outlined below based on the elimination of an annual anticipated amount of 3,000 tonnes of POPs waste:

Interest and repayment	600-700 USD/t
Operating costs	350-450 USD/t
Labour costs (salary for 22)	250-350 USD/t
Total	1,200-1,500 USD/t

Annual treatment capacity - 10,000 tonnes
Three reactors, six TRBP and a hydrogen plant (from natural gas) are needed at an estimated cost of 30 million USD. Subdividing of the capital costs on interest and repayment, operation and labour costs are outlined below based on the elimination of an annual anticipated amount of 10,000 tonnes of POPs waste:

Interest and repayment	350-450 USD/t
Operating costs	350-450 USD/t
Labour costs (salary for 40)	150-200 USD/t
Total	**850-1,100 USD/t**

The cost estimates largely includes license, design, hydrogen production and overhead. Labour costs are of course country dependent. By experience from increasing international demands for technology control and assessment, analytical costs can comprise up to 50% of the project costs for demonstration facilities.

6.4.14 Evaluation of the GPCR technology

Technical evaluation
The technical evaluation is beside the topics mentioned above also based on supplementary information extracted from the "Assembled Chemical Weapons Assessment Program, Supplemental Report to Congress, June 2001" report. GPCR has historical, full-scale commercial experience. There are still believed to exist some technical risks associated with scale-up of batch processing with assembled chemical weapon feed streams and generation of carbonaceous material in GPCR, although the vendor claims that these has been overcome within e.g. the ACWA program.

The primary destruction process for the chemical agent operates at low temperature and ambient pressure. The GPCR process utilizes four major hazardous process chemicals: sodium hydroxide, hydrogen, kerosene and natural gas. Some of these materials are used in large quantities, and all pose some routine exposure risk to workers during feed preparation and maintenance of process equipment. However, all process materials for the GPCR process have moderate to low toxicity and persistency, are commonly used in industry, and can be handled in accordance with well-established industrial safety practices.

Analysis
Containment of phosphorous elements in the waste fraction will lead to product gases containing phosphine at a level of 0.01-0.06%. Further reduction of the phosphine level would require modification of the scrubber system. The scrubber removes HF. Benzene was also detected at 0.02-0.07% in GPCR product gas possibly as a contaminant. However, levels in stack gases could not be determined because samples could not be sent to off-site laboratories. GPCR product gases from sulphur containing waste contained hydrogen sulphide at 1.9% and benzene at 0.2%. Levels in stack gases again could not be determined because samples could not be analysed at off-site laboratories.

Wood spiked with PCP was treated in the GPCR with no detectable PCP (at levels as low as 1,300 µg/m^3) in the product gas. GPCR has previously been permitted under "Toxic Substance Control Act" for PCB destruction, with tests showing >99.9999% DE.

Figure 6.4.4 The Thermal Reduction Batch Processor, Canada June 2002

Scrubber
The scrubbing systems for GPCR off gas are of a common, commercial design. However, the materials of construction for the GPCR off gas scrubber system need to be addressed. Eco-Logic states that now appropriate materials of construction have been selected based on 2001 and 2002 engineering studies.

Maturity
The maturity of the industrial GPCR provides a certain degree of confidence that the system can be operated as a stable treatment unit. However, some controllable instability observed during demonstration of GPCR is of concern for larger scale utilization. Specifically, gas evolution resulting from ramping up the temperature too quickly is of concern. Due to the batch nature of GPCR, the system could become unstable if heat ramp-up to the TRBP is sudden and gas evolves at a faster rate than can be controlled downstream. While the system has a control system for automatic shutdown, the large mass of material with a high heat capacity present in the TRBP could continue to create an upset that can only be controlled with a proper high-pressure abatement strategy.

Individual feeds require individual control strategies for heat input to the TRBP, and additional data for each feed is required to develop these strategies. In addition, the passage of excess energetic (e.g., un-dissolved burster material) to the TRBP is still of some risk because the operational safety margins for expected feeds are not known.

There are known or standard preventive and routine maintenance requirements for the commercial GPCR. Requirements for cleaning carbonaceous residues and other solids out of TRBPs, GPCR reactors, and downstream gas polishing units could be extensive.

Eco-Logic states that the above comments are irrelevant to conventional hazardous waste – they have proven that the problems identified can be easily handled, or do not occur. We agree with Eco-Logic in their comments, they have already proved at several occasions that they can operate in a stable way.

Monitoring
The effectiveness of the monitoring and control approach was also validated in demonstration testing for GPCR. The GPCR process control software is identical to that already used in an existing large-scale Eco-Logic commercial unit and is proposed for use at full-scale. The technology provider states that a full-scale system would not be significantly more complex than the demonstration unit - as demonstrated by commercial operations in Western Australia.

During an automatic shutdown of GPCR, the shutdown procedures for GPCR were implemented properly, indicating that the control system had performed adequately. The computer control system and its programmed alarms and interlocks were adequate to allow for safe and controlled shutdowns each time they occurred as intended.

However, control of the heat input to the TRBP (the primary control of GPCR) is manual, putting a large responsibility on the operator. There is a potential in GPCR for the slow, controlled rate of heating to exceed the level at which gas evolution is effectively controlled. Pressure spikes in the TRBP occurred during several validation runs, but they were handled by the control system.

Figure 6.4.5 A $1m^3$-version of the TRBP, Canada, June 2002

Nonetheless, the amount of gas evolution may be of concern at full-scale. In demonstration and at full-scale, high gas evolution is controlled by operating two compressors at all times with a third used as a backup. As a minimum, the nature of GPCR requires "trial and error" treatment methods with multiple runs of every type of feed proposed for full-scale. This is required in order to gain experience with how fast the heat transfer to the TRBP can be ramped up.

Completeness of effluent characterization

Sufficient characterization of the effluent process streams was achieved with the exception of the effluent gas stream associated with GPCR agent operations. Currently, there is no reliable sampling and analysis approach for the effective measurement of chemical agents in the GPCR process effluent gas stream. In addition, most of the gas samples from the product gas burner and some of the product gas samples were not collected during some of the runs due to a change in test facility policy. This led to an incomplete characterization and the inability to validate the gas stream mass balance for GPCR with certain compounds (from "Assembled Chemical Weapons Assessment Program, Supplemental Report to Congress, June 2001").

Two concerns exist relating to the GPCR system, chemical agent monitoring in the GPCR product gas stream and control of energetic levels in the feed, which can be resolved through improved design and additional development.

GPCR utilize process materials that are commonly used in industry, and can be handled in accordance with well-established industrial safety practices. GPCR is a remote operation, which generally protect workers from chemical and physical hazards. However, there are still inherent risks associated with a high volume of hazardous chemicals used in the process, and the use of high temperature hydrogen in the GPCR process.

GPCR operates at high temperatures (above 815°C), and utilizes hydrogen (a potentially explosive or flammable gas) in the process. However, the safeguards, monitoring, and controls that minimize worker impact in the event of a facility accident are similarly beneficial with respect to public impact. These provisions mitigate the risk of an accidental release of agent or process chemicals that could otherwise disperse to the public. Even if an accident occurred during operations, public impact is minimized or eliminated since several layers of system and facility secondary containment should sufficiently contain the effects and prevent public exposure.

All waste streams generated during demonstration were characterized with the exception of GPCR gas effluents during agent operations. Proposed full-scale disposal options were specified for all waste streams. There are no external liquid effluents. The only solid products from the total solution include solid residue from GPCR. Solid residue from GPCR collected during the demonstration passed the TCLP (toxicity characteristic leaching procedure) requirements. The gaseous emissions from GPCR will undergo "hold, test and release" prior to use as a fuel.

All primary destruction processes and their associated intermediate waste streams are held tested and reworked (if necessary) before release. GPCR product gas (containing hydrogen, methane, CO_2, CO and acid gases) is scrubbed with caustic and then held for agent testing. Once cleared, the product gas is burned in a boiler or other energy recovery device and the combustion products are then passed through a catalytic converter.

Figure 6.4.6 The GPCR reactor in Canada, June 2002

The gas product from GPCR is in principle a hazardous waste, but may be burned in the process if it meets certain requirements (the boiler or industrial furnace (BIF) exemption). Based on demonstration results, it appears that the GPCR product gas exceeds the minimum required heating value of 5,000 BTU/lb, which is used as a key test to determine the applicability of the BIF exemption.

In summary, there are no liquid effluents, and the gaseous and solid effluents from demonstration appear to present a low hazard. GPCR gaseous effluents are held, tested, and reworked (if necessary) prior to release. However, the overall impact on human health and the environment could not be fully ascertained due to the lack of validation for the method for detection of agent in GPCR gas effluents.

GPCR has a history of successful permitting for PCB destruction in the US. The permitting strategy includes discussion of options for effluents to air (GPCR gases to boiler, and other air effluents through plant filters (burning and/or active carbon filter) with no expected permitting issues), no discharges to water are proposed, and all solid wastes are treated and decontaminated completely of agent and may be released for general use or sold to the public.

Environmental evaluation

Material consumption

Material efficiency is outlined in Table 6.4.8 and is found to be above average for this technology.

Table 6.4.8 Comparative assessment of material consumption

Material consumption	Unit	Gas Phase Chemical Reduction (GPCR)
Construction materials (*1)	kg/kg waste	≤0.01
Means of operation excl. energy - non-renewable	kg/kg waste	-
Means of operation excl. energy - renewable (*2)	kg/kg waste	0.18-0.56
Overall assessment		2

-: Insignificant

*1: All materials are weighted equally and no consideration has been paid to scarcity and whether the material is renewable.

*2: Addresses in reality the consumption of NaOH only.

Energy consumption

Energy consumption, as outlined in Table 6.4.9, is rated as middle in comparison to the other reviewed elimination technologies.

Table 6.4.9 Comparative assessment of energy consumption

Energy consumption	Unit	Gas Phase Chemical Reduction (GPCR)
Energy consumption	MJ/kg waste	29 - 35
Overall assessment		3

Chemicals, emissions and elimination efficiency

It should be noted that the DE and DRE values quoted represents specific highly chlorinated substances as PCBs. However, such DE and DRE values do not address the issue of, whether more toxic decomposition products of the treated substances are created during the process. It is emphasized that no indication of such reactions exist, and the issue is raised mainly to bring attention to whether it would be possible to supplement the very specific parameters of PCBs by more broad parameters covering also relevant decomposition products.

Considering, furthermore, the very low level of dioxin emission to all media and residues from the GPCR-process it seems appropriate to rate this process as good and clearly above middle as outlined in Table 6.4.10 below.

Table 6.4.10 Assessment of emissions and elimination efficiency

Elimination efficiency	Unit	Gas Phase Chemical Reduction (GPCR)
Destruction efficiency	%	?
Destruction and removal efficiency	%	99.98-≥99.996
Dioxin emission to air	ng I-TEQ/ kg waste	1.1
Dioxin emission - all media and residues	ng I-TEQ/ kg waste	1.1
Overall assessment		1

?: No data available

Other issues

The GPCR-process does not generate any hazardous waste that requires further treatment or special disposal. The amount of solid waste is very low, while the amount of wastewater hardly can be regarded as a problem, considering it is cleaned by an activated carbon filter. For these reasons, the GPCR process is ranked high as outlined in Table 6.4.11.

Table 6.4.11 Residues

Residues	Unit	Gas Phase Chemical Reduction (GPCR)
Waste for further treatment/disposal - hazardous waste	kg/kg waste	-
Waste for further treatment/disposal - solid waste	kg/kg waste	0.01
Waste for further treatment/disposal - wastewater	lit/kg waste	2.5-2.9
Overall assessment		2

-: Insignificant

6.5 Base catalysed dechlorination (BCD)

6.5.1 Introduction

In April 2002, the review expert team visited the ongoing Base Catalysed Dechlorination (BCD) process plant used on the Olympic Coordination Authority site at Homebush Bay, New South Wales, Australia for degradation and final elimination of organic chlorine compounds.

The original plant design was based on a pipe flow reactor concept. Problems encountered during the commissioning phase and subsequent plant modifications resulted in the conversion of this pipe flow reactor into a batch plant utilising an agitated, externally heated reaction vessel, with caustic shearing and oil pre-heating systems.

This description specifically covers the BCD plant in its current agitated vessel configuration.

The Sydney Olympic Site

The Enterra BCD process was licensed by the New South Wales (NSW) Environmental Protection Authority (EPA), to treat Scheduled Chemical Waste (SCW) and dioxin/furan impacted soils and wastes, at the Sydney Olympic site.

During the general remediation earthworks on the Olympic site, any materials suspected to be contaminated with SCW and/or dioxin/furan, were segregated out for separate treatment. This segregation resulted in approx. 450 tonnes of soil contaminated with SCW and dioxin/furans. In addition about 10 tonnes of pure SCW concentrate required treatment.

Under the NSW Environmentally Hazardous Chemicals Act (1985), an SCW is defined as any chemical listed under Schedule 1 of the regulations appended to the act. These compounds are mainly persistent chlorinated organic pesticides including Chlorobenzenes (CBs) and Chlorophenols (CPs). In the case of the Sydney Olympic project, the SCW compounds of concern were determined to be as follows:

- 1,2,4-trichlorobenzene;
- 1,2,4,5-tetrachlorobenzene;
- pentachlorobenzene;
- hexachlorobenzene;
- 2,3,4,6-tetrachlorophenol;
- pentachlorophenol;
- hexachlorophenol;
- DDT;
- DDE;
- DDD; and
- α-chlordane.

Other compounds of concern that required treatment included 2,4,5-trichlorophenol, 2,4,6-trichlorophenol, 1,2-dichlorobenzene, 1,4-dichlorobenzene, 1,2,3,4-tetrachlorobenzene and 2,3,4,5-tetrachlorophenol.

Enterra used an Indirect Thermal Desorption (ITD) plant to remove the contaminants from the soil, generating approx. 13 tonnes of highly concentrated condensate sludge. In addition to this, a small amount of miscellaneous waste containing SCW and variable amounts of soil and other solid materials, including 2 tonnes of spent activated carbon, was pre-processed using a ball mill and subsequently treated directly in the BCD reactor.

The initial aggregate concentration of CPs and CBs in the contaminated soil was about 20,000 mg/kg (ppm). After thermal desorption the aggregate CB and CP content was reduced to less than 1 mg/kg (ppm). Dioxin/furans were not detected in the treated soil, which was disposed of to a licensed landfill.

The 10 tonnes of concentrated CBs and CPs and 13 tonnes of sludge condensate generated from the ITD process were then processed in the batch BCD reactor. For all batches processed, the reactor output was less than 1 mg/kg (ppm) SCW and less than 10 μg/kg (ppb) dioxin. As it can be seen, this data shows that the destruction efficiency for Schedule Chemical Wastes is typically around 99.9999%.

The Enterra plant was licensed to run under a licence strictly controlled and monitored by the NSW EPA. The EPA licence regulated issues such as off-gas discharge, with regular periodic monitoring, validation of treated waste, discharge water quality, noise monitoring, dust/air quality monitoring and all other environmental considerations

6.5.2 Description of the technology

Chlorinated organic compounds can be detoxified by reaction with sodium or potassium hydroxide in an oil carrier liquid at temperatures between 300°C and 350°C. In the presence of an organic accelerator, which is a source for free radicals in the system, the de-chlorination reaction proceeds to a very high level of completion, within a few hours, leaving a residue that is a suspension of carbon, sodium chloride and unspent sodium hydroxide in the carrier oil. This reaction product usually requires no further treatment.

This process has been patented worldwide by the BCD Group in the USA. Enterra Pty Ltd is a licensee of the BCD Group. Enterra Pty Ltd and the BCD Group are jointly promoting this technology as the BCD process.

The BCD process has been successfully applied for the destruction of scheduled organo-chlorine wastes including the following:

- PCBs (Polychlorinated biphenyls);
- HCB (Hexachlorbenzene);
- PCP (Pentachlorphenol);
- Lindane;
- DDT;
- Dioxin;
- Hexane chlorides;
- Chlorinated pesticides; and
- Phosphor pesticides.

The BCD process has the advantage of being able to treat compounds with up to 50% of chlorine (typical concentrations are usually 25-30% chlorine).

The reaction
The products of the BCD reaction are carbon, sodium chloride (common salt), potassium chloride (where potassium hydroxide is used) and unspent sodium hydroxide (caustic soda) suspended in the oil carrier liquid.

The raw materials used for the Sydney Olympic project are sodium hydroxide, accelerator (a vegetable oil, fatty acid or alcohol) carrier oil and the organo-chlorine compound (i.e. waste), which can be in solid form or often in solution or a slurry in the carrier oil. The reaction process is conducted on-site in a 3 m3 carbon steel, externally electrically heated vessel equipped with appropriate condensing and vapours treatment systems. The reactor is pressurised and all oxygen is excluded by the introduction of nitrogen gas utilised as a safety blanket.

Reaction mechanism
The chemical reaction that was thought to occur is broadly represented in the following equation. It can be interpreted as a hydro-dechlorination reaction where the chlorine atoms on the aromatic nucleus are replaced by hydrogen atoms. Detailed chemical reaction mechanism can be seen in below.

$$\mathbf{R\text{-}(Cl)_X} + \mathbf{R^1} \xrightarrow[\text{Catalyst}]{\text{NaOH}} \mathbf{R - H} + x\,\mathbf{NaCl} + \mathbf{R^{11}}$$

Where:

$R\text{-}(Cl)_X$: organo-chlorine compound;

R^1 : hydrogen donor (oil);

R - H : hydrogenated organo-chlorine compound, and

R^{11} : dehydrogenated donor.

Whilst the above reaction does occur to some extent, particularly when low concentrations of organo-chlorine compounds are treated, the main product that is observed is carbon. This cannot be explained by the simple hydro-dechlorination reaction mechanism shown above.

$$\mathbf{R\text{-}(Cl)_X} \quad + \quad \mathbf{R^1} \xrightarrow[\textbf{Catalyst}]{\text{NaOH}} \mathbf{C} \quad + \ x\ \mathbf{NaCl} \ + \ \mathbf{R^{11}}$$

The exact mechanism for (what is) a carbonisation reaction is not yet clear. It is likely from the evidence currently available that the organo-chlorine compound is attacked by free radicals formed by a reaction between the sodium hydroxide and the accelerator. The concentration of these free radicals builds quickly in the initial phase of the process - stabilized it seems by the carbon particles formed.

Intermediate products that arise from the sequential dechlorination of an aromatic nucleus are not observed to any significant degree. Thus, for hexachlorobenzene, which contains six chlorine atoms, pentachloro, tetrachloro or other lower chloro substituted benzenes are not detected - the main reaction product is carbon. This observation seems to persist regardless of the nature of the original organo-chlorine compound.

Clearly, ring opening reactions are occurring during the dechlorination of the organochlorine compounds but there is no agreed mechanism as to exactly how this occurs. Chlorine atoms that are stripped from the original compound are rapidly mineralised as sodium chloride in the reaction medium. This is insoluble in the carrier oil and remains suspended in the mixture.

Limitation to the process

Any reaction, which consumes caustic in preference to bonding with free chlorine, decreases the efficiency of the treatment process. If reactants such as these can be identified in the feed, additional caustic can be added to compensate. Acidic feed materials generally consume caustic and additional caustic is required to be added to compensate for the neutralisation effect that would normally use the caustic fed with the batch.

Formulations which contain aluminium or zinc in large quantities can also react with caustic to form a gel and slow down the reaction. Sulphur containing feed will create sulphuric acid and oxides of sulphur in addition to reacting with caustic to produce hydrogen sulphide and give rise to corrosion problems at elevated temperatures.

Simple process flow diagram

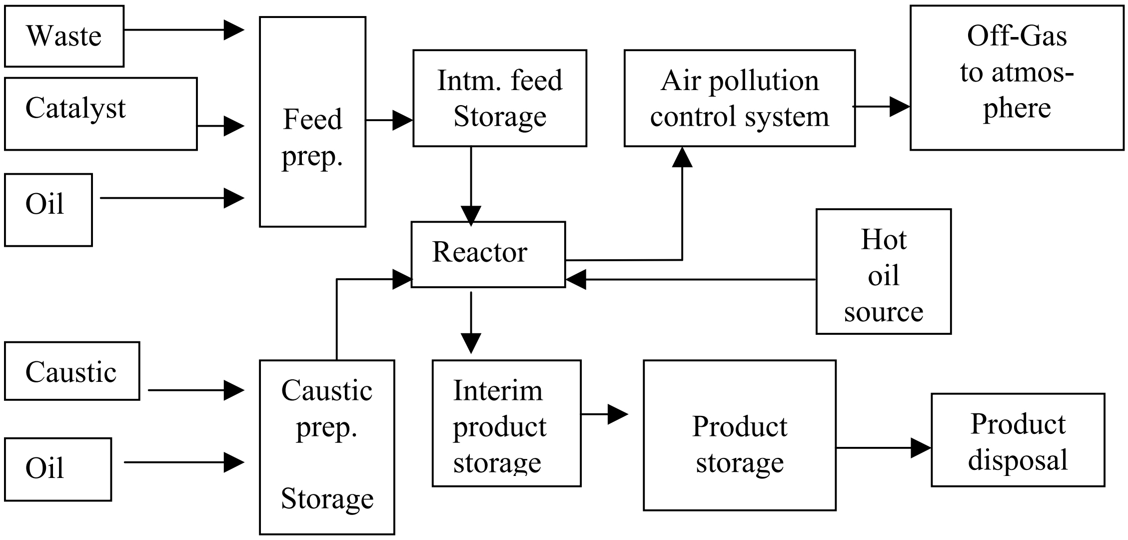

Figure 6.5.1 Simplified flow diagram of the plant

The process can be sub-divided in six unit operations:

- Waste or feed preparation;
- Caustic preparation;
- Hot oil pre-heating and transfer;
- Caustic and waste injection;
- Reaction, sampling and testing; and
- Treated product transfer.

Disadvantage
Beside the fact that this process can only treat (directly) fluids, the process also suffers from being a batch process and not a continuous process. This can be partly overcome by erecting several parallel processes, but that might influence the cost per kg treated waste. Furthermore, the process demands the heating up and successive cooling down of bearing oil for the process to run, which is demanding much energy. Finally, the process produces a rest product that needs conventional incineration, and because of the high load of chloride herein there is an intrinsic risk of dioxin production from this.

Advantage
Toxic material comprising up to 100% pure chlorinated hydrocarbons can be destroyed in 30 to 90 minutes. This is one of the big advantages of the BCD-technology compared to incineration technology that can only treat material

containing from 2 to 10% chlorine. Furthermore, the gas production from the process is low and seems to be very low in dioxin emission.

6.5.3 Description of the plant

The main processing plant and control room are constructed within two standard 40 foot ISO container framework. These ISO container frameworks have been issued with CFC plates for all modes of transportation. Various support facilities required for the operation of the plant are located adjacent to the processing plant. One container framework is assembled on top of the second container framework.

The bottom container framework contains the following process plant: control room, pre oil heating tank, oil circulation pump, in line heaters and piping, waste feed tank, caustic shearing tank, condensate tanks, refrigeration system associated with APC system, associated process piping and bound floor area.

The top container framework contains the following process plant: waste loading system, waste preparation system, caustic loading chute, reactor, air pollution control system and emission monitoring system.

Various piping spool pieces and junction boxes are provided between the container framework, to enable connection or disconnection of the two-container framework.

The various support facilities are located adjacent to the plant and these include the following: waste storage container(s), caustic and catalyst storage container, bulk carrier oil storage tank, intermediate carrier oil storage tank, electrical generator, emergency electrical generator, nitrogen supply system, air cooled radiator system, sludge drying facility, intermediate product storage tank and bulk product storage tanks.

All storage facilities are provided with containment bounding arrangement. This bounding arrangement ranges from clay lined bunds, metal tray bunds and individual containment tanks, depending upon the size, location and material required to be contained.

6.5.4 Description of the operation

The following is a typical reaction batch procedure that also describes the process flows involved in the destruction of organo-chlorine compounds in the plant.

Feed preparation
Approx. 50 to 100 kg of pure waste and an equal quantity of carrier oil are mixed and heated to 60^0C in the feed preparation vessel. The required amount of catalyst is also added at this stage of the process. (If the feed is already in the liquid phase at ambient temperatures, this feed preparation stage is not necessary, as the waste can be injected directly into the reactor.)

The waste feed mixture is then transferred into the intermediate feed storage tank and sampled for analysis to enable the preparation of a batch sheet. The waste feed mixture is maintained at 60^0C in the feed storage tank while awaiting laboratory analysis and charging of the reactor with oil and caustic.

If the plant has been shut down or returned to service after maintenance, the reactor will be empty and at ambient temperature. Pending on availability of hot oil supply, the oil for the next batch may be heated in the reactor itself or supplied from hot oil supply tank.

If the reactor is to be used to heat up the oil for the batch, the required quantity of oil is transferred from clean oil storage tank. The reactor is then purged with a nitrogen blanket, the agitator is started and the band heaters are turned on to heat the oil to the required reaction temperature. The time taken to heat the oil from ambient to 350^0C is approximately 4 to 5 hours.

Caustic preparation
Oil and caustic are added to the caustic-mixing vessel where they are stirred using a high speed shear mixer. Oil/caustic slurry is made in such a quantity to allow it to be made available to the reactor at all times during the reaction stage.

Oil pre-heating
A separate oil pre-heating system is used to heat the carrier oil for each batch. Hot oil at 325^0C can also be made available to the reactor vessel at all times during the reaction stage in a similar manner to the oil/caustic slurry.

Charging of the reactor
When the reactor is ready to receive hot oil, approximately 800 litres of hot carrier oil is pumped from the oil pre heat tank to the reactor. The reactor is then heated to 345^0C with the aid of external band heaters on the reactor vessel. The required amount of oil/caustic slurry as per batch calculation sheet is then injected into the reactor.

Caustic is injected in stages due to heat loss in the reactor by addition of the oil/caustic slurry which is at 60^0C. After each injection stage, the temperature is allowed to rise to reaction temperature, before more oil/caustic is injected. The bulk of the heat loss is due to the heat of dissolution for caustic from the solid to liquid phase. The reaction mixture is maintained above 330^0C at all times when adding oil/caustic slurry.

The mixture is agitated and heated and maintained above 330^0C after addition of all the required caustic for the batch. The waste is then injected at a controlled rate into the hot oil and caustic mixture. At all times, the reaction is conducted in an oxygen free environment under a nitrogen gas blanket.

Rather than using preheating of the oil, the carrier oil may also be heated in the reactor if necessary, however batch cycle time will be increased. In the initial heat up cycle, moisture and low boiling volatiles are driven off and pass into a condensing system. The treatment of these gases is discussed in more detail below.

At a temperature of about 325^0C, roughly corresponding to the melting point of the sodium hydroxide the chemical reaction commences with a rapid attack of the organo-chlorine compounds by free radicals resulting in the formation of a chlorine free carbonaceous product, sodium chloride and water. The onset of the reaction is observed by a rise in the temperature of the venting gas stream from the reactor, due to the release of water which is steam at 325^0C.

In practice there is also an observed rise in temperature of a few degrees in the reaction medium when the reaction starts. This can be controlled by the rate of additional organo-chlorine compounds to the reactor.

The concentration of the organo-chlorine compounds falls rapidly and within 0.5 to 1.5 hours at the reaction temperature, the SCW concentration has been reduced to below 1 ppm (the level below which the fluid is regarded as “non scheduled” waste).

Waste treatment in the reactor

Prior to the injection of waste into the reactor, the on site laboratory is notified. This is done to enable laboratory personnel to set up and commence emission monitoring during the treatment cycle, as per EPA licence requirements. Emission monitoring is performed by the use of sorbent tubes, connected to sampling points between carbon filters in the off-gas stream.

Waste injection can commence once emission monitoring is in progress. Emission monitoring during waste injection continues for at least three hours, even though the waste injection time is approximately 1.5 hours.

As de-chlorination reactions are highly exothermic, the waste is injected into the reactor at a controlled rate ranging from 5 - 15 litres per minute depending on concentration of the waste. During each stage of the injection, temperature is monitored closely, so that when waste is injected, an increase in temperature is noted. Injection stops when the temperature reaches an upper allowed limit and no further waste is injected until the temperature drops to the reaction temperature again.

The chemical reaction commences with the thermal decomposition of the organo-chlorine compounds with rapid attack of free radicals resulting in the formation of carbon, sodium chloride and water. The production of water increases the reactor pressure, as the water is converted to steam.

The rate of reaction is observed by a rise in the temperature of venting gas stream, as the reactor vents to maintain the set operational pressure of 125 kPa.

The waste is injected at a controlled rate in maintaining the gas stream temperature 50^0C to 80^0C below the liquid reactor temperature. Each injection of waste is followed by injection of clean oil to flush the injection line to prevent any blockage that may arise due to solidification and/or settling of feed in the injection line.

Sampling and testing
When all the waste or feed for the batch has been injected, the laboratory is notified in preparation for analysis of a treated sample. The reactor is held at 330 ^{0}C for one hour and a sample is taken after this period. The sample is cooled and sent to the laboratory to be analysed for SCW.

If the analysis of the first sample detects SCW above the onsite screening criteria of 0.5 ppm, additional caustic may be injected into the reactor pending level of SCW. A second sample will then be taken for on site analysis. The reactor is maintained at 330^{0}C during the sampling and testing period by turning the band heaters on and off.

When the batch sample has a SCW concentration less than or equal to 0.5 ppm using the on-site laboratory, the batch is regarded as having been completed and is now ready to be discharged from the reactor.

Reactor product discharge
When the batch cycle has been completed, the batch is ready to be discharged into the dump tank. In preparation for the discharge of reactor into the dump tank, the following operations and checks are carried out.

- heat tracing on-line connecting the reactor to the dump line is switched on so that the temperature at the line is 330^{0}C;
- the reactor vent valve is closed and the reactor is pressurised to 200 kPa using nitrogen gas;
- the pressure in tank dump tank is lowered to 25 kPa by venting via the filter of the plant; and
- oxygen level of the tank is checked to ensure that it is below 3%.

When the above-mentioned operations and checks have been completed, the nitrogen supply valve to the reactor is opened followed by the reactor drain valve. When the pressures of these two tanks have equalised, the dump operations are deemed to be complete and the reactor drain valve is closed. Clean oil is used to flush the dump transfer line and the oil ends up in the dump tank. The dump tank is provided with an external water spray system, to cool the tank and these are turned on after the dumping operation is complete.

Intermediate product storage
When the dump tank is full, the contents of the dump tank are pumped out to the intermediate product storage tanks. Prior to pumping out of the dump tank, the dump tank needs to be depressurised and cooled down below 60^{0}C.

Treatment of vapors and gases
During the reaction, water is liberated and some small fraction of the carrier oil is also volatilised. In addition, there may in some circumstances be carry over of organo-chlorine compounds. The latter are collected and are returned to the

reaction vessel to prevent any collection of organo-chlorine compounds in the plant at the end of the run.

Non condensable gases, mainly nitrogen and methane are released to the atmosphere after passing through a carbon absorption system. Discharge of these gases is monitored through the analysis of a Poly-Urethane-Foam (PUF) cartridge, which is analysed for SCW and dioxin/furan at a frequency determined by the NSW EPA.

Disposal of the products
At the conclusion of the reaction the heaters are turned off and the reactor pressurised. The hot reaction mixture is dumped into a dump tank and allowed to cool in the dump tank under the nitrogen gas blanket. After several batches, when the dump tank is full and the temperature below 80^0C, the contents of the dump tank are transferred into the product storage tank.

The product of reaction is a suspension of carbon, sodium chloride and unspent sodium hydroxide in carrier oil. This material is a non-scheduled waste.

The residual product is then removed from site and utilised by a licensed oil-recycling company. On the Sydney Olympic Project, the product oil has been sprayed on coal stockpiles, prior to being sent through the coke oven at a nearby steelworks. Activated carbon is treated in the BCD plant. This treatment equals 2-3 bathes per year.

6.5.5 Plant capacity

The plant has a capacity to handle 100 kg of pure SCW containing 25% to 30% chlorine per batch. Batch cycle time is approx. 12 hours. Plant availability is estimated to be about 90-95% and approx. 5-10% downtime. The plant is operated in two12-hour shifts operating 7 days a week, for about 7,200 hours. The plant has a 10 year life cycle with a potential of 600 batches per year corresponding to a total of 60 tonnes a year.

6.5.6 Practical experience

The BCD concept has been used in several places for soil cleaning purposes, and has references from many places in the world. For the destruction of concentrated/pure chemicals, however, the only known reference is the BCD plant on the Olympic Site in Sydney Australia.

6.5.7 Maintenance and services requirements

The components used in the plant were normally a readily available "off the shelf" from most engineering type suppliers. The compact construction of the plant, however, makes repairs difficult. Beside the danger of very hot caustic, there is no problem with dangerous chemicals. However, when the chemicals are heated to 400^0C there is danger of gas explosions under wrong conditions.

The reactor product ends up in a big horizontal tank with a small manhole in the end. When the reactor product becomes cold, it is difficult to get out of the tank and creates bad working conditions. Because the entrance to the reactor is a small 1/2" tube, it makes it difficult to load solid materials. In order to be able to suspend the solids in liquid, the solids are crushed in an open ball mill, causing bad working conditions.

The following services and raw materials are required for the operations of the plant.

Supply lines
The following infrastructure support is needed to obtain full operation:

- Electricity, 250 kW installed load with maximum load of 350 kVA supply;
- Emergency power to keep reactor stirrer and instrumentation operational during power failure;
- Water hose on tap. Zero usage on plant except for eyewash and safety shower supply;
- Compressed air; and
- Nitrogen supply for blanketing reactor. Use liquid nitrogen on hire.

Raw materials
The following raw materials are deemed necessary to obtainment full operation, Carrier oil, Catalyst and Caustic.

6.5.8 Occupational health and safety

All waste to be processed was stored in open top 200 litre drums with lids. The waste was heated with the aid of a band drum heater to melt the waste. The melting of the waste was carried out in the feed preparation enclosure of the plant, which is vented to two activated carbon canisters.

The melted waste was then loaded into the feed preparation vessel containing the carrier oil. Operators wore appropriate personnel protection equipment (PPE) during the loading operations to prevent exposure to vapour and dust from the waste.

Also the loading of caustic into the caustic shear tank is carried out in the feed preparation enclosure. Operators wore PPE during the caustic loading operations to prevent exposure to caustic dust. Some waste required size reduction to enable both material handling and treatment. This was carried out in a small ball mill.

6.5.9 Operational risks

After a fire at the BCD-plant (not the Enterra BCD Plant) in Australia, a full HAZOP risk analysis has been carried out on the BCD plant. The fire was generated because a product tank receiving 400^0C hot product oil lost its nitrogen blanketing and the auto ignition temperature of the hot oil was exceeded. However, based on the risk analysis, the BCD plant must generally be considered to be a low risk technology.

6.5.10 Plant mobilisation/demobilisation

According to information received from the vendor the cost of plant mobilisation in case of re-location from one site to another is approx. US$ 50,000 (corresponding to about 5% of the capital cost) and takes approx. 2 to 3 months, including all site preparation work. The announced costs seem doubtfully low compared with general experience from other "mobile" installations.

6.5.11 Capacity building

As the BCD technology has been implemented in various versions globally, it is proved that concept holder can transfer the know how of running the plant to a new company. However, the pipe flow reactor concept is not suited to the BCD process as the solid loading contributed many process problems. These problems were overcome by conversion of the pipe flow reactor design to a stirred batch reactor design.

6.5.12 Environmental impact of the technology

The assessment of the environmental impacts is based on the criteria presented in Section 6.2.

Materials consumption

The total mass of a full scale BCD facility including fundament is estimated to 40-50 tonnes. The main construction parts are:

- Construction steel (approx. 23-32 tonnes);
- Concrete for foundations, etc. (approx. 15 tonnes); and
- The remainder consists of materials and items like electrical engines and cables, stainless steel, aluminium, rock wool and PVC.

The amount of waste treated in the plant will be around 60-180 tonnes per year depending on the waste type. Assuming an overall life of around 10 years of plant constructions the consumption of construction materials is in the range of 0.02-0.08 kg pr. kg of waste treated. Assuming an overall recycling rate of approx. 90%, which should be considered realistic in most countries, the consumption of construction materials is reduced to less than 0.01 kg material pr. kg of waste treated. Compared to the consumption of means of operation indicated below, the consumption of construction materials should be regarded as insignificant.

The main means of operation and consumption related to selected waste types are listed in Table 6.5.2. Among the minor ancillary materials consumed, but not listed in Table 6.5.2, are nitrogen used in the process and activated carbon used for cleaning of air emissions. After use, the carbon is treated in the plant parallel to other waste.

Table 6.5.2 Consumption of important means of operation

Means of operation	Unit	Waste types (*1)	
		Mixed organo-chlorines	Sludge contaminated by organo-chlorines
Electricity	kWh/kg waste	156	52
Sodium hydroxide (*2)	kg NaOH/ kg waste	2	1.3
Carrier oil	kg oil/ kg waste	12-13	4-4.3
Catalyst (wax)	kg wax/ kg waste	0.2	0.07

*1: Waste types are characterised as follows:

Mixed organo-chlorines: contains 25% chlorine and <1% sulphur.

Sludge: contaminated by organo-chlorines contains 1-2% chlorine, very low amounts of sulphur and dioxins may be present.

*2: Figures stated as 100% NaOH.

Of the means of operation listed in Table 6.5.2 electricity is an energy source and will be considered only as such. The carrier oil and the catalyst are assumed to be based on mineral oil and therefore must be classified as non-renewable resources. Besides, they add to the energy consumption as energy is being used for extraction and refining. Finally, both materials contain energy. Sodium hydroxide should be regarded as a renewable resource as well as a source of energy consumption as energy is being used for extraction, preparation and refining.

The material consumption for the BCD-process related to the selected waste types is presented in Table 6.5.3.

Table 6.5.3 Material consumption related to the BCD-process

Material consumption	Unit	Waste types (*1)	
		Mixed organo-chlorines	Sludge contaminated by organo-chlorines
Construction materials	kg/kg waste	<0.01	<0.01
Means of operation - non-renewable	kg/kg waste	12-13	4-4.4
Means of operation - renewable	kg/kg waste	2	1.3

*1: Waste types are characterised as follows:

Mixed organo-chlorines: contains 25% chlorine and <1% sulphur.

Sludge: contaminated by organo-chlorines contains 1-2% chlorine, very low amounts of sulphur and dioxins may be present. Pesticide mix contains 10% chlorine, 2.5% sulphur, 86% carbon and 1% hydrogen.

Energy consumption

The energy consumption related to consumption of electricity, energy materials and significant means of operation is calculated in Table 6.5.4.

Table 6.5.4 Energy consumption related to the BCD-process

Material	Unit	Waste types	
		Mixed organo-chlorines	Sludge contaminated by organo-chlorines
Electricity (*1)	MJ/kg waste	565	190
Sodium hydroxide (*2)	MJ/kg waste	44	29
Carrier oil (*3)	MJ/kg waste	550-600	185-200
Catalyst (*4)	MJ/kg waste	14	5
Total	MJ/kg waste	1,170-1220	410-425

*1: 1 kWh = 3.63 MJ. The choice is made not to compensate for loss of energy due to conversion and transport as the actually loss depends on the primary energy source combined with local conditions. Often energy efficiency related to electricity may be down to around 35% in case the primary energy source is coal used on central power plants without utilisation of heat.

*2: The energy used for extraction, preparation and refining is assumed to come up to around 22 MJ/kg.

*3: The energy consumption related to consumption of oil is based on a figure of 46 MJ/kg oil of which 42 MJ is the energy content and 4 MJ is the energy used for extraction and refining of oil.

*4: The energy consumption related to consumption of wax is based on a figure of 69 MJ/kg wax of which 43 MJ is the energy content and 26 MJ is the energy used for manufacturing processes.

It should be noted that the carrier oil will be present in the residual product from the process. To the extent the heat value of the carrier oil in the residual product could be utilised, e.g. combustion under circumstances allowing heat recovery from the combustion process, it would be fair to deduct the anticipated heat energy recovered from the energy consumption calculated in Table 6.5.3.

In rounded figures this would a mean reduced energy consumption of approx. 400 MJ/kg mixed organo-chlorine waste. Whether a heat recovery activity may be established or not depends on local conditions and cannot be guarantied. Such a heat recovery activity is therefore not reflected in the figures stated in Table 6.5.4.

Chemicals, emissions, residues and elimination efficiency
According to Enterra, the emissions and residues related to the selected waste types can be stated as in Table 6.5.5.

Table 6.5.5 Generation of emissions and residues from the BCD-process

Emissions and residues	Unit	Waste types (*1)	
		Mixed organo-chlorines	Sludge contaminated by organo-chlorines
Emission to air	Nm^3/ kg waste	0.2	0.07
Wastewater (condensed steam)	Lit. /kg waste	0.3-0.4	0.1-0.13
Residual product	Lit./kg waste	18	6

*1: Waste types are characterised as follows:

Mixed organo-chlorines: contains 25% chlorine and <1% sulphur.

Sludge: contaminated by organo-chlorines contains 1-2% chlorine, very low amounts of sulphur and dioxins may be present.

Concerning the emissions of substances and the content in residuals from the process, the figures in Table 6.5.6, which relates to batch no 96 processed on 26 November 2001 and wastewater sample of 23 November 2001, are anticipated to be representative for both waste types listed.

Table 6.5.6 Content of substances in emissions and residues from the BCD-process

Substance	Concentration registered			Criteria
	Air emission (*1) μg/Nm^3	Wastewater μg/lit	Residual product mg/kg	
1,2,4 Trichlorobenzene	< 0.15	0.1	0.26	The criteria on air emissions for each substance are 1 ppm, which is assumed to correspond to 7.6 - 12 mg/Nm^3 depending on the substance in question. In the residual product the aggregated content of organo-chlorines must be below 1 mg/kg and dioxins/furans below 0.01 mg/kg I-TEQ.
1,2,4,5 Tetrachlorobenzene	0.46	<0.02	0.22	
Pentachlorobenzene	0.42	<0.02	0.14	
Hexachlorobenzene	< 0.24	5.6	<0.03	
2,3,4,6 Tetrachlorophenol	< 1.9	<0.8	<0.03	
Pentachlorophenol	< 2.2	<0.5	<0.03	
Dioxins/furans (as pg I-TEQ) (*2)	-	-	4.01 x 10^{-4}	

-: No data available

*1: Emission figures are transformed from original data in ppm assuming 760 mbar and 20^{0}C .

*2: No exact measurements of emission to air are available. The emission is cleaned by a carbon absorption unit, and the air is afterwards passed through a PUF cartridge. The content of dioxin in this cartridge is used as indicator of whether further investigations of dioxin emission are required. The trigger level for such investigations has so far not been exceeded and it must be assumed fair to accept that the actual emission is very low and most likely at a level not calling for concern.

Using the amount of organic chlorine as the measurement unit, DE ("destruction efficiency" and DRE (destruction and removal efficiency) may be estimated as shown in Table 6.5.7.

Table 6.5.7 Assessment of DE and DRE related to the BCD-process

	Waste type	
Content of organic chlorine in:	Mixed organo-chlorines	Sludge contaminated by organo-chlorines
1 kg untreated waste	0.250 kg	0.01-0.02 kg
Residual product from 1 kg waste (*1)	8 mg	3 mg
Air emission from 1 kg waste (* 2)	0.0007mg	0.0003 mg
Wastewater from 1 kg waste (* 3)	0.002 mg	0.001 mg
DE	99.997 %	99.97-99.985 %
DRE	> 99.9999…	> 99.9999…

*1: A mass weight of 0.9 kg/l of the residual product and a total content of 0.5 mg organic chlorine pr. kg residual product is assumed;

*2: The air emission is assumed to contain approx. 3.5 μg/Nm^3 of organic chlorine;

*3: A total content of approx. 5 μg organic chlorine/lit is assumed.

It should be noted that the calculation of DE and DRE is based on concentrations of a few specific substances in emissions and residues and not on broad parameters like organic chlorine or total organic carbon. It must be considered likely that other organic chlorinated substances will be present in emissions and residues. Therefore the values calculated for DE and DRE are most likely too optimistic.

Other issues
The amounts of residuals for disposal are stated in table 6.5.6 in the rows "residual product" and "wastewater". The residual product is not schedule waste, but must be characterised as liquid hazardous waste, as it contains carrier oil, NaOH and NaCl (15-20% weight based).

The amount of residual product must be considered rather high. Furthermore, resource recovery of the residual product requires a facility specialised in liquid hazardous waste. If the residual product should be disposed of under inappropriate circumstances, like e.g. uncontrolled burning, significant formation of dioxins and other organo-chlorines may take place. This situation is not reflected in the values for DE and DRE calculated above.

6.5.13 Economy

Plant and operational cost
Process plant built to Australian Standard, with a PLC control system will cost approx. 0.8-1.3 Mill USD. The plant operational cost will depend on the specific project hereunder the site location and the requirements specific to the project and the cost detailed below are an indicative cost.

Soil cleaning costs
The costs of Indirect Thermal Desorption (ITD) range from 3.3-6.6 USD per kg depending on the contamination matrix and quantity of material to be treated. The condensate/sludge produced from the ITD process would then be processed through the BCD plant.

BCD License
In addition to an EPA license, a BCD process license is required for the operation of the plant:

- The BCD Sub Licence will include Technical Data Package containing Standard Operating Instructions and other relevant technical data required for the operations of the plant and technical assistance training and operations of the plant;

- The price of the Licence is set by BCD Group in the US for each individual Licence and varies according to the details of the Licence issued. The Royalty payable is based on a sliding scale of 2%, 3% or 4% on the gross margin value of only the BCD Technology component of each individual project.

Main plant operational elements
The main plant operational costs elements are listed below:

- 2,500 l of carrier oil per batch;
- 200-250 kg of NaOH per batch;
- Electrical heating required to heat oil and caustic to 350^{0}C;
- Activated carbon use in the air pollution control system;
- Supervision / Operational / Laboratory labour cost;
- On site laboratory screening analytical cost; and
- Cost of external laboratory analysis for validation.

The costs of processing in the BCD plant range from 11-15.6 USD per kg although excluding costs of analysis by external laboratory. The costs cover one reactor treating one batch per day. The analysis costs vary depending on licence requirements by local/regional and national environmental authorities.

Analytical costs
The analytical costs vary depending on the level of testing required as per EPA Licence requirements for the project. For the OCA Project, the EPA Licence stipulated the following testing requirement for each batch:

- Feed sample;
- Air monitoring samples between the carbon filters;
- Final reaction product;
- Air emission to the atmosphere;
- Final treated water samples; and
- Dioxin analysis was required for each batch treated.

As plant operations required a quick turn around time, Enterra in conjunction with Cape Technologies developed and used an immunoassay test for dioxin. These were carried out in the on-site laboratory. The cost of this test is 300 and 165 USD for a 6 and 24 hours turn around time respectively. However, a validation dioxin analysis by an external laboratory was still required in this project. Initially, this was required for each batch and subsequently one for every 6 batches, at a cost of 880 USD per sample.

In addition, plant emission, mainly consisting of non-condensable gasses, mostly nitrogen from the purging process and methane from the cracking process of the oil, was also monitored and tested for SCW and dioxin. The emission criterion is less than 0.01 mg/kg or 10 μg/kg ITEQ.

As the processing was carried out on a "temporary" site, the underlying soil required validation analysis after the plant and all equipment has been removed. The frequency of soil analysis was determined by the NSW EPA.

Total costs
The total costs (Table 6.5.8) for treatment of chemical substances leaving out the pre-treatment of polluted soil can be summarised as follows:

Table 6.5.8 Total costs (USD)

Item	Costs (USD)
Plant capital costs	0.8 to 1.3 Mill.
Interest and repayment	included in treatment costs
Treatment costs (incl. raw materials, license and overhead)	5,5- 22/kg (mean 13.8/kg)
Treatment costs of residual products	included in treatment costs
Labour costs (8 persons)	included in treatment costs
Analytical costs	12/kg
Total costs*	**25.8/kg**

*: Including only the mentioned parameters. It is anticipated that the cost of final treatment of residual product is of minor importance. As can be seen, the demand to perform the expensive dioxin analysis has been intensive. They count for about 43% of the total expenses. It may be anticipated that the analytical cost for the different technologies investigated in this report should more or less be the same. Therefore seen from that point the total treatment costs would normally be much lower.

6.5.14 Evaluation of the BCD technology

The evaluation is solely based on the performed site visit at the Olympic Stadium Homebush, Australia in April 2002 and is not based on either thorough testing or huge inside information as for some of the other plants.

Technical Evaluation

The plant is placed on non paved area, creating the risk of polluting the ground due to spills. All the facilities are placed in containers (laboratory, maintenance, water cleaning, offices etc.) next to the plant, see **Fejl! Ukendt argument for parameter.**5.2.

Figure 6.5.2 Facilities in containers

The plant itself was planned as an escalation of a smaller pilot plant. From the beginning everything was designed to be able to fit into a mobile unit. As the construction phase went on, more and more things had to be built in the plant, and because it was designed to be mobile, everything is placed in a very small place, resulting in a very compact plant.

Figure 6.5.3 BCD plant April 2002, control room

Figure 6.5.4 BCD plant April 2002. Reaction tank and holding tank

Maturity
The maturity of the plant is not yet complete. The plant can only treat liquid organics (containing high amount of halogen) or waxy material that can be melted into liquid form. The drums are emptied via an elevator. The emptied drums are washed manually, making it necessary to use personal protection equipment. The wash water is treated as well.

Smaller solids can be crushed in a ball mill before suspended into liquid and treated. The ball mill is open and also making it necessary to use personal protection equipment. The cycle time is very long, mainly due to analytical procedures.

The responsible persons working with the development of the plant in Australia have done a large amount of work and improved the process. Now, in contrast to the original process, the reaction is running to an end leaving no halogenated compounds in the reaction mixture.

The residual product from the reaction mixture ends up in a large horizontal tank with a small manhole in the end. When the residual product becomes cool it is difficult to get out of the tank which impacts the general working conditions significantly.

Capacity
The rather low capacity is a problem taking into account the relatively high production costs. Many things could however lower the production costs, and reducing analytical costs which count for more than 40% of the total costs. Despite this, it still needs to be proved before the process can be really compatible.

Mobility
The plant is a mobile structure, but the consultant is very critical to the announced re-location costs, which should only count for 10% of the initial capital costs. The pricing for re-location is assessed to be higher and follows in line with e.g. GPCR and Semi mobile incineration units (up to 40-50% of investment capital costs).

Workers' health and safety
Workers' health and safety conditions are assessed as generally acceptable at the BCD plant, although the workers' safety on small, narrowed industrial complex structures should always be in focus.

Environmental evaluation

Material consumption
The BCD system has an outstanding high consumption of mineral oil used in the operation placing this solution un-disputably as the worst in this regard (see Table 6.5.10).

Table 6.5.9 Comparative assessment of material consumption

Material consumption	Unit	Base Catalysed Dechlorinated (BCD)
Construction materials (*1)	kg/kg waste	<0.01
Means of operation excl. energy - non-renewable	kg/kg waste	4-13
Means of operation excl. energy - renewable (* 2)	kg/kg waste	1-2
Overall assessment		5

*1: All materials are weighted equally and no consideration has been paid to scarcity and whether the material is renewable;

*2: Addresses in reality only the consumption of NaOH;

Energy consumption

The BCD system is indisputably ranked low due to outstanding high energy requirements coming from consumption of electricity as well as the carrier oil (Table 6.5.10).

Table 6.5.10 Comparative assessment of energy consumption

Energy consumption	Unit	Base Catalysed Dechlorination (BCD)
Energy consumption	MJ/kg waste	400-1,200
Overall assessment		5

The great variation depends on whether support fuel is needed or not. As an average the need for support fuel should be anticipated to be in the low end of the interval.

Chemicals, emissions and elimination efficiency

The BCD-process is rated above middle primarily due to the values for DE and DRE. The process suffers from a high content of dioxin in the residual product, and no data on emission of dioxin to air is available although the actual emission must be assumed low. However, there is no reason for assuming the CIS and the CKI processes to perform better than BCD on the issue of dioxin as all experience with incineration based systems points at quantities of dioxin in fly ash and other flue gas cleaning residues (Table 6.5.11).

Table 6.5.11 Emissions and elimination efficiency

Elimination efficiency	Unit	Base Catalysed Dechlorination (BCD)
Destruction efficiency	%	99.97-99.997
Destruction and removal efficiency	%	> 99.9999
Dioxin emission to air	ng I-TEQ/ kg waste	Low (*1)
Dioxin emission - all media and residues	ng I-TEQ/ kg waste	2,200-6,600 (*2)
Overall assessment		2

?: No data available

*1: No exact measurement of emission to air is available. The emission is cleaned by a carbon absorption unit, and the air is then passed through a PUF cartridge. The content of dioxin in this cartridge is used as indicator of whether further investigations of dioxin emission are required. The trigger level for such investigations has so far not been exceeded and it must be assumed fair to accept that the actual emission is very low and most likely not subject to concern.

*2: The figure stated covers the residual product only. A mass weight of 0.9 kg/lit. of the residual product is assumed; The figure is calculated as 6-18 kg residual product/kg waste times 0.9 kg/lit. times 4.01 x 10^{-4} mg I-TEQ/kg (reference is made to Table 6.5.5 - 6.5.6).

Other issues

The BCD process presents a special set of problems, as it generates a relatively high quantity of residual product composed of carrier oil together with remains of NaOH and a significant content of chlorine from the decomposed substances. Uncontrolled burning of this product could lead to significant dioxin formation and appropriate disposal must include treatment on a facility specialised in treatment of liquid chemical waste. For this reason, the BCD process is ranked low (Table 6.5.12).

Table 6.5.12 Other environmental issues

Residues	Unit	Base Catalysed Decomposition (BCD)
Waste for further treatment/disposal - hazardous waste	kg/kg waste	5.4-16
Waste for further treatment/disposal - solid waste	kg/kg waste	-
Waste for further treatment/disposal - wastewater	lit/kg waste	0.1-0.4
Overall assessment		4

-: Insignificant

6.5.15 Comments from BCD. CZ

In the Czech Republic, the company BCD.CZ is in the process of treating a pesticide polluted site (the "Spolana site area"). As the BCD technology occurs in various outfits based on obtainment of licences, the authors of this report have agreed to include extra information received from the CEE based BCD experience in the Czech Republic. As the technology actually is being used, we believe it is fair to include the comments which are shown in the following:

"COWI has requested an understandable detailed cost breakdown, including plant and financing costs related only to the treatment of pure chemicals such as pesticides, production wastes, PCB's in their pure form etc and not to the clean up of contaminated sites.

The companies which have or have had BCD licenses are not companies whose prime function is to sell chemical plant and technology packages to third party operators, but are operating companies themselves who offer primarily a package solution to particular problems.

This involves erecting a plant to treat the wastes, at their own cost, with or without external engineering support, and operating the plant themselves to treat pollutants. The cost of the equipment is to a certain degree proprietary commercial data. This does NOT mean that we, BCD.CZ are unwilling to supply plant and technology. We would be prepared to consider all options within the geographical limits of our licence, but would generally prefer either to do the job as a contract, or to enter into a teaming arrangement with local entities. Everything is possible, but to date the sale of plant and technology to third parties is not included in the licensing agreements with the BCD Group. The plant described below, which treats concentrates and where needed 150 t/month pure chemicals, is built to EU safety and environmental standards, costs us US $ 4 mio.

With the exception of the particular operation in the Basque country, the operations of BCD Technologies in Brisbane and the operation of S.D Meyers de Mexico, all other projects have been site remediations which included the treatment of pesticide residues which were on the particular sites as well as the treatment of contaminated soil and other matrices.

Our remediation project in the Czech Republic is primarily the remediation of a complex contaminated site, included in the complete package is the decontamination and demolition of complicated buildings, the treatment of the building rubble and large quantities of surrounding soil as well as the treatment of pure chemicals, chemical waste and production residues. This last group we expect to total roughly 300 tonnes. Contaminant concentrates from treating the bulk streams in the desorber are expected to be about 3,000 tonnes, excluding aqueous condensate.

However, we have extracted the cost data related to the treatment of pure chemicals and present this data. The sales price for treating highly chlorinated organic chemicals (55/65% Cl) ranges from;

US $ 2,150 to US $ 2,500 per tonne of pure chemical

The price range reflects the differences in any costs for disposal of reaction residue. The basis for this cost is:

A plant with 2 lines and a combined capacity of 150 t/month pure chemicals. Recycling of carrier oil and treatment or partial treatment of reaction residue, depreciation of the plant and all installation investment over 5 years, royalties and management (1 PM and 1 accountant), raw materials and utilities, labour (4 shift system with 1 supervisor and 2 operators/shift), OHSA, disposal costs, emission control, analysis, QC/QA, repair and maintenance.

Residue treatment and disposal:

The BCD process requires a relatively large quantity of reaction carrier oil. Pure chemicals such as pure PCB's are added to this oil in the reactor. The limiting quantity, please note quantity not concentration, of initial PCB waste is limited only by the solids content of the mix. In the case of pure chemicals, this is NaCl, residual NaOH and any carbon from breakdown of the parent molecule. We limit the solids content to 30% in order to have efficient stirring in the reactor.

The approach taken by some operators is to use cheap fuel oil and to export the mix after the reaction completion has been verified as fuel oil e.g. in a cement kiln. This is particularly attractive if the medium being treated is transformer oil contaminated with residual PCB's.

Our approach is different. We use refined, sulphur free oil, such as a lube oil cut, and treat the reaction products. The carrier oil is recovered with efficiency over 80% and recycled to the reactor to be re-used. The salt and residual caustic are removed in a hot water wash, similar to de-salting operations in petroleum refining. In the case of our present job, the strong alkali solution will be used locally to neutralise acidic wastewater from other plants. Whatever process you use, somewhere you have to dispose of the salt.

The solid residue remaining from pure chemicals is carbonaceous and slurried with oil that leaves as fuel, in our case to a controlled incinerator, who charges for the privilege. For this project, solid residue will be almost completely mineral; sand, clay etc. This we recycle to the thermal desorber to remove residual oil, which returns to the BCD reactor with the pollutant concentrate.

Comments by COWI:

Based on the new information, we recognise that costs have been considerably lowered from 27 USD/kg to 2.1-2.5 USD/kg, however still exceeding anticipated treatment costs of e.g. GPCR and the CIS technologies. The treatment of the residual product corresponds to observations from the Australia plant site.

6.6 Container based incineration system (CIS)

6.6.1 Introduction

The container-based incineration system is designed for the incineration of solid, pasteous and liquid hazardous waste such as waste oil, organic solvents, paint sludge, laquers, plastic, synthetic material, rubber halogenated waste, pesticides, PCB, hospital waste and infectious waste (optional). The CIS is a small (mobile) rotary kiln and is just now being tested in Latvia and we look forward to hear about the future experiences of its performance.

The capacity of the plant is 2,000-4,000 ton pr. year, depending on the bulk density and the heat value of the waste. The CIS cannot incinerate pure PCB, as the chlorine content in the waste must not exceed 10 %, subsequently only allowing a treatment capacity of 400-800 tonnes/year of e.g. PCB containing 50 % (w/w) of chlorine. However, in the mean time it can destroy other non halogenated hazardous waste. The incinerator is a turnkey installation consisting of two standard 40 ft. and one 20 ft. containers thus simplifying transportation and installation on site. The unit is complete with feeding system, rotary kiln, secondary combustion chamber, flue gas cooling system, flue gas cleaning, electrical wiring, control system, etc.

The operating temperature of the rotary kiln is 1,100°C and the subsequent secondary combustion chamber ensures destruction of the organic components at a residence time of 2 seconds at 1,100°C. The flue gas cooling system consists of a quench in which the flue gas is cooled by evaporation of water before it enters a heat recovery boiler. The boiler produces hot water, which can be utilised in several ways, for example for district heating.

The flue gas cleaning system is equipped with bag filter, quench and wet scrubber, which according to vendor information ensure fulfilment of the emission requirements specified in e.g. the EU Directive 94/67/EC on incineration of waste.

The market platform for semi-mobile incineration units is relatively large, why it has been decided to include the one produced by Chemcontrol A/S and Soil Recovery A/S from Denmark. These companies have operational experiences from similar installations from Denmark and Malaysia. Furthermore, a cooperative agreement between the Latvia responsible authorities and the Danish vendor establishing a similar plant facility in Latvia has keen interest for this review project focussing on the CEE Region.

6.6.2 Description of the technology

Chemcontrol A/S and Soil Recovery A/S have designed and constructed a mobile Container-based Incineration System (CIS), for high temperature incineration of toxic and hazardous wastes, hospital waste and other industrial wastes, designed on a modular basis to facilitate shipping and erection. Each module is completed with all pipe-works and electrical installations and during pre-assembly all connections between modules are made and the entire plant is "hot-dry" tested before deliverance meaning that all basic functions have been tested. Oil has been burned in the kiln reaching normal operation temperature.

The CIS has a rotary kiln incineration system with a flue gas cleaning system, and works at an operating temperature of 1,100°C to 1,200°C in is a fully automatic and computer controlled operation.

The CIS is designed for incineration of all kinds of organic hazardous wastes ranging from general industrial waste over hospital waste to highly halogenated chemical waste. It can process waste that is solid, liquid and pasteous including:

- Solvents (e.g. gasoline, turpentine, thinner, toluene, alcohol, or acetone);
- Halogenated and sulphur containing solvents (e.g. trichlorethylene, freon, carbon disulphide, mercaptans, PCB, etc);
- Mineral oils (e.g. lubricating oil, gas oil, or diesel oil, possibly mixed with water, soil, or gravel etc.);
- Organic pesticides, (e.g. Aldrin, Chlordane, Dieldrine, DDT, Endrin, Heptachlor, Hexachlorbenzene, Mirex, Toxaphene, POPs, empty pesticide containers etc.);
- Special waste (e.g. medicines, isocyanates); and
- Others (e.g. bitumen, amines, acetic acid, latex, glue, phenols synthetic oils, organic acids, paint).

Incineration
Incineration is a high-temperature thermal oxidation process in which organic molecules are decomposed into gases and non-combustible solids. The solids consist of ash and slag and are disposed of by land filling. Stack gases are largely water vapour and carbon dioxide, but include acid gases, toxic gases like dioxins, and toxic ash and metal oxide particles. To control pollution, incinerators should be equipped with gas cleaning equipment, such as a scrubber, electrostatic filters and activated carbon filters.

The rotary kiln system has proven especially good for hazardous waste because a rotary kiln can handle solids, solvents and gases at the same time. For municipal waste, normally all solid waste, a roasting furnace is the normal device.

The functional basis for all kilns is the same and can be characterised with the 3 **T**'s (**T**emperature, **T**ime, and **T**urbulence).

Temperature
Through the years a lot of time and resources have been spent on optimisation of the operation temperature in the different furnace designs. Normally the kiln for incineration of hazardous waste is not that long about 10-12 m and with a diameter of 3.5-5 m and the temperature in the kiln is normally kept at 1,100-1,300°C. However, the demands of the authorities are not pointed at the temperature in the kiln but in the secondary incineration chamber (the last place the gasses are destroyed). By incineration of halogenated compounds the authorities demands a temperature of minimum 1,100°C.

Time
The retention time for the gasses in the incinerator is very important for the quality of the incineration. Normally a retention time for the flue gasses in the secondary incineration chamber must be minimum 2 seconds at 1,150°C and can be lower by higher temperatures.

Turbulence
The above mentioned demands are not good enough if not all the gasses are exposed to these conditions. To secure this there is a demand that the turbulence shall correct in the secondary incineration chamber. A Reynolds number of > 65,000 is looked upon as a suitable measure for the turbulence.

Hazardous waste incineration
Hazardous waste incinerators have a main chamber for burning wastes and a secondary incineration chamber to achieve maximum destruction of hazardous organic by-products. Air and natural gas are burnt to keep the combustion gases at the appropriate temperature (1,150°C) for at least two seconds (residence time). Off gases are cooled to approx. 20°C before entering the gas cleaning processes.

Properly managed incineration can, in principle, destroy pesticide waste with a Destruction and Removal Efficiency (DRE) of 99.99 percent or higher. Some incinerators even claim DRE values of up to 99.99995 percent. However, the DRE is defined as DRE = M_i-M_s/M_i x 100, where M_i is the mass of a chemical fed into the destruction system during a known period of time and M_s is the mass of the chemical released in stack gases during the same period of time. The releases of chemicals via fly ash, bottom ash and scrubber water is not reported this way.

A better measurement of destruction is the "Destruction Efficiency (DE)" which is defined as *DE=* M_i *-*M_o*/*M_i *x 100, where* M_i *is the mass of a chemical fed into the destruction system during a known period of time and* M_o *is the mass of that same chemical released in stack gases, fly ash, scrubber water, bottom ash and any other incinerator residue*.

This principle shall also cover when reporting on the generation of products of incomplete combustion (PIC). The most famous PICs are dioxins and furans and when the emission of PICs are reported is must also cover the mass of PICs that is released in stack gases, fly ash, scrubber water, bottom ash and any other incinerator residue.

Disadvantages

Effective incineration is complex and depends on many factors, such as: equipment and process design, process control and maintenance of the correct residence time, temperature and turbulence, type of products incinerated, and capacity and effectiveness of air pollution control devices.

Public perception of incineration is becoming increasingly negative due to real and perceived threats posed by incineration to the environment and public health. The main concerns are the formation of polychlorinated dibenzodioxins and polychlorinated dibenzofurans (often referred to simply as dioxins) when chlorinated waste is incinerated. Also the releases of heavy metals and dust are of concern.

Dioxins, which are extremely toxic and persistent in the environment, are formed as the result of a reaction during the cooling of the stack gases. The formation of dioxins has been minimised in modern incinerators either by cooling down in boilers taking out the heat of the flue gas or by quenching off gases quickly to below 250^{o}C and the release of dioxins, heavy metals and dust are carefully controlled by passing off gases through intensive flue gas cleaning processes.

Reports of many different kinds of releases from incineration plants are in modern flue gas cleaning systems collected either in the dust filters, in the scrubber systems or in the activated carbon filters. Activated carbon filters will collect all kind of organic products, and as the activated carbon is incinerated after use, these compounds are collected and destroyed.

A disadvantage though is the poor control of the residual products placed as hazardous waste on landfill, which may contain high levels of POPs and other toxic chemicals.

High temperature incinerators are complex pieces of equipment, which require highly skilled personnel and constant monitoring to maintain stable operating conditions.

The requirements to stable operating conditions are uniform for all reviewed technologies, but are of further importance for open-processes than for closed processes. Many studies have revealed that uncontrolled release of e.g. dioxins from incineration process can be controlled although increased risks for emissions are recognised during start-up and close-down of operation.

Advantages

The process of incineration has shown to be a very useful way of transforming a big amount of dangerous waste types into reduced amount of environmental less problematic compounds to be placed in landfills. However as noted above, the lack of control of the content of dioxins and other POP's, particularly in the residues, is still problematic.

Incineration of organic chemical waste has the following advantages:

- Reduction of volume of waste from 100% to about 12-13% of slag and 6-7% of fly ash and material from flue gas cleaning;

- Detoxification of many different toxic compounds at the same time especially carcinogens, pathologic materials and all kind of toxic chemicals;

- Reduction of the impact on the environment, e.g. if the alternative is direct land filling where organic and soluble inorganic compounds easy leaks out into the environment; and

- Energy recovery, especially when big amounts of waste are available in a continuous stream from the waste producers.

Finally, the incineration processes at a single process destroys all organic compounds and change their dangerous chemistry radically to something less dangerous. These advantages, in combination with extensive use for municipal waste treatment and combined energy utilisation (distinct heating and electricity utilization) are the background for the very general use of incineration and have made the basis for the development of many different incineration systems.

6.6.3 Description of the plant

Feeding system (1)
The solid waste feeding system of the CIS consist of a hopper with a screw conveyor. The CIS may be supplied with a shredder system leading the shredded waste into the hopper. The hazardous waste is placed into the hopper and then screwed into the rotary kiln.

Liquid wastes are pumped into the kiln through lance, and the continuous correct dosing of the waste is secured via the CRS-system (Control, Regulating and Supervision system).

Rotary Kiln (2)
The rotary kiln has a thermal capacity of 7.26 GJ/hour, and is designed to incinerate 300 kg waste per hour, with an average heating value of 24.2 MJ/kg. The design ensure a residence time of 100 minutes in the kiln of the waste, sufficient to ensure complete burn out of the waste.

Slag bath
The slag handling system consist of a water filled bath and a heavy conveyor system, elevating and draining the residues before discharging into a transport container.

Temperature and oxygen concentration in the kiln is controlled currently by a Programmable Logic Controller (PLC) ensuring a fully automatic operation.

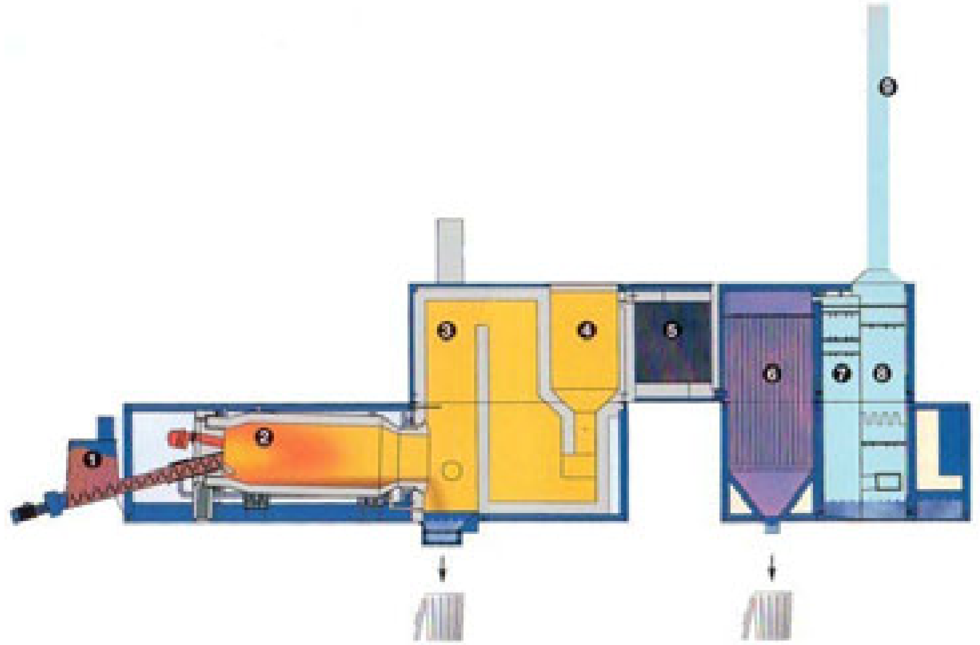

Figure 6.6.1 Flow diagram of CIS

The secondary combustion chamber (3)
The secondary combustion chamber ensures a complete destruction of organic rest products in the flue gas by incineration at 1,100-1,200˚C for 2 seconds.

Quench (4)
The secondary combustion chamber is succeeded by the primary quench where the flue gas is cooled with water, reducing the temperature from 1,100/1,200°C to 600°C. This temperature drop has made it possible to introduce a heat recovery boiler section.

Heat recovery boiler (5)
In the heat recovery boiler the hot flue gas is cooled from 600°C to 180°C. The boiler delivers hot water at a temperature of 130°C. The hot water can be utilised in several ways, for example for the production of district heating.

Bag filter (6)
The bag filter secure that EU requirements to dust removal are met. It is important to keep the right temperature (below 260°C) of flue gas entering the filters to avoid destruction of filters.

Secondary quench (7)
The secondary quench is a vertical column unit with water cooling of the flue gas from 180°C to about 75°C and removal of HCl from the flue gas.

Wet scrubber (8)
The wet scrubber is a vertical column unit with packing and where solution of sodium hydroxide is removing the SO_2 in the flue gas.

Stack
The stack is 15 m high and made of 4 mm steel lined with a polymer.

6.6.4 Description of the operation

Comprehensiveness
The CIS system will incinerate solid, pasteous and liquid hazardous waste such as waste oil, organic solvent, paint sludge, lacquers, plastic, synthetic material rubber, halogenated waste, pesticides, PCB, hospital waste and infectious waste. The waste needs in some occasion to be pre-treated until the waste can pass the circular opening of 400 mm in diameter. That means that the installation of a shredder system for the pre-treatment of the hazardous waste must be taken into consideration. A proper shredder system may be rather expensive.

Robustness
The CIS system is guarantied to operate 7,000 hours per year. The system has already documented its operational guarantees in Malaysia, where it has been running for a year. It takes one to two years to learn how to run the system properly. The components are delivered by the vendor, and about 80-90% are standard components.

The CIS system is delivered with a 2 year guarantee. A longer guarantee may be negotiated. In the system launched for e.g. Latvia, a 1-year commissioning and 2 years of guarantee related to the equipment has been agreed.

Residual products
The CIS system produces:

- Ash/slag;
- Fly ash (basic);
- Scrubber sludge (basic);
- Fly ash (boiler - acidic);
- Quench sludge (acidic);
- Wastewater (to be neutralised, precipitated, flocculated and filtrated); and
- Air emission.

A landfill is needed to deposit these rest products. There exists analysis for dioxin of flue gas and wastewater, but the CIS has never been tested for dioxin etc. in the other rest products (slag, fly ash, sludge).

6.6.5 Plant capacity

The capacity of the plant is 2,000-4,000 ton pr. year, depending on the bulk density and the heat value of the waste. Furthermore, the waste can contain up to 2.5 % Sulphur (S) and 10 % halogen (mostly chlorine (Cl), which makes this technology more "narrow-minded" versus treatment of high content of POPs.

6.6.6 Practical experience

In 1999, the CIS was started up in Austria at the Austrian hazardous waste treatment plant near Vienna. The CIS are used for treatment of mercury containing batteries in Austria. The organic content of the batteries are burnt in the CIS, after which the flue gas is treated to remove the mercury content.

In 2000, Chemcontrol sold two CIS-plants to Kualiti Alam (concession national treatment facility for hazardous waste in Malaysia) in Malaysia for treatment of hazardous waste.

Furthermore, in 2001 a CIS-test plant facility was erected at the mother company Kommunekemi A/S. In 2002, Soil Recovery A/S, another Kommunekemi subsidiary, who has taken over the business with the CIS, entered a final agreement with the Latvian Ministry of Environment setting up a plant facility during 2003/2003 with anticipated start operations in 2nd half 2004. The plant facility is co-financed by the Danish EPA and the Latvian authorities. Furthermore, the Danish EPA through its DANCEE programme has released funds for a technical assistance framework supporting the Latvian authorities complying with any national, regional and international regulation and implementation of necessary public information activities.

6.6.7 Maintenance and service requirements

To operate the CIS incineration facility, the following support staff is necessary; blacksmiths, electricians, machine operators, laboratory personnel (internal, external), landfill operators and water cleaning operators.

Furthermore, to obtain full operation of the facility, the following infrastructure is considered necessary:

- Electricity (120 kW);
- Water (2" feeding line, 5-10 m^3/h);
- Diesel;
- Pressure air;
- Sewage system;
- Fire extinguishing system;
- Sodium hydroxide; and
- Activated carbon.

Maintenance is somewhat hindered by the very compact construction of the plant. Because of the small construction many features are on one hand placed at the outside easy to go to, but on the other hand there are important features difficult to reach. However, the fact that the plant has been running already for several years in Malaysia, and 2-3 years in Austria, tells that maintenance is manageable even though there has been several problems as described later.

6.6.8 Occupational health and safety

The most obvious occupational health problem that could be detected at the visit is situated around the hopper. The feeding is done by help of truck emptying drums down into the hopper. If there are any dusty powders, dust will appear in the working area. Apart from this, the hopper is supplied with a hood and a ventilation system that transfers any vapours into the incineration zone.

Also by emptying drums with liquids into the hopper, splashes can be expected, polluting the working area and the nearby instruments.

The emptying of drums into the hopper is surely a weakness of the CIS system.

6.6.9 Operational risks

An emergency stack is connected to the secondary combustion chamber, to be used if the temperature in the combustion chamber and the filter bags gets out of range.

There are 3 levels of interlocking to control the system:

- The first level always stops feeding of waste;
- Second level secure the plant component; and
- The third level is used in case of emergency including opening of the emergency stack.

This emergency stack has been used rather often in the trial run, because it can be difficult to control the calories in the waste introduced into the rotary kiln. If the temperature becomes too high, it is necessary to stop the feeding of waste, close the duct to the filters, or open the emergency stack, which will cause that un-cleaned flue gas reaches the atmosphere. Furthermore, the CIS-system has had the problem that by feeding high loads of zinc compounds there have been high emissions of zinc.

6.6.10 Plant mobilisation/demobilisation

The CIS system is semi-mobile of nature. It will take 2-3 months to dismantle - move and re-locate the system. The relocation costs will estimate 20% of the initial capital costs corresponding to about 500,000 USD incl. decommissioning, transport, crane assistance, re-installation and re-commissioning. However, new installation of supply lines, planning approval etc. will mean further costs, why a general perception is that a relocation to obtain full operational mode will require additional costs equivalent to approx. 50% of the capital investment costs. A new system capable of treating about 2,500 tonnes/year cost approx. 3 million USD. The time from signing off contract to start-up operation of the CIS-system, a 1- year period must be anticipated.

6.6.11 Capacity building

In co-operation with Chemcontrol, Soil Recovery may submit key personnel for a period in order to assist in the day-to-day operation and handling of the incoming waste. There may be training of key staff, especially transport crew, laboratory staff, sampling personnel and plant operators. The needed capacities are available within the vendor organisation. However, the amount of these services will be designed for each contract.

6.6.12 Environmental impact of the technology

The assessment of the environmental impacts is based on the criteria presented in Section 6.2.

Materials consumption

According to information received the total mass of the plant including fundament comes up to around 270 tonnes. The main construction parts are:

- Construction steel (approx. 60 tonnes);
- Concrete for fundament etc. (approx. 170 tonnes); and
- Fire resistant bricks inside the oven (approx. 30 tonnes).

The remainder consists of materials and items like electrical engines and cables, stainless steel and fibre glass.

The amount of waste treated in the plant will be around 2,100 tonnes per year. Assuming an overall life of around 10 years of plant constructions, the consumption of construction materials will be around 0.013 kg pr. kg of waste treated. Assuming an overall recycling rate of approx. 90%, which should be considered realistic in most countries, the consumption of construction materials is reduced to <0.002 kg material pr. kg waste treated. Compared to the consumption of means of operation indicated below the consumption of construction materials should be regarded as insignificant.

The main means of operation and consumption related to selected waste types are listed in Table 6.6.1 and 6.6.2. Among the minor ancillary materials consumed but not listed in Table 6.6.2 may be mentioned activated carbon used for cleaning of air emissions and TMT used for precipitation of heavy metals in the wastewater. After use, the carbon is treated in the plant parallel to other waste.

Table 6.6.1 Consumption of important means of operation related to the CIS-process

Means of operation	Unit	Waste types (*1)	
		Pesticide waste	Mixed chemical waste
Electricity	kWh/kg waste	0.27	0.27
Diesel oil as support fuel	kg oil/kg waste	0-0.83	0-0.83

Sodium hydroxide for air scrubber (*2)	kg NaOH/ kg waste	0.09	0.01
Sodium hydroxide for wastewater treatment (*2)	kg NaOH/ kg waste	0.09	0.01-0.02

*1: Waste types are characterised as follows:

Pesticide waste contains 10% chlorine and 2.5% sulphur and has a heat value of 12.3 MJ/kg.

Mixed chemical waste contains 0.3% chlorine and 0.3% sulphur and has a heat value of 24.2 MJ/kg;

*2: Figures stated as 100% NaOH.

Of the means of operation listed in Table 6.6.1, electricity is an energy source and will be considered only as such. The diesel oil is a non-renewable resource besides that it adds to the energy consumption, as energy is being used for extraction and refining besides that diesel oil contains energy. Finally, sodium hydroxide should be regarded as a renewable resource as well as a source of energy consumption as energy is being used for extraction, preparation and refining. The material consumption for the CIS-process related to the selected waste types is presented in Table 6.6.2.

Table 6.6.2 Material consumption related to the CIS-process

Material consumption	Unit	Waste types (*1)	
		MIxed organo-chlorines	Sludge contaminated by organo-chlorines
Construction materials	kg/kg waste	<0.002	<0.002
Means of operation - non-renewable	kg/kg waste	0-0.83	0-0.83
Means of operation - renewable	kg/kg waste	0.018	0.02-0.03

*1: Waste types are characterised as follows:

Pesticide waste contains 10% chlorine and 2.5% sulphur and has a heat value of 12.3 MJ/kg.

Mixed chemical waste contains 0.3% chlorine and 0.3% sulphur and has a heat value of 24.2 MJ/kg

Energy consumption

The energy consumption related to consumption of electricity, energy materials and significant means of operation is calculated in table 6.6.3. The overall energy consumption depends significantly on the need for support fuel. The interval stated indicates the variation observed. Based on information received from Chemcontrol it is should be deemed fair to accept that on average, the consumption will be in the lower end of the interval stated.

The CIS-process being an incineration process typically develops excess heat that may be recovered and used for district heating and other purposes. Whether a heat recovery activity may be established or not depends on local conditions. In general, the heat output is 1 MW/hour corresponding to approx. 12 MJ/kg waste and can give rise to an income in case the heat can be utilised. As heat utilisation cannot be guarantied, the choice is made not directly to reflect such a heat recovery activity in the figures stated in Table 6.6.3.

Table 6.6.3 Energy consumption of the CIS-process

Material	Unit	Waste types	
		Pesticide waste	Mixed chemical waste
Diesel oil (*1)	MJ/kg waste	0-38	0-38
Electricity (*2)	MJ/kg waste	1	1
Sodium hydroxide (*3)	MJ/kg waste	4	0.4-0.7
Total	MJ/kg waste	5-43	1.4-40

*1: The energy consumption related to consumption of diesel oil is based on a figure of 46 MJ/kg gas, of which 42 MJ is the energy content and 4 MJ is the energy used for extraction and refining of gas;

*2: 1 kWh = 3.63 MJ. The choice is made not to compensate for loss of energy due to conversion and transport as the actual loss depends on the primary energy source combined with local conditions. Often energy efficiency related to electricity may be down to around 35% in case the primary energy source is coal used on central power plants without utilisation of heat;

*3: The energy used for extraction, preparation and refining is assumed to come up to around 22 MJ/kg.

Chemicals, emissions, residues and elimination efficiency

According to Chemcontrol the emissions and residues related to the selected waste types can be stated as in *Table 6.*6.4.

Table 6.6.4 Generation of emissions and residues from the CIS-process

Emissions and residues	Unit (*1)	Waste types (*2)	
		Pesticide waste	Mixed chemical waste
Emission to air	Nm^3/ kg waste	12	16
Wastewater (from scrubber)	Lit. /kg waste	0.6	0.07
Slag	kg DM/ kg waste	0.37	0.13-0.8
Quench	kg DM/ kg waste	1.6	0.05-1
Fly-ash bag-house filter	kg DM/ kg waste	0.09	0.02-0.18

*1: DM = dry matter

*2: Waste types are characterised as follows:

Pesticide waste contains 10% chlorine and 2.5% sulphur and has a heat value of 12.3 MJ/kg.

Mixed chemical waste contains 0.3% chlorine and 0.3% sulphur and has a heat value of 24.2 MJ/kg.

Concerning the constituents in emissions and residuals from the process, the figures in Table 6.6.5 and Table 6.6.6, which relates to measurements during spring 2002 (reference to Mr. Lennart Scherman, Chemcontrol, October 2002) are anticipated to be representative for both waste types indicated.

Table 6.6.5 Content of substances in emissions and residues - registered concentrations for pesticide waste

Substance	Concentration registered					Criteria
	Air emission $\mu g/Nm^3$	Waste-water $\mu g/lit$	Slag mg/kg	Quench mg/kg	Flyash mg/kg	
Total organic carbon	< 1	?	?	?	?	Air emission: < 10 mg/Nm^3 Slag: < 2% DM
Dioxins/furans (as I-TEQ)	6×10^{-5}	?	?	?	?	Air emission: < 0.1 ng/Nm^3

?: No data available.

Table 6.6.6 Content of substances in emissions and residues - registered concentrations for mixed chemical waste

Substance	Concentration registered					Criteria
	Air emis-sion $\mu g/Nm^3$	Waste-water $\mu g/lit$	Slag mg/kg	Quench mg/kg	Flyash mg/kg	
Total organic carbon	< 1	?	?	?	?	Air emission: < 10 mg/Nm^3 Slag: < 2% DM
Dioxins/furans (as I-TEQ)	8×10^{-5}	?	?	?	?	Air emission: < 0.1 ng/Nm^3

?: No data available.

Using the amount of organic carbon as the measurement unit, DRE (destruction and removal efficiency) may be estimated as stated in Table 6.6.7. The data available does not allow estimation of DE (destruction efficiency).

It should be noted that the general criteria on the content of TOC in the slag allows up to 2% carbon to be present, which reflects a DE value for organic carbon of 97-98%.

Table 6.6.7 Assessment of DRE

Items	Waste type	
Content of organic carbon in:	Pesticide waste	Mixed chemical waste
1 kg untreated waste (*1)	0.3-0.5 kg	~ 0.6 kg
Air emission from 1 kg waste (*2)	<12 mg	< 16 mg
Wastewater from 1 kg waste	?	?
Slag from 1 kg waste	?	?
Quench output from 1 kg waste	?	?
Fly ash from 1 kg waste	?	?
DRE	> 99.996 %	> 99.997%

?: No data available

*1: Content of carbon is estimated partly based on heat value (reference to Mr. Lennart Scherman, Chemcontrol, October 2002).

*2: Calculated based on figures in Table 6.6.5 - 6.6.6.

It is noted that no data on the content of dioxin in the fly-ash is available. For incineration plants, this figure is often high and must be assumed to be high unless the opposite is documented by measurements.

Attention must also be paid to the fact that incineration of hazardous waste in a small unit like CIS is a process depending strongly on the heat value of the waste and therefore occasionally/potentially difficult to control. In serious cases it may be necessary to close down the process and allow flue gas to be released to the environment without being subject to flue gas cleaning. Such incidents, which are difficult to quantify, are not reflected in the figures stated above, but should not be overlooked.

Other issues

The amount of residuals for disposal are stated in Table 6.6.6 in the rows "slag", "quench", "fly ash" and "wastewater". As stated above fly ash must be assumed to contain high concentrations of dioxin and will likely have to be disposed of as hazardous waste for land filling. Also the slag and the quench are residues requiring landfill capacity.

6.6.13 Economy

For the treatment of about 3,000 ton/year is needed one CIS plant including boiler and flue gas cleaning, at the costs of 2.6-3 mill. USD. Operational costs are highlighted in Table 6.6.8 below.

Table 6.6.8 Break down of CIS costs per kg hazardous waste

Item	Costs (USD)	Comments
Plant capital costs	2.6 - 3 mill.	One basic CIS model
Interest and repayment	0.02 USD/kg	
Treatment costs (incl. raw materials, license and overhead)	0.3 USD/kg	Average for liquid and solid waste
Treatment costs of residual products	0.02 USD/kg	
Labour costs (3 persons)	0.35 USD/kg	2 operators and 1 operation manager
Analytical costs	0.3 USD/kg	Average 2 analysis per hour
Total costs	1.00 USD/kg	All prices based on Danish price level.

The estimated prices include license, design, and overhead. Labour costs are of course country dependent. As has been seen from other technologies, the analytical costs are high and can comprise up to 30-40% of the project costs. The analytical costs also include 4 independent analyses per year by the authorities of dioxin, dust and other required parameters of air and water emissions.

Furthermore, the hopper system of the CIS requires that the waste is fed in small pieces and as an adequate mixture of solid and liquefied waste. Fluids can not be fed in this way, and paint containers will be too big and must be shredded first.

Costs of shredder system have not been included. In addition to the plant capital cost, pre-treatment and storage facility is needed for liquid, solid and pasty waste. The plant capital cost for such equipment such as shredder tanks mixer and pumps is in the range of USD 150,000 to 1,500,000, meaning that the total costs of the plant may reach 4-4.5 mill. USD and more or less double the amount paid for interest and repayment.

6.6.14 Evaluation of the CIS technology

Technical evaluation

The Container-based Incineration System (CIS) is made as scale 1:10 copy of the big rotary kiln incinerators at Kommunekemi, the central hazardous waste incineration facility in Denmark. The CIS has been operating in Austria and in Malaysia for more than 3 years now, and had many early problems in the commissioning period.

There have been problems with sufficient oxygen content (maybe too much waste fed in) some of the stuffing boxes were un-tight, rotary kiln lining, etc. Some of the more specific problems encountered are looked upon beneath. However according to the company, these problems have been corrected and improved in the recent edition of the CIS.

The hopper system
The Hopper consists of a container of about 1 m^3 in volume equipped with 2 screws pressing the waste down into a screw conveyer. The screw conveyor is leading to the incinerator. The waste in the screw conveyor must constantly make a plug to avoid air coming in this way

This system demands that the waste is fed in small pieces and as an adequate mixture of solid and liquefied waste. Fluids cannot be fed this way.

Figure 6.6.2 The hopper of the CIS, Denmark, May 2002

The screw conveyor has been improved to avoid the waste to stick to it. When the screw conveyor is not totally tight, then gas from the incinerator can be pressed out backwards and make the content in the hopper create vapours. However, the incinerator is only allowed to be operational if the screw conveyor is covered of waste.

The control box and main switches on the outside of the incinerator are placed near the hopper and easily risk getting dirty when emptying drums into the hopper.

Incinerator Kiln
There have been problems in controlling the inlet temperature in the rotary kiln, resulting in build up of slag inside the kiln. Furthermore, there have been problems in controlling the temperature between the boiler and the filter. If the temperature is too high when the flue gas enters the filter bag section, the expen-

sive filter bags melt/ignite and start to burn. Both problems seem to have been solved in the new generation of CIS.

Quench
The regulation of the quench has given some problems. Especially in closing down periods ("interlock mode") when opening of emergency stack then water continued to be pumped into the plant, causing dust clogging like stones on the damper. This created the problem that they could not close in the boiler and the heat continued into the bag house filters and they melted. Furthermore, also the boiler tubes were choking.

Bag house filter
There have been problems with high humidity in the bag house filter resulting in clogging of the active carbon and dust, giving rise in the emissions.

Special waste
There have been some problems with certain types of waste containing volatile heavy metals (e.g. zinc) The amount of volatile metals in the waste must be kept low in order for the scrubber system to clean the flue gas.

Maturity
There have been many early start failures to the CIS, but these failures is anticipated to result in an optimised and more mature design of the newly build CIS standing at Kommunekemi. Again this has to be proven by the performance of the CIS in e.g. Latvia during operations in 2004/2005.

Versatility/robustness
The advantage of the CIS system is the 1:1 scale set-up test field at Kommunekemi enabling full scale testing of any waste types. Furthermore, the mother company has extensive in-house capacity and capabilities incinerating hazardous waste and sufficient financial strength enabling the facility to work on the commercial market ensuring full in-line supervision and maintenance support.

Capacity
The CIS as it stands has a capacity of 2,000-4,000 tonnes a year (corresponding to 400-800 tonnes/year of POPs containing 50% chlorine) depending on the type of waste. However, as the CIS is just a rotary kiln incinerator, it can be delivered in any size wanted, depending of the price although the present outfit and installations complies with a 2,000-4,000 tonnes annual capacity.

Mobility
The CIS is as semi-mobile as the other plants mentioned in this report (except CKI).

Worker's health and safety
Worker's health and safety is high around the CIS, where the workers seldom are in contact with the waste, as it could be seen at our inspection of the plant. However by the emptying of the drums with waste the hopper (or the shredder) has to be opened with possibility for exposure of vapours to local atmosphere.

Furthermore a problem exists around the emptied drums that are still polluted with residues of hazardous waste, if a shredder is not used.

Environmental evaluation

Material consumption

The CIS solution allows a high flow of waste materials through the system. Thereby the CIS system obtain a higher material efficiency and deserves to be rated above average in this regard (Table 6.6.9).

Table 6.6.9 Material consumption of the CIS system

Material consumption	Unit	Container-based Incineration System (CIS)
Construction materials (*1)	kg/kg waste	<0.002
Means of operation excl. energy - non-renewable	kg/kg waste	-
Means of operation excl. energy - renewable (*2)	kg/kg waste	0.01-0.1
Overall assessment		2

-: Insignificant

*1: All materials are weighted equally and no consideration has been paid to scarcity and whether the material is renewable;

*2: Addresses in reality only the consumption of NaOH.

Energy consumption

The DRE value for CIS is based on a balance for total organic carbon. The low DRE value for organic carbon and low dioxin emission to air should be recognised. However, as stated above the dioxin content in flue gas residues should be expected to be high and the overall destruction efficiency remains to be proven considering that up to 2% carbon is allowed in the slag (Table 6.6.10).

Table 6.6.10 Energy consumption of the CIS system

Energy consumption	Unit	Container-based Incineration System (CIS)
Energy consumption (*1)	MJ/kg waste	1-43
Overall assessment		2

*1: The large variation depends on whether support fuel is needed or not. As an average, the need for support fuel should be anticipated to be in the low end of the interval.

Destruction efficiency

Attention must also be paid to the fact that incineration of hazardous waste in a small unit like CIS is a process depending strongly on the heat value of the waste and therefore occasionally/potentially difficult to control. In serious cases it may be necessary to close down the process and allow flue gas to be released to the environment without being subject to flue gas cleaning. Such incidents, which are difficult to quantify, are not reflected in Table 6.6.11 below, but should not be overlooked.

Table 6.6.11 Emissions and elimination efficiency

Elimination efficiency	Unit	Container-based Incineration System (CIS)
Destruction efficiency	%	?
Destruction and removal efficiency	%	>99.996
Dioxin emission to air	ng I-TEQ/ kg waste	≤1.3
Dioxin emission - all media and residues	ng I-TEQ/ kg waste	?
Overall assessment		4

?: No data available

-: Insignificant

Other issues

Regarding the CIS process, the fly ash, the slag and the quench residues will likely have to be disposed of as hazardous waste to a special landfill due to the content of dioxin, other POP's as well as other pollutants indicating that there is a need for landfill capacity. Table 6.6.12 outlines other issues.

Table 6.6.12 Other environmental issues

Residues	Unit	Container-based Incineration System (CIS)
Waste for further treatment/disposal - hazardous waste	kg/kg waste	0.02-0.18
Waste for further treatment/disposal - solid waste	kg/kg waste	0.2-2
Waste for further treatment/disposal - wastewater	lit/kg waste	0.07-0.6
Overall assessment		4

6.7 Cement kiln (CKI)

6.7.1 Introduction

A cement kiln is a kiln that slowly rotates to expose limestone, sand and clay evenly to very high temperatures (1,400-2,000^{o}C) to make cement clinker. Organic waste can be injected into the kiln with the fuel or directly into the flame. The high temperature and long residence time (6-10 seconds) effectively oxidise the organic waste. Acid gases resulting from organo-chlorine chemicals are supposed to be mostly neutralised by the alkaline cement eliminating the need for a caustic scrubber. Only modern cement kilns with bag house filters and bypass systems can be used for pesticide incineration. Special modifications and parts are needed for injecting pesticides into the kiln, which can be costly.

6.7.2 Description of the technology

Burning of hazardous industrial wastes in cement kilns are being used for the disposal of hazardous wastes in France and Norway and a number of other European countries.

The principal processes employed in making cement clinker can be broadly classified as either "wet" or "dry" depending on the method used to prepare the kiln feed.

In the wet process the feed material is slurried and fed directly into the kiln. In the dry process the kiln exhaust gases are used to dry the raw meal (a mixture of limestone and other raw materials) while it is being milled.

A cement kiln typically comprises a long cylinder of 50 to 150 metres, inclined slightly from the horizontal (3% to 4% gradient) which is rotated at about 1 to 6 revolutions per minute. The solid material passes down the kiln as a result of rolling and slipping as the kiln rotates. The material flows counter current to the combustion gases and fuel is fired at the lower (front) end of the kiln. Gases discharged from the kiln are normally cleaned of particulate matter by passing them through an electrostatic precipitator. Dust collected in the precipitator can be returned to the process.

Kiln fuel firing systems are designed to minimise energy consumption and to provide appropriate flame shape for clinkering the raw materials.

Operating conditions within the kiln are maintained and controlled by monitoring numerous plant operating parameters throughout the system. These include feed material composition, gas temperatures and gas flow rates. These parameters are used for control of feed flow rates into the unit (for raw meal and fuel) and for controlling discharge gas flows from the unit.

The clinker manufacturing process starts by producing a fine powder containing strictly controlled proportions of:

- limestone - to provide calcium carbonate, and
- clay - to provide silica, alumina and iron oxides.

When the powder is homogenised and heated to 1,450˚C in the kiln, the lime molecules combine with all the silica, alumina and iron oxide molecules to form clinker. The raw materials are transformed into clinker in several stages:

- up to 550˚C the mixture is dried and the clay dehydrates;
- from 550˚C to 900˚C pre-heating and decarbonisation takes place (calcining);
- from 900˚C to 1,300˚C the di-calcium silicates, aluminates and ferro-aluminates are formed; and
- from 1,300˚C to 1,450˚C the formation of tri-calcium silicate takes place.

The material can only form at this temperature and consequently the material must reach this temperature to make clinker.

After reaching this temperature, the clinker is rapidly cooled. The clinker is finely grounded, 3% to 5% gypsum is added to control the setting rate and other additives (slag, fly-ash, limestone filler, etc.) may be introduced to form the final product.

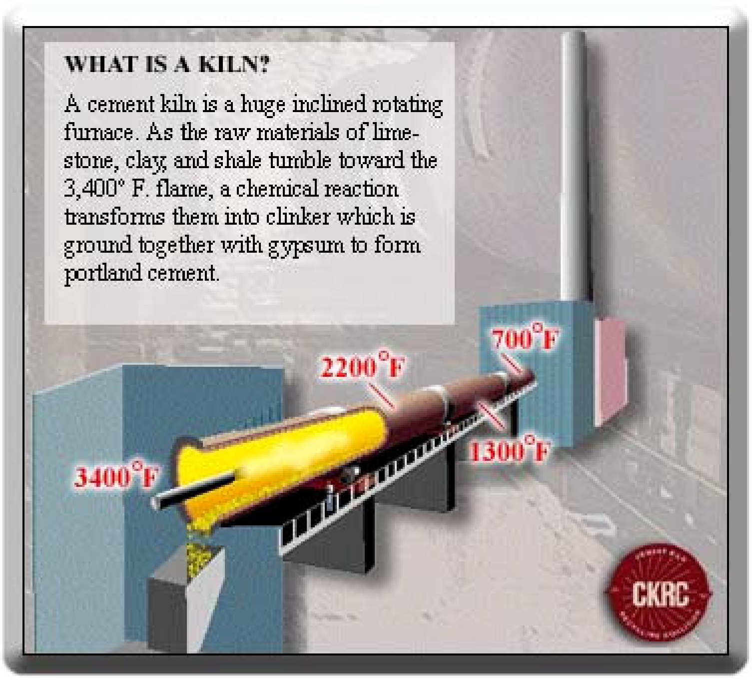

Figure 6.7.1 Schematic diagram of a typical cement kiln

At the very high temperature of the cement kiln, and with the long residence times available, high destruction efficiency is possible for scheduled wastes including POP's.

The highly alkaline conditions in a cement kiln are supposed to be ideal for decomposing chlorinated organic wastes. Chlorinated liquids, chlorine and sulphur are neutralised in the form of chlorides and sulphates, however measurements shows that there is still some HCl-emission from a cement kiln burning halogenated waste.

The quantities of the inorganic and mineral elements added in treating scheduled wastes are usually limited (and in general will be a small proportion of the large feed requirements of a commercial kiln), and should not adversely affect the quality of the clinker product. No liquid or solid residues requiring disposal are generated as all residues are bound within the product.

In some dry and some wet cement kiln processes there is a slight concentration of heavy metal in the by-pass dust waste produced when inorganic materials are included in the scheduled waste being treated. Dust waste can be utilised as fertiliser, for liming or is dumped.

Incineration
The treatment process in a cement kiln is principle the same as in a dedicated incineration plant. The big difference lies in the pre-treatment part and in the flue gas cleaning part.

Pre-treatment
The specialist at cement kiln knows how to make cement and not how to treat hazardous waste. Hazardous waste always needs a lot of pre-treatment before it can be treated in a destruction plant. This pre-treatment demands knowledge and skills not normally present in a cement kiln. Also it is important that the management at a cement kiln acknowledge this fact and build up a special team for hazardous waste pre-treatment.

Flue gas cleaning
Flue gas cleaning in a cement kiln destroying hazardous waste is less demanding than in a dedicated hazardous waste incineration plant because the cement process performed in a caustic environment neutralise all acidic gasses produced by the incineration of halogen and sulphur containing compounds. Also heavy metals may be precipitated as hydroxides in the cement.

However, dust emission is a big problem for many cement kilns, and as long this has not been taken under control, hazardous waste treatment in such a plant is regarded as "not immediate recommended". If any dioxins are being produced in the cooling process, it may be released hanging on the dust. Furthermore, if heavy metals are being treated they may also be found in the dust. Even HCl has been seen leaving the cement kiln via the flue gases, so emissions must be under control before treating hazardous waste in a cement kiln.

Wastewater and rest products
One of the big advantages of destruction in cement kilns is that there is not produced any polluted wastewater or other polluted residue products beside dust in stock emission.

6.7.3 Description of the plant

The treatment of hazardous waste in Norway is in fact divided between two plants i.e. NOAH who does all the pre-treatment and NORCEM the cement factory who destructs the pre-treated hazardous waste. NOAH has two plants; a pre-treatment plant for organic hazardous waste in Brevik neighbour to the NORCEM and a treatment plant for inorganic hazardous waste on the island Langoya. There is an agreement between NOAH and NORCEM regulating the economic relationship.

In Brevik, NOAH has a modern high tech hazardous waste pre-treatment plant. The plant consist of an administration building, a laboratory, a storage house for received drums, a shredder system for the drums containing organic liquids and solids, a filtering system for the removal of metal from the solids, a mixing system for solid waste with wood chips, a holding tank for the solid waste mixed with solid and a tank yard for solvents. Please refer to Figure 6.7.2.

All emissions are monitored and controlled. The whole area is paved with a local closed sewage system. An automatic fire extinguishing system has been erected, and they have their own fire brigade. In case of fire there is a holding system for the water used to extinguish the fire.

At NORCEM the plant consists of an area for reception of bulk hazardous waste, a system of hydraulic pressures, screw and envelop conveyors, holding tanks for reception of solvents, system of lances for the introduction of the hazardous waste into the cement kiln, an electro filter to filter dust from the flue gas and a bag house filter to improve the dust filtering.

6.7.4 Description of operation

NOAH

NOAH receives waste in drums, in tankers and in bulk. The drums are placed in a storage house after leaving the quarantine area. The bulk liquid is placed in nitrogen covered tanks (100 m3) and the bulk solid is placed in a bunker and mixed with other bulk solid and wooden chips.

Figure 6.7.2 The shredder and waste sorting plant, Norway, August 2002

The solid waste in drums are shredded and mixed with bulk waste and then mixed with wood chips to dry up the waste. All iron in the process is removed by sieving the dried waste before the deliverance to NORCEM. Iron would be a problem in the cement production. The sieving of the waste sucked into wood chips is obviously not a problem as could have been expected. We have not been informed how the iron residues are cleaned afterwards.

Hazardous fluid waste received in drums is shredded in a closed system and the metal is removed before the waste is send to a holding tank and from there to the tank yard.

NOAH has 5-10 chemical experts or waste evaluators that are responsible for the reception and the evaluation and proper treatment of the waste. The ground staff at the plant does not have any special education, but they can ask for assistance from the waste evaluators in special situations.

A thorough risk analysis has been made of the company, and most sensitive areas are covered by nitrogen, and mounted with gas measurement instruments.

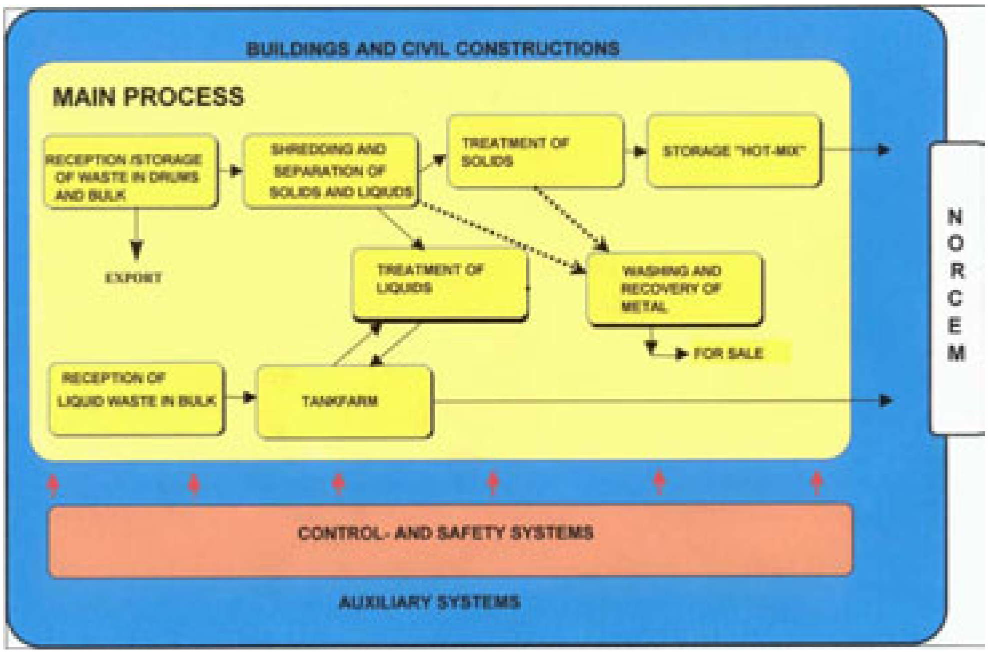

Figure 6.7.3 Process diagram for the NOAH pre-treatment

The working environment is found to be good due to the fact that all chemical processes take place in a closed environment. There is no smell of chemicals at the plant. For a more detailed process diagram, please refer to Figure 6.7.3.

NORCEM

NORCEM treats 1.6 million tonnes limestone per year during app. 6,800 hours of operation. As fuel they use about 17 tonnes of fuel per hour (or 65% coal and 35% alternative fuels). The main fractions are 6-10 tonnes coal, 3-5 tonnes animal meal, 3-5 tonnes per hour of residue derived fuel (municipal waste), and 3-5 tonnes hazardous waste).

NORCEM had an electro filter before the agreement with NOAH was assigned. As part of the agreement, NORCEM installed a bag house filter after the electro filter. The bag house filter covers around 1/3 of the air emission (200,000 m^3/hour, whereas the remaining 100,000 m^3/h is still only covered by an electro filter.

A reception facility to the solid hazardous waste and a tank facility to the fluid hazardous waste were also erected. The capacity is about 500 m^3 for the solid waste and 260 m^3 for fluid waste.

The bunker for solid hazardous waste is one of 3 equal bunkers (Figure 6.7.4) where the two others are used for bone flour and residue derived fuel (municipal waste). Underneath the bunkers is a huge hydraulic station, constructed so it possible to press the waste into a screw conveyor that is feeding an envelop conveyor belt feeding the cement kiln.

Figure 6.7.4 Hazardous waste bunker, NORCEM, Norway, August 2002

The transport to NORCEM of solid waste mixed with wood chips and al iron removed is done in open containers on a truck (500 m) and tipped into the ventilated bunker. For safety reasons, the tanks for the fluid waste were placed inside a mountain. NOAH pumps the solvents 400 m up to the tanks in the mountain. From there NORCEM pumps the solvents 400 m down.

The introduction of coal, meat, animal meal, and waste oil is done through a special lance into the cement kiln. The cement kiln (dry process) is 80 m long and is regulated for the control room. The solid waste is used in the calcinations end (1,000-1,100°C) of the cement kiln, whereas the fluid waste is used in the hot end (>2,000°C). The solid waste will be led through the kiln and be treated at high temperatures too.

This cement process does not produce any scrubber water and no slag. The process has unplanned stops, but as soon as this is detected, the use of hazardous waste is aborted, and because it takes several hours before the temperature is going down in the incinerator, the left-behind waste is burned before total stop for repair.

One of the steering parameters is the chlorine content. According to the agreement NORCEM can feed up to 100 kg of chlorine per hour. Too much HCl in the flue gas will give production problems. As the amount of waste used per hour corresponds to about 5 tonnes, 100 kg corresponds to a Cl-content of about 2%, or at 6,500 hours to 1,300 tonnes/year of POPs containing 50% chlorine.

In the solid waste, the Cl is mixed down to 1% and S to about 3%. The amount of S from the solid hazardous waste is calculated in kilo, corresponding to amount in tonnes from the limestone and is therefore not seen as a problem.

Limitations
The biggest problem for the cement kiln arises from the factor that it does not have a scrubber system. Therefore there is a rather large emission of SO_2 (1,734 kg/24 hours ~ 240 mg/m^3) and mercury (39 kg/year ~20 µg/m3). Surprisingly there also is an emission of HCl although small and below the EU limits (42 kg/24 hours ~ 6 mg/m^3). The SO_2 comes from the limestone (S) and the Hg

mostly comes from the coal and the limestone. The emission of dust is about 211 kg/24 hours ~ 30 mg/m^3. The emission of dioxins from NORCEM is 0.199 g/year ~ 0.1 ng/m^3. The emission of dust and dioxin is within existing EU-limits.

6.7.5 Plant capacity

The heat value of the mixed solid waste and the fluid waste is around 13-17 MJ/kg. About 2.5 tonnes per hour of hazardous waste is used in 6,500 operational hours corresponding to 16-17,000 ton/year at NORCEM.

NOAH estimates an annual treatment capacity of 30,700 tonnes of waste based on two shifts. At present, they treat approx. 16-17,000 ton in 2,400 hours of operation. There are 28-29 full time employees at NOAH and two at NORCEM.

NOAH does not receive pesticides and PCB but they can treat it. They can however not empty a PCB container. All other types of container are treatable in their shredder system. In terms of POPs treatment, this is of course a serious limitation. However, a shredder system able to shred PCB capacitors may be installed for a combined solution if necessary.

6.7.6 Practical experience

The 3 years of practical experience from NOAH/NORCEM has not been copied yet in other parts of the world. However, in France, Holland, Belgium, United Kingdom and USA, the fuel concepts are developed where hazardous companies blend certain kinds of solvents and sell this to the cement kilns as replacement for coal firing. But this total concept for both solvents and solids developed in Norway is not seen anywhere else as far it is known.

6.7.7 Maintenance and service requirements

The cement process has a run time of about 80-85%, including 4 yearly times of planned maintenance. The pre-treatment plant at NOAH has a crew that constant takes care of maintenance. A lot of procedures have to be followed when maintaining a hazardous waste plant and the mechanics that has to perform the maintenance must be able to read, understand and follow written instructions.

To operate the facility, the following staff support is considered necessary:

- Blacksmiths;
- Electricians;
- Machine operators;
- Laboratory personnel (internal, external); and
- Water cleaning operators.

Furthermore, the pre-treatment plant has service lines of electricity, water, pressure air, nitrogen, sewerage system, fire extinguishing system, sodium hydroxide and activated carbon.

6.7.8 Occupational health and safety

The working environment is assessed as close to optimal, due to the fact that almost all chemical processes are made in closed environments. Chemicals can not to be smelled at the plant. The driving with the solid waste sucked into wood chips do not pose any problem the distance being only 300 m and the receiving bunkers are closed and well ventilated.

6.7.9 Operational risks

A thorough risk analysis has been made of NOAH, and the most sensitive areas are covered by nitrogen, and mounted with gas measurement instruments.

6.7.10 Plant mobilisation/demobilisation

Mobilisation, demobilisation is not possible with this technology which is a combined technology.

6.7.11 Capacity building

NORCEM/NOAH has no plans for commercial utilisation of the technology and technique.

6.7.12 Environmental impact of the technology

The assessment of the environmental impacts is based on the previous used criteria.

Materials consumption
As the main activity of NORCEM is manufacturing of cement, consumption of materials related to destruction of POPs is anticipated to include only those extra facilities deemed necessary to undertake the destruction activities. The extra facilities comprised a bag filter with its own bag house and reception/storage facilities for solid and liquid hazardous waste located partly at NORCEM and partly at NOAH. The total mass of these facilities, including fundament, is estimated to around 15,000 tonnes. The main construction parts are:

- Construction steel (approx. 500 tonnes);
- Concrete for fundament etc. (approx. 12,000 tonnes); and
- Asphalt (approx. 2,500 tonnes).

The amount of waste treated in the plant is around 16,500 tonnes per year. Assuming an overall life of around 10 years of plant constructions, the consumption of construction materials will be in the range of 0.09 kg pr. kg of waste treated. In technical terms, most of the construction will have an effective life of 20 years or more. The real life will depend heavily on the conditions for cement manufacturing operation.

Assuming an overall recycling rate of approx. 90%, which should be considered realistic in most countries, the consumption of construction materials is reduced to <0.01 kg material pr. kg waste treated. Thus consumption of construction materials should be regarded as insignificant.

The means of operation includes:

- Wood chips for absorption of the liquid waste; and

- Extra diesel oil and electricity for various processes including mixing of wood chips with liquid waste, operation of bag filter and transport operations.

It has, however, not been possible to quantify the consumption of these means of operation. The waste treated is characterised as mixed chemical waste containing around 1% chlorine and various concentrations of sulphur having a heat value of 13-17 MJ/kg.

Energy consumption
Alternative fuels correspond to 30-35 % of the thermal energy at NORCEMs plant in Brevik. Hazardous waste represents approx. 10% of the total energy. The substitution rate was 10-12% until 1999. The new equipment has resulted in a considerable increase. In 2001, a total of 65,000 tonnes of waste derived fuels were used.

The heating value is in average 60% of the heating value of coal. The Cement Kiln Incineration may be rated above average or even best on the energy issue. This is due to the effective utilisation of the heat value of the waste directly as process energy. Besides that, other operations at the cement plant may hardly be influenced by the burning of mixed chemical waste.

Chemicals, emissions, residues and elimination efficiency
Emissions and residues from the operation is limited to air emission only as the fly ash is integrated in the cement produced and the factory has no emission of process wastewater.

The total emission of dioxin to air in 2001 is stated at 0.199 g/year approximately corresponding to 0.1 ng/Nm^3 (reference to NORCEM information on measurements by the authorities, August 2002). Assuming this figure to equal I-TEQ, the emission corresponds to approx. 12 ng I-TEQ/kg waste. As part of this emission is caused by ordinary cement manufacturing, the correct figure is <12 ng I-TEQ/kg waste.

No other data relevant for assessing the content of organic substances in the emission to air and fly ash is available. It should be noted, that unless otherwise documented, it must be assumed that the fly ash from the process may contain significant quantities of dioxin. As the relevant data are not available, it is not possible to assess neither DRE (destruction and removal efficiency) nor DE (destruction efficiency) of the process.

Other issues
As the Cement Kiln Incineration process eliminates waste products by integrating these into the final product - the cement - this process may be ranked highest. However, as discussed above it is debatable whether this way of disposing of fly ash etc. should be considered acceptable. Based on the information we know, the CKI is ranked middle on this matter.

6.7.13 Economy

NORCEM had an electro filter before the idea of using hazardous waste came up. When they started to use hazardous waste they installed a bag house filter after the electro filter. NORCEM invested 140 million NOK (app. 24 million USD) for the above mentioned facilities, whereas NOAH invested about 400 million NOK (app. 68 million USD) for the building of the total new pretreatment plant. Table 6.7.1 outlines main economic parameters.

The price of the waste treatment can be seen in the pricelist, but for chlorinated waste it is typical about 5-6,000 NOK (app. 950 USD) per ton. On the other hand, the treatment of PCB cost 35,000 NOK (6,000 USD) per ton and for pesticides, official prices are 15,000 NOK (2,500 USD) per ton.

Table 6.7.1 Main costs

Item	Costs (USD)
Plant capital cost	92* mill.
Interest and repayment	Commercial price by direct contracting
Treatment costs (incl. raw materials, license and overhead)	2.5/kg (pesticides) 1/kg(Chlorinated substances) 6/kg (PCB)
Treatment costs of residual products	included
Labour costs	included
Analysis costs	included
Total costs	**1-6,000/ton depending on type of chemical**

* Comprises 24 million USD investments in the cement kiln and 68 million USD for the hazardous waste treatment plant. Both investments are necessary for the correct treatment, but the idea is that many kinds of hazardous waste carry the economic burden, not only POPs.

6.7.14 Evaluation of the CKI technology

Technical evaluation

The most appropriate waste for disposal in cement kilns are those which provide additional energy value as a substitute fuel or material value as a substitute for portions of the raw material feed (e.g. calcium, silica, sulphur, aluminium or iron). Liquid wastes or low ash wastes are relatively easy to burn in a cement kiln. The material is fed in dry or in slurry form (especially for the 'wet' process), or as a fuel supplement into the burning zone of the kiln. In this zone, the temperature of 1,450oC is able to perform high destruction efficiency as the gas passes through the kiln. No liquid or solid residues requiring disposal are generated since all residues are bound within the product.

For the typical counter current process configuration, polluted-soils and solid waste cannot be fed into the firing end of the kiln, since they would discharge in the clinker without adequate treatment; besides, they cannot be fed into the cool end of the kiln, as the waste would volatilise and would not be adequately destroyed. When operated properly, destruction of chlorinated compounds in cement kilns can be >99.00% complete with no adverse effect on the quality of the exhaust gas. Anyway, it can be seen that NORCEM as even a very modern cement plant has an emission of 42 kg of HCl per 24 hours. And if the POPs are containing sulphur then the emission of SO2, is already over the allowed limits.

However, the contribution of waste materials to the exhaust gases are relatively low given that the waste are only used as a minor supplement to the main energy or raw material stream. Furthermore, is important that the cement kiln has modern dust emission reducing equipment. Many pollutants will have a tendency to stick to the dust.

NORCEM has a flue gas emission of 300,000 m^3/hour and emits 8.8 kg dust per hour (~30 mg/m^3) giving rise to 0.1 ng/m^3 dioxin (on the limit according to EU-directive). Cement kilns are allowed to have a dust emission of 30 mg/Nm^3 according to the EU-directive. As can be seen, a reduction of the dust emission would most possibly also cause a fall in the dioxin emission. For comparison, the dust emission from a hazardous waste is around 2-3 mg/m^3 and must not exceed 10 mg/m^3 according to the EU-directive.

As it can be seen, the Norvegian solution with a company as NOAH conducting a lot of special pre-treatment makes the use of the cement kiln solution possible. The energy from the hazardous waste is used in the cement production. However, it must be remembered that liquid hazardous waste traditionally consists of polluted water, with a water content up to 90%. This kind of waste must also be treated, and that is not very wanted by the cement kilns. In Norway they come around the problem by sucking this kind of waste into wood chips, making the waste still burnable. Furthermore, the incomming waste to NOAH in general has a low water content. Water containing waste is treated elsewhere.

Many of the older types of cement kilns, which are seen all over the CEE Region, are not assessed as suitable for international compliant hazardous waste treatment. Only a few of the cement kilns in developing countries meet the technical requirements that, in principle, makes them egliable for incineration of certain groups of hazardous waste including POPs. Expert advice is needed to assess whether kilns can be used and special equipment is required to inject the hazardous waste into the kiln, or if extra filters are needed, not mentioning scrubber systems etc. Such equipment is expensive and should only be installed and used under expert supervision.

Furthermore, an important feature that has been complied with in Norway, but has a tendency not always to be considered, is to concentrate the work with the hazardous waste on specialists. People working in a cement plant are specialists in making cement, nobody is better than them to do that. However, they are not experts in how to treat hazardous waste. Consequently, the pre-treatment of hazardous waste shall be put in specialist hands in special designed surroundings as in NOAH in Norway.

The erection of a plant facility, like the one at NOAH in Norway is expensive and estimated costs exceeds 90 million USD. The updating of the cement kiln with a bag house filter and miscellaneous additionals costed 20 million USD. Such systems must be regarded as non-applicable to the CEE Region due to total lack of affordability.

Finally, the global cement industry these years is under stress for constant consolidation, which make today's ownership and eventual related investment projects (pre-treatment, etc.) vulnerable for structural change in the ownership set-up.

Environmental evaluation

Material consumption

The cement kiln incineration solution has been difficult to rank low despite the lack of precise data and should be expected to perform rather good on this issue. The fact that the main energy source is coal which is not renewable and is a major green house gas source is not considered in this report (Table 6.7.2).

Table 6.7.2 Comparative assessment of material consumption

Material consumption	Unit	Cement Kiln Incineration (CKI)
Construction materials (*1)	kg/kg waste	<0.01
Means of operation excl. energy - non-renewable	kg/kg waste	-
Means of operation excl. energy - renewable	kg/kg waste	-
Overall assessment		1

-: Insignificant

*1: All materials are weighted equally and no consideration has been paid to scarcity and whether the material is renewable.

Energy consumption

The Cement Kiln Incineration turns out to be a good energy solution, which is due to the utilisation of the heat value directly in the process. Furthermore, other operations at the cement plant may hardly be influenced by the burning of mixed chemical waste (Table 6.7.3).

Table 6.7.3 Comparative assessment of energy consumption

Energy consumption	Unit	Cement Kiln Incineration (CKI)
Energy consumption	MJ/kg waste	-
Overall assessment		1

-: Insignificant

Chemicals, emissions, residues and elimination efficiency

Considering these issues the Cement Kiln Incineration is rated "below average", or more or less equal to the CIS-system. This rating is among others due to lack of data of how much dioxin is created in the cooling of the fly ash. Unless otherwise documented, it must be assumed that the fly ash from the process may contain quantities of dioxin. Furthermore, it is not clear how the control is carried out of the emission by-passing the bag house filter systems.

It is also noted that it is rather difficult to document the environmental performance of CKI as substances and decomposition products originating from hazardous waste is strongly diluted by emissions and residues originating from raw materials for cement manufacturing.

Special attention must be paid to the procedure of integrating fly ash and other flue gas cleaning residues in the final product - the cement. It is noted that many countries (e.g. Denmark) as a general policy does not accept the strategy of dilution as a way of solving the problem of disposal of residual products containing hazardous substances.

Furthermore, an amount of 30-35% alternative fuel gives rise to an emission of 0.1 ng/Nm^3 of dioxin or <12 ng I-TEQ/kg waste (Table 6.7.4). This is a high level compared to dedicated hazardous waste destruction plants. Reference is made to the GPCR-plant with an emission of 1.1 ng I-TEQ/kg waste and the CIS-plant with an emission of 1.3 ng I-TEQ/kg waste.

Table 6.7.4 Emissions and elimination efficiency

Elimination efficiency	Unit	Cement Kiln Incineration (CKI)
Destruction efficiency	%	?
Destruction and removal efficiency	%	?
Dioxin emission to air	ng I-TEQ/ kg waste	<12
Dioxin emission - all media and residues	ng I-TEQ/ kg waste	?
Overall assessment		4

?: No data are available:

The figure stated covers the residual product only. A mass weight of 0.9 kg/litre of the residual product is assumed.

Other issues

As the Cement Kiln Incineration process eliminates waste products by integrating these into the final product - the cement - this process may be ranked highest. However, as discussed above it is debatable whether this way of disposing of fly ash etc. should be considered acceptable. Based on the information we know, the CKI is ranked average on this matter (Table 6.7.5).

Table 6.7.5 Other environmental issues

Residues	Unit	Cement Kiln Incineration (CKI)
Waste for further treatment/disposal - hazardous waste	kg/kg waste	0?
Waste for further treatment/disposal - solid waste	kg/kg waste	0?
Waste for further treatment/disposal - wastewater	lit/kg waste	0?
Overall assessment		3

6.8 Cyclone reactor

The main information outlined about the Russian developed cyclone reactor is extracted from the NEFCO PCB Fast Track Project - Feasibility report, February 2002.

6.8.1 Introduction

The company JSC Tekhenergokhimprom, a privatised company of some 20 employees, with the department for concepts and design located in Moscow, Russia and with test facilities in Orekhovo-Zuevo has developed the basic technology. Their basic business is waste treatment, and hereunder the incineration of hazardous waste. They are not themselves interested in transformer handling and cleaning, but they are interested in PCB destruction and are completely open to the possibility of co-operating with a transformer cleaning company.

The testing centre in Orekhovo-Zuevo for treatment of highly toxic waste was established in 1973. It started with destruction of different types of chemical waste. Already then, the technology was one of the controlled incineration with high-temperature neutralisation of the acids in gas/solid phase reactions. Similar facilities have for a long time been used to clean wastes from the pesticide industry.

Formerly, Tekhenergokhimprom was a state owned company which in 1980 was nominated as the key institute for the incineration and neutralisation of solid and liquid chemical wastes as well as sludge in the RF.

6.8.2 Description of the technology

The description is based on 4 pilot test lines for incineration of toxic waste containing organic chemicals in which chlorine, phosphorous or sulphur is a constituent. Being a test facility, the various lines are manually operated. The assessed test line includes:

- A pilot test line for the incineration of up 40-400 kg/h of liquid toxic waste (in organic or in aqueous phases). The line has a vertical combustion chamber. Due to the common bag filter, the capacity is limited to 100 kg/h when burning aqueous waste;

- A pilot line for incineration of 100 kg/h of solid waste with a shredder for particle size reduction followed by fluidised bed incineration;

- A pilot line for incineration of 150 kg/h of sludge or paste-like wastes (with a screw feeder); and

- A small pilot line with horizontal incineration chamber for 10 kg/h of liquid wastes.

The tests have been public approved by two organisations, the first one approving the technical description of the facility, and the second issuing an operating permit granted by the Moscow Health Authorities and is valid for a 3-year period (2000-2003). This permit comprises the incineration of all toxic organic substances (Russian class 1-4) covering PCB.

In the beginning of the 90s it became necessary for the organisation to reorient the work from mostly research towards commercial incineration of toxic wastes from the Moscow region. Among other, also non-PCB containing transformer liquids are being incinerated here. For this, the liquid from an old transformer at a potential client is sampled and analysed for chlorine content. And if not found, the transformer is then transported to the site and emptied. In case chlorine is found, they refuse to handle the oil from that transformer.

Actual projects
This drive for commercialisation has led to the following projects of interest for development of a future platform for POPs elimination technologies based on existing CEE market platform:

- A 100 kg/h test facility for organic toxic waste, solid as well as liquid, was established in South Korea in 1995. This facility was used to demonstrate the technology and served as a basis for deciding to go ahead with the next;

- A 1.3 t/h full-scale facility for incineration of liquid organic waste was established in 1998 (erected in three months, and using the cyclone reactor type described below) also in South Korea with requirements for combustion temperature exceeding 1200°C. The Korean operating permit for this facility was granted 25 September 2000 for any type of liquid waste (also PCB). Before PCB can be incinerated, however, some tests must be carried out. In this unit, a combustion air pre heater heats the air to 3-400°C. The heat recovery system is part of the quench design. This unit is fully automated and has been designed for continuous operation, however, still requiring some 2-3 operators (examples of duties: tank operations, removal of salt from bag filters, changing of nozzles etc.);

- Khimprom in the city Ufa, Russia, where a unit has been established a few years ago for the destruction of pesticides; and

- The Korean waste handling company having purchased the above units has sold one unit to Japan for handling of 5 t/d of PCB and 4 t/d of PCB-polluted organic washing liquids from transformers, using 35 t/d of soda-containing wastewater for neutralisation. By July 2001, the work was in progress for delivery of design documents as well as a cyclone unit later in 2001.

6.8.3 Description of cyclone process

The heart of the Cyclone Process is the incineration chamber. The one from the test installation in Orekhovo-Zuevo is shown in Figure 6.8.1.

As illustrated, the name Cyclone Reactor comes from the swirl movement of the combustion gases – this same movement that ensures a high degree of turbulence and thus efficient mixing.

Figure 6.8.1 Brick lined top of cyclone reactor in Orekhovo-Zuevo

The cyclone reactor is a vertically mounted cyclone type incinerator in which the combustion air and the fuel enter with a velocity around 100 m/s thus ensuring intimate mixing and high turbulence. The retention time here is around 0.3 seconds and the temperature 1,600-1,700 °C (lining with chromium magnesite or Al_2O_3).

The caustic solution is then added through nozzles and the temperature drops to between 1,250 and 1,400 °C, and in the subsequent brick-lined afterburner is ensured another 1.7 seconds of retention time.

The main principles (process diagram) of the entire installation are shown below.

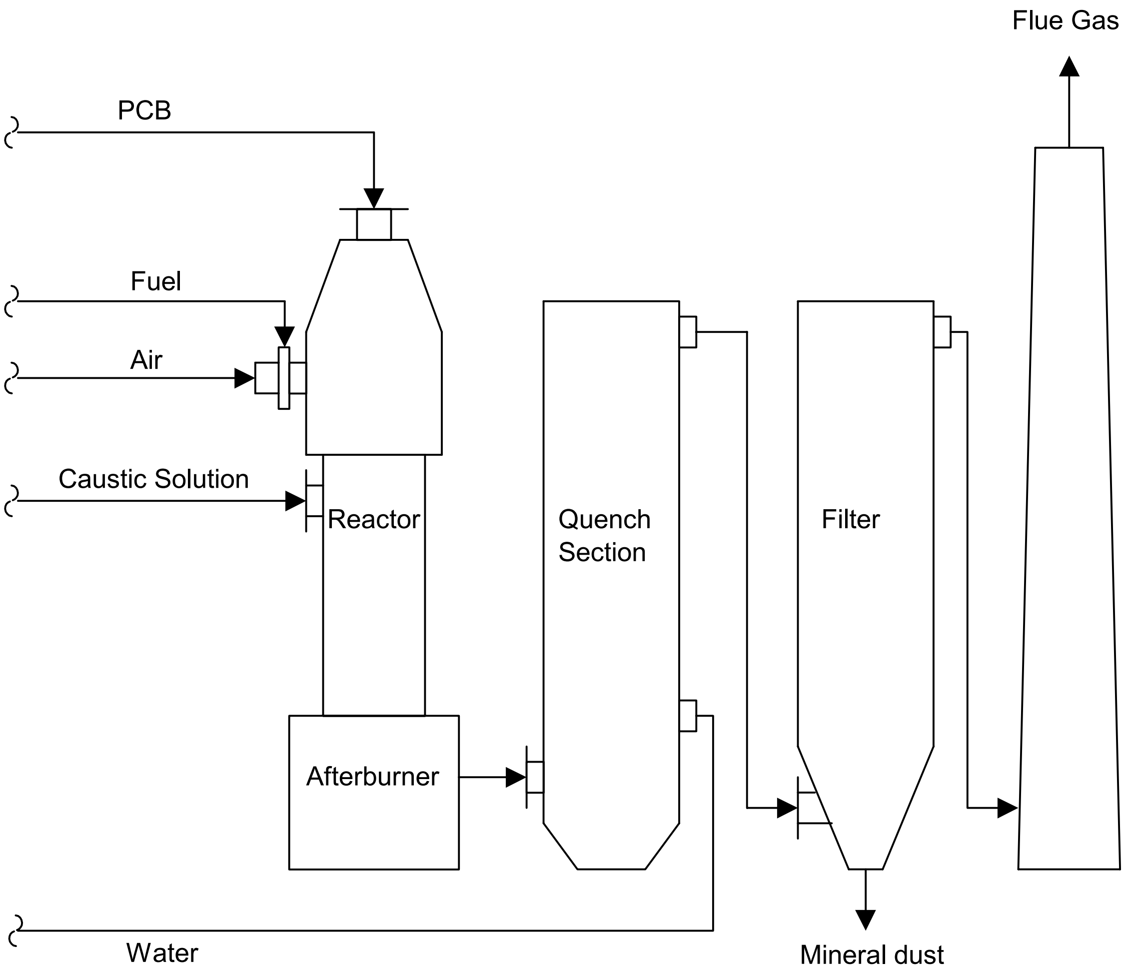

Figure 6.8.2 Process flow diagram for the cyclone process

The cyclone reactor technology contains a high-temperature gas/solid phase reaction. This takes place between the caustic (dissolved Na_2CO_3 or NaOH or $Ca(OH)_2$) and the acid gases formed by the incineration of S-, P- or Cl-containing organic substances.

In all cases, the reaction products come out as a powder of salts, retained in bag filters as opposed to the other processes where more or less polluted brine is the waste product. Because it is introduced into the hot combustion zone, liquid spent caustic solutions may be used as a cheap source of sodium hydroxide. If not available, a solution is prepared from purchased chemicals.

The primary reaction is the gas phase reaction (simplified) where practically all hydrochloric acid reacts with the caustic:

$$NaOH + HCl \rightarrow NaCl + H_2O$$

The remaining caustic reacts with carbon dioxide:

$$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$$

This core of the method was patented in Russia, but the patent was not maintained and is thus no longer valid, and the system has been copied in Germany and in Scotland.

With certain chemicals, the salts are actually melting and collecting on the surface of the incineration chamber, and subsequently flow out from the bottom. But in the case of PCB, it is to be expected that NaCl powder will travel through the system to be collected in the bag filter.

The exact temperatures and injection points depend on the product to be incinerated. In the case of PCB, the design would be with the support fuel in the top of the combustion cyclone and the PCB intimately pre-mixed with the caustic solution a little further down. The need for support fuel depends on the material to be incinerated.

In the combustion process it is important to have a surplus of steam to avoid any tendency for soot formation from incinerating of the cyclic organic components (the shift reaction will ensure the formation of CO instead). Steam is present from the natural gas incinerated as well as from the subsequent injection of NaOH solution. With certain cyclic organic chemicals it is necessary to add more in the form of water; but this is not required for the combustion of PCB.

Downstream of the afterburner, the hot gases enter a quench tower, where the temperature is taken down to approx. 200°C (possible range 160-220°C) the exact level being determined by the bag filter operation. At these temperatures the salts solidify from the gas phase, forming a fine powder.

High temperature fibres are then used in the bag filter, thus allowing the flue gas to stay well clear of lower temperatures where the salts would become sticky due to the high humidity in the flue gas.

During earlier tests, the company Taifun made 3-5 analyses for dioxins in this powder, but even traces could not be detected, and further analyses were therefore abandoned. In the flue gas, many measurements of dioxins have been made, and these results have shown values below 0.1 ng/Nm^3.

Experience with difficult chemicals

In 1992, when producing a pesticide similar to Agent Orange (with high concentrations of dioxins and furans) the Khimprom factory realised they had problems with waste incineration as temperatures of 2,000 or even 3,000°C would be required. It was because of this JSC tested the product and obtained the results now published in the article in “Ekip” from February 2000. In this article is clearly demonstrated the influence of incineration temperature on dioxin emissions when incinerating a dioxin.

Much research work is behind the curve presented in this article. So, if the incineration process may be controlled well enough, then traditional incineration is a fine way to dispose of such toxic chlorinated organic components. It is this work, on the incineration of components very similar to PCB that gives reason to believe, that the test will prove PCB incineration to be very efficient and satisfactory in a CEE developed context.

6.8.4 Description of operation

One of the potentially important features of the process is the lining with insulating bricks. In Korea, fine quality bricks made of 95% pure corundum exists which makes them very resistant to heating and cooling. In Russia, only an 85% quality is available. The practice in Korea to start up and shut down the unit every day should therefore not be attempted with a Russian-made installation. Here, continuous operation should be foreseen as much as possible. A PCB collection tank should hold at least a week's consumption before the unit is started up. Hereafter the unit should be operated continuously until the tanks is empty. Such mode of operation requires 5 shifts with 2-3 operators in each shift.

The cyclone reactor facility is not very complicated to operate. The four important parameters to master and control are:

- Retention time: should be two seconds above 1,200 °C (experience based on incinerating dioxin-containing waste), and this is ensured in the brick-lined canal after the burner;
- Operating temperatures in chamber and afterburner;
- Amount of excess oxygen in the flue gas; and
- Turbulence in combustion chamber for homogenous mixing.

As a supplement to the above, the CO level is monitored closely, mainly because combustion of CO is slower than that of dioxins. Experience has shown that if CO is below 5 mg/m^3, the dioxin level is below 0.1 ng/m^3. For this reason there shall be at least approx. 3% oxygen in the flue gas (excess air in the combustion).

Furthermore, it has been experienced that dioxin levels rise (a fivefold number has been measured, or 0.5 ng/m^3) during start-up and shutdown of the unit. For this reason, waste should only be injected, once the unit is heated up and operating.

In Korea, among many other types of hazardous waste, three types of chlorinated chemicals (methylene chloride/chloroform, carbon tetrachloride, and chlorobenzene) have been incinerated in the cyclone reactor without any traces of dioxins measured in the flue gas.

6.8.5 Evaluation of the cyclone reactor plant

In general, the process is well proven and mature, but not for the specific application of PCB destruction. Like any other elimination technologies, the cyclone reactor has positive and negative effects.

Advantages
The main advantages are:

- Clean waste powder is claimed (has to be tested), consisting almost entirely of NaCl and Na_2CO_3 salts. This may either be recycled to chemical industry (for NaOH and Cl_2 production), or ultimately placed on a controlled dumpsite; and

- Any kind of spent caustic with organic pollution may be used for the neutralisation since this is injected directly into the flame and any such pollutants are undergoing the same efficient combustion as the PCB.

Disadvantages
The main disadvantages are:

- Start-up and shutdown is slow due to the necessary protection of the brick lining; and

- This technology can only treat dissolved POPs, such as fluid PCB, but no solids.

Technical evaluation

The patented system for injection of caustic solution directly into the hot reaction chamber results in the direct formation of gaseous NaCl, thus removing Cl from the reactants. For this reason, the formation of dioxins is claimed much less likely than in traditional incineration and it is also believed that the binding of Cl also contributes to the complete destruction of PCB.

Downstream of the hot zone, all equipment may be made of plain carbon steel.

Maturity of technology
The technology has been proven on other toxic organic substances such as pesticides and on organic chemicals with relatively high levels of dioxins, but not specifically on PCB. The system has been in operation for the last 30-40 years with different chemicals; the older systems were designed for much lower combustion temperatures though, because at that time problems with dioxins were not designed for.

Incineration is the best known of all technologies. The traditional criterion for PCB incineration with minimum 1,100 °C and min. 2 seconds retention time is complied with. Together with practical experience with incineration of other halogenated components – additional research is carried out at present. Tentative results show that operating improvements are obtainable by the Cyclone Reactor with caustic injection in the hot zone.

Any of the following caustic liquids may be used – also those that might be polluted with organic matter: NaOH, Na_2CO_3, KOH, K_2CO_3 (the two carbonates are the least expensive, and therefore normally chosen, when fresh chemicals are to be purchased).

Versatility/robustness
The process is claimed capable of coping with any concentration of PCB in the liquid waste to be incinerated and it can handle many types of halogenated organic compounds.

Capacity
The capacity of the Cyclone Reactor can be tailor-made for a range of 40 kg/h to around 16 tonnes per hour. It can therefore easily be designed to accommodate the desired capacity under the ongoing NEFCO-PCB Fast Track Project.

Utility requirements have – on a preliminary basis been determined to:
- Electric power: minimal, for pumps only;
- Natural gas: 1,700 kg/ton PCB (could be kerosene instead);
- Sodium hydroxide: 740 kg/ton PCB;
- Cooling/quenching water. 27 ton/ton PCB, and
- Some nitrogen is required for purging during start-up and shutdowns.

More accurate estimates will be available after specific tests related to actual waste.

Mobility of facility
If designed with kerosene as main fuel, the facility is not bound by anything but requirements to water and a modest power supply. This process therefore has the biggest potential for being designed as a mobile facility. It may fit into a few containers. However, the necessary brick lining is fragile if transported on bumpy roads, thus limiting the practicality of a mobile unit.

Workers health and safety
Occupational health levels are to be determined and optimized during the operation of the plant in the NEFCO funded PCB Fast Track project. This shall include waste handling, pre-treatment, start-up, operation and close down of plant.

Environmental evaluation

Airborne emissions
Small amounts of CO and NO_x can be found in the flue gas. Some salt dust will - depending on the quality of the bag filter – pass through the filter and emitted

with the flue gas. Tests shall decide if the plant can meet the emission requirements e.g. set forward by the EU-directive on incineration of waste.

Noise
Low, a draft fan is part of the installation and does make itself heard.

Waterborne emissions
None, only cooling water is used.

Waste generation
A dry powder/ash consisting mainly of NaCl and of a little $NaHCO_3$ is produced. It remains to be proven as a result of a test, but it is expected that there will be very little and possibly no traces of dioxins in the ash. Perhaps there will not even be traces of PCB.

It is therefore expected that these ashes may be disposed of in a properly conceived waste dumpsite. This however, still has to be proven.

Energy conservation
Some heat recovery will be built into the quench section, serving to preheat the air used in the incineration to 300-350°C. The requirement to sudden cooling of the flue gases in order to avoid the formation of dioxins puts a limit to, how much heat recovery is possible with such an incineration process for e.g. PCB destruction.

Compliance with emission norms
It is expected, however at the present stage not sufficient documented, that applicable norms for e.g. dioxins will comply.

Prohibitive features
Of the CEE facilities investigated so far, the cyclone technology appears to be technically and environmentally the most promising. The problem with solid waste has been tried minimised, and there is real operating experience on dioxin incineration with one unit. Further tests will show if the facility cope with the environmental demands according to the EU-directive.

6.9 Comparative evaluation of the 4 reviewed POPs elimination technology plants

6.9.1 Environmental evaluation

The environmental comparative assessment of the 4 reviewed elimination technologies presented in the previous chapters (the cyclone incinerator excluded) focuses on the following issues:

1. Consumption of materials;
2. Energy consumption;
3. Chemicals, emissions, residues and elimination efficiency; and
4. Other issues.

Consumptions of materials
The key figures concerning consumption of materials are summarised in Table 6.9.1. The main focus is given to consumption of means of operation as the comparative assessment with respect to construction materials should be regarded as a rough and partly incomplete assessment that does not consider issues like material scarcity and renewability.

Still, the comparison regarding construction materials is interesting indicating a trend consistent with the figure shown by consumption of means of operation, namely that the CIS solution allows for a higher flow of waste materials through the system than the chemical decomposition systems. The CIS system thus obtains a higher material efficiency and deserves to be rated best in this regard.

The GPCR technology equals the CIS technology on the comparison of material consumption. The BCD system on the other hand stands out as having an out standing high consumption of mineral oil used in the operation placing this solution un-disputably as the worst in this regard. The CKI solution has to be ranked low due to the lack of precise data.

Table 6.9.1 Comparative assessment of material consumption

Material consumption	Unit	Gas-Phased Chemical Reduction (GPCR)	Base Catalysed Dechlorinaion (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Construction materials (*1)	kg/kg waste	≤0.01	<0.01	<0.002	<0.01
Means of operation excl. energy - non-renewable	kg/kg waste	-	4-13	-	-
Means of operation excl. energy - renewable (*2)	kg/kg waste	0.18-0.56	1-2	0.01-0.1	-
Overall assessment		2	5	2	1

-: Insignificant

*1: All materials are weighted equally and no consideration has been paid to scarcity and whether the material is renewable;

*2: Addresses in reality only the consumption of NaOH.

Energy consumption

Concerning energy consumption the key figures are summarised in *Table 6.*9.2. The picture shown resembles the picture of material consumption, which is hardly surprising as the consumption of means of operation also strongly influences the energy consumption. However, a significant difference is that the Cement Kiln Incineration could turn out to be the best solution, which is due to the utilisation of the heat value. Besides that, other operations at the cement plant may hardly be influenced by the burning of mixed chemical waste. Unfortunately, any solid conclusions in this regard are prevented by the lack of precise data.

Comparing the CIS system with the GPCR system, CIS is assessed slightly better as the energy consumption in most cases should be expected to be lower than for the GPCR system. Generally, the better the heat value of the waste, the better performance of CIS compared to GPCR and vice versa.

Again the BCD system is indisputably ranked lowest due to outstanding high energy requirements coming from consumption of electricity as well as the carrier oil.

Table 6.9.2 Comparative assessment of energy consumption

Energy consumption	Unit	Gas-Phased Chemical Reduction (GPCR)	Base Catalysed Dechlorination (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Energy consumption (*1)	MJ/kg waste	29 - 35	400-1200	1-43	-
Overall assessment		3	5	2	1

-: Insignificant

*1: The great variation depends on whether support fuel is needed or not. As an average, the need for support fuel should be anticipated to be in the low end of the interval.

As cement kiln incineration could turn out to be the best solution, the choice has been made not to use the rating of "best" for other systems.

Chemicals, emissions, residues and elimination efficiency

The knowledge available concerning emissions and elimination efficiency is presented in *Table 6.*9.3. Unfortunately, the available data are in several ways inadequate, but seems anyhow to present a trustworthy picture. The DRE figures for the GPCR process are slightly better than the DRE figures for the BCD and the CIS processes. It should be noted that the DRE values quoted for the GPCR and the BCD processes represent specific highly chlorinated substances, while the DRE value for CIS is based on a balance for total organic carbon.

Considering the very low level of dioxin emission to all media and residues from the GPCR process it also seems appropriate to rate this process as the "best".

The BCD process is rated second primarily based on the values for DE and DRE. The process suffers from a high content of chloride in the residual product, and no data on emission of dioxin to air is available from the destruction (by incineration) of the residual product. It is however recognised that all experience with incineration based systems points at quantities of dioxin in fly ash and other flue gas cleaning residues. Thus, there is no reason for assuming the CIS and the CKI processes to perform better than BCD on the issue of dioxin.

The CIS is rated low. The DRE value for organic carbon and low dioxin emission to air should although be recognised. However, as stated above, the dioxin content in flue gas residues should be expected to be high and the overall destruction efficiency remains to be proven considering that up to 2% carbon is allowed in the slag.

Attention must also be paid to the fact that incineration of hazardous waste in a small unit like CIS is a process depending strongly on the heat value of the waste and therefore occasionally/potentially difficult to control. In serious cases it may be necessary to close down the process and allow flue gas to be released to the environment without being subject to flue gas cleaning. Such incidents, which are difficult to quantify, are tried reflected in the figures below, and should not be overlooked.

The Cement Kiln Incineration is also rated low due to lack of data. It is noted that it is rather difficult to document the environmental performance of CKI as substances and decomposition products originating from hazardous waste destruction are diluted in emissions and residues originating from raw materials from the cement manufacturing.

In this case, special attention must be paid to the procedure of integrating fly ash and other flue gas cleaning residues in the final product - the cement. Until better knowledge has been developed, it must be assumed that this procedure in reality is a way of "hiding" dioxin in cement and spread it into the society and the environment as a consumer product.

Table 6.9.3 Comparative assessment of emissions and elimination efficiency

Elimination efficiency	Unit	Gas-Phased Chemical Reduction (GPCR)	Base Catalysed Dechlorination (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Destruction efficiency (DE)	%	?	99.97-99.997	?	?
Destruction and removal efficiency (DRE)	%	99.98-≥99.996	> 99.9999	>99.996	?
Dioxin emission to air	ng I-TEQ/ kg waste	1.1	?	≤1.3	<12
Dioxin emission - all media and residues (*1)	ng I-TEQ/ kg waste	1.1	2200-6600 1)	?	?
Overall assessment		1	2	4	4

?: No data available

*1: The figure stated covers the residual product only. A mass weight of 0.9 kg/lit. of the residual product is assumed.

Other issues

Other environmental issues focus on the amount of waste generated by the processes and the hazards related to this waste. No other issues are deemed relevant to consider.

As the Cement Kiln Incineration process eliminates waste products by integrating these into the final product - the cement - this process may be ranked highest. However, as discussed above it is debatable whether this way of disposing of fly ash etc should be considered acceptable.

The GPCR process distinguishes itself from the BCB and CIS processes by not generating any hazardous waste that requires further treatment or special disposal. The amount of solid waste is very low, while the amount of wastewater hardly can be regarded as a problem, considering that is cleaned by an activated carbon filter. For these reasons, the GPCR process is ranked "highest" of the remaining processes.

Regarding the CIS process, the fly ash, the slag and the quench residues are likely to be disposed of as hazardous waste to a special landfill due to the content of dioxin as well as other pollutants indicating that there is a need for landfill capacity. Thus the CIS process is ranked below the GPCR process.

The BCD process presents its own special set of problems, as it generates a relatively high quantity of residual product, which is composed of carrier oil together with remains of NaOH and a significant content of chlorine from the decomposed substances. Uncontrolled burning of this product could lead to significant dioxin formation and appropriate disposal must include treatment on a facility specialised in treatment of liquid chemical waste. For this reason, the BCD process is also ranked below the GPCR-process (Table 6.9.4).

Table 6.9.4 Other environmental issues

Residues	Unit	Gas-Phased Chemical Reduction (GPCR)	Base Catalysed Decomposition (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Waste for further treatment/disposal - hazardous waste	kg/kg waste	-	5.4-16	0.02-0.18	0?
Waste for further treatment/disposal - solid waste	kg/kg waste	0.01	-	0.2-2	0?
Waste for further treatment/disposal - wastewater	lit/kg waste	2.5-2.9	0.1-0.4	0.07-0.6	0?
Overall assessment		2	4	4	3

0?: No data are available, but could be 0.

-: Insignificant

6.9.2 Technical evaluation

Capacity

The best capacity for highly chlorinated waste is the GPCR technology as shown in Table 6.9.5.

Table 6.9.5 Capacity

	Unit	Gas-Phased Chemical Reduction (GPCR)	Base Catalysed De-chlorination (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Capacity (50% Cl)	Ton/year	2,000	60	400-800	1,300
Overall assessment		1	5	2	2

Comprehensiveness

The CIS and the CKI have the advantage to be continued operations, whereas the GCPR is continuous only with fluid waste, and both the BCD and the GCPR are batch operated with solids.

All the plants can treat most types of containers and most types of wastes, although they all have their special compounds they have to avoid or minimise. Table 6.9.6 outlines the performed assessment.

Table 6.9.6 Comprehensiveness

	Gas-Phased Chemical Reduction (GPCR)	Base Catalysed De-chlori-nation (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Types of waste	solid & fluid	fluid	solid & fluid	solid & fluid
Type of operation	batch (solid)	batch	continuous	continuous
Overall assessment	3	4	2	2

Maintenance
Information about maintenance expenses has been few, but it is anticipated that the plant with the most moving parts are most expensive and that the heavy system of the CKI results in low maintenance. Table 6.9.7 shows the assessment of maintenance.

Table 6.9.7 Maintenance

	Gas-Phased Chemical Reduction (GPCR)	Base Catalysed Dechlorinated (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Maintenance	few moving parts	few moving parts	moving parts	heavy
Overall assessment	2	2	3	2

Transfer of know-how
The companies behind the GPCR and the CIS have already developed programmes for transfer of know-how, which is not the case in the same extent for the BCD and CKI technologies. The technology transfer for CKI is not practised at all, whereas the BCD company was open for development of this.

Table 6.9.8 highlights the assessment of transfer of know-how abilities, which for a CEE context is of major importance, due to a relatively weak, highly complex industrial sector.

Table 6.9.8 Transfer of know-how

	Gas-Phased Chemical Re-duction (GPCR)	Base Cata-lysed De-chlorination (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Transfer of know-how	Existing programme	Willing to develop a programme	Existing programme	No programme
Overall assessment	1	2	1	3

Special supply lines

The supply lines are more or less the same. The GPCR though has a need for hydrogen supply, which requires high attention. Table 6.9.9 outlines the assessment.

Table 6.9.9 Special supply lines

	Gas-Phased Chemical Re-duction (GPCR)	Base Cata-lysed Dechlorination (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Special supply lines	Hydrogen, nitrogen, natural gas	Nitrogen,	Nitrogen, natural gas	Long pipe for transport of waste
Overall assessment	3	2	2	2

Residual products

The GPCR has very good control with all residual products, whereas both BCD and CIS have no data on the final residual product. The CKI has no residual products, and in this scheme that would normally be rated high, but as the residual products are ending in the cement and we have no data for this, the CKI is rated as if we have no data. Table 6.9.10 outlines the assessment of residues environmental impact.

Table 6.9.10 Residual products under control

	Gas-Phased Chemical Re-duction (GPCR)	Base Cata-lysed Dechlorination (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Rest products	Small amounts, controlled	Lack of data for residual products	Lack of data for residual products	No residual products
Overall assessment	2	4	4	4

Occupational health

The protection of workers was looked upon during visit at the various plants. The CKI has a problem with cement dust, but seen from a POP waste angle, the working surroundings were well planned and clean, and the same was seen at the GPCR and at the CIS plant. At BCD people had to wear protection suits and masks, which seemed necessary at that plant. This may be improved. Table 6.9.11 outlines the assessment.

Table 6.9.11 Occupational health

	Gas-Phased Chemical Re-duction (GPCR)	Base Cata-lysed Dechlori-na-tion (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Occupational health	Found OK by inspection	Found less OK by inspection	Found OK by inspection	Found OK by inspection
Overall assessment	2	4	2	2

Operational risk

Risk analysis performed for all plants, however this does not mean that there is no risk so all plants are rated about middle in Table 6.9.12.

Table 6.9.12 Operational risk

	Gas-Phased Chemical Re-duction (GPCR)	Base Cata-lysed Dechlori-na-tion (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Occupational risk	Risk analysis	Risk analysis	Risk analysis	Risk analysis
Overall assessment	2	2	2	2

Mobility

The mobility of each of the 4 review technologies is relatively. The immediate costs related to relocation normally equal 40-50% of the capital investment costs. However, the BCD was reviewed most mobile, while the CKI technology is strictly stationary. Table 6.9.13 outlines the assessment performed on mobility.

Table 6.9.13 Mobility

	Gas-Phased Chemical Re-duction (GPCR)	Base Cata-lysed De-chlorination (BCD)	Container-based Incineration System (CIS)	Cement Kiln Incineration (CKI)
Mobility	Semi mobile	Rather mobile	Semi mobile	Not mobile
Overall assessment	3	2	3	5

6.10 Summary and discussion

In Table 6.10.1 please find the overall rating scheme as a conclusive result of the performed detailed review based on 21 selected review criteria covering technical, environmental and economic issues.

Table 6.10.1 Overall rating of the review of selected POP elimination technologies

Parameters	GPCR	BCD	CIS	Cement Kiln
1. Materials consumption	2	5	2	1
2. Energy consumption	3	5	2	1
3. Emission	1	2	4	4
4. Others	2	4	4	3
5. Overall environmental evaluation - mean	8/4=2	16/4=4	12/4=3,0	8/4=2.2
Environmental evaluation	**2**	**4**	**3**	**2 .2**
6. Treatment costs	1	5	1	1
7. Analytical costs	1	5	1	1
8. Capital investment costs	4	1	1	5
9. Marginal costs of investment	2	5	1	1
10. *Cost of relocation (not part of "mean" below)*	(3)	(2)	(3)	(5)
11. Overall economic evaluation - mean	8/4=2	16/4=4	4/4=1	8/4=2
Economic evaluation	**2**	**4**	**1**	**2**
12. Capacity	1	5	2	2
13. Comprehensiveness	3	4	2	2
14. Maintenance (Robustness)	2	2	3	2
15. Transfer of Know-How	1	2	1	3
16. Special supply lines	3	2	2	2
17. Rest products under control	2	4	4	4
18. Occupational health	3	4	2	2
19. Operational risks	2	2	2	2
20. Mobility	(3)	(2)	(3)	(5)
21. Overall technical evaluation - mean	17/8=2.1	25/8=3.1	18/8=2.3	19/8=2,4
Technical evaluation	**2.1**	**3.1**	**2.3**	**2.4**
Total mean (5+11+21/3)	**6.1/3: 2.0**	**11.1/3: 3.7**	**6,3/3: 2,1**	**6.6/3: 2.2**

6.10.1 Critical assumption

It has to be emphasised that Table 6.10.1 is entirely subjective and the scheme should only be read together with the total text of this chapter. However, the scoring and the weighing of scores are based on our best estimate. Furthermore, who can decide what is most important: technology, environment or economy? What about the missing issues? In fact it can be proven mathematically that this way of comparing things is not possible. Nevertheless, the scheme hopefully makes it easier for relevant CEE key resources to discuss and overview the extensive amount of relevant information in a single glance with the risks of over-simplifying the complexity of the technology related review.

Evaluation

During 2002, the consultant's expert team visited plants in Australia, Canada, Norway and Denmark, made detailed interviews, asked critical questions, performed literature review and customers re-evaluation of the technologies to the extent possible. The detailed description of the technical, environmental and economic elements of each technology is our conception of the technologies based on our visit and of our reading of technical material. Finally, prior to publishing, the participating vendors have reviewed the early drafted material for major corrections of errors and any mishaps.

We have evaluated the technologies against each other. The cyclone reactor though, has not been visited and examined by the present authors, but we rely on information received from other COWI employers working closely with this technology. However, due to lack of exact knowledge on key areas of economy and environmental performance, it has been decided not to give any evaluation of that plant.

As outlined in Table 6.10.1, the technical, environmental and economic criteria were reviewed in detail.

Technical performance

When reviewing the technical performance it was revealed that the GPCR, the CIS and CKI are rated above average.

Generally, the 3 technologies are equal in technical performance. The BCD plant on the contrary came out below average in the technical evaluation, mostly due to low capacity, weak performance of comprehensiveness, and weaker occupational health control.

Environmental performance

In the environmental performance, the report finds the performance of the GPCR the best, whereas the CIS and the CKI are still rated above average, but not as good as the GPCR, mainly due to lack of knowledge about emissions in residual products. Again, the BCD plant was evaluated below average on all points beside on emission where it was fine and above average.

Economic performance
In the economic performance, the report outlines the performance of the CIS plant as the best on all points. The GPCR and the CKI is still above average, but not as good as the CIS (even if you take into account that the CIS can not treat as much halogen containing materials per hour as the GPCR), mainly due to the capital investment costs. Again, the BCD plant is evaluated to below average on all points beside capital investment costs.

Evaluation summary
Looking on the overall evaluating process, a group of 3 technologies seems to perform (technical, environmental and economical) better than the BCD technology. These are GPCR, CIS and CKI that are evaluated above average in mean. On the other hand, the BCD plant is evaluated to below average and not as mature and versatile as the other plants.

The three plants in the first group are more or less equal in the environmental and the technical evaluation, but are diverting in the economical part. The capital investment costs are higher for the GCPR than for the comparable CIS. The cement kiln is in that respect in a class by itself. On the other hand, if one uses an existing up-to date cement kiln, then the treatment costs per tonne are comparable.

The general conclusion of the performed detailed review outlines that based on global market survey and filtration of incoming information on a number of merging technologies, two technologies seems to have the potential as optional POPs waste eliminators in the CEE Region, the GPCR and CIS technologies.

This is further underlined by the fact that the CIS technology has scheduled operational activities ongoing in Latvia (Latvia is also in the recent DG-Environment report on Obsolete Pesticides Status in the candidate countries grouped in category 1 - countries which are far advanced in their efforts solving the obsolete pesticides problems).

In parallel, the GPCR technology is in progress of scheduled activities in the Slovak Republic via a basket funded project (Slovak government, private industry, GEF funds, etc.). Both technologies wish to utilise these market platform options as demonstration objects for further exploitation. As described earlier in the report, the market in the CEE Region is not at present open for commercially operated POPs waste elimination technologies. However, through these two "ice-breaking" initiatives, a new era within OP/POPs elimination is hopefully initiated leading to more broad solutions on hazardous waste in general in a specific CEE context complying with not only national priorities, but also with international binding environment protocols and conventions related to POPs and related chemicals.

Annex 1: Russian planning procedures for the establishment of elimination capacity

In the following, a brief discussion of the legal and regulatory requirements stated in official documents of the Russian Federation is outlined as an example of the number of proceedings a given POPs elimination technology must follow obtaining an operational certificate. On one hand, these requirements still have their roots in the USSR era and on the other hand they reflect present trends of the environmental cooperation between the 12 CIS countries. Thus, the requirements in the RF are to a certain extent similar to those existing or prepared in other CIS countries.

Introduction of a given technology for POPs elimination in the Russian Federation, like in other CIS countries, will have to follow requirements stated in a great number of legal and regulatory documents. The key documents for POPs elimination projects in the Russian Federation are the overall Law on Environmental Protection (2002) and the Law on the Environmental Expertise (1995). Similar laws exist in other CIS countries. There is also a mechanism for international environmental expertise within the CIS.

State environmental expertise

According to the laws, the projects related to development of new technologies, as well as projects of several other profiles in the CIS countries are subject to the procedure of the State Environmental Expertise, which assumes environmental impact assessment and presenting its materials to the state expertise together with other relevant documentation. There are 4 major participants of the EIA: (1) the client, (2) local authorities, (3) the public and (4) the state bodies for environmental expertise and other executive bodies.

1): The client is a legal entity or a person responsible for the organisation of the EIA (on their own or involving other legal entities and persons) and submitting the EIA materials and other documentation to the environmental expertise.

3): The public means one or several persons or legal entities, as well as organisations without legal status, except the client and other persons carrying out activities related to the considered project in accordance with their responsibilities prescribed by law or contractual relations with the client.

The EIA procedure is typically carried out in 3 phases:

- Development of the EIA plan;
- Preparation of the draft EIA materials; and
- Preparation of the final EIA materials.

For investment projects (which the establishment of POPs elimination capacity would be regarded as) the client should perform these 3 phases at every stage of development of project documentation presented to the state environmental expertise. And the outputs of each phase are to be discussed with the public. The volume of the EIA materials typically should not exceed 200 pages. For particularly complex projects the materials could exceed 200 pages. Maps, drawings and other data could be presented as annexes to the materials.

In cases where the project documentation is classified and the public access can not be provided to all documents, only the environmental part of the materials is to be made available for all the participants of the EIA, including the public. According to the RF legislation, environmental information cannot be classified.

Other relevant laws and regulations
The document called "Regulation on licenses for hazardous waste management" (approved by the Resolution of RF Government No 556 of 20 May 1999) appoints the State Committee for the Environmental Protection (now integrated into Ministry of Natural Resources) and its territorial bodies as the offices providing licenses for management of hazardous waste and keeping the register of licenses. The routine for a license withdrawal is also specified.

The RF Law on protection of the Atmospheric Air (No. 96-FZ of 4 May 1999) contains among others the requirement regarding control of emissions during waste treatment and incineration. A set of international environmental standards in accordance with the ISO 14000 series is from 1999 introduced in the country as the national standards.

The Governmental Resolution No. 183 of 2 February 2000 specifies responsibilities for the establishing limits (maximum permissible/allowable impact on the atmospheric air, methods of control, type of sources under control) by the Ministry of the Natural Resources and the Ministry for Health Protection. The former is addressing the aspects other than affecting the human health, since the latter take care of this. The emission limits for a stationary source are provided by territorial bodies of the Ministry of Natural Resources based upon sanitary-epidemiological resolutions confirming compliance with the sanitary regulatory requirements.

The "Regulation regarding emission of harmful (polluting) substances into the atmospheric air and harmful physical impact on it" (approved by the RF Governmental Resolution No 183 of 2 March 2000), addresses *inter alia* the situation, when a legal entity, having sources of harmful (polluting) emissions, cannot meet the maximum permissible emission rates (MPER).

In this case, the territorial environmental authorities upon consultations with the sanitary/epidemiological authorities may establish a set of temporarily adapted emission rates (TAER). Although, doing so, they are to:

- specify the time schedule for gradual decrease of emissions down to the maximum permissible rates;
- submit the TAER to the authorities of the RF constituent (Oblast level) for approval; and

- establish the TAER for the time period of gradual decrease of emissions down to the MPER and approve the decrease plan developed by the legal entity getting the TAER and responsible for the plan implementation.

The industrial safety control is the subject to the law on "industrial safety of the hazardous industrial facilities".

The RF "Law on sanitary-epidemiological wellbeing of the population" (No 52-FZ of 30 March 1999) describes the rights and responsibilities regarding, *inter alia*, collection and treatment of waste and regulation (setting the norms and sanitary rules, certification, state registration of substances and products, sanitary-epidemiological supervision, socio-hygienic monitoring).

The above listed key RF regulations must be followed in order to obtain any possibility for establishing possible POPs elimination capacity. In below, please find alternative routing (export) guidance.

Transboundary (transit) transport of hazardous waste (within the national obligations under the Basel Convention) is controlled in accordance with the joint Order of the Ministry of Natural Resources, Ministry for Health Protection, State Technical Supervision Board and State Customs Committee of the Russian Federation (No 787/396/256/910 of 31 December 1998).

Two Federal Target Programmes, one on dioxins/furans and the second on obsolete pesticides, assuming their country-wide inventories, were started in the Russian Federation in 1996. However, the financing was not sufficient for their completion, which still leaves RF in a position where large stocks of OP/POPs are stockpiled. Even in a country like Russia, counting for more than 100,000 tonnes of OPs products, no substantial elimination capacity has been established due to lack of finance, awareness on technical solutions and opportunities and political constraints.

Conclusively, a given POP elimination technology must be based on e.g. Russian outlined regulative procedures and in order to obtain operational permits, follow an extensive number of regulations and permissible routings. The fact that experiences with elimination of highly toxic chemicals is limited in the region, and no other conventional solutions like e.g. incineration of municipal waste in many Western European countries have "paved-the-road", not necessarily only for incineration technologies, but in general sense for performing elimination activities, makes it very difficult for any technology to penetrate the market platform in CIS and also the CEE Region.

The typical list of the EIA materials presented for the State Environmental Expertise of a project in CIS countries, is

1. Front page:

   - The Client, its domicile and contact details;
   - Project title and location of implementation;
   - Name and contact details of a person, responsible for provision of further

information regarding the presented documentation;
- Type of the document in case of investment project (statement of intentions, appraisal/pre-feasibility study, feasibility study/design);
- Specification of the document version (draft, final version, amendments);
- Abstract of the document (one paragraph); and
- Signature and stamp of the client.

2. Brief (up to 15 pages) description of the work (executive summary) with its major conclusions; description of contradictions, including those identified during discussion; remaining problems, including choice of alternative solutions;

3. Table of contents for the materials;

4. Objective and purpose of the envisaged project;

5. Description of project alternatives (alternative location of the site, technology and other options within the client's competence), including the proposed and the "zero" ("no-project") options;

6. Possible contradictions of the envisaged project and its alternatives to the objectives of the national, regional or local policy regarding environmental protection and nature management, to the regulatory documents;

7. Description of the elements of the environment which could be affected by the proposed project or its alternatives;

8. Description and comparative analysis of possible types of environmental impact of the project and its alternatives and the impact scale;

9. Description and comparison for the project and its alternatives of the direct impact (within the project area and during the project implementation) and of the indirect impact (taking place later and/or at some distance from the project area);

10. Demand and availability of renewable natural and energy resources for the project and its alternatives;

11. Impact mitigation measures for the project and its alternatives, including re-use of resources;

12. Description of forecast techniques, background environmental data and assessment of the impact forecast reliability for the project and its alternatives;

13. Identified information gaps and uncertainties in impact forecasts for the project and its alternatives;

14. Brief description of environmental management and monitoring programs as well as post-project (decommissioning) analysis;

15. Description of criteria and reasoning for the project option choice;

16. Non-technical summary understandable for general public and accompanied with maps, charts, etc;

17. Protocols of the public consultations of the materials including the following:

    17.1 Method of informing the public about the place and time of the public consultations;

    17.2 Place and time of the public consultations;

    17.3 List showing positions and contact details of representatives of the local authorities organising the public consultations;

    17.4 List of participants of the public consultations with the contact details of the organisations they represent or their private contact details (optional);

    17.5 Issues discussed in presentations by the participants of the public consultations and list of presentation abstracts (if they are provided by the participants);

    17.6 All the presented comments and suggestions with the specified names of the authors;

    Recording of the public consultations should be carried out and the records (hard copies, tapes) should be filed by the local authority which organised the public consultations.

    The minutes/protocol of the consultations should be prepared, signed by the secretary and chairman of the consultation meeting. It should be also signed and stamped by the representative of the local authority that arranged the consultations. The protocol should be within 10 days upon the consultations forwarded by registered mail to all the registered participants of the consultations.

18. Overview of comments and suggestions received from the public and description of the mode of their reflection by the client or non-reflection with specification of reasons for non-reflection;

19. Mailing list of the information forwarded to the public at all the stages of EIA;

20. List of persons involved in preparation of the EIA materials;

21. Mailing list for the final version of the EIA materials, including among others: (i) the ministries and other agencies and bodies, provided their co-

approvals for the suggested project; (ii) the participants of the EIA presented their written comments on the draft materials;

22. Index, and

23. Annexes including only the materials prepared for the EIA of the project and its alternatives and the materials illustrating the conclusions upon the EIA.

    The Annexes are not distributed together with the set of materials. They are kept by the client and should be provided to the EIA participants upon request.