Specific NOx briefing

This paper is part of the "EEB Background briefing on 2017 LCP BREF transposition (for coal-fired power plants)"

Published in August 2020

Written by Goran Kovacevik and Christian Schaible

Contact: goran.kovacevik@eeb.org and Christian Schaible christian.schaible@eeb.org

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Current regulations for DeNOx on coal/lignite fired Large Combustion Plants >50 MW thermal input

Prior to the adoption of the revised 2017 LCP BREF, operators across EU Member states have been installing primary (for lignite plants) and secondary (for hardcoal) abatement techniques to achieve <200 mg/Nm^3 NOx for >300MWth boilers.

This is based on EU legislation dating back to 2001 (LCP-D)[1]/ 2010 (IED)[2] requiring these levels to be met for existing plants as from 2016 (except for those plants where Member States made use of certain optional derogations, such as the Transitional National Plan and the Limited Lifetime Derogation in Chapter III of the IED). The 200mg/Nm^3 level for plants >300MWth has also been set as upper range in the 2006 LCP BREF[3].

Under the revised 2017 LCP BREF[4], the upper BAT-AELs (negotiated EU de facto limits) for NOx (BAT.20) set the following limits for existing plants:

- Max 175 mg/Nm^3 (yearly average) for lignite and FBC hard coal boilers put in operation latest 7 January 2014;
- Max150 mg/Nm^3 (yearly average) for PC hard coal boilers put in operation latest 7 January 2014.

The BAT levels accepted – the lower range – state that:

- <85mg/Nm^3 is achievable for lignite-fired boilers using the SCR DeNOx technique.

  NOTE: the level of 85mg/Nm^3 is the maximum emission level expected when SCR is installed in lignite boilers, as stated in the footnote 4 in BAT 20. The EEB holds data from the only EU lignite plant with SCR in operation since March 2015 (the Sostanj 6 unit), showing that levels of 46mg/Nm^3 are achieved[5]. The US Plant Oak Grove achieved constantly (2012-2014) emission levels at 50-80mg/Nm^3 when converted to EU methods.

[1] Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants (the LCP Directive)

[2] Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control Recast)

[3] Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques for Large Combustion Plants, July 2006

[4] Best Available Techniques (BAT), Reference Document for Large Combustion Plants, 2017 https://eippcb.jrc.ec.europa.eu/reference/large-combustion-plants-0

[5] Data is available in the EEB Industrial Plant data viewer, look for plant ID SL0019 (TES T), Details and Documents / CEM folder https://eebidp.sharepoint.com/sites/IndustryDatabase/Test%20library/Forms/AllItems.aspx?id=%2Fsites%2FIndustryDatabase%2FTest%20library%2FLCP%2FSL%2FSI0019%2FCEM&p=true&originalPath=aHR0cHM6Ly9lZWJpZHAuc2hhcmVwb2ludC5jb20vOmY6L3MvSW5kdXN0cnlEYXRhYmFzZS9FdjBCMWtneUpZWkpwT29tREQ3SzFtTUJzRm1oR09WWXBzMzdTMzVoc05sUlJRP3J0aW1lPXhTS3ZpazdzMTBn

- 65mg/Nm³ for hardcoal pulverised combustion.

  NOTE: far lower levels can be achieved for hardcoal PC boilers that combine primary measures with SCR, for instance in certain key regions in China levels as low as 20mg/Nm³ have been achieved.

The lower figures included in the BAT-AELs are based on "good" performers in the EU from data collected in 2010 (for hardcoal plants), and on the US lignite plant Oak grove that implements SCR as well as "expert judgment" (for lignite plants). EU lignite plants that went in operation before 2014 were not required to fit secondary NOx abatement measures. Therefore, they optimised primary measures to 120-190mg/Nm³, due to the laxist ELV set.

For this reason, the EEB did submit a split view requesting that the upper BAT-AEL for existing plants should be brought down to 100 mg/Nm³ for lignite fired PC/FBC boilers, and max 85mg/Nm³ for hardcoal PC boilers, because these are the typical emission levels achieved with secondary abatement techniques in place. However, the EIPPCB did not "accept" our first split view on lignite.

The upper emission levels set for "new plants" are:

- 50 – 85 mg/Nm³ (yearly average) for PC lignite and FBC hard coal boilers (including new and existing plants);
- 65 – 85 mg/Nm³ (yearly average) for PC hard coal boilers.

  NOTE: these levels are in facts based on emissions data submitted according to "good performer" 2010 emissions data, meaning that those levels are in fact also achieved in existing (pre-2014) plants. These levels largely confirm that the application of SCR is BAT for both lignite and hardcoal fired plants.

DeNOx abatement techniques for lignite fired boilers

Since the first limitation of the air pollution for LCPs, operators have been required to improve their environmental performance. Depending on the type of feedstock (lignite or hardcoal) and on the type of the boiler (PC or FBC), operators were implementing various abatement techniques. Lignite fired units, starting with the entry into force of the LCP Directive and as from the year 2016 (the deadline for alignment with the IED), could achieve emission limits 200mg/Nm³ by "simple" installation and/or optimization of various primary abatement techniques.

For hardcoal boilers the 2006 LCP BREF had already set an upper BAT-AEL level (daily averaged) of 200mg/Nm³. This is achievable by implementing secondary abatement techniques, Selective Non-Catalytic Reduction (SNCR), and Selective Catalytic Reduction (SCR).

Since 2016, all EU lignite-fired boilers are obliged to reduce emissions to 200mg/Nm³, which can be achieved with primary techniques only. However, certain operators that made use of the Chapter III transitional derogation(s) have been allowed to emit more. On the other hand, all EU hardcoal plants have been required to implement SCR by 2016, except some operators that made use of the derogations under the Chapter III of the IED, such as the Transitional National Plan (TNP)[6]. The list of countries that allowed these optional derogations are Bulgaria, Croatia, Czech Republic, Finland, Greece, Hungary, Ireland, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and the United Kingdom. The UK has all its coal plants in Chapter III derogations such as the TNP, even the one fitted with SCR (Ratcliffe), that could technically easily achieve an emission limit below 85mg /Nm³.

At the end of the derogations on 30 June 2020 (for the TNP opted in plants), these plants faced the requirement to implement those secondary techniques, and could either opt for a 1500 hours max/year operating regime, or shut down.

The real issue is however concerning the lignite boilers, and their capacity to achieve the current emission levels of 200mg/Nm³, followed by the new BAT-AELs set in the revised LCP BREF upper level of 175mg/Nm³ (compliance deadline is August 2021). Depending on what the competent authority will require in its permit, the operators will have to install SCR or SNCR (in case no secondary abatement technique is in place), optimise existing SNCR or, in the worst case, get away with derogations and continue with just an optimisation of primary measures.

The secondary techniques have a different degree of emission reduction potential, and at the same time a large difference in terms of the cost of putting them into operation. The costs and benefits, cross-media implications for one or the other are therefore presented.

SNCR on lignite boilers

SNCR is a standalone NOx control technique and is combined with other primary techniques such as combustion controls. Conceptually, it is quite a simple technology, where a reduction agent (urea/ammonia) is injected directly in the boiler chamber and reduce NOx formation trough a chemical reaction. The potential of SNCR reduction vary over a wide range, typically 30-50%. If the size of the boiler increases, the reduction efficiency would decrease, especially for boilers ≥500 MWth[7]. Some of the parameters that might have an influence on the abatement efficiency are: temperature, residence time, type of NOx reducing reagent, reagent injection rate, uncontrolled NOx level, distribution of the reagent in the flue gas, and CO and O_2 concentrations. Inadequate optimisation of the abovementioned parameters, such as an inappropriate temperature window

[6] The list of TNPs is available here.

[7] Selective Non-catalytic Reduction (SNCR) of Nitrogen Oxide Emissions: A Perspective from Numerical Modeling, 2017

(too low) for chosen reagent (ammonia/urea) to react, a short or long residence time, a high or low reagent injection rate, an uncontrolled/uneven distribution of the reagent for the specific boiler unit, will affect the reduction efficiency of the SNCR, creating **ammonia slip (NH_3)** as a by-product.

The main disadvantage of the SNCR system is the ammonia slip resulting from incomplete reaction of the NOx reducing reagent. An uncontrolled creation of it may result in one or more additional problems. These includes: the formation of ammonium bisulfate or other ammonium salts, which can plug or corrode the air heater and other downstream components; ammonia absorption on fly ash, which may make disposal or reuse of the ash difficult; the formation of a white ammonium chloride plume above the stack; and the detection of an ammonia odour around the plant.

Ammonia emissions to air leads to the formation of secondary PM2.5, which causes environmental and human health damage. It is therefore very important to prevent any ammonia slip. Ammonia slip should be always <2mg/Nm³, which is the case if a SCR DeNOx is used, but the BREF allows to go up as high as 10mg if SNCR is used (achieving a 50-60% NOx abatement) without wet abatement. This should not be considered as 'state of the art' for any >300MWth boiler. An additional issue related to the use of the reagent is the creation of N_2O, which contributes to greenhouse gas emissions.

Some hardcoal plants achieving NOx levels <85mg/Nm³ have reported much lower ammonia slip based on continuous monitoring, but these use SCR combined with wet abatement (wetFGD): Eg1 one reference plant[8] # 367 Maasvlakte 66mg/Nm³ (yearly average NOx level) with NH3 slip at 0.2mg/Nm³, E.g. 2 reference plant #253 Torrevaldaliga Nord 69mg/Nm³ (yearly average NOx level) with NH_3 slip of 0.5mg/Nm³. However, the NH_3 emission loads per year (for the reference year 2010) are still considerable: #367: 2,2 tonnes NH_3 (540 MWel output); #253: 8,4 tonnes NH_3 (660 MWel output).

SNCR on hardcoal boilers

The EEB does not regard SNCR on hardcoal boilers as constituting BAT because of its low abatement efficiency. It is in any case unlikely that the upper emission 2017 BREF limit of 150mg/Nm³ would be achieved in >300MWth hardcoal plants under stable conditions and without proper prevention of ammonia slip (see above).

However, the 2017 LCP BREF allows higher NOx levels up to 320mg/Nm³ (daily average) for hardcoal PC boilers if those would not operate more than 1500 hours/year. It is therefore very likely that operators choosing that compliance option would rather rely on SNCR for those plants. There is a high risk that the TNP opted hardcoal plants may consider that as a lower costs compliance strategy to be achieved after June 2020, when exiting the TNP derogation, e.g. the UK plants. In some cases it

[8] See the full list of reference plants mentioned in the pre-cited 2017 LCP BREF, in Annex 13.1

may be judged as a reasonable trade-off by national NGOs to force hardcoal / lignite plants to stay in a reserve operation[9].

SNCR – New technology approaches

The following section presents basic knowledge of recorded alternative approaches, using upgraded technologies, to be considered as possible compliance techniques with the new NOx BAT-AEL for lignite boilers. As the regulations for stricter ELV have been set in the past, the tech suppliers of SNCR technologies have been putting efforts in finding technical solutions for increasing the reduction potential, and at the same time decrease the overall expenses for their techniques.

Typical new approaches incorporate adjusted or improved primary measures (e.g. low NOx burners) with adequate upgrade of the existing SNCR. The so called "Hybrid systems - SNCR/SCR" adjust the existing SNCR upgrading with a few layers of catalyst (SCR) to match the efficiency of a typical new SCR unit. SNCR would be installed to remove normally 40% of NOx, with SCR downstream removing 80% of the remainder. This would achieve an overall reduction of 88%, with a significantly smaller SCR component than with a full SCR system alone. Removing 88% of 450 mg/Nm^3 NOx would reduce the level to 54 mg/Nm^3, which would go much further beyond the stricter BAT-AEL level referred to for hardcoal boilers. Some could also oxidise mercury to soluble HgO.

Some of the recorded advanced technologies are the following:

- SNCR Trim[10] has been applied to more than 21 coal-fired utility boilers ranging from 35 to 720 MWth. Typical NOx reductions of 25–35%. Capital costs are approximately 4-8 €/kWth for a single level of injectors;
- Rich Reagent Injection[10] (RRI) has been demonstrated to achieve 30% NOx reductions in two existing cyclone-fired boilers with overfired air. The capital cost for RRI alone is approximately 7-10 €/kWth;
- NOxSTAR[10] full-scale demonstrations have achieved 45–50% NOx reduction, with the possibility to reach 70–80% for some applications. Capital costs are high, ranging from 50-65 €/kWth;
- Rotamix[10] have been applied on a 250 MW boiler and 350 MW boiler, and reductions are reported to be 25-40%. Capital costs of 13-21 €/kWth for a 250 MW boiler and 8 -13/kWth for a 350 MW boiler and larger.

[9] Note that the EEB position was to reject this 1500 hours sub-derogation for hardcoal plants because there is no proper cost-benefit justification to allow that high number of derogation. For lignite plants the EEB proposed an absolute shutdown deadline set for 2024 in those cases.

[10] US EPA's Air Pollution Control Cost Manual report, Section 4 "Reference Chapter 1 Selective Noncatalytic Reduction"

- Advanced SCR[11] applied to 200 TPH Boiler (TAIWAN) has shown potential for reduction up to 78%, ensuring resulting stack emissions of NOx below 100mg/Nm3. A SCR system cost was 50% of the full SCR option, and all performance guarantees where met.

BAT-AELs compliance– Cost of secondary techniques

Alignment with the new BAT-AEL's for existing thermal power plants can be achieved by installing new alternative SNCR/SCR or fitting a SCR system.

Choosing the most appropriate approach for installation of the techniques will depend on a number of factors, inter alia, the age of the installation, the level of current emission, fuel characteristic, existing measures, physical space for an appropriate upgrade of the existing system, and in particular the level of the ELV set by the authority.

There are available online tools for calculation of cost vs removal potential for DeNOx techniques. The Task Force on Techno-Economic Issues (TFTEI) under the Convention on Long Range Transboundary Air Pollution, promote the tool ERICCa_LCP - Cost Calculation Tool for Emission Reduction Measures in LCPs. The user manual and the technical document are available here[12].

Capital costs for SNCR installations are generally low due to the small amount of capital equipment required, and the cost per unit of output decreases as the size of the source increases. Most of the cost of using SNCR is operating expense. A typical breakdown of annual costs for utilities is 25% for capital recovery and 75% for operating expense. However, due to the low reduction potential of the SNCR technique, it seems that any analysis of cost versus environment ratio gives basis to operators for further investment. Instead, the table below summarises a breakdown of capital cost for systems such as: SCNR/RRI, hybrid system SNCR/SCR, and SCR as standalone technique, to create a basis for information that could lead to a clearer indication of the level of investment required to properly achieve the new BAT AEL's target.

[11] Selective Non-catalytic Reduction (SNCR) of Nitrogen Oxide Emissions: A Perspective from Numerical Modeling, 2017
[12] http://tftei.citepa.org/en/work-in-progress/costs-of-reduction-techniques-for-lcp

The operators / competent authorities will mainly address the cost-proportionality of various compliance scenario:

Source	**Process**	**NOx removal**	**New or retrofit**	**Comments**	**Cost for 500 MWel, €million**
SteamPro/ PEACEmodelling (2013)					
SteamPro/ PEACE	SCR	80%	new	includes nominal balance of the plant (BOP)[13] and erection	24.00
SteamPro/ PEACE	SCR	90%	new	includes nominal BOP and erection	27.43
SteamPro/ PEACE	SNCR	40%	new	includes nominal BOP and erection	2.18
SteamPro/ PEACE	SNCR/ SCRhybrid	60%+ 80% (88%)	new	includes nominal BOP and erection	20.20
Parsons Brinckerhoff North America (2013)					
SCR Supplier (US)	SCR		retrofit	includes BOP and erection	45.75
SCR Supplier (US)	SCR		retrofit	includes BOPand erection	85.80 – 102.95
2017 LCP BREF (based on 2013 information, BREF Chapter 3 page 218-234)					
Austria and Germany	SCR		new	based on cost per m³/h exhaust; includes BOP and erection but not catalysts; certain assumptions	43.37

[13] The term 'BOP' – Balance of plant refers to all additional cost (auxiliary/supporting actions) for retrofit/installation of the new technique excluding the cost of the technique itself

Austria and Germany	SCR	60 – 90%	retrofit	not clear if BOP or erection included	25.16 – 50.33
Eurelectric reference	SCR		unclear	not clear if BOP or erection included	34.32 – 57.20
Eurelectric reference	SNCR/ SCR hybrid			two thirds of equivalent SCR	17.16 – 40.03
UK submission to LCP BREF review (2011)					
Barmoor	SCR	to 200 mg/ Nm³	retrofit	not clear if BOP or erection included	40.18
Barmoor	SCR	to 50 mg/ Nm³	retrofit	not clear if BOP or erection included	54.90
Worldwide database	SCR		retrofit	average €/kW; excludes civils and boiler modifications	60.61 low 92.62 average 193.24 high
JEP/EA/Defra	SCR		retrofit		85.76
Catalyst suppliers	SCR		unclear	Considered to be significantly underestimated	11.43
*US EPA Report	RRI + SNCR	25% + 40%	retrofit		5.18

*Data source: US EPA's SNCR Guidelines Update, 2004 and Coal and Gas Assumptions, Parsons Brinckerhoff, 2014[14].

BUND (FoE Germany) and Klima-Allianz (Climate Alliance) Germany commissioned a study on NOx emissions 2016/2017 from German Coal and Gas Assumptions, Parsons Brinckerhoff, 2014 coal power plant in line with the new LCP BREF transposition to Őkopol GmbH[15].

[14] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/315717/coal_and_gas_assumptions.PDF

[15] https://meta.eeb.org/2018/10/25/german-coal-turns-up-pollution-to-save-money-for-penny-pinching-firms/

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Published in August 2020

The study gives an overview for both lignite and hard coal power plants, current abatement techniques in place, remaining operating lives of power plants, providing economical values for NOx reduction for various cases. By introducing a NOx limit value of 85 mg/Nm^3, on an annual average, emissions from large coal-fired power plants in Germany would be reduced by more than half (-52%). For lignite-fired power plants, an annual NOx limit value of 85 mg/Nm^3 results in an annual NOx reduction of about 55,700 tons (-55 %) from German lignite power plants. The reduction would cost approx. 0.074 cents per kilowatt-hour generated. For lignite-fired power plants with a remaining lifetime of less than 5 years (up to 2024), for which catalyst installation is judged as economically unreasonable, 150 mg/Nm^3 is proposed as the annual average limit value[16]. This is achievable with cost-effective reagent injection (SNCR technology) meaning a potential extra cost of about 0.019 cents per kilowatt-hour produced.

If German hard coal-fired power plants, where to comply with a NOx limit value of 85 mg/Nm^3 on an annual average the annual NOx reduction would be of about 26,700 t (-47 %). The further NOx reduction would possibly lead to an additional cost of about 0.036 cents per kilowatt-hour generated.

In all cases the cost to the polluter (for catching up with state of the art pollution prevention standards already judged economically viable for the sector) needs to be put in perspective to the social benefits such as from avoided extra air pollution generating human health costs. The EEB would suggest adapting to US price levels the Value of Statistical Life cost method used by the European Environmental Agency (EEA), which is outdated[17].

Results of primary abatements techniques in combination with SNCR in Belchatow LCP – Unit 3, located in Poland with capacity of 380 MWel using lignite as resource were published[18]. The achieved results were decrease of daily average NOx emissions, measured at the emission monitoring system downstream ESP, from 200 mg/Nm^3 to less than 150 mg/Nm^3, providing a basis for promotion of SNCR as possible technology for achievement of ELVs set at a level of 150mg/ Nm^3 [19].

The measured production of ammonia slip, as by-product, was less than 5 mg/Nm^3. The applied technology is consisting of Reduction agent (doped urea 40%), compressed air and dilution water; one Pressure reduction station dilution water; four mixing and measuring module; two levels of SNCR injection lances; one temperature mapping system and one NH3 measuring system.

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[16] The EEB has expressed reservations on this assumption. In our view the benefits for meeting a NOx emission level of maximum 80mg/Nm^3 for all German lignite plants – requiring SCR-- would already outweigh the costs to operators after just 5 years. The reason is that SCR would allow much lower NOx emissions than 80mg/Nm^3.

[17] See section 5.3 https://eeb.org/library/an-eu-industrial-strategy-for-achieving-the-zero-pollution-ambition-set-in-the-european-green-deal/

[18] Comparison of two SNCR applications in Belchatow, ERC Krakow, May 2018

[19] Refer to IPDV - PL 0335 CEM data for year 2016

In ELEKTROWNIA „RYBNIK" S.A. (ERSA)[20], Rybnik Power Plant member of the EDF Group, there was certain tests on the Unit 4 with capacity up to 225 MWe. Installation of new Low-NOx burners and overfire-air system, latter followed by installation of SNCR. Achieved NOx-Emissions were in the range of 157 – 213 mg/Nm^3.

The SCR should be considered as a standard technique for DeNOx for any boilers >300MWth. In the BREF Document for Large Combustion Plants, Chapter 5 "Environmental performances and operational data for NOX emissions", there are references showing NOX emissions to air from well-performing coal PC boilers larger than 300 MWth. Reported plants are using an SCR in combination with one or various primary techniques for reducing NOX emissions: such as Plant 34V – Vattenfall, Nordjyllandsværket unit 3, Aalborg, Plant 219 – Enel Produzione S.p.A. - Impianto termoelettrico di Fusina - FS4 – Venezia, Plant 253V – Enel Produzione S.p.A. - Torrevaldaliga Nord – Civitavecchia, Plant 367 – E.on - Maasvlakte-1, Plant 662 – FHKW Mellach.

Some of those plants have already closed, but short-term (half-hourly or hourly) averages provided from those plants, dating back to 2010 data, range from 45 mg/Nm^3 to 190 mg/Nm^3.

In the EEB industrial plants data viewer[21], many hard coal boilers show 2017 NOx emissions levels below 80mg/Nm^3[22] e.g.: DK0087 (Fynsvaerket) with 35mg/Nm^3; DK0083 Amaegervaerket 3 with 38mg/Nm^3 with ELV set on 200mg/Nm^3; DE0181 HKW Flensburg with 42mg/Nm^3; NL0027 Rotterdam 43mg/Nm^3, DK0013 Esbjergvaerket with 46mg/Nm^3 with ELV set on 200mg/Nm^3; SK0038 Evo I (unit 15 and 16) 51mg/Nm^3, NL0152 Hemweg8 with 52mg/Nm^3; DE5086 HKW Moorburg with 61mg/Nm^3 with ELV set on 70mg/Nm^3; NL0523 RWE Emshaven unit A with 64mg/Nm^3 with ELV set on 100mg/Nm^3; IT0154 Torrevaldaliga Nord 65mg/Nm^3 (stack 1), 72mg/Nm^3 (stack 2) and 67mg/Nm3 (stack 3).

The lignite fired boilers do not show the same results. Only the following plants achieve levels below 85mg/Nm3 so far: BG0013 Maritsa 3 achieving 93,5mg/Nm3 with ELV set on 200mg/Nm^3; CZ0060 Mondi Steti achieving 98,8mg/Nm^3 with ELV set on 150mg/Nm^3 (from 01/07/2020); and DE0268 Goldenberg 104,7mg/Nm^3. The EU lignite plant with a SCR (TEŠ T, Si0019) shows high NOx emissions of 140mg/Nm^3 due to a generous permit limit (150mg/Nm^3), meaning that the operator is not required to use the SCR to its technical potential.

[20] Rybnik Most Recent Operational Experiences with SNCR Applications for Coal-Fired Boilers, ERC Powergen Europe 2014, Cologne

[21] https://public.tableau.com/profile/schaible#!/vizhome/UnderDevelopment_EEB_LCP_DataViewertest4_15880952402100/HomePage?publish=yes

[22] Select the "compare plants" function, select show data by "Emissions (concentrations)", select under pollutants NOx and select fuel type and size