TEXTE
44/2016

Innovative techniques – best available techniques in selected sectors

Sub-project 1: Large combustion plants (revision of BAT reference document as from 2010)

For our Environment

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Innovative techniques – best available techniques in selected sectors

Sub-project 1: Large combustion plants (revision of BAT reference document as from 2010)

by

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Abstract

This report was created to aid the revision process of the BAT reference document "Large Combustion Plants" (LCP). It includes the summary of the national data collection of 50 LCPs in Germany. In addition to this, a first evaluation was carried out. Directions on how to use and interpret the presented data are given in chapter 2 and 5. To cover the topics of load flexibility and start-up/shutdown sequences, an additional chapter is included in this report. In this, the load-dependent emissions of power plants are presented, using the example of a hard coal-fired plant and a natural gas-fired CCGT plant. Furthermore, a draft for a biomass chapter is given, which could be implemented in the future BAT reference document.

Kurzbeschreibung

Der vorliegende Bericht ist im Rahmen der Unterstützung der Revision des BVT-Merkblattes „Großfeuerungsanlagen“ auf nationaler Ebene entstanden. Er enthält die wesentlichen Ergebnisse der Datenerhebung an rund 50 deutschen Großfeuerungsanlagen. Zusätzlich ist eine erste Datenauswertung dargestellt. Wichtige Hin-weise für die weitere Datenbehandlung und Auswertung werden in Kapitel 2 und 5 gegeben. Um dem zunehmenden Thema der Kraftwerksflexibilität Rechnung zu tragen, wurden für jeweils eine steinkohlebefeuerte und eine GuD-Anlage eine Fallstudie für den Zusammenhang der Emissionen von der Last bzw. den An- und Abfahrvorgängen durchgeführt. Am Ende dieses Berichtes findet sich ein Entwurf für das Kapitel über Biomasse im zukünftigen BVT-Merkblatt.

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The figures shown in the descriptions of evaluated plants or installations were taken from supplementary material, which was added to the questionnaires by the plant operators. They are used with the expressed content of the copyright owners and are authorised for publication in the context of this report. As this report is anonymised, it is not useful to indicate the sources or give references and is therefore not done.

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Glossary

General

AAV	Annual average value
AOX	Adsorbable organohalogens
BAT	Best Available Techniques
BImSchG	Bundes-Immissionsschutzgesetz, Federal Immission Control Act
BImSchV	Bundes-Immissionsschutzverordnung, German Federal Immission Control Ordinance; 13. BImSchV: Ordinance on Large Combustion Plants and Gas Turbine Plants (as amended and promulgated on 20 July 2004) 17. BImSchV: Ordinance on Waste Incineration and Co-Incineration (as amended and promulgated on 14 August 2003)
CCGT	Combined Cycle Gas Turbine
CFB	Circulating Fluidised Bed
CHP	Combined Heat and Power
COD	Chemical Oxygen Demand
Cont.	Continuous measurement
DV	Daily average value
DeNO_x unit	NO_x reduction unit (reduction of nitrogen-oxides to nitrogen)

DLE	Dry Low Emission burner design (gas turbine)
EEG	Erneuerbare Energien Gesetz, renewable energy law
Eff.	Efficiency (see separate Glossary below)
EIPPCB	European Integrated Pollution Prevention and Control Bureau
Equivalent full load operating factor	Calculated as fuel energy input during the reference year divided by the total operating time under normal operating conditions and then divided by the total rated thermal input of the whole combustion plant (i.e. the sum of all the combustion units).
ESP	Electrostatic Precipitator
EUROFER	European Steel Association
FGD	Flue Gas Desulphurisation
FGT	Flue gas treatment
GT	Gas Turbine
HA	Hourly Average
HFO	Heavy Fuel Oil
HHV	Half-hourly average values
HP/MP/LP	High Pressure/Medium Pressure/Low Pressure
HRB	Heat Recovery Boiler
ICA	Instrumentation, control and automation technology

IED	Industrial Emissions Directive (2010/75/EU)
KrWG	Kreislaufwirtschaftsgesetz, German Law of Life-Cycle Management
LCP	Large Combustion Plants
LFO	Light Fuel Oil
NG	Natural gas
Nm^3	Unit of volume at standard conditions – temperature of 273.15 K and pressure of 101 325 Pa
Normal Operating Conditions	The conditions during which a combustion plant is operating and discharging emissions into the air, excluding other-than-normal operating conditions (OTNOCs). Please note that normal operating conditions may include operation with higher load factors (i.e. closer to nominal load factor), as well as lower load factors (i.e. closer to minimal start-up load), depending on the plant demand/design.
OTNOCs	Other Than Normal Operating Conditions; Apart from operation under special permit conditions and start-up and shutdown periods, the following examples are considered Other Than Normal Operating Conditions: unplanned shutdowns, malfunctioning or breakdown of the abatement equipment or part of the equipment for which no derogation was granted by the competent authority under Article 37 of Directive 2010/75/EU, leaks, testing of new fuels/techniques, malfunctioning of instruments related to the process control, malfunctioning of instruments for emission monitoring.
PCDD/PCDF	Polychlorinated Dibenzodioxins and polychlorinated Dibenzofurans

Percentile	A percentile is the value of a variable below which a certain percent of observations fall (Wiki…)
Perio.	Periodic measurement
RDF	Refuse Derived Fuel
Rolling average value	As per Chapters III and VII, as well as Annex V, of Directive 2010/75/EU, the rolling period over 5 years is an important parameter for understanding the operational mode of the combustion plant. Therefore, by default, the rolling average is considered over the preceding 5 years. However, if the plant has been recently constructed or if there has been a major retrofit during this period that significantly changed the performance of the combustion unit, the number of years considered for the rolling average value is indicated.
SCR	Selective Catalytic Reduction
SNCR	Selective Non-Catalytic Reduction
ST	Steam turbine
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TRTI	Total rated thermal input (expressed as MW_{th}) (see separate Glossary below)
TSS	Total Suspended Solids
TUHH-IET	Institute of Energy Systems of the Hamburg University of Technology

UBA	Umweltbundesamt, German Federal Environmental Agency
UR	Utilisation ratio (see separate Glossary below)
OUR	Fuel utilisation factor (see separate Glossary below)
Validated	A value is validated, if the measuring uncertainty, which has been determined during the calibration process, is subtracted from the measured values.
vol-%	Volume percent
wt-%	Weight percent
WHG	Wasserhaushaltsgesetz, German Water Resources Act
WWT	Waste water treatment

Terminology related to "Efficiency"

Total rated thermal input	The rate at which any fuel (or a combination of fuels) can be burned at the maximum continuous rating of the combustion unit multiplied by the lower heating value of the respective fuel(s); expressed as MW_{th}. The total rated thermal input of a combustion plant is the sum of the total rated thermal inputs of each of its units.
Nominal (capacity)	Nominal capacity is the maximum continuous output or input power of a generating or consuming plant for which it has been ordered and installed (in accordance with the corresponding delivery agreements).
Gross electric power output	Electrical power output of the generator; if more than one generator is located at the combustion installation, the individual gross electrical power outputs are summed up.
Net electric power output	Calculated as "Gross electric power output" minus the electricity consumption of the plant/installation and its auxiliary systems.
Heat power output - Steam	Heat flow in form of any steam generated only by the reference combustion unit, excluding the steam which is used to produce electricity or steam used for heating hot water supply. (This variable is called "Gross heat power output - steam" in the questionnaire).
Heat power output - Hot water	Heat flow in form of any hot water produced directly by the reference combustion unit (e.g. water heating provided by the flue-gas generated in the combustion equipment) or indirectly through auxiliary systems (e.g. cooling system which delivers heat to the district heating system). (This variable is called "Gross heat power output - hot water" in the questionnaire).

Mechanical power output	Mechanical power can be obtained as the total rated thermal input multiplied by the efficiency for nominal load factor (i.e. 100 % load), not considering the efficiency of the compressor. The generated steam, which is further used for mechanically driving the equipment, should be excluded from the mechanical energy category and should be considered as part of the steam generation. (This variable is called "Gross mechanical power output" in the questionnaire).
Efficiency	Efficiency is expressed as the quotient of the utilizable power output and the power input. In each case, efficiency is to be given only for stationary or quasi stationary operating states. The most informative efficiencies are those, which compare the nominal power output (electrical, mechanical or thermal) to the total rated thermal input. They are called nominal efficiencies.
Gross electrical efficiency	$\frac{Gross\ electric\ power\ output}{Total\ rated\ thermal\ input}$
Net electrical efficiency	$\frac{Net\ electric\ power\ output}{Total\ rated\ thermal\ input}$
Thermal efficiency (steam or hot water)	$\frac{Heat\ power\ output}{Total\ rated\ thermal\ input}$
Mechanical efficiency	$\frac{Mechanical\ power\ output}{Total\ rated\ thermal\ input}$
Gross overall efficiency	$\frac{Heat\ power\ output + Gross\ electric\ power\ output}{Total\ rated\ thermal\ input}$
Net overall efficiency	$\frac{Heat\ power\ output + Net\ electric\ power\ output}{Total\ rated\ thermal\ input}$

Terminology related to "Utilisation ratio"

Fuel energy input (as lower heating value)	Calculated as the lower heating value of the fuel or a combination of fuels (corresponding to the fuel diet reported in the questionnaire) multiplied by the consumption of the fuel(s) during the reference year. If the combustion plant is composed of several combustion units its thermal input is the sum of the thermal inputs of each of its units.
Gross electric energy output	Calculated as the integral of the electrical power output of the generator over the operating time. Usually, a time period of one year is chosen.
Net electric energy output	Calculated as "Gross electric energy output" minus the energy used in the combustion unit and its auxiliary systems (material unloading/handling/storage facilities, FGT facilities, WWT facilities, fans, compressors, raw water treatment, cooling system, etc.). For calculating the net production, the consumption of other industrial activities at the industrial installation site is not considered.
Gross heat output - Steam	Calculated as the integral of the heat power output - Steam over the operating time. The heat content of any steam generated only by the reference combustion unit, excluding steam which is used to produce electricity or steam used for heating hot water supply.
Net heat output - Steam	Calculated as "Gross heat output - steam" minus the energy used in the combustion unit and its auxiliary systems (material unloading/handling/storage facilities, FGT facilities, WWT facilities, fans, compressors, raw water treatment, cooling system, etc.). For calculating the net production, the consumption of other industrial activities at the industrial installation site is not considered.

Gross heat output - Hot water	Calculated as the integral of the heat power output - Hot water over the operating time. The heat content of any hot water produced directly by the reference combustion unit (e.g. water heating provided by the flue-gas generated in the combustion equipment) or indirectly through auxiliary systems (e.g. cooling system which delivers heat to the district heating system); for shared auxiliary systems, calculate on a pro-rata basis the contributions related to the reference combustion plant.
Net heat output - Hot water	Calculated as "Gross heat output - Hot water" minus the energy used in the combustion unit and its auxiliary systems (material unloading/handling/storage facilities, FGT facilities, WWT facilities, fans, compressors, raw water treatment, cooling system, etc.). For calculating the net production, the consumption of other industrial activities at the industrial installation site is not considered.
Gross mechanical energy output	Calculated as the integral of the mechanical power output over the operating time. Mechanical energy can be determined as the fuel energy input multiplied by the efficiency of the combustion unit, not considering the efficiency of the compressor. Alternatively, if data is available from continuous measurements, mechanical energy can be calculated as the integral over the reference year of the differential of pressure (in Pa) multiplied by the corresponding volumetric flow rate of the gas/liquid (in m^3/s) to which combustion unit provided energy. Please consider only the cases where mechanical energy is provided directly to the system; the generated steam, which is further used for mechanically driving the equipment, should be excluded from the mechanical energy category and should be considered part of the steam generation (see endnote 11).

Mechanical energy output	Calculated as "Gross mechanical energy output" minus the energy used in the combustion unit and its auxiliary systems (material unloading/handling/storage facilities, FGT facilities, WWT facilities, fans, compressors, raw water treatment, cooling system, etc.). For calculating the net production, the consumption of other industrial activities at the industrial installation site is not considered.
Utilisation ratio	A utilization ratio is the quotient of the usable target energy output in a particular time period and the total energy input. The most informative utilisation ratios are those, which compare the annual energy output (electrical, mechanical or thermal) to the fuel energy input.
Gross electrical utilisation ratio	$\frac{Gross\ electric\ energy\ output}{Fuel\ energy\ input}$ (This variable is called "Gross electrical power" in the questionnaire)
Net electrical utilisation ratio	$\frac{Net\ electric\ energy\ output}{Fuel\ energy\ input}$ (This variable is called "Net electrical power output - electricity exported" in the questionnaire)
Gross thermal utilisation ratio	$\frac{Gross\ heat\ output\ (Steam + Hot\ water)}{Fuel\ energy\ input}$ (This variable is called "Gross thermal power" in the questionnaire)
Net thermal utilisation ratio	$\frac{Net\ heat\ output - (Steam + Hot\ water)}{Fuel\ energy\ input}$ (This variable is called "Net thermal power output - heat exported" in the questionnaire)

Gross mechanical utilisation ratio	$\frac{Gross\ mechanical\ energy\ output}{Fuel\ energy\ input}$ (This variable is called "Gross mechanical power" in the questionnaire)
Net mechanical utilisation ratio	$\frac{Net\ mechanical\ energy\ output}{Fuel\ energy\ input}$ (This variable is called "Net mechanical power output" in the questionnaire)
Fuel utilisation factor	The sum of all arising net utilisation ratios (i.e. mechanical, thermal and electrical) of the plant. (This variable is called "Total fuel utilisation" in the questionnaire)

Executive Summary

The report concludes a research project, by which the Institute of Energy Systems of the Hamburg University of Technology supported the German Federal Environmental Agency in the course of the revision of the BAT reference documents for Large Combustion Plants (LCP). This document deals with LCP with a total rated thermal input of 50 MW_{th} or more and is in revision since 2011.

The main topics that are handled in this report are:

- National data collection process and accompanying tasks
- Separate data collection for and analysis of load-dependent emissions for a CCGT plant and a hard coal-fired plant
- Development of a draft for the contribution to the biomass chapter of the prospective BAT reference document LCP

The national data collection makes up the most extensive part of this. For the selection of reference plants, it was tried to include representative plants of all possible categories, considering defined criteria, such as total rated thermal input, year of commissioning, type of fuel, technology of the plant, operation mode and others. With the support of plant operators, associations and agencies, it was attempted to integrate a multitude of plants which would most likely represent the best available technique. Finally, 48 reference plants from Germany were chosen and reported to the EIPPCB. As the questionnaire, which was created by the EIPPCB includes a special definition for the term "plant", 63 questionnaires were handed out for the 48 reference plants. Table 1 shows the distribution of the reference plants by their type of fuel and their total rated thermal input.

Table 1: Classification of the submitted questionnaires

	Gaseous	Liquid	Solid
TRTI in MW			
< 100	14	1	5
> 100 - 300	5	2	2
> 300	6	-	28

In a second level, the questionnaires were further divided, depending on the type of fuel and the firing technology or plant configuration.

In the first part of this report, the activities carried out in the research project are classified and remarks on "national particularities" are made. Subsequently, a fuel specific summary and detailed descriptions of the evaluated plants are given. To examine the fuel-dependent emission behaviour, a case study for a CCGT plant and a hard coal-fired plant were carried out and are also presented in this report. Concluding the data collection process, a chapter handling the "lessons learned" is added, which includes recommendations for future evaluation processes of the BAT reference document LCP.

This executive summary gives an overview of the most concise results of the data evaluation process. A focus is on the efficiencies and air emissions of the evaluated LCPs. A tabular summary, including the value range, for each group of plants is presented. With this, only a very brief and shallow overview of the results of the research project is given, as plant specifications and characteristics cannot be included in this executive summary, but have to be seen in direct context with the presented values. For the sake of clarity, some plant groups have been pooled, although they show great differences in terms of plant technology or fuel. If uncertainties of questions on the presented values arise, please refer to the detailed plant descriptions or the questionnaires. Lastly, it must be stated that the chosen reference plants do not represent the conclusive entirety of German LCPs and especially not the entirety of LCPs in the European Union.

Efficiency and Utilisation Ratios

With the data gathered from the questionnaires, the following efficiency parameters and utilisation ratios are presented in the tables below:

- nominal gross elctrical efficiency
- gross electrical utilisation ratio
- net electrical utilisation ratio
- thermal utilisation ratio
- fuel utilisation factor

Very distinct differences occur between plants in CHP operation and plants for heat generation and plants for electricity generation. Plants in CHP operation can be identified by the fact that an electrical utilisation ratio as well as a thermal utilisation ratio is stated. Generally, CHP operation leads to a high fuel utilisation factor. On the other hand, it is usually accompanied by a decrease in the electrical utilisation ratio. The highest fuel utilisation ratios are featured by plants that are used solely for heat generation.

Gaseous Fuels

Table 2 shows the efficiencies and utilisation ratios for CCGT plants. The CCGT plants are all fired with NG. The nominal gross electrical efficiencies are between 36 and 58 %, the fuel utilisation factors range from 46 to 88 %. It can be seen that plants in CHP operation achieve lower electrical utilisation ratios but higher fuel utilisation factors due to their relatively high thermal utilisation ratios.

Table 2: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Combined Cycle Plants"

TRTI in MW	Plant no.	Efficiency	Utilisation ratio			Fuel utilisation factor
		(el., gross, nom.) in %	(el., gross) in %	(el., net) in %	(th.) in %	(net.) in %
< 100	111-1	-	-	37.1	29.2	66.3
	111-2	-	-	37.1	29.2	66.3
>100-300	105	47.4	37.3	36.8	50.7	87.6
	104	46.4	40.4	39.9	14.6	54.5
	135	51.1	48.2	46.9	-	46.9
>300	118	58.6	54.1	53.0	15.5	68.5
	136	61.1	58.2	57.3	-	57.3
	119	60.4	58.0	57.5	-	57.5
Value range		**46 - 61**	**37 - 58**	**36 - 58**	**15 - 51**	**46 - 88**

Table 3 shows the efficiencies for NG compressor stations. Except for one plant, which uses a gas engine, all other plants use gas turbines. They are used for the mechanical driving of a NG compressor. Other energy forms are not provided by the plants, which is why the fuel utilisation factor would equal the mechanical utilisation ratio. As the mechanical energy output is not measured, values for the utilisation ratio cannot be stated.

Table 3: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Compressor stations"

TRTI in MW_{th}	Plant no.	Efficiency (mc., nom.) in %
< 50	166	37.9
	163	34.1
	161	33.6
	165	36.2
	159	34.4
	164	25
> 50	160	35.4
	162	34.2
	158	39
Value range		**25 - 39**

Table 4 shows the efficiencies and utilisation ratios for gas-fired boilers. This group of plants is very heterogeneous in terms of the main fuel used and technology applied. Plant no. 114 for example is a corner tube boiler, fired with NG and used solely for heat generation. Plant no. 157 is also used for heat generation in the industry and is fired with process gas, whereas plants no. 144 and 145 are in CHP operation and are fired with blast furnace gas. These differences are reflected in the utilisation ratios. While plants for heat generation show high fuel utilisation factors of 92 to 95 %, the plants in CHP operation only achieve 35 to 47 %.

Table 4: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Gas-fired Boilers"

TRTI in MW_{th}	Plant no.	Efficiency	Utilisation ratio			Fuel utilisation factor
		(el., gross, nom.) in %	(el., gross) in %	(el., net) in %	(th.) in %	(net) in %
< 100	114-1	-	-	-	94.6	94.6
	114-2	-	-	-	92.4	92.4
	114-3	-	-	-	94.2	94.2
> 100 - 300	157-1	-	-	-	92.0	92.0
	157-2	-	-	-	92.0	92.0
> 300	145	43.8	40.9	38.3	8.1	46.3
	144-1	36.5	40.8	38.0	1.6	39.6
	144-2	38.1	36.7	34.5	1.4	35.9
Value range		**36 - 44**	**36 - 41**	**34 - 39**	**1 - 95**	**35 - 95**

Liquid Fuels

Table 5 shows the efficiencies and utilisation ratios for liquid fuel-fired plants. Only two plants are included in the evaluation, both of which are fired with LFO. Plant no. 115 is a fire-tube boiler used for heat generation only and for this reason shows a relatively high fuel utilisation factor. Plant no. 112 on the other hand is a gas turbine for peak load electricity production with a respectively small fuel utilisation factor.

Table 5: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Liquid Fuel-fired Plants"

TRTI in MW_{th}	Plant no.	Efficiency	Utilisation ratio			Fuel utilisation factor
		(el., gross, nom.) in %	(el., gross) in %	(el., net) in %	(th.) in %	(net.) in %
< 50	115	-	-	-	92.1	92.1
> 100-300	112-1	25.2	24.9	24.6	-	24.6
	112-2	25.2	24.8	24.6	-	24.6
Value range		**25 - 26**	**24 - 25**	**24 - 25**	**92 - 93**	**24 - 93**

Solid Fuels

Table 6 shows the efficiencies and utilisation ratios for the group "hard coal-fired boilers". For this group, a new categorisation by the total rated thermal input is introduced as most of the plants are in the former category "> 300 MW_{th}". This additional differentiation is not part of European or German legislation and is only done here to aid a clear discussion basis. The net electrical utilisation ratios are in the range of 9 to 40 %, the fuel utilisation factors between 35 and 87 %. The plants, that show a high fuel utilisation factor but low electrical utilisation ratios, are in CHP operation. Larger hard coal-fired plants with lower thermal utilisation ratios or without CHP operation achieve relatively high net electrical utilisation ratios of 31 to 40 %.

Table 6: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Hard Coal-fired Boilers"

TRTI in MW_{th}	Plant no.	Efficiency	Utilisation ratio			Fuel utilisation factor
		(el., gross, nom.) in %	(el., gross) in %	(el., net) in %	(th.) in %	(net) in %
> 100 - 300	156	17.6	-	9.0	62.6	76.2*
> 300 - 800	134	20.9	20.6	18.7	68.3	87.0
	141	41.8	38.0	34.5	16.0	50.6
	146	34.8	18.1	15.9	64.2	80.0
> 800 - 1600	138	38.5	35.4	31.9	4.7	36.5
	124-1	37.4	34.3	32.4	15.8	48.2
	139	39.1	37.2	32.8	16.8	49.6
	123	40.1	41.7	38.4	2.4	40.8
> 1600	124-2	39.8	38.0	35.5	-	35.5
	122-1	40.7	38.6	36.4	-	36.4
	122-2	40.7	38.9	36.6	-	36.6
	131	44.1	41.2	38.0	-	38.0
	142	40.5	40.7	37.6	-	37.6
	121	39.9	40.0	37.4	0.1	37.5
	132	42.8	41.5	39.4	-	39.4
Value range		**17 - 45**	**18 - 42**	**9 - 40**	**0 - 69**	**35 - 87**

* this plant provides thermal and mechanical energy, the mechanical utilisation ratio of 4.7 % is already included in the fuel utilisation factor.

Table 7 shows the efficiencies and utlilisation ratios for the group "lignite-fired boilers". Again, a new classification by the total rated thermal input was introduced. The net electrical utilisation ratios are between 18 and 42 %, the fuel utilisation ratios between 33 and 86 %. Plant no. 109, which shows the highest fuel utilisation ratio and the lowest electrical utilisation ratios, is in CHP operation. Larger lignite-fired plants with lower thermal utilisation ratios or without CHP operation achieve net electrical utilisation ratios of 33 to 42 %, which is a similar range as for hard coal-fired plants.

Table 7: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Lignite-fired Boilers"

TRTI in MW_{th}	Plant no.	Efficiency	Utilisation ratio			Fuel utilisation factor
		(el., gross, nom.) in %	(el., gross) in %	(el., net) in %	(th.) in %	(net) in %
> 100 - 300	109	22.6	19.4	18.1	67.8	85.9
> 300 - 1000	137	36.0	35.6	33.2	-	33.2
> 1000 - 2000	128-1	35.4	37.9	34.8	1.0	35.9
	128-2	35.4	38.1	35.1	1.4	36.5
	128-3	35.4	37.5	34.7	1.1	35.8
	128-4	35.4	37.9	35.2	0.6	35.8
	129-1	35.4	37.0	34.2	0.5	34.7
	129-2	35.4	36.9	34.0	0.8	34.9
	130	37.7	36.4	33.7	-	33.7
> 2000	127-1	38.1	40.1	37.5	8.6	46.2
	127-2	38.1	40.1	37.6	6.4	44.1
	116	43.1	44.2	41.6	-	41.6
	117-1	37.3	43.5	41.1	3.2	44.3
	117-2	37.3	43.1	40.8	3.1	43.9
	133	39.8	38.5	34.4	7.6	42.0
Value range		**22 - 44**	**19 - 45**	**18 - 42**	**0 - 68**	**33 - 86**

Table 8 shows the efficiencies and utlilisation ratios for the group "biomass-fired boilers". The individual total rated thermal input of all plants in the evaluation is in the range of 50 to 100 MW_{th}. The majority of the plants in used for CHP. The electrical utilisation ratios are with 16 to 31 % relatively small, when compared to coal-fired plants. This is mainly due to the plant size. The fuel utilisation ratios are between 30 and 60 %.

Table 8: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Biomass-fired Boilers"

TRTI in MW_{th}	Plant no.	Efficiency	Utilisation ratio			Fuel utilisation factor
		(el., gross, nom.) in %	(el., gross) in %	(el., net) in %	(th.) in %	(net)in %
< 100	108-1	18.9	19.5	16.5	42.8	59.3
	108-2	18.9	19.5	16.5	42.8	59.3
	125	34.3	34.3	30.9	-	30.9
	107	29.9	29.6	26.2	12.4	38.6
	655	23.3	26.9	24.0	6.6	30.6
Value range		**18 - 35**	**19 - 35**	**16 - 31**	**6 - 43**	**30 - 60**

Emissions

For the presentation of the emissions, this executive summary focuses on the air emissions. The water emissions and the solid residues are not treated in this summary, because of a high grade of inconsistency of the available values.

During the data collection process, the air emissions were not always submitted within the same reference framework. Partially, OTNOCs are included in the stated values. In most cases, the values are validated. Most of the values given in the questionnaires represent HHV, which have been determined by continuous measurements. All these characteristics pose important boundary conditions, when trying to compare the submitted values. It has to be noted, that these conditions are not regarded in this executive summary, which is why the plant specific remarks given in the corresponding chapters have to be taken into consideration when trying to derive objective estimations in detail.

Gaseous Fuels

Table 9 shows the air emissions for CCGT plants. Some of the plants are equipped with an auxiliary firing in the HRB, which influences the emission levels. Due to the high quality of fuel, the NG-fired CCGT plants show relatively small emission values for CO and NO_x. Only primary emission abatement measures are taken. The NO_x emissions are between 15 and 77 mg/Nm^3, while the CO emissions range in their maximum up to 25 mg/Nm^3. The reference oxygen content for plants without auxiliary firing is 15 %.

Table 9: Evaluation level IV, Table b: Air emissions for the Group "Combined Cycle Plants"

TRTI in MW_{th}	Plant no.	NO_X	CO
		Ø in mg/Nm³	Ø in mg/Nm³
< 100	111-1	43.0	16.0
	111-2	43.0	16.0
> 100 - 300	105	29.1	24.2
	104	76.4	20.1
	135	27.7	0.2
> 300	118	45.8	3.3
	136	31.5	3.2
	119a	22.3	6.8
	119b	15.2	1.4
Value range		**15 - 77**	**0 - 25**

Table 10 shows the air emissions for the group "compressor stations". Plants no. 158 to 165 are NG-fired gas turbines with a reference oxygen content of 15 %, while plant no. 166 is a gas engine with a reference oxygen content of 5 %. The plants are operated in very different load regimes and the emission values are taken periodically, which influences the measured emission levels strongly. Due to the fuel, only NO_x and CO emissions are relevant. For NO_x reduction, primary measures are taken in all plants. For CO emission reduction, two plants are equipped with CO catalysts. The NOx emissions range from 49 to 294 mg/Nm³, while CO emissions lie between 11 and 225 mg/Nm³. The emissions of the gas engine are relatively low, due to the much lower reference oxygen content.

Table 10: Evaluation level IV, Table b: Air emissions for the Group "Compressor stations"

TRTI in MW_{th}	Plant no.	NO_X		CO	
		Ø in mg/Nm³	Secondary measures	Ø in mg/Nm³	Secondary measures
< 50	166	561.5	(shut-down planned)	237.5	(shut-down planned)
	163	200	(DLE planned)	224.5	-
	161	25.5	-	19	-
	165	-	-	-	-
	159	293.1	(DLE planned)	11.6	-
	164	64.5	-	11.5	CO catalyst
> 50	160	197.7	(shut-down planned)	61.7	(shut-down planned)
	162	201	(DLE planned)	22.5	CO catalyst
	158	49.5	-	56	(CO catalyst planned)
Value range		**50 - 562**	**-**	**11 - 238**	**CO catalyst, -**

Table 11 shows the air emissions for the group "gas-fired boilers". The differences in the fuel used are reflected in the air emissions of the plants. Plants no. 114 and 157 only show NO_x emissions between 69 and 92 mg/Nm^3, CO emissions between 1 and 7 mg/Nm^3 and no dust or SO_x emissions due to their sulphur- and dust-free fuel. The emissiosn of the blast furnace gas-fired plants no. 144 and 145 differ. CO and NO_x are comparable to the other plants, whereupon plant no. 145 is equipped with an SCR. In addition to this, dust emissions range from 1.8 to 3.3 mg/Nm^{3}and SO_x emissions from 98 to 115 mg/Nm^3.

Table 11: Evaluation level IV, Table b: Air emissions for the Group "Gas-fired Boilers"

TRTI in MW_{th}	Plant no.	NO_x		CO		Dust		SO_x	
		Ø in mg/Nm³	Secondary measures	Ø in mg/Nm³	Secondary measures	Ø in mg/Nm³	Secondary measures	Ø in mg/Nm³	Secondary measures
< 100	114-1	85.0	-	6.2	-	0.04	-	-	-
	114-2	91.3	-	2.0	-	0.04	-	-	-
	114-3	76.0	-	1.7	-	0.00	-	-	-
> 100 - 300	157-1	69.6	-	2.0	-	-	-	-	-
	157-2	70.6	-	1.0	-	-	-	-	-
> 300	145	84.1	SCR	22.8	-	2.60	-	114.1	-
	144-1	58.4	-	1.0	-	1.80	-	98.5	-
	144-2	57.3	-	1.1	-	3.30	-	106.7	-
Value range		**57 - 92**	**SCR, -**	**1 - 23**		**0 - 4**		**98 - 115**	

Liquid fuels

As there are only two plants in this group, a separate table is not included in this summary. Plant no. 112 is in addition to this not obliged measure air emissions. Plant no. 115 uses the high quality fuel LFO, which is why only CO and dust emissions are monitored. The CO emissions are around 1.5 mg/Nm³ and the dust emissions around 0.5 mg/Nm³.

Solid fuels

The air emissions of solid fuel-fired plants lie in a wide range, as these fuels are less homogenous and include a broader variety of unwanted substances than LFO or NG do. For this reason, solid fuel-fired plants are often equipped with secondary abatement measures.

Table 12 shows the air emissions for the group "hard coal-fired boilers". For almost all plants NO_x, CO, dust, SO_x and Hg are measured in the flue gas. Secondary measures are taken for NO_x, SO_x and dust emission abatement. For the SO_x emission values, the sulphur content should also be regarded. Plant no. 156 displays relatively high emission values, as it uses a different technology as well as a different approach to flue gas treatment. All other plants are pulverised coal firings, which are equipped with a SCR, an ESP and a wet FGD. The NO_x emissions are between 78 and 215 mg/Nm³, the dust emissions are between almost 0 and 12 mg/Nm³. The SO_x emissions are between 36 and 287 mg/Nm³ and the Hg emissions are between almost 0 and 0.006 mg/Nm³.

Table 12: Evaluation level IV, Table b: Air emissions for the Group "Hard Coal-fired Boilers"

		NO_x		CO	Dust		SO_x				Hg	
TRTI in MW_{th}	Plant no.	Ø in mg/Nm³	Secondary measures	Ø in mg/Nm³	Ø in mg/Nm³	Secondary measures	Ø S-content of coal in %	Ø in mg/Nm³	Secondary measures	Ø SO_x-removal in %	Ø in mg/Nm³	Method to obtain data
> 100 - 300	156	98.3	-	228.1	0.1	Cyclone, fabric filter	0.93	350.9	Dry adsorption	78.2	0.001	Perio. (4x)
> 300 - 800	134	196.0	SCR	16.3	2.9	ESP	-	48.8	FGD	97.4	0.001	Perio. (6x)
	141	78.4	SCR	25.2	0.3	ESP	0.71	51.1	FGD	96.1	0.006	Perio. (5x)
	146	178.2	SCR	15.6	11.1	ESP	0.9	107.7	FGD	-	0.004	Perio. (12x)
> 800 - 1600	138	141.6	SCR	2.3	2.6	ESP	1.08	132.9	FGD	92.0	0.004	Cont.
	124-1	201.5	SCR	8.4	8.3	ESP	-	36.3	FGD	97.9	0.004	Perio. (9x)
	139	183.9	SCR	0.2	1.3	ESP	1.08	122.4	FGD	93.3	0.004	Cont.
	123	175.6	SCR	10.1	2.6	ESP	0.69	40.4	FGD	-	0.003	Cont.
> 1600	124-2	214.4	SCR	9.4	4.2	ESP	-	286.8	FGD	83.1	0.003	Perio. (9x)
	122-1	195.2	SCR	1.9	0.6	ESP	0.84	115.3	FGD	91.4	0.002	Cont.
	122-2	196.1	SCR	3.1	2.2	ESP	0.84	123.1	FGD	90.5	0.001	Cont.
	131	168.4	SCR	1.9	8.5	ESP	-	99.3	FGD	87.7	0.002	Cont.
	142	182.6	SCR	1.0	3.5	ESP	-	116.0	FGD	91.7	0.001	Cont.

		NO_x		CO	Dust		SO_x				Hg	
	121	187.4	SCR	7.6	5.6	ESP	-	82.7	FGD	-	0.001	Cont.
	132	182.6	SCR	2.8	4.7	ESP	-	81.2	FGD	91.0	-	-
Value range		**78 - 215**	**SCR, -**	**0 - 229**	**0 - 12**	**ESP, cyclone, fabric filter**	**0 - 2**	**36 - 351**	**FGD, dry adsorption**	**78 - 98**	**0 - 0.006**	

Table 13 shows the air emissions for the group "lignite-fired boilers". For almost all plants NO_x, CO, dust, SO_x and Hg are measured in the flue gas. Secondary measures are taken for SO_x and dust emission abatement. For the SOx emission values, the variable sulphur content should also be regarded. Plant no. 109 displays relatively high emission values, as it uses a different technology as well as a different approach to flue gas treatment. All other plants are pulverised coal firings, which are equipped with an ESP and a wet FGD. NO_x is reduced by primary abatement measures. The NO_x emissions are between 120 and 194 mg/Nm^3, the dust emissions lie below 12 mg/Nm^3. The SO_x emissions are between 14 and 302 mg/Nm^3 and the Hg emissions are between 0.003 and 0.018 mg/Nm^3.

Table 14 shows the air emissions for the group "biomass-fired boilers". For almost all plants NO_x, CO, dust, SO_x and Hg are measured in the flue gas. Secondary measures are taken for NO_x, SO_x and dust emission abatement. The emissions are influenced strongly by the quality of biomass used. Some of the plants are CFB boilers and some are grate firings, which require different flue gas treatment facilities. Secondary measures are SNCR for NO_x reduction, dry adsorption FGD as well as cyclones and fabric filters for dust removal. The NO_x emissions are between 119 and 184 mg/Nm^3, the dust emissions are between 0 and 4 mg/Nm^3. The CO emissions range from 11 to 28 mg/Nm^3, SO_x emissions are between almost 0 and 43 mg/Nm^3 and the Hg emissions are between 0.0005 and 0.003 mg/Nm^3.

Table 13: Evaluation level IV, Table b: Air emissions for the Group "Lignite-fired Boilers"

TRTI in MW_{th}	Plant no.	NO_x		CO	Dust		SO_x				Hg	
		Ø in mg/Nm³	Secondary measures	Ø in mg/Nm³	Ø in mg/Nm³	Secondary measures	Ø S-content of coal in %	Ø in mg/Nm³	Secondary measures	Ø SO_x-removal in %	Ø in mg/Nm³	Method to obtain data
> 100 - 300	109	169.1	SNCR	95.1	5.7	Cyclone, fabric filter	0.35 (BK)	79.7	Dry adsorption	85.0	-	-
> 300 - 1000	137	195.6	-	148.1	11.5	ESP	0.9 (RH)	14.9	FGD	98.7	0.003	estimated
> 1000 - 2000	128-1	194.2	-	96.2	7.3	ESP	1.1 (L)	191.6	FGD	96.1	0.009	Perio. (9x)
	128-2	195.0	-	115.0	6.5	ESP	1.1 (L)	210.0	FGD	95.7	0.009	Perio. (9x)
	128-3	194.0	-	150.1	7.6	ESP	1.1 (L)	222.2	FGD	95.7	0.009	Perio. (9x)
	128-4	190.7	-	151.4	6.1	ESP	1.1 (L)	229.6	FGD	95.6	0.009	Perio. (9x)
	129-1	189.3	-	179.0	6.6	ESP	1.1 (L)	235.1	FGD	95.7	0.009	Perio. (9x)
	129-2	192.7	-	168.0	7.1	ESP	1.1 (L)	236.1	FGD	95.7	0.009	Perio. (9x)
	130	193.1	-	75.0	2.7	ESP	0.9 (RH)	64.0	FGD	97.0	0.003	estimated
> 2000	127-1	120.3	-	53.4	1.6	ESP	0.71 (L)	220.0	FGD	95.4	0.007	Perio. (9x)
	127-2	120.9	-	26.8	1.3	ESP	0.71 (L)	199.7	FGD	95.5	0.007	Perio. (9x)
	116	168.2	-	0.8	0.8	ESP	0.9 (RH)	76.6	FGD	94.4	0.005	estimated
	117-1	171.4	-	11.8	3.1	ESP	1.6 (MD)	296.7	FGD	95.6	0.015	Cont.
	117-2	162.2	-	23.2	2.8	ESP	1.6 (MD)	302.0	FGD	95.4	0.018	Cont.

TRTI	Plant	NO_x		CO	Dust		SO_x				Hg	
	133	168.4	-	19.4	4.6	ESP	1.77 (MD)	215.1	FGD	97.6	0.014	Cont.
Value range		**120 - 194**	**SNCR, -**	**0 - 179**	**0 - 12**	**ESP, cyclone, fabric filter**	**0 - 2**	**14 - 302**	**FGD, dry adsorption**	**85 - 99**	**0 - 0.02**	

Table 14: Evaluation level IV, Table b: Air emissions for the Group "Biomass-fired Boilers"

TRTI in MW_{th}	Plant no.	NO_x		CO	Dust		SO_x		Hg	
		Ø in mg/Nm^3	Secondary measures	Ø in mg/Nm^3	Ø in mg/Nm^3	Secondary measures	Ø in mg/Nm^3	Secondary measures	Ø in mg/Nm^3	Secondary measures
< 100	108-1	176.2	SNCR	15.7	0.42	Cyclone, fabric filter	42.1	Dry adsorption	0.0030	
	108-2	184.0	SNCR	21.6	0.34	Cyclone, fabric filter	42.6	Dry adsorption	0.0020	-
	125	119.7	-	27.5	3.31	Cyclone, fabric filter	1.6	Dry adsorption	0.0007	-
	107	153.6	-	11.8	0.42	Fabric filter	0.7	-	-	-
	655	164.2	SNCR	17.7	3.31	Cyclone, fabric filter	30.92	Dry adsorption	0.0005	-
Value range		**119 - 184**	**SNCR, -**	**11 - 28**	**0 - 4**	**Cyclone, fabric filter**	**0 - 43**	**Dry adsorption, -**	**0 - 0.003**	**-**

1 Introduction

This report was created as a part of a research project by the Institute of Energy Systems of the Hamburg University of Technology (TUHH-IET) on behalf of the German Federal Environment Agency (UBA). It deals with the revision of the BAT-reference document "Large Combustion Plants (LCP)", a reference document that comprises large combustion installations with a total rated thermal input of 50 MW_{th} or more. The first "Best Available Techniques" (BAT) reference document was released in 2006 by the European Commission. Since 2011, it is under revision. The leading organ for this process is the "European Integrated Pollution Prevention and Control Bureau" (EIPPCB) in Seville, Spain. It is supported by the "Technical Working Group" (TWG), which is comprised of several representatives from all European countries, as well as NGOs (industry, environmental organisations).

The relevance of the BAT reference documents is increased by the European Industrial Emission Directive (2010/75/EU; IED) when compared to its predecessor, the IVU (Directive 2008/1/EC). In the future, the emissions value ranges derived from the BAT reference documents will be obliging for permit processes in the EU states. Due to this, a revision of the BAT reference document is necessary, especially with respect to the deducible conclusions. It is for this reason that the BAT refrence document is of large interest for many different stakeholders (e.g. operators, agencies, associations). The European regulations, which will be derived from the IED and the BAT reference document, affect the German legislations; especially the 13. and 17. BImSchV, as well as appendices 31 and 47 of the waste water regulations.

The revision of the BAT reference document is based on the predecessor report. To obtain a solid data base for the evaluation, data from a total of about 500 combustion installations was gathered, 60 of which are from Germany. They can principally be categorised by their total rated thermal input, the plant technology and the combusted fuel. The collection of data was based on a questionnaire, which developed by the EIPPCB with the aid of the TWG.

The individual plants are described in detail in this report. In addition to this, a proposal for the way of presenting and evaluating the data is made. The final evaluation step, the definition of the BAT and the according emission limit values, is not done. In a further part of the research project, load-dependent emissions for part load and for start-up/shutdown are described, using the example of one CCGT plant and one hard coal-fired plant. Finally, this report contains a draft of the biomass-LCP chapter, which could be included in the future BAT reference document.

The report at hand shows the work done at the TUHH-IET on the one hand, but can also be seen as a reference text for the interested expert audience on the other. Furthermore, it aims to provide useful information to the EIPPCB, especially concerning the analysis and evaluation of the data. In this context, the chapters "National Particularities" and "Lessons Learned" are of importance.

2 General

2.1 Task and Classification of the Activities done in the Research Project

As already stated in the introduction, the aim of the research project was to support the UBA within the framework of the German contribution to the revision of the BAT reference document LCP. For this, the following main topics were treated:

- National data collection and accompanying tasks:
  - Formulation of a "Wish-list", including change requests for the revision of the BAT reference document
  - Selection of German reference plants, taking into consideration the total rated thermal input, the year of commissioning, the type of fuel, the mode of operation and other particularities
  - Development of a draft for the European evaluation questionnaire and support for the evaluation process for the EIPPCB
  - Assistance for the LCP operators and the involved agency in queries concerning the questionnaire
  - Processing, description and pre-evaluation of the national data collection
- Separate data collection for and analysis of load-dependent emissions for a CCGT plant and a hard coal-fired plant
- Development of a draft for the contribution to the biomass chapter of the prospective BAT reference document LCP

For the evaluation, a catalogue of possible reference plants was created. It was attempted to compile a representative selection of plants to cover all possible categories. Initially, only plants that were commissioned in 2002 or later and plants with retrofitting measures in the recent past were chosen. This was done based on the assumption that these plants would most likely represent the state of the best available technique. The record year of 2002 was chosen as a reference year, because older plants were allready included in the predecessor research project[1]. In the further course of the data collection process, at a hint from LCP operators, associations and agencies, additional plants were included in the pool, if they posed potential BAT-suggestions. In each case, the voluntary cooperation of the LCP operator was necessary. For this reason, a few originally chosen plants had to be excluded from the data pool and were partially replaced by others.

Each of the German LCP, which has been chosen as reference power plants, is described in detail in the chapter 3. In addition to this, the characterisation of the two load-dependent emissions is provided in report, as well as the draft of a contribution to the biomass chapter.

During the data gathering process, the IET-TUHH checked the submitted questionnaires several times in an iterative way and, if necessary, asked for revision by the concerning the plant operator. The templates for BAT were not checked and rated by the TUHH-IET. These suggestions were made and filled-in into the questionnaire by the LCP operators

[1] Rentz, O. ; Gütlin, K. ; Karl, U.: Erarbeitung der Grundlagen für das BVT-Merkblatt Großfeuerungsanlagen im Rahmen des Informationsaustausches nach Art. 16(2) IVU-Richtlinie, Forschungsbericht 200 46 317 / Deutsch-Französisches Institut Für Umweltforschung Universität Karlsruhe (TH). 2002. – Forschungsbericht

themselves and thus are based mainly on subjective aspects. For the same reason, the TUHH-IET did not identify emission limit values and did not deduce any conclusions for the national reference plants.

2.2 National Particularities

The operating permissions for German LCP are regulated by the BImSchG and the associated ordinances. At the moment, these regulations show various deviations from the IED and the definitions given in the questionnaire. While the questionnaire defines a "combustion plant" by the existence of exactly one stack/emission point, the German approval practices are not uniform, but can differ from one location to another, depending on their historical background. At some locations, for instance, there are multiple LCPs, which are combined into one "combustion plant", whereas at other locations, each LCP is approved as an individual "combustion plant". This caused some problems during the data collection, as it was often not possible to divide the existing, approved "combustion plant" (existing of multiple LCPs) into one "combustion plant" according to the questionnaire.

In the 13. BImSchV (as amended and promulgated on 20th of July, 2004) and the 17. BImSchV (as amended and promulgated on 14th of August, 2003) it is prescribed that all relevant plants have to be equipped with measuring equipment, which is to be used for continuous measuring, analysis and evaluation of emissions and other important process parameters. The monitoring data has to be stored as well as automatically analysed and if necessary telemetrically transmitted.

In the questionnaire, segment "air emissions", the time reference for the values can be stated. For German plants, these are usually validated HHV. They result out of standardised values with subtraction of the measurement uncertainty, which has been determined during the calibration process. However, in some cases DA were given. In Germany, it is further regulated that the emission limit value on a half-hourly average basis is twice the emission limit value on a daily average basis. In the European regulations, validated hourly, daily and monthly averages are relevant. The first BAT reference document from 2006 includes BAT associated emission levels, which are based on daily average values in normal operation mode.

For standardisation, the values are converted to standard temperature and pressure as well as to reference oxygen content. If the actual oxygen content is smaller than the reference content, a conversion of emission values is not permissible in Germany. This regulation is valid for all pollutants, which can be reduced by emission abatement measures (secondary measures). For example: The NO_x emission values from a plant with SCR and a smaller oxygen content than the reference oxygen content may not be converted. In special cases it can occur that a conversion is also not permissible if only primary measures for emission abatement are taken, for example when primary measures for NO_x emission abatement are interpreted as flue gas treatment measures. If this is the case, remarks are given in the questionnaire.

As already described, the validation of the emission values, the uncertainty of the measuring equipment is subtracted from the actual measured value. The validated value is therefore smaller than the measured value. The uncertainty of the measuring equipment is ascertained by a German testing institute (§ 26) and is the integrated into the evaluation device.

It has to be noted that the emission level characteristics can change, if OTNOCs are included and if the plant has often been operated in part loads. These conditions are likely to become more frequent due to the energy turnaround and the hereby increased (fluctuating) power production from renewable energy sources. The reference year for the presented emissions values is 2010. After 2010, the share of renewable energy sources further increased. The possibility of a changed emission behaviour of the presented plants compared to the reference year 2010 can therefore not be excluded.

The 13. BImSchV extends the IED by compulsory emission limit values for Hg for solid fuel-fired LCP. The same is true for emission limit values for CO for solid and liquid fuel-fired plants. For plants firing LFO and comparable fuels the dust emissions can also be given as soot level. By the legislation in force, a monitoring of the emission limit values of gas turbines has only to be done for loads greater than 70 %. For this reason, values for lower loads are included in the OTNOCs. Natural gas-fired gas turbines of small size (§ 15 par. 8 of the 13. BImSchV: < 100 MW_{th}) do not require continuous measurement.

3 Data Collection

3.1 General Explanation of the Data Collection, the First Evaluation Level, the Classification and the further Level-Structure

In this project the 48 German large combustion installations, which were submitted by the federal environmental agency (UBA) in cooperation with the Institute of Energy Systems (TUHH-IET) of the Hamburg University of Technology to the EIPPCB, are evaluated. The German plants that were submitted from the association of the chemical industry and the EUROFER are not included in this report.

Some of the submitted installations consist of multiple “Combustion Plants”. In these cases one questionnaire for each “Combustion Plant” was submitted. A “Combustion Plant” is defined in the IED as a plant with a single air emission source or measuring point and part of the whole “Combustion Installation”. Hence, 63 questionnaires for 48 installations were submitted. For the evaluation these questionnaires were divided into three categories in the first level, depending on the state of aggregate state of the main fuel (gaseous, liquid, solid) and the total rated thermal input. The resulting classification of the questionnaires is shown in Table 15.

Table 15: Evaluation level I: Classification of the submitted questionnaires

	Gaseous	Liquid	Solid
Q_{th} in MW			
< 100	14	1	5
> 100 - 300	5	2	2
> 300	6	-	28

$\Sigma = 63$

In a second level, the questionnaires of each column of Table 15 were further divided, depending on the type of fuel and the firing technology or plant configuration. This is exemplified in Figure 1 for gas-fired plants.

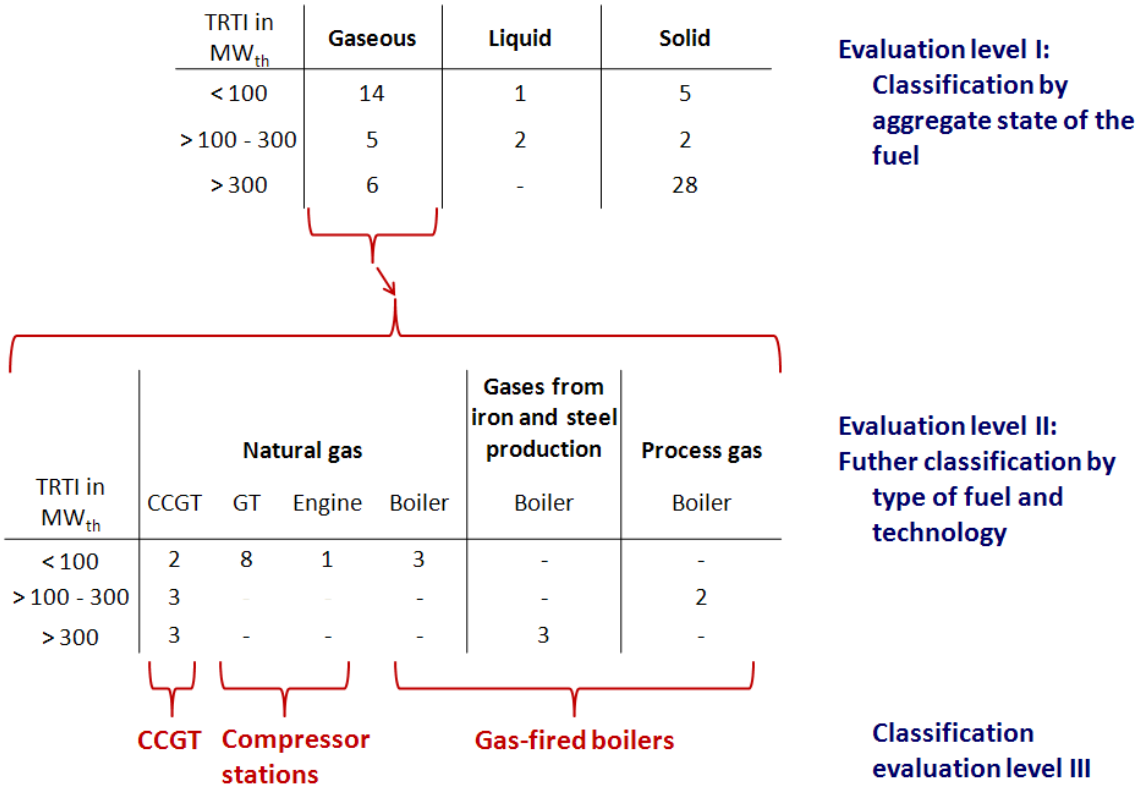

Figure 1: Further categorisation of the gas-fired plants (for evaluation levels I - III)

Each column of evaluation level II represents a main group. The individual groups will be described more detailed in evaluation levels III - IV. Some of the columns of the second level contain only very few questionnaires. Therefore, some columns are combined to one group as indicated for example in Figure 1 for gas-fired boilers. In this way the 62 questionnaires were divided in the seven following main groups:

- Combined cycle (CCGT) plants
- Compressor stations
- Gas-fired boilers
- Liquid fuel-fired plants
- Hard coal-fired boilers
- Lignite-fired boilers
- Biomass-fired boilers

It can be helpful to categorize the plants even further, for example by fuel, total rated thermal input or firing-system. This is especially true for solid fuel-fired LCPs with a total rated thermal input of 300 MW_{th} or more. Also, gas-fired boilers show a wide variety of applied technologies, so that further partitioning is reasonable. This is, however, not done in this evaluation due to the small number of evaluated plants for each category. In European context, with a larger number of evaluated, similar plants, this approach might be useful.

For each of these seven main groups there is one table in the third level and four tables in the fourth level. In the third level, a table with the most important plant characteristics is shown. These characteristics contain the total rated thermal input, the commissioning year and the year of the last retrofit, the mode of operation as defined in the IED, the annual total operating time under normal operating conditions, the equivalent full load operating factor, the combined generation of heat and electricity as well as information about any specific features of the plants. For each main group four tables (IVa-IVb) and, if useful, corresponding diagrams with the following content are generated in the fourth level:

- IVa: Efficiencies
- IVb: Air Emissions
- IVc: Water Emissions
- IVd: Templates for BAT

The Table IVa shows the efficiencies of the plants, including the nominal gross electrical efficiency, the gross electrical utilisation factor calculated with the operation data of the reference year, the net electrical utilisation ratio, the thermal utilisation ratio as well as the fuel utilisation factor. It has to be noted, that the presented values are calculated with the nominal values given in the questionnaire. It is therefore not always clear, especially for plants with CHP operation, to which load the values refer. The utilisation ratios are calculated calorimetrically. For plants that contain steam turbines the cooling system is of substantial influence for the energy efficiency. As there is no uniform information on this topic and because of seasonal differences in individual plants, the cooling system is not stated. It is furthermore not possible to draw a conclusion between the cooling system and the achievable efficiency of a plant, as it is influenced by multiple circumstances. The cooling system is stated in the individual descriptions and can be found in the questionnaires.

The air emissions and possible secondary measures for emission abatement are listed in Table IVb. The air emissions values - given as HHV or DV - are predominantly normalised, validated and refer to dry conditions. The concentration values usually do not include OTNOCs. Deviations in the reference conditions are indicated in the figures and tables. In addition to the values presented in the tables, the figures include the meaningful values for the 5th and the 95th percentile, if given by the operator. NG-fired gas turbines with less than 100 MW_{th} are excluded from obligations to continuous measuring by the 13. BImSchV. In this cases, periodic measurements are done. The values given in Tables IVb are then average values for the regarding measuring period. In the groups 'Combined Cycles' and 'Compressor Stations' the presented air emissions are limited to NO_x and CO. For the boilers with different fuels and the liquid fuel-fired plants dust and SO_x emissions are also displayed. For coal- and biomass-fired plants the Hg emissions and the rate of desulphurisation are additionally stated. Other pollutants that are asked for in the questionnaire are not displayed because of little number of submitted values. The measurement of these other pollutants is not relevant for the operating permit and therefore usually not existent for most of the plants. In the detailed description of each plant a table with all the air and water emission values submitted by the operator is shown. For plants that combust waste or waste wood a number of other pollutants, like dioxins, are also of interest for the operating permit. They are given in the questionnaires and in the detailed plant descriptions, but are not given in the summarising table.

In Table IVc, which contains information about the water emissions, only 10 of the 37 pollutants, which were asked for in the questionnaire, are shown. Emissions are measured periodically, often only twice to twelve times a year. Depending on the plant and the waste water origin, not all pollutants have to be measured because they are not relevant for the operation permit. The ecological impact of the waste heat from the cooling system, which is often discharged into nearby surface water, is not addressed in the questionnaires and thus not included in this report (see BREF "Industrial Cooling Systems"). The provided templates for BAT, which were subjectively submitted by the operators, are summarised in Table IVd. In that, the number of submitted templates and a summary of the proposed technology for each plant are given. The templates are furthermore categorised by the topic they deal with as well as by the depth of detail.

On the basis of the given BAT-suggestions and the associated emission values, a first estimate for the emissions limit values can be derived. The BAT-suggestions must be seen in their particular technological background.

It should be noted that the individual BAT-suggestions cannot be combined into one "reference plant", which includes all suggestions. The compatibility and functionality of such a system is most likely not at all given.

The data collection is based on the current state of the plants. Technologies, which are researched and tested at the moment, e.g. for the reduction of specific Hg emissions, CCS, the application of ion exchangers for WW, etc. are therefore not included. They provide the possibility of future BAT, e.g. if the testing results are promising this far, but long-term results are not available yet. Most of these technologies were not included in the BAT templates, as they were not state of the art in 2010 in Germany, which was the reference year for the data collection.

3.2 Technologies for the Combustion of Gaseous Fuels

For the combustion of gaseous fuels the following three basic concepts exist in industrial scale:

- Gas turbine
- Gas engine
- Gas boiler

In addition to this, combinations of these technologies are possible (e.g. a Combined Cycle plant with auxiliary firing). With the exclusion of gas turbines for peak load (with very low annual hours of operation), the use of a gas turbine without a heat recovery boiler is uncommon because of the low efficiency.

They most common gaseous fuel is NG. In addition to this, process gases of the chemical or iron and steel industry are used. Sporadically, mine gas, biogas and sewage gas and combusted in LCP. Liquid fuel-fired gas turbines are covered in chapter 3.3. Nonetheless, the majority of the German gas turbines can be fired bivalent, so that in case of an interrupted gas supply, liquid fuels, such as LFO can be used.

In this project 25 questionnaires of 20 gas-fired units are evaluated. They can be categorised, depending on the type of fuel and technology (evaluation level II).

Table 16: Evaluation level II: Categorisation of gaseous fuel-fired plants

	NG				Gases from iron and steel production	Process gas
Q_{th} in MW	Comb. cycle	Gas turbine	Engine	Boiler	Boiler	Boiler
< 100	2	8	1	3	-	-
> 100 - 300	3	-	-	-	-	2
> 300	3	-	-	-	3	-

For the gaseous fuel-fired plants in Germany predominantly NG-fired units were submitted (20 questionnaires). Additionally, the data of two installations (three questionnaires) firing gases from iron and steel production as well as the data of one installation (two questionnaires) firing process gas were provided. As shown in the table, most of the units are rather small with a total rated thermal input of less than 100 MW_{th}.

All three mentioned possible basic concepts are represented by the submitted installations. The selection of installations contains gas turbines without HRB, driving NG compressors, a gas-fired engine for the same purpose, several boilers firing different fuels for the generation of electricity or CHP as well as numerous CCGP plants with and without auxiliary firing. Other processes, like the combination of a gas turbine with HRB but without steam turbine, gas turbines with exhaust gas utilisation in the boiler of a coal-fired power plant, are possible.

In evaluation level III the gas-fired plants are further divided into the groups: combined cycle plants, compressor stations and gas boilers. The comparison of the plants and their emissions is still complicated due to distinctions of the plants within these groups. There are for example combined cycle plants with and without auxiliary firing and with and without the use of combined heat and power. In the category compressor stations the gas engine differs technically in great extent compared to the gas turbines. The boilers combust very different fuels and show differences in the use of combined heat and power. In the following chapters the specifics of each plant will be described in detail.

3.2.1 Combined Cycle Plants

3.2.1.1 General Discussion and Explanation of the Technology and the Emission Abatement Measures

In principle, the technologies and measures for emission control did not change compared to the predecessor report from 2002. Hence, for a detailed description please refer to this report[2]. In the recent past, however, power plants with higher power output and efficiencies have been developed. At a Germany power plant, the worldwide largest gas turbine is tested since 2008 in a simple gas turbine process. Since 2011 the gas turbine is tested in a combined cycle process. The manufacturer reports a net electrical efficiency of 40 % for a simple gas turbine process with an electric power output of 375 MW_{el}; for the combined cycle operation the net electrical efficiency increases to 60 % with an electric power output of 570 MW_{el}. The NO_x- and CO-emissions are 25 and 10 mg/m^3 (stp, dry), respectively. The increase in efficiency compared to older plants is predominantly due to the following measures:

- Optimised sealing system for a low loss gas turbine design
- Advanced materials for increased combustion and flue gas temperatures
- Improved cooling of components
- Optimised pressure ratios and elevation of the inlet temperature
- Compressor with modern blade design

In addition to that, the operating flexibility of the turbine is increased due to air cooling. The advantage of the air cooling compared to steam cooling is the fact, that the cooling medium is operable at any turbine power output and that the turbine is more independent of the steam cycle[3,4].

3.2.1.2 Presentation of the Results (evaluation levels III and IV)

For the group "Combined Cycle Plants", eight questionnaires for seven combustion installations are available. Combustion installation no. 111 consists of two combustion plants, which is why two questionnaires had to be filled in. Table 17 shows the evaluation level III with important plant characteristics.

[2] RENTZ, O. ; GÜTLIN, K. ; KARL, U.: Erarbeitung der Grundlagen für das BVT-Merkblatt Großfeuerungsanlagen im Rahmen des Informationsaustausches nach Art. 16(2) IVU-Richtlinie, Forschungsbericht 200 46 317 / Deutsch-Französisches Institut Für Umweltforschung Universität Karlsruhe (TH). 2002. – Forschungsbericht

[3] SIEMENS AG: SGT5-8000H Größerer Kundennutzen durch die neue Gasturbine von Siemens. In: Sonderdruck aus VGB PowerTech (2007)

[4] SIEMENS AG: The SGT5-8000H – tried, tested and trusted / Siemens Energy ,Inc. 2010. – Forschungsbericht

Table 17: Evaluation level III: Group "Combined Cycle Plants"

TRTI in MW_{th}	Plant no.	TRTI in MW_{th}	Year of commissioning (last retrofit)	Operating mode (according to EIPPCB)	Total operating time under normal conditions	Equivalent full load operating factor	CHP	Other
< 100	111-1	88 each	2005 ()	Base load	6084	93.9	Yes	2 GT, 2 HRB, 1 ST
	111-2				6052	93.9		
> 100 – 300	105	100	2005 ()	Base load	8284	87.5	Yes	Auxiliary firing
	104	165	2005 (2006)	Base load	6591	64.4	Yes	Auxiliary firing
	135	2 x 180	1994 ()	Base load	4081	94.8	No	Railway electricity, 2 GT, 2 HRB, 1 ST
> 300	118	714	2005 (2006)	Base load	7913	85.1	Yes	-
	136	900	2007 (2011)	Base load	3914	75.6	No	First comm. in 2011 -> incomplete reference year
	119	1424	2009/2010 ()	Base load	6430	75.0	No	2 GT, 2 HRB, 1 ST

* Concerning Combined Cycle Plants, the term „total rated thermal input“ is not porperly defined in the questionnaire. Thus, at least two reasonable values can be given: the value of the design specification and the maximal thermal input, which is of interest for definition of permittable emission values. As the condition of the ambient air is of large influence on the thermal input, a specification would be useful in the questionnaires and should be considered in the next revision-process. For this report, it is often not clear on which air conditions the values in the questionnaires are based on.

From the relatively long total operating time under normal conditions it could be concluded, that CCGT plants are usually operated to cover the electrical base load. The actual reason for the long annual operating time has to be seen in low gas prices due to the financial crisis. Only plant no. 136 shows a total operating time under normal conditions of fewer than 4000 hours, because it was commissioned the year (2011).

The high equivalent full load operating factors indicate that CCGT plants are often operated at high loads. Plants with low thermal inputs (less than 300 MW_{th}) are throughout used for CHP. Only one of the four larger plants (thermal input of more than 300 MW_{th}) is used for CHP. Except for plant no. 135, commissioned in 1994, the evaluated plants are all very new (commissioned in 2005 or later). Some plants are Greenfield plants, which are build on newly developed building areas, and others are Brownfield plants, which are added to already existing industry parks. For this reason, restrictions in the layout as well as in technical questions may have occurred for some plants. Table 18 shows the efficiencies and the utilisation ratios.

Table 18: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Combined Cycle Plants"

TRTI in MW_{th}	Plant no.	Efficiency	Utilisation ratio			Fuel utilisation factor
		(el., gross, nom.) in %	(el., gross) in %	(el., net) in %	(th.) in %	(net.) in %
< 100	111-1	-	-	37.1	29.2	66.3
	111-2	-	-	37.1	29.2	66.3
>100-300	105	47.4	37.3	36.8	50.7	87.6
	104	46.4	40.4	39.9	14.6	54.5
	135	51.1	48.2	46.9	-	46.9
>300	118	58.6	54.1	53.0	15.5	68.5
	136	61.1	58.2	57.3	-	57.3
	119	60.4	58.0	57.5	-	57.5

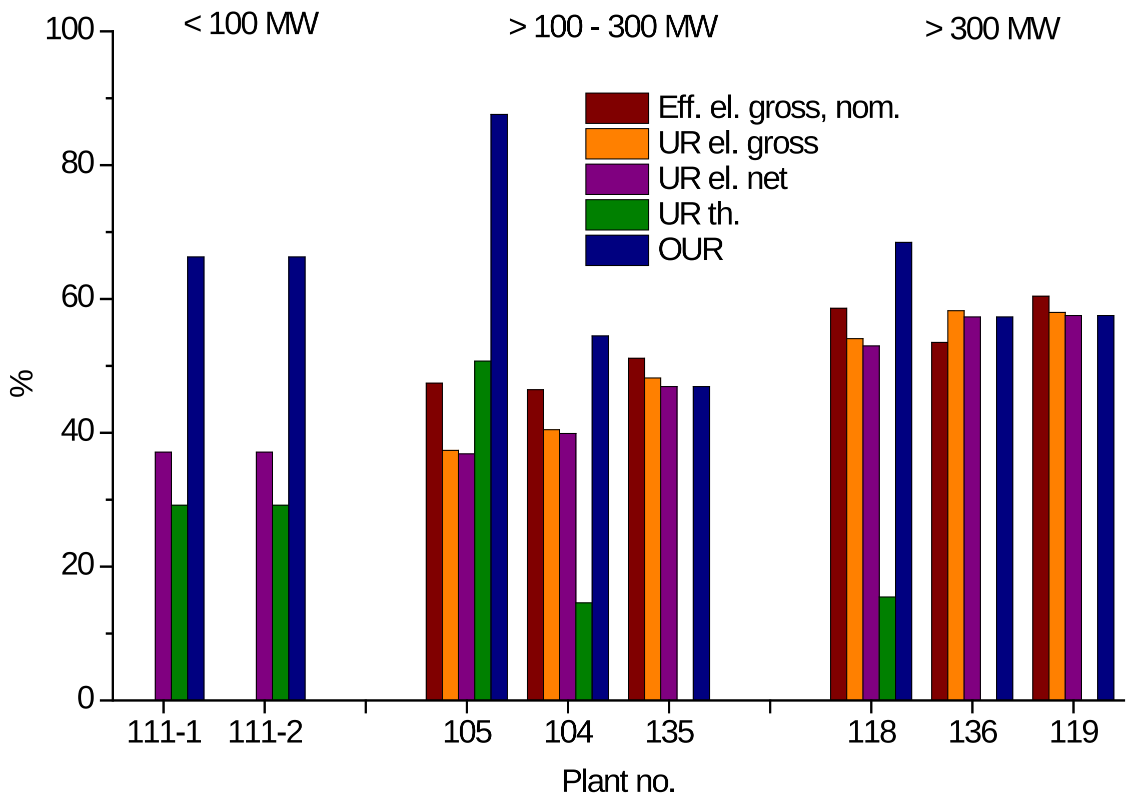

Figure 2: Evaluation level IV, Table a: Efficiencies and utilisation ratios for the Group "Combined Cycle Plants"

The compression of the combustion- and cooling-air makes for a large part of the house-load power. The exact value is strongly dependend on the condition of the ambient air (temperature, pressure and relative humidity). For this reason it is useful to specify the exact air condition when stating values for the power output of the gasturbine. This becomes even more necessary when trying to compare different gasturbines and their efficiencies. A common reference value is 15 °C, 60 % relative humidity and 1,013 bars. It could not be conclusively investigated if the here presented values all apply to this reference state.

The fuel utilisation factors are uniformly high for CCGT plants, even if they are not used for CHP. When the plant is used for CHP, the fuel utilisation factor can be up to 87.6 % (plant no. 105).

Table 19 shows the emissions with the flue gas of CCGT plants. The exception makes plant no. 119, for which two "emissions" sheets were provided. To obtain a better overview, Figure 3 and Figure 4 show the NO_x and CO emissions. The given values are based on a reference oxygen content of 15 vol-%, are validated, do not include OTNOCs and represent the AAV as the annual average of the HHV. Exceptions are indicated in the diagrams as well as in Table 20. Plant no. 104, for example, is equipped with an auxiliary firing system, so that the reference oxygen content for this plant is 10.8 vol-%. This has to be considered when evaluating the data. In addition to the average values, the 5th and the 95th percentile are given, provided that they were stated in the questionnaire.

Table 19: Evaluation level IV, Table b: Air emissions for the Group "Combined Cycle Plants"

TRTI in MW_{th}	Plant no.	NO_x	CO
		Ø in mg/Nm^3	Ø in mg/Nm^3
< 100	111-1	43.0	16.0
	111-2	43.0	16.0
> 100 - 300	105	29.1	24.2
	104	76.4	20.1
	135	27.7	0.2
> 300	118	45.8	3.3
	136	31.5	3.2
	119a	22.3	6.8
	119b	15.2	1.4

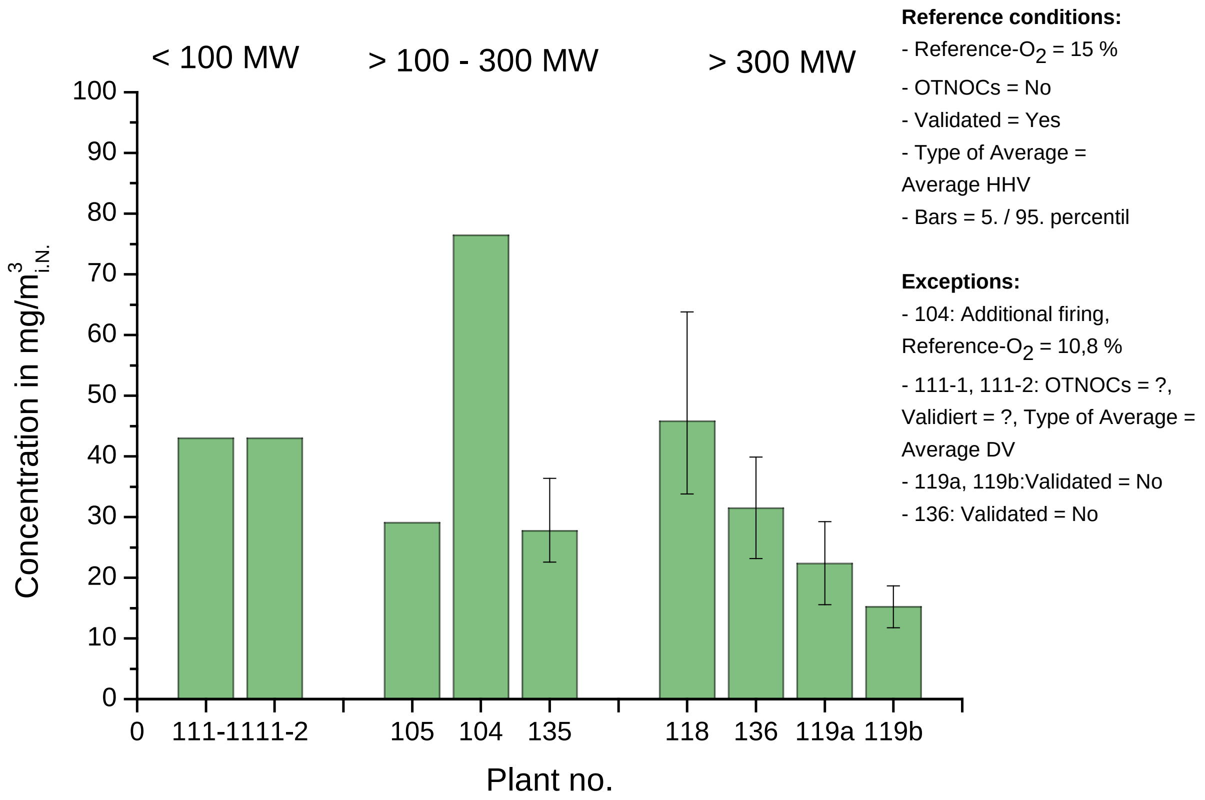

Figure 3: Evaluation level IV, Table b: NO_x emissions for the Group "Combined Cycle Plants"

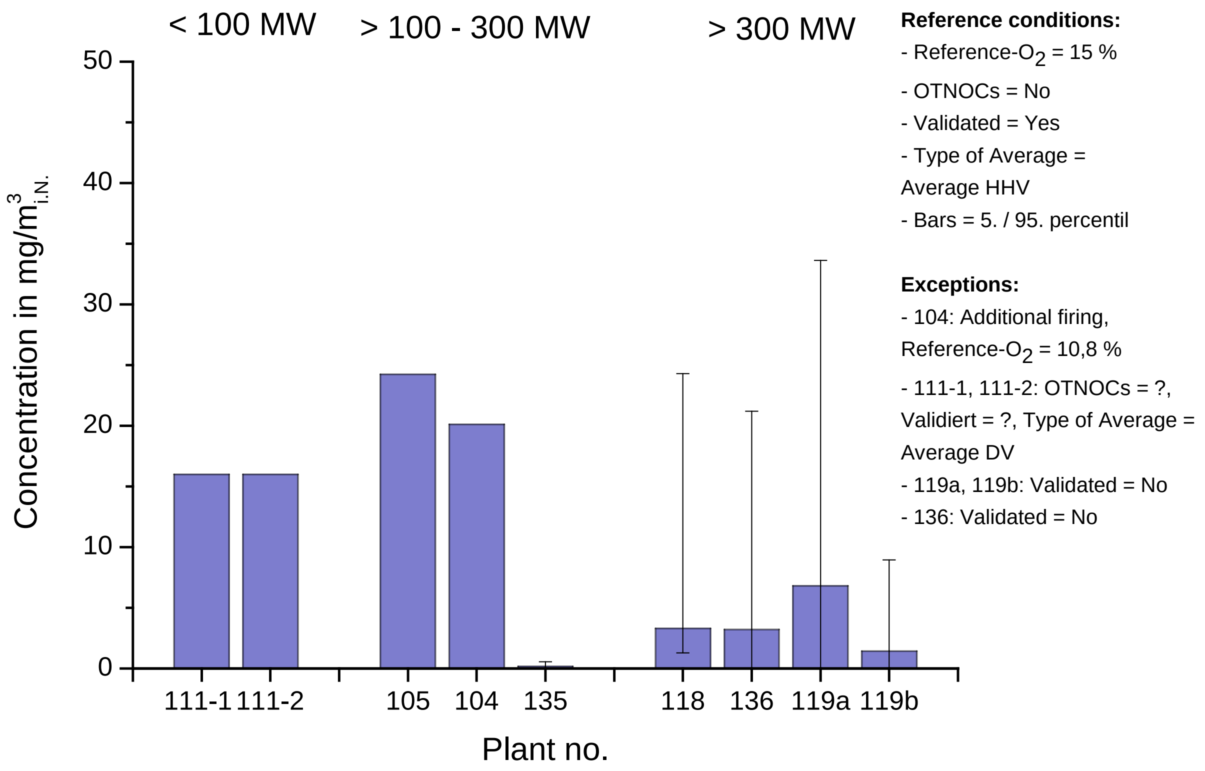

Figure 4: Evaluation level IV, Table b: CO emissions for the Group "Combined Cycle Plants"

Table 20: Reference conditions and exceptions for the Group "Combined Cycle Plants"

Plant no.	Ref. O_2 in %	Includes OTNOCs	Validated	Type of average	fuel	Other
Reference	15	No	Yes	HHV	NG	-
104	10.8	-	-	-	-	Auxiliary firing
105	-	-	-	-	-	Auxiliary firing
111	-	-	-	DV	-	2 GT, 2 HRB, 1 ST
119	-	No (in Table 19 and Figures 3 and 4); Yes (in the questionnaire)	No	-	-	-
135	-	-	-	-	-	Railway electricity, 2 GT, 2 HRB, 1 ST
136	-	No (in Table 19 and Figures 3 and 4); Yes (in the questionnaire)	No	-	-	First comm. in 2011 –> incomplete reference year

The NOx emissions of all plants are low. With exception of plant no. 104, which is equipped with an auxiliary firing and therefore has different reference oxygen content, the AAV is below 50 mg/Nm^3. Plant no. 119 displays the smallest value.

The CO emissions of all plants are below 25 mg/Nm^3. It can be seen that the larger plants (no. 118, 119 and 136) show the lowest values (between 1.4 and 6.8 mg/Nm^3).

For the interpretation of the given values, it should be noted that the majority of the plants was operated throughout the year with high equivalent full load operating factors, as can be seen in Table 18. This means that start-ups and shutdowns were only done infrequently. It should be noted that the information presented in table 19 and figures 3 and 4 do not include OTNOCs, while the individual descriptions of the plants do include OTNOCs. This approach was chosen for the summary to achieve better comparability between the plants.

For part load as well as for start-up and shutdown, the emission levels rise. In chapter 3.2.1.4, which deals with the part load emissions of a CCGT plant, it is shown that the NOx emissions for 50 % load are about twice as high as for normal operation. The same is true for start-up. In addition to this, the CO emissions increase by several powers of ten. Given the case that gas turbines will have to be operated much more flexible due to the fluctuating power input into the power grid, the air emissions, shown in Table 19, are likely to increase in the future.

The water emissions for CCGT plants are given in Table 21. It can be seen that the waste water streams originate from different sources. The given values refer to treated waste water (T) or to non-treated waste water (NT), which is why the comparability of the value is not always given.

Table 21: Evaluation level IV, Table c: Water emissions for the Group "Combined Cycle Plants"

TRTI in MW_{th}	Plant no.	TOC in mg/l	COD in mg/l	N (total) in mg/l	P (total) in mg/l	Cu in mg/l	Cd in mg/l	Hg in mg/l	Pb in mg/l	Discharge point	Origin of the WW
< 100	111-1a, 111-2a	-	6.0	4.6	0.060	0.0017	0.0001	-	0.001	Environment (T)	Cooling system
	111-1b, 111-2b	-	13.7	18.4	0.051	0.0300	0.0003	-	0.002	Environment (T)	Water conditioning facility
	111-1c, 111-2c	-	-	-	-	-	-	-	-	Environment (NT)	Cooling system
> 100 - 300	105	-	-	-	-	0.1300	0.0500	-	0.030	-	-
	104	-	-	-	-	-	-	-	-	Sewage system (T)	Neutralisation pond and fire water system
	135a	29.3	-	-	-	0.0173	0.0010	0.0001	0.007	Lake (T)	Cooling system
	135b	27.3	-	3.3	-	-	-	-	-	Lake (T)	Water conditioning facility
> 300	118a	-	21.3	16.5	0.029	0.0465	0.0003	-	0.001	River (T)	Water conditioning facility, Steam system
	118b	-	14.6	1.3	0.019	0.0179	0.0001	-	0.001	River (NT)	Steam system
	136	-	5.0	10.0	0.050	0.0205	0.0005	-	0.005	River (T)	Water conditioning facility, Dampfsystem
	119	-	5.0	10.0	0.050	0.0675	0.0005	-	0.005	River (T)	Water conditioning facility, Steam system, Cooling system

Table 22 summarises the submitted templates for BAT. As the FGT systems of CCGT plants are comparatively uncomplex, only few suggestions were made. The five submitted templates all deal with the plant configuration, with a medium level of detail. More specific topics are NOx reduction measures, efficiency increases and the application of CHP operation.

Table 22: Evaluation level IV, Table d: BAT submissions for the Group "Combined Cycle Plants"

TRTI in MW_{th}	Plant no.	No. of templates	Short summary	Technical domain	Level of detail
< 100	111-1, 111-2	1	Plant configuration (CHP, equipment)	Whole plant	Medium
> 100 – 300	104	0	-	-	-
	105	0	-	-	-
	135	1	Plant configuration (Railway electricity, equipment, NO_x reduction)	Whole plant	Medium
> 300	118	1	Plant configuration (emission reduction, equipment)	Whole plant	Medium
	136	1	Plant configuration (larger GT, high efficiency, emission reduction)	Whole plant	Medium
	119	1	Plant configuration (modern GT, high efficiency, emission reduction)	Whole plant	Medium

3.2.1.3 Descriptions of Evaluated Plants or Installations

CCGT Plant, Reference no. 111

Reference no. 111 is a CCGT installation for the generation of electricity and heat for district heating, which was commissioned in 2005. The installation consists of two NG-fired turbines and two two-stage downstream heat recovery boilers without additional firing (two plants). The live steam (67 bar/500 °C) is fed into a common extraction/condensation turbine. Steam can be extracted at 10 bar/210 °C to provide heat for district heating. The cooling system is an open once-through cooling with river water.

The total rated thermal input of plant 111 is 176 MW_{th}, the gross electric power output is 84 MW_{el} and the gross thermal power output is 97.2 MW_{th}.

Table 23 and Table 24 show the energy input and output for the reference year as well as the total operating time under normal operating conditions for both gas turbines. The reference year for the given values is 2010. The rolling average values are based on a total operating time of five years.

Table 23: General operating data for reference no. 111 – GT 1

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	5.03E+05	5.15E+05
Net electric energy output	MWh_{el}	1.89E+05	1.98E+05
Net heat output – steam	MWh_{th}	1.47E+05	1.42E+05
Total operating time under normal operating conditions	h	6084	6802
Equivalent full load operating factor	%	93.9	86

Table 24: General operating data for reference no. 111 – GT 2

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	5.00E+05	5.06E+05
Net electric energy output	MWh_{el}	1.92E+05	1.95E+05
Net heat output – steam	MWh_{th}	1.46E+05	1.40E+05
Total operating time under normal operating conditions	h	6052	6711
Equivalent full load operating factor	%	93.9	85.7

In the reference year, the plants were operated for more than 6000 h, with an equivalent full load operating factor of 93.9 %. The net electrical utilisation ratio was 38 % and the thermal utilisation ratio was 29 %, so that the fuel utilisation factor was 67 %. With the rolling average values the operating time was about 6700 h with an equivalent full load operating factor of 86 %. The net electrical utilisation ratio was 38 % and the thermal utilisation ratio 28 %, so that a fuel utilisation factor of 66 % can be calculated.

Environmental aspects

The installation produces typical air emissions for gaseous fuel-fired power plants. In accordance to the official authorisation, the air pollutants NO_x and CO are continuously measured in the flue gas of both gas turbines. Primary measures are taken for emission abatement directly in the gas turbine.

Table 25 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas of the first turbine. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that it is not clear if the presented values are validated or not and if they do include OTNOCs or not. The reference oxygen content is 15 %.

Table 25: Air emissions for reference no. 111 - GT 1

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm³	32.5	-	42.99	-	-	50	DV	Cont.	-	-	75
	kg/year	6.7E+04										
CO	mg/Nm³	0	-	15.99	-	-	30	DV	Cont.	-	-	100
	kg/year	2.2E+04										

Waste water is discharged in three streams directly into a river. The first is cooling water, which is not treated. The second stream is filtrated waste water from the steam system. The values of the water emissions for this steam are given in Table 26. The third stream is neutralised waste water from the steam system and from the water conditioning. The values for this stream are shown in Table 27.

Table 26: Water emissions for reference no. 111 - Steam system

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
COD	(mg/l)	4	6.04	16	-	Grab sample	-	2/year	20
				-					
N (total)	(mg/l)	3.82	4.58	4.97	-	Grab sample	-	2/year	0.05
				-					
P (total)	(mg/l)	0.01	0.0595	0.1	-	Grab sample	-	2/year	0.1
				-					
Cd	(mg/l)	0.0001	0.0001	0.0005	-	Grab sample	-	2/year	0.005
	(kg/year)			-					
Pb	(mg/l)	0.0002	0.0013	0.0021	-	Grab sample	-	2/year	0.05
	(kg/year)			-					
Cr	(mg/l)	0.001	0.0015	0.0016	-	Grab sample	-	2/year	0.05
	(kg/year)			-					
Cu	(mg/l)	0.001	0.0017	0.0032	-	Grab sample	-	2/year	0.1
	(kg/year)			-					
Ni	(mg/l)	0.0001	0.0008	0.0015	-	Grab sample	-	2/year	0.05
	(kg/year)			-					
AOX	(mg/l)	0.01	0.015	0.048	-	Grab sample	-	2/year	0.1
	(kg/year)			-					

Table 27: Water emissions for reference no. 111 - neutralised water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
COD	(mg/l)	5	13.69	67.6	-	Grab sample	-	2/year	150
				2305					
N (total)	(mg/l)	0.75	18.36	105	-	Grab sample	-	2/year	100
				3091.46					
P (total)	(mg/l)	0.1	0.0513	0.27	-	Grab sample	-	2/year	0.15
				8.2629					
Cd	(mg/l)	0.0001	0.0003	0.0011	-	Grab sample	-	2/year	0.005
	(kg/year)			0.0421					
Pb	(mg/l)	0.0001	0.0022	0.0083	-	Grab sample	-	2/year	0.05
	(kg/year)								
Cr	(mg/l)	0.0001	0.0039	0.0083	-	Grab sample	-	2/year	0.05
	(kg/year)			0.6735					
Cu	(mg/l)	0.0009	0.0028	0.011	-	Grab sample	-	2/year	0.05
	(kg/year)			0.4630					
Ni	(mg/l)	0.0001	0.0008	0.0015	-	Grab sample	-	2/year	0.05
	(kg/year)			-					
AOX	(mg/l)	0.01	0.021	0.039	-	Grab sample	-	2/year	1
	(kg/year)			3.5360					
As	(mg/l)	0.0004	0.0021	0.0038	-	-	-	-	0.1
	(kg/year)			0.3368					

Table 28 shows the solid residues, which are produced in the installation.

Table 28: Solid residues for reference no. 111

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
aqueous rinsing liquids containing dangerous substances	-	110111	9.41	-	-
machining emulsions and solutions free of halogens	-	120109	1.1515	-	-
mineral-based non-chlorinated engine, gear and lubricating oils	-	130205	0.6125	-	-
mixtures of wastes from grit chambers and oil/water separators	-	130508	8	-	-
absorbents, filter materials (including oil filters not otherwise specified), wiping cloths,	-	150202	0.9	-	-
lead batteries	-	160601	1.995	-	-
mixture of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06	-	170107	3.31	-	-
plastic	-	170203	0.075	-	-
screenings	-	190801	2.11	-	-
saturated or spent ion exchange resins	-	190905	6.915	-	-

Special characteristics

The installation was modernised to meet the demand of electricity and district heating more flexible. In solo-operation, one or both gas turbine can be operated without the steam cycle, which allows for a high grade of flexibility. Due to the combined generation of heat and power, a very high fuel utilisation factor can be achieved. This configuration is therefore suggested as BAT by the operator.

CCGT Plant, Reference no. 105

Reference no. 105 is a CCGT plant for the combined generation of electricity and process steam, which was commissioned in 2005. The plant consists of two gas turbines, which are fuelled by NG and one downstream two stage heat recovery boiler without additional firing. The live steam parameters are 60 bar and 475 °C. The steam is not re-heated. The produced steam is fed into an extraction/back-pressure turbine. Steam can be extracted at 10 bar and 255 °C as well as at 5 bar and 180 °C and is used in the paper industry. As the plant is heat-operated, there is no cooling system.

The total rated thermal input of the plant is 100 MW_{th}, the gross electric power output is 37.95 MW_{el}. Table 29 shows the energy input and output for the reference year as well as the total operating time under normal operating conditions. The reference year for the given values is 2010. The rolling average values are based on five years of operation.

Table 29: General operating data for reference no. 105

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	7.25E+05	6.88E+05
Gross electric energy output	MWh_{el}	2.71E+05	2.56E+05
Net electric energy output	MWh_{el}	2.67E+05	2.52E+05
Gross heat output – steam	MWh_{th}	3.67E+05	3.59E+05
Net heat output – steam	MWh_{th}	3.26E+05	3.25E+05
Total operating time under normal operating conditions	h	8284	8389
Equivalent full load operating factor	%	87.5	82

In the reference year, the plant was operated almost continuously with an equivalent full load operating factor of 87.5 %. The net electrical utilisation ratio is 36.8 %. With a thermal utilisation ratio of 44.9 % the fuel utilisation factor is 81.7 %. With the rolling average values a net electrical utilisation ratio of 36.6 % can be calculated as well as a thermal utilisation ratio of 47.4 %, which lead to a fuel utilisation factor of 84 %.

Environmental aspects

The plant produces typical air emissions for gaseous fuel-fired power plants. In accordance to the official authorisation, the air pollutants NO_x and CO are continuously measured in the flue gas. Primary measures are taken for emission abatement directly in the gas turbine.

Table 30 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas of both gas turbines. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do not include OTNOCs. The reference oxygen content is 15 %.

Table 30: Air emissions for reference no. 105

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm^3	10.17	-	29.06	-	-	46.77	HHV	Cont.	Yes	150	75
	kg/year	6.5E+04										
CO	mg/Nm^3	2.1	-	24.23	-	-	45.24	HHV	Cont.	Yes	200	100
	kg/year	5.4E+04										

There is no WWT facility. The water emissions are shown in Table 31.

Table 31: Water emissions for reference no. 105 - non-treated waste water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Cd	(mg/l)	-	0.05	-	-	Grab sample	-	2	0.05
	(kg/year)			-					
Pb	(mg/l)	-	0.03	-	-	Grab sample	-	2	0.1
	(kg/year)			-					
Cr	(mg/l)	-	0.024	-	-	Grab sample	-	2	0.5
	(kg/year)			-					
Cu	(mg/l)	-	0.13	-	-	Grab sample	-	2	0.5
	(kg/year)			-					
Ni	(mg/l)	-	0.015	-	-	Grab sample	-	2	0.5
	(kg/year)			-					
V	(mg/l)	-	0.01	-	-	Grab sample	-	2	4
	(kg/year)			-					
Zn	(mg/l)	-	-	-	-	Grab sample	-	2	4
	(kg/year)			-					
AOX	(mg/l)	-	-	-	-	Grab sample	-	2	1
	(kg/year)			-					

Table 32 shows the solid residues.

Table 32: Solid residues for reference no. 105

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Street-cleaning residues	-	200303	2	Utilisation - others	no information available
Absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by dangerous substances	-	150202	1	Utilisation - others	no information available
Mineral-based non-chlorinated engine, gear and lubricating oils	-	130205	1	Utilisation - others	no information available
Mixed municipal waste	-	200301	2	Utilisation - others	no information available

Special characteristics

For the minimisation of NOx emissions, the gas turbines are equipped with a dry-low-NOx-system. The CHP is not used for district heating but for a paper production plant.

CCGT Plant, Reference no. 104

Reference no. 104 is a CCGT plant for the generation of electricity and heat, which was commissioned in 2005. The plant is located at a combustion site with a total rated thermal input of 488 MW_{th}. It consists of a gas turbine, which is fuelled with NG and a downstream heat recovery natural circulation boiler with additional firing. Live steam parameters are 115 bar and 535 °C. There is no reheater. The steam is fed into a extraction/condensation steam turbine, in which steam at 20 bar/115 °C can be extracted for district heating. The open circuit cooling system can either be operated as circulated cooling system (cooling tower only) or as once through cooling system (river cooling). The cooling water is taken from a neighbouring river in which it is also emitted.

The total rated thermal input of the plant is 165 MW_{th}, the gross electric power output is 76.6 MW_{el}. The gross heat power output (hot water) by means of flue gas heat recovery is 15 MW_{th}, while the gross heat power output by means of extraction of steam from the turbine is 85 MW_{th}. In case of 100 % extraction operation the power of the steam turbine is reduced to 20.6 MW_{el}. The amount of extracted steam accounts for changes in the efficiency. For condensation operation without extraction the nominal electrical efficiency is 46.4 %, while the thermal efficiency is 9.1 %. For CHP operation the nominal electrical efficiency is 37.9 % and the thermal efficiency is 60.6 %.

The steam turbine as well as the new district heating system were commissioned between 2010 and 2012, the reference year (2010) is not representative for the current operation mode.

Table 33 shows the energy input and output for the reference year as well as the total operating time under normal operating conditions. The reference year for the given values is 2010. Five years have been taken into account for the rolling average value.

Table 33: General operating data for reference no. 104

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	7.78E+05	8.77E+05
Gross electric energy output	MWh_{el}	2.83E+05	3.20E+05
Net electric energy output	MWh_{el}	2.79E+05	3.15E+05
Gross heat output – hot water	MWh_{th}	1.02E+05	9.99E+04
Net heat output – hot water	MWh_{th}	1.02E+05	9.99E+04
Total operating time under normal operating conditions	h	6591	7548
Equivalent full load operating factor	%	64.4	70.4

In the reference year, the equivalent full load operating factor was 64.4 %. The net electrical utilisation ratio was 35.9 %. With a thermal utilisation ratio of 13.1 % the fuel utilisation factor (without steam turbine) was 49 %. For the rolling average value a net electrical utilisation ratio of 35.9 % can be calculated as well as a thermal utilisation ratio of 11.4 %.

Environmental aspects

The plant produces typical air emissions for gaseous fuel-fired power plants. In accordance to the official authorisation, the air pollutants NO_x and CO are continuously measured in the flue gas. Primary measures are taken for emission abatement directly in the gas turbine (low-NO_x-burners).

Table 34 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do not include OTNOCs. The reference oxygen content is 10.8 %.

Table 34: Air emissions for reference no. 104

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm³	54	-	76.41	-	-	88	HHV	Cont.	Yes	91.2	-
	kg/year	1.5E+05										
CO	mg/Nm³	5	-	20.12	-	-	54	HHV	Cont.	Yes	82.7	-
	kg/year	3.9E+04										
Dust	mg/Nm³	-	-	-	-	-	-	-	-	-	-	5
	kg/year	-										

The waste water, which comes from neutralisation and fire water holding, is pre-treated on site (oil/water separator) before it is discharged into the sewerage. FGT is not necessary and there are no solid residues.

The plant does not produce any solid residues.

Special characteristics

The plant is operated flexibly to meet the demands of electricity consumption in the grid and heat consumption in the district heating. For this reason, short-term load changes are necessary. The plant was built to replace an older gas turbine plant with a more flexible and efficient technology.

To increase the power of the gas turbine, evaporative cooling has been installed to decrease the inlet temperature for the compressor.

CCGT Plant, Reference no. 135

Reference no. 135 displays a multi shaft CCGT plant, consisting of two gas turbines and one steam turbine, which was commissioned in 1994 (plant 1) and 1995 (plant 2). It is solely used to supply electricity to the German railway-grid (16.67 Hz). The installation consists of two gas turbines, which are fuelled with NG and two downstream heat recovery boilers without additional firing. Live steam parameters are 62 bar/530 °C. The steam of both heat recovery boilers is fed into a single condensation steam turbine. The cooling system for the water/steam cycle is a mechanical draught cooling tower. Figure 5 shows a sketch of the installation's design.

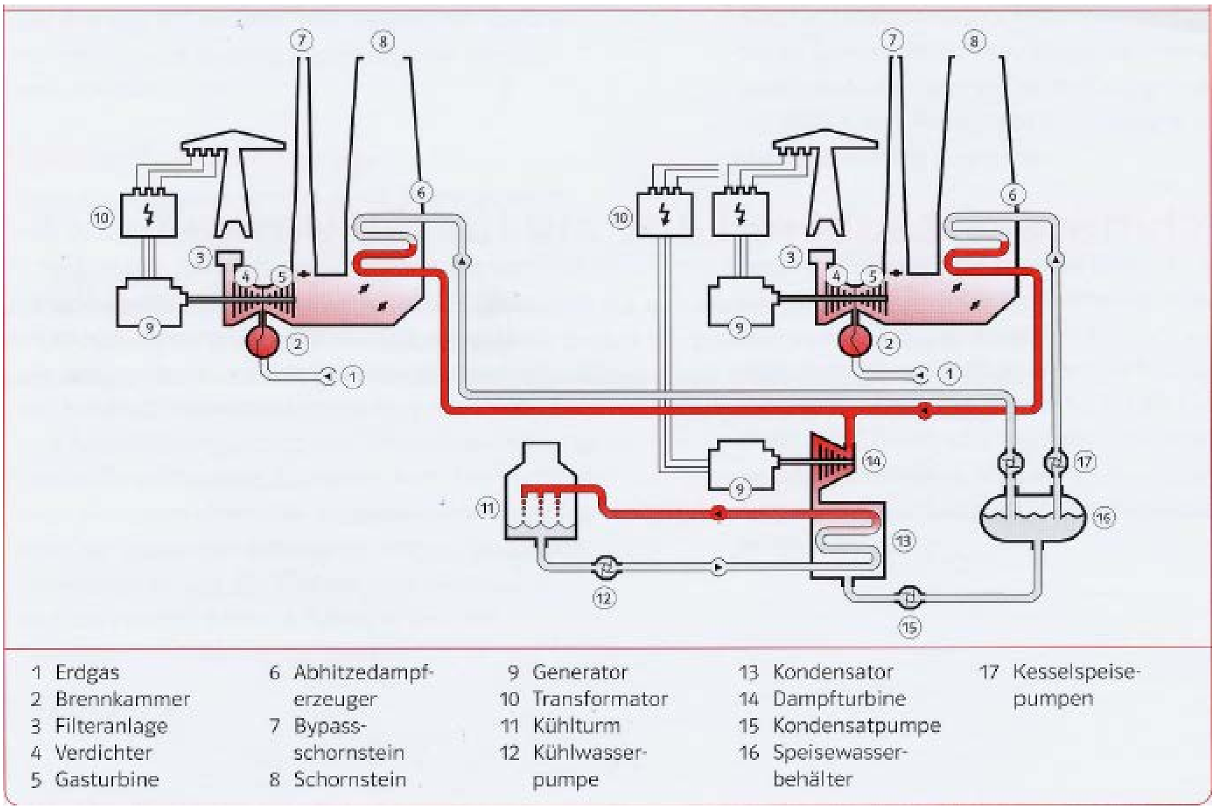

Figure 5: Sketch of the design of reference no. 135

The total rated thermal input of the installation is 360 MW_{th}, the gross electric power output is 184 MW_{el}, which leads to a nominal gross electrical efficiency of 51.1 %.

Table 35 shows the energy input and output for the reference year as well as the total operating time under normal operating conditions. The reference year for the given values is 2010. Five years have been taken into account for the rolling average value.

Table 35: General operating data for reference no. 135

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	1.39E+06	1.26E+06
Gross electric energy output	MWh_{el}	6.71E+05	5.90E+05
Net electric energy output	MWh_{el}	6.53E+05	5.75E+05
Total operating time under normal operating conditions	h	4081	3591
Equivalent full load operating factor	%	94.8	97.5

The installation is operated to meet the demand of the German railway-grid. In the last years the installation was operated for about 4000 h/a, the equivalent full load operating factor was 95 %. The net electrical utilisation ratio was 47 % (reference year) and 45.6 % (rolling average value).

Environmental aspects

The installation produces typical air emissions for gaseous fuel-fired power plants. In accordance to the official authorisation, the air pollutants NO_x and CO are continuously measured in the flue gas of both gas turbines. Primary measures are taken for emission abatement directly in the gas turbine. The construction of the hybrid burner (diffusion and premixing stage) in combination with an adapted burning chamber ensures low NO_x-concentrations.

Table 36 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do not include OTNOCs. The reference oxygen content is 15 %.

Table 36: Air emissions for reference no. 135

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm³	10.52	22.58	27.74	36.4	37.52	47.12	HHV	Cont.	Yes	200	100
	kg/year	1.1E+05										
CO	mg/Nm³	0	0	0.18	0.55	0.6	4.07	HHV	Cont.	Yes	200	100
	kg/year	369										

Taking account of the legal and regulatory provisions, the cooling water is discharged directly. Other waste water streams (from demineralisation system cleaning) are pre-treated on site. The water emissions are shown in Table 37 and Table 38.

Table 37: Water emissions (cooling water) for reference no. 135

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validate	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	134700	-	-	-	-	-	-
Temp.	(°C)	-	18.6	-	-	-	-	-	<30
pH		-	8.2	-	-	-	-	-	6.9 to 9.5
TOC	(mg/l)	-	29.3	-	-	Grab sample	-	-	-
	(kg/year)			-					
Cl^-	(mg/l)	-	398	-	-	Grab sample	-	-	800
	(kg/year)			-					
Cd	(mg/l)	-	0.001	-	-	Grab sample	-	-	0.05
	(kg/year)			-					
Hg	(mg/l)	-	0.0001	-	-	Grab sample	-	-	0.05
	(kg/year)			-					
Pb	(mg/l)	-	0.0066	-	-	Grab sample	-	-	0.1
	(kg/year)			-					
Cr	(mg/l)	-	0.0051	-	-	Grab sample	-	-	0.1
	(kg/year)			-					
Cu	(mg/l)	-	0.0173	-	-	Grab sample	-	-	0.05
	(kg/year)			-					
Ni	(mg/l)	-	0.0105	-	-	Grab sample	-	-	0.1
	(kg/year)			-					
Zn	(mg/l)	-	0.0323	-	-	Grab sample	-	-	0.1
	(kg/year)			-					

Table 38: Water emissions for reference no. 135 - (demineralisation system cleaning) after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	1500	-	-	-	-	-	-
Temp.	(°C)	-	24.3	-	-	-	-	-	-
pH		-	7.4	-	-	-	-	-	-
TSS	(mg/l)	-	11.2	-	-	Grab sample	-	-	50
	(kg/year)	-							
TOC	(mg/l)	-	27.3	-	-	Grab sample	-	-	32
	(kg/year)	-							
N (total)	(mg/l)	-	3.26	-	-	Grab sample	-	-	10
	(kg/year)	-							
NO_2^-/NO_3^-	(mg/l)	-	2.27	-	-	Grab sample	-	-	nitrate 5 nitrite 0.2
	(kg/year)	-							
NH_3-N	(mg/l)	-	0.98	-	-	Grab sample	-	-	4.8
	(kg/year)	-							
As	(mg/l)	-	0.0155	-	-	-	-	-	0.1
	(kg/year)	-							
AOX	(mg/l)	-	0.0357	-	-	Grab sample	-	-	1
	(kg/year)	-							

The only by-product is sludge from the WWT, which contains high amounts of limestone and can be utilised. In the reference year, 332 t of this by-product were generated.

Special characteristics

The installation is operated to meet the demand of the German railway-grid. The facility is the first to combine a gas turbine with a 16.6 Hz-generator and is therefore suggested as BAT by the operator.

The installation of two separate gas turbines allows for a good part load efficiency. The net electrical efficiency is 49.6 % at full load and falls to 42 % at 50 % load (in reference to the whole installation). In case of further load reduction, one of the gas turbines is shut down, which leads to an increase in the net electrical efficiency to 48 %. In this way the net electrical efficiency at 25 % load is still 40 %.

To achieve better flexibility, there is stack for each gas turbine, which allows for solo operation of the turbines. The first gas turbine can reach maximal load after just 26 minutes, 40 minutes after start up 120 MW_{el} are available. To start up the heat recovery boiler, three to six hours are necessary. Operation in CCGT mode allows for load changes of 20 MW_{el}/min.

CCGT Plant, Reference no. 118

Reference no. 118 is a CCGT plant for the combined generation of electricity and heat, which was commissioned in 2005. The plant consists of a gas turbine, which can be fuelled with NG and LFO and a downstream three pressure heat recovery boiler without additional firing. The live steam parameters are 131 bar/565 °C, the reheater steam parameters are 31 bar/565 °C. The steam is fed into an extraction/condensation turbine. For the generation of hot water for district heating (11 bar/130 °C), steam can be extracted from the steam turbine as well as the heat recovery boiler. The cooling system is a once-through cooling with river water. If the cooling water temperature after the condenser is higher than 30 °C, an additional cooling tower has to be used. This can happen on hot summer days.

The total rated thermal input of the plant is 714.2 MW_{th}. The gross electric power output is 418.6 MW_{el} and the nominal gross heat power output (hot water) is 265 MW_{th}.

Table 39 shows the energy input and output for the reference year as well as the total operating time under normal operating conditions. The reference year for the given values is 2009.

Table 39: General operating data for reference no. 118

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	4.81E+06	-
Gross electric energy output	MWh_{el}	2.60E+06	-
Net electric energy output	MWh_{el}	2.55E+06	-
Gross heat output – hot water	MWh_{th}	7.44E+05	-
Net heat output – hot water	MWh_{th}	7.44E+05	-
Total operating time under normal operating conditions	h	7913	-
Equivalent full load operating factor	%	85	-

In 2009 the plant was operated almost continuously. The equivalent full load operating factor was 85 %. The net electrical utilisation ratio was 53.0 %, the thermal utilisation ratio 15.3 %, which lead to a fuel utilisation factor of 68.3 %.

Environmental aspects

The plant produces typical air emissions for gaseous fuel-fired power plants. In accordance to the official authorisation, the air pollutants NO_x and CO are continuously measured in the flue gas. Primary measures are taken for emission abatement directly in the gas turbine. 24 individual burners are installed in the combustion chamber, which allow for homogeneous combustion.

Table 40 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do not include OTNOCs. The reference oxygen content is 15 %.

Table 40: Air emissions for reference no. 118

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm³	22	35	47	65	67	87	HHV	Cont.	Yes	-	75
	kg/year	5.9E+05										
CO	mg/Nm³	1	2	4	25	37	160	HHV	Cont.	Yes	-	100
	kg/year	2E+05										
SO_x	mg/Nm³	-	-	-	-	-	-	-	Estimated value	-	-	-
	kg/year	2600										

The annual load for SO_x is 2600 kg/year. It should be noticed, that only NG was combusted in the reference year.

Taking account of the legal and regulatory provisions, the waste water is discharged into a river. The first waste water stream is made up of non-treated cooling water. The second stream is non-treated waste water from the water/steam cycle. Table 41 shows the properties of the water emissions for these non-treated waste waters. The last waste water stream is composed of neutralised water from the water conditioning and the steam cycle. The emissions for this stream are shown in Table 42.

Table 41: Water emissions for reference no. 118 – non-treated waste water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	11743	-	-	-	-	-	-
Temp.	(°C)	-	-	30	-	-	-	-	-
pH		6.4	6.8	8.2	-	-	-	-	-
COD	(mg/l)	-	-	15	-	Grab sample	No	23	-
	(kg/year)			176.2					
Cd	(mg/l)	-	-	0.0001	-	Grab sample	No	12	-
	(kg/year)			0.001					
Pb	(mg/l)	-	-	0.001	-	Grab sample	No	12	-
	(kg/year)			0.012					
Cr	(mg/l)	-	-	0.001	-	Grab sample	No	12	-
	(kg/year)			0.012					
Cu	(mg/l)	-	-	0.02	-	Grab sample	No	12	-
	(kg/year)			0.235					
Ni	(mg/l)	-	-	0.001	-	Grab sample	No	12	-
	(kg/year)			0.012					
Zn	(mg/l)	-	-	0.02	-	Grab sample	No	12	-
	(kg/year)			0.235					
AOX	(mg/l)	-	-	0.01	-	Grab sample	No	3	-
	(kg/year)			0.12					
N (total)	(mg/l)	0.5	1.4	3.4	-	Grab sample	No	22	-
	(kg/year)			16.4					
P (total)	(mg/l)	-	-	0.02	-	Grab sample	No	12	-
	(kg/year)			0.2					

Table 42: Water emissions for reference no. 118 - neutralised water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validate	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	9077	-	-	-	-	-	-
Temp.	(°C)	-	-	30	-	-	-	-	-
pH		6.4	7	8.4	-	-	-	-	-
COD	(mg/l)	15	22	73	-	Grab sample	No	22	80
	(kg/year)			199.7					
Cd	(mg/l)	0.0002	0.0003	0.0008	-	Grab sample	No	11	0.05
	(kg/year)			0.003					
Pb	(mg/l)	-	-	0.001	-	Grab sample	No	11	0.1
	(kg/year)			0.009					
Cr	(mg/l)	0.001	0.0015	0.002	-	Grab sample	No	11	0.5
	(kg/year)			0.014					
Cu	(mg/l)	0.02	0.052	0.14	-	Grab sample	No	11	0.5
	(kg/year)			0.47					
Ni	(mg/l)	0.002	0.004	0.008	-	Grab sample	No	11	0.5
	(kg/year)			0.036					
Zn	(mg/l)	0.11	0.18	0.28	-	Grab sample	No	11	1
	(kg/year)			1.6					
AOX	(mg/l)	0.02	0.05	0.08	-	Grab sample	No	11	0.2
	(kg/year)			0.45					
N (total)	(mg/l)	8.2	17.6	22.7	-	Grab sample	No	22	60
	(kg/year)			159.8					
P (total)	(mg/l)	0.02	0.03	0.05	-	Grab sample	No	22	3
	(kg/year)			0.27					

There are no solid residues from the process. Other solid wastes, which accumulate at the plant, are shown in Table 43.

Table 43: Solid residues for reference no. 118

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Packaging made of wood	Unloading facilities	15 01 03	2.84	-	R 13
Soakage and filtration material	WWT facilities	15 02 02*	0.853	-	D 13 (collective waste disposal order)
Glass, plastic and wood contaminated by dangerous materials	-	17 02 04*	21.48	-	R 13 (collective waste disposal order)
Iron and steel	-	17 04 05	4.11	-	R 04
Cable except these which fall under 170410	-	17 04 11	2.5	-	R 04
Insulating material which contains dangerous materials	-	17 06 03*	1.2	-	D 15 (collective waste disposal order)
Various build waste expect these which fall under 17 09 01, 17 09 02, 17 09 03	-	17 09 04	11.06	-	R13
Waste from sand bucket	-	19 08 02	38	-	R 12
Sludge from water clearing	-	19 09 02	21.8	-	R 12

Special characteristics

The plant is operated flexibly to meet the requirements of district heating and electrify demand. For this reason, short term load changes are necessary. The plant was build to replace an older gas boiler.

CCGT Plant, Reference Plant no. 136

Reference no. 136 is a CCGT plant for the generation of electricity, which was commissioned in 2011. The plant consists of a gas turbines, which is fuelled with NG and a downstream heat recovery boiler without additional firing. The high pressure part of the boiler is operated as once-through (Benson), while the mid and low pressure parts are natural circulation boilers (with a separate drum). The live steam parameters are 173 bar and 588 °C, the reheater steam parameters are 35 bar/587 °C. The steam is expanded in a condensation turbine. The cooling system for the water/steam cycle is a once-through cooling with river water. Figure 6 shows a sketch of the plant layout.

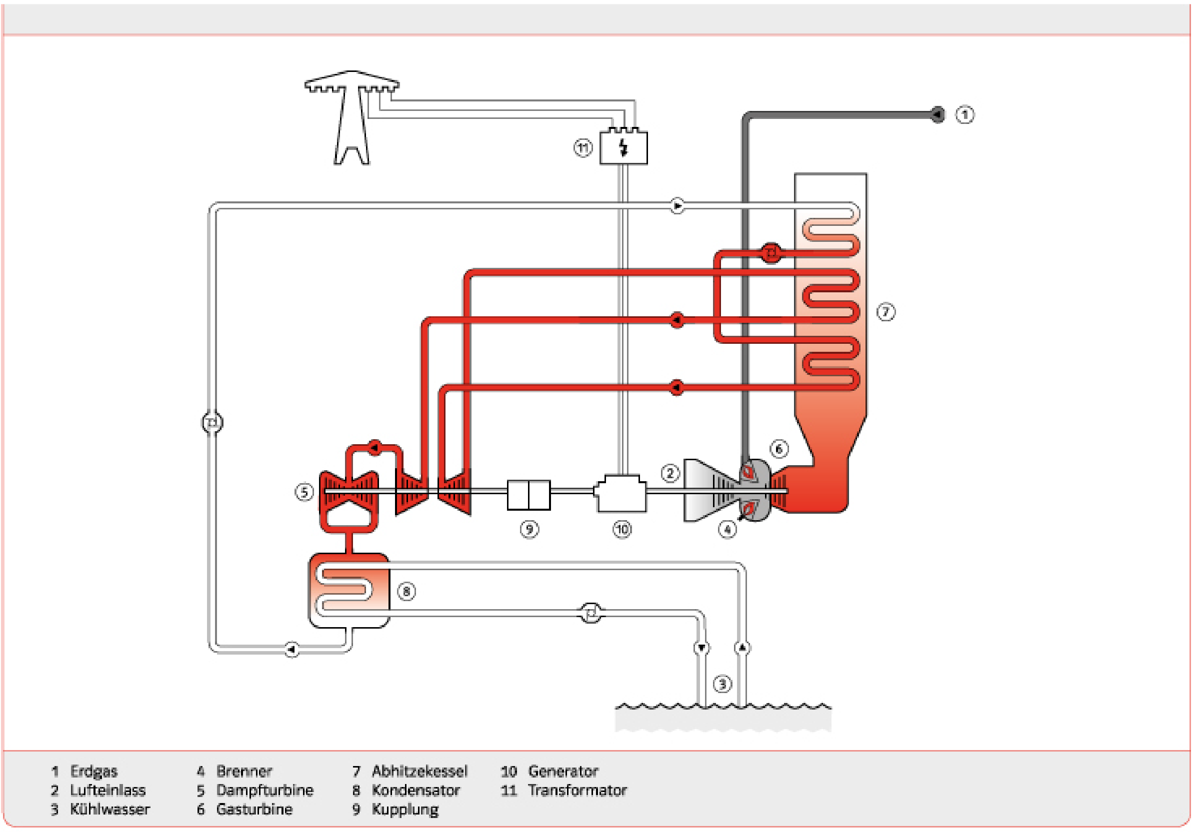

Figure 6: Sketch of the design of reference no. 136

The plant is located at a combustion site with five individual plants and a total net electric power output of 1821 MW_{el}. Combustion installation no. 119 is also located at this site. The total rated thermal input of the plant is 900 MW_{th} (for an ambient air temperature of +9 °C), the gross electric power output is 550 MW_{el}, which leads to a nominal gross electrical efficiency of 61.1 %.

Table 44 shows the energy input and output for the reference year as well as the total operating time under normal operating conditions. The reference year for the given values is 2011.

Table 44: General operating data for reference no. 136

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	3.04E+06	-
Gross electric energy output	MWh_{el}	1.77E+06	-
Net electric energy output	MWh_{el}	1.74E+06	-
Total operating time under normal operating conditions	h	3914	-
Equivalent full load operating factor	%	75.6	-

In 2011 the plant was operated for about 4000 h. The equivalent full load operating factor is 75.6 %. The net electrical utilisation ratio is 57.2 %.

Environmental aspects

The plant produces typical air emissions for gaseous fuel-fired power plants. In accordance to the official authorisation, the air pollutants NO_x and CO are continuously measured in the flue gas. Primary measures are taken for emission abatement directly in the gas turbine.

Table 45 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas of both gas turbines. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are not validated and do include OTNOCs. The reference oxygen content is 15 %.

Table 45: Air emissions for reference no. 136

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm^3	21.2	23.17	31.46	39.86	41.01	79.11	HHV	Cont.	Yes	150	75
	kg/year	3.1E+05										
CO	mg/Nm^3	0.17	0	3.21	21.2	23.69	348.9	HHV	Cont.	Yes	200	100
	kg/year	1E+06										

Taking account of the legal and regulatory provisions, two waste water streams are discharged into a river. The first waste water stream is made up of cooling water and other non-treated waste water from the water/steam cycle (including surface runoff). The second stream is neutralised waste water from the water/steam cycle and the water conditioning. The water emissions are shown in Table 46.

Table 46: Water emissions for reference no. 136 - neutralised water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	2200	-	-	-	-	-	-
Temp.	(°C)	-	-	-	-	-	-	-	-
pH		7	-	9.1	-	-	-	-	6.5 to 9.5
TSS	(mg/l)	-	25	-	-	-	-	-	30
	(kg/year)	-							
COD	(mg/l)	2.5	5	41	-	-	-	-	50/80
	(kg/year)	-							
N (total)	(mg/l)	10	-	10	-	-	-	-	10
	(kg/year)	-							
Cd	(mg/l)	0.0005	-	0.0005	-	-	-	-	0.05
	(kg/year)	-							
Pb	(mg/l)	0.005	-	0.005	-	-	-	-	0.1
	(kg/year)	-							
Cr	(mg/l)	0.005	-	0.005	-	-	-	-	0.5
	(kg/year)	-							
Cu	(mg/l)	0.005	-	0.036	-	-	-	-	0.5
	(kg/year)	-							
Zn	(mg/l)	0.01	-	0.01	-	-	-	12	1
	(kg/year)	-							
Ni	(mg/l)	0.005	-	0.006	-	-	-	-	0.5
	(kg/year)	-							
V	(mg/l)	0.01	-	0.01	-	-	-	12	4

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
	(kg/year)			-					
P (total)	(mg/l)	0.05	-	0.05	-	-	-	-	3
	(kg/year)			-					

There are no solid residues.

Special characteristics

The gas turbine of plant 136 is the most powerful gas turbine in the world. The process further consists of a three-stage waste recovery steam generator and a steam turbine. The once-through cooling system for the condenser uses river water. Gross electrical efficiencies of 60 % can be achieved, which is why the plant is suggested as BAT by the operator.

CCGT Plant, Reference no. 119

Reference no. 119 is a CCGT installation for the generation of electricity and heat, which was commissioned in 2010. The installation consists of two gas turbines, which are fuelled with NG and two downstream heat recovery boilers without additional firing (two plants) and a common steam turbine. The high pressure part of each boiler is operated as once-through (Benson), while the mid and low pressure parts are natural circulation boilers (with a separate drum). There are two stacks and hence two emission measuring points. The live steam parameters are 132 bar and 560 °C, the reheater steam parameters are 30 bar/558 °C. The steam is expanded in a condensation steam turbine. The cooling system is an open once-through cooling with river water. Figure 7 shows a sketch of the installation's layout.

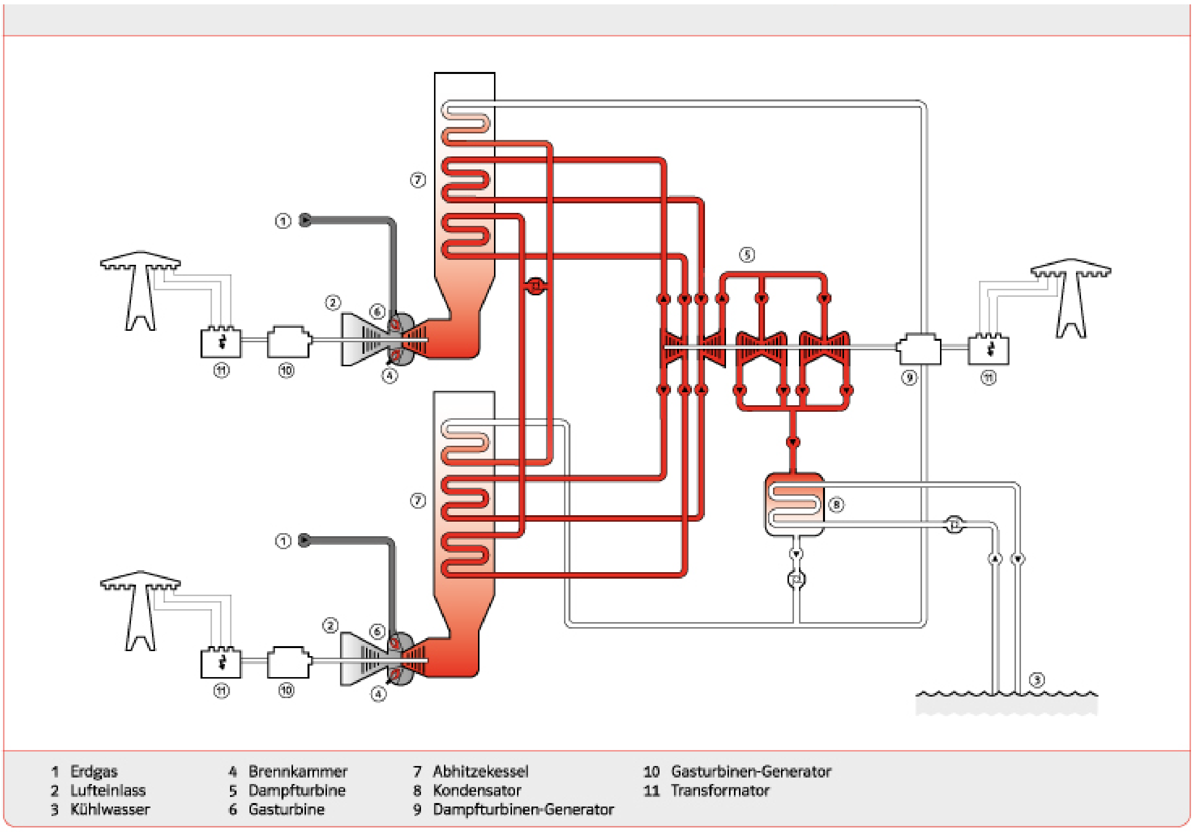

Figure 7: Sketch of the design of reference no. 119

The installation is located at a combustion site with five individual plants and a total net electric power output of 1821 MW_{el}. Combustion plant no. 136 is also located at this site. The total rated thermal input of installation no. 119 is 1424 MW_{th}, the gross electric power output is 860 MW_{el}, which leads to a nominal gross electrical efficiency of 60.4 %.

Table 47 shows the energy input and output for the reference year as well as the total operating time under normal operating conditions. The reference year for the given values is 2011. The rolling average values are based on the total operating time since commissioning.

Table 47: General operating data for reference no. 119

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	6.86E+06	6.87E+06
Gross electric energy output	MWh_{el}	3.98E+06	4.00E+06
Net electric energy output	MWh_{el}	3.95E+06	3.94E+06
Total operating time under normal operating conditions	h	6430	6188
Equivalent full load operating factor	%	75.0	77.9

In 2011 the installation was operated for about 6400 h. The equivalent full load operating factor was 75 %. The net electrical utilisation ratio was 57.5 %. For the rolling average values, the equivalent full load operating factor was 78 % and a electrical utilisation ratio of 57.3 % can be calculated.

Environmental aspects

The installation produces typical air emissions for gaseous fuel-fired power plants. In accordance to the official authorisation, the air pollutants NO_x and CO are continuously measured in the flue gas of both gas turbines. Primary measures are taken for emission abatement directly in the gas turbine.

Table 48 and Table 49 show the concentrations and the annual loads for the measured air-pollutants in the flue gas of both gas turbines. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are not validated and do include OTNOCs. The reference oxygen content is 15 %.

Table 48: Air emissions for reference no. 119 – GT 1

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm³	13.35	15.53	22.34	29.25	30.25	52.88	HHV	Cont.	-	150	75
	kg/year	3.1E+05										
CO	mg/Nm³	0.044	-	6.82	33.62	37.64	447.2	HHV	Cont.	-	200	100
	kg/year	3.5E+05										

Table 49: Air emissions for reference no. 119 – GT 2

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm³	8.73	11.77	15.22	18.67	19.18	24.5	HHV	Cont.	-	150	75
	kg/year	3.1E+05										
CO	mg/Nm³	0.0001	-	1.42	8.95	10.18	186.8	HHV	Cont.	-	200	100
	kg/year	3.5E+05										

Taking account of the legal and regulatory provisions, two waste water streams are discharged into a river. The first waste water stream is made up of cooling water and non-treated waste water (including rain water) from the water/steam cycle. The second stream is neutralised waste water from the water/steam cycle and the water conditioning. The water emissions are shown in Table 50.

Table 50: Water emissions for reference no. 119 - neutralised water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	3100	-	-	-	-	-	5E+04
Temp.	(°C)	-	-	-	-	-	-	-	-
pH		6.9	-	8.9	-	-	-	-	6.5 to 9.0
COD	(mg/l)	5	-	5	-	-	-	-	50
	(kg/year)	-							
N (total)	(mg/l)	10	-	10	-	-	-	-	10
	(kg/year)	-							
P (total)	(mg/l)	0.05	-	0.05	-	-	-	-	3
	(kg/year)	-							
Cd	(mg/l)	0.0005	-	0.0005	-	-	-	-	0.05
	(kg/year)	-							
Pb	(mg/l)	0.005	-	0.005	-	-	-	-	0.1
	(kg/year)	-							
Cr	(mg/l)	0.005	-	0.005	-	-	-	-	0.5
	(kg/year)	-							
Cu	(mg/l)	0.005	-	0.13	-	-	-	-	0.5
	(kg/year)	-							
Ni	(mg/l)	0.005	-	0.012	-	-	-	-	0.5
	(kg/year)	-							
V	(mg/l)	0.01	-	0.01	-	-	-	-	4
	(kg/year)	-							
Zn	(mg/l)	0.01	-	0.018	-	-	-	-	1

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
	(kg/year)			-					

There are no solid residues.

Special characteristics

The two gas turbines, which are operated in combustion installation no. 119, display world-leading technology for F-class gas turbines. The process further consists of a three-stage waste recovery steam generator and a steam turbine. The once-through cooling system for the condenser uses river water. Due to its high grade of flexibility, the plant is used for quick response load changes and grid stabilisation against the background of the fluctuating energy production from renewable energy sources. For condensation operation mode and full load, the nominal gross electrical efficiency of almost 60 % can be achieved, which is why the installation is suggested as BAT by the operator. In part load, the efficiency decreases. The rolling average value for the efficiency is still 57 %. The installation is suggested as BAT because of its high capability of fast load changes and its high efficiency standard.

3.2.2 Compressor Stations

3.2.2.1 General Discussion and Explanation of the Technology and the Emission Abatement Measures

NG compressor stations are used for increasing the pressure in NG pipelines and are therefore located directly at the pipeline. As the pressure of the NG drops during the transport, it has to be increased periodically. In the compressor stations, a part of the NG is extracted from the pipeline and used for the generation of mechanical energy for the compressor. In most cases, the compressor is driven by a gas turbine, which is coupled to the compressor. For LCP, the application of gas engines or CCGT plants is also possible. The required power output of the compressor is linked to the amount of the NG that has to be transported. As this variable is subject to daily and seasonal changes, the power output of the compressor is fluctuating. For this reason, often more than one compressor is located at a compressor site.

Due to the relatively clean fuel, only CO and NO_x emissions in the flue gas are relevant. Normally, there are not water emissions. NO_x is reduced solely with primary measures like low-NO_x-burners. For the abatement of CO modernised combustion chambers and catalysts (secondary measure) are available.

3.2.2.2 Presentation of the Results (evaluation levels III and IV)

For the group "Compressor Stations" nine questionnaires for nine individual plants are available. As can be seen in Table 51, the majority of reference plants accounts for a thermal input of less than 50 MW_{th}. They are located at LCP sites with an aggregated total rated thermal input of more than 50 MW_{th}. The compressor of plant no. 166 is driven by a gas engine, all other plants use gas turbines. It should be noted that the here presented results could not be checked completley by the author due to short-term updates in the data pool. The reference year for the given data is 2010.

The operating mode and the year of commissioning of the plants vary widely (from 1974 to 2009). While plant no. 158, one of the newest plants, was operated in base load for almost 6000 hours a year, plant no. 165 is in the category "emergency load" and was only operated for 8 hours, although it is not designed as emergency load plant. The oldest plant (no. 164) is also used for emergency load with an similar situation as for plant no. 165.

Plant no. 166 was retrofitted with an exhaust gas catalyst in 1988 ("clean burn"). Plant no. 164 and plant no. 162 were retrofitted with CO catalysts (in 1988 and 1996, respectively). Plants no. 158, 161 and 165 are equipped with DLE-technology (CO catalyst retrofit for plant no. 158 required). Plant no. 162 will be equipped with DLE-technology. Depending on their predicted operating hours, plants no. 159 and 163 will also be retrofitted with DLE-technology. Plants no. 160 and 166 will be shut down in the near future. None of the plants is used for CHP. Table 51 gives a summary of the plants' characteristics.

Table 51: Evaluation level III: Group "Compressor Stations"

TRTI in MW_{th}	Plant no.	TRTI in MW_{th}	Year of commis-sioning (last retrofit)	Operating mode (according to EIPPCB)	Total operating time under normal conditions	Equivalent full load operat-ing factor	CHP	Techno-logy	Other
< 50	166	22	1985 (1988)	Medium load	1784	83	No	Engine	Shut-down planned
	163	26	1985 ()	Emergency load	437	59	No	GT	Re-cupe-rator, (DLE)
	161	32	1998 ()	Medium load	2781	85	No	GT	DLE
	165	33	2009 ()	Emergency load	8	79	No	GT	DLE
	159	28	1992 ()	Medium load	3168	64	No	GT	Re-cupe-rator, (DLE)
	164	43	1974 (1988)	Emergency load	21	*	No	GT	(re-place-ment)
> 50	160	53	1982 ()	Medium load	2658	69	No	GT	Shut-down planned
	162	62	1985 (1996)	Peak load	456	92	No	GT	(DLE)
	158	67	2000 ()	Base load	5996	74	No	GT	DLE, (CO-cata-lyst)

* Due to the low operating hours, no representative statement can be made for the equivalent full load operating factor. The gas turbine was only started to test its availability.

Table 52 shows the efficiencies and utilisation ratios for the compressor stations. The mechanical useful energy is not measured and can therefore not be stated. Hence, the calculation of utilisation ratios is not possible. The newest plant (no. 158) displays the highest efficiency for the gas turbines, the engine's efficiency (no. 166) is with 37.9 % substantially higher than that of older gas turbines. Plants no. 159 and 163 were retrofitted with a recuperator, which allows for heat recovery from the flue gas and thus enhances the efficiency. The oldest plant (no. 164) displays the lowest efficiency, but relatively low emission values (see below).

Table 52: Evaluation level IV, Table a: Efficiencies for the Group "Compressor stations"

TRTI in MW_{th}	Plant no.	Efficiency (mc., nom.,) in %
< 50	166	38
	163	33.8
	161	33.4
	165	34
	159	34.5
	164	24.9
> 50	160	35.3
	162	34.2
	158	38.9

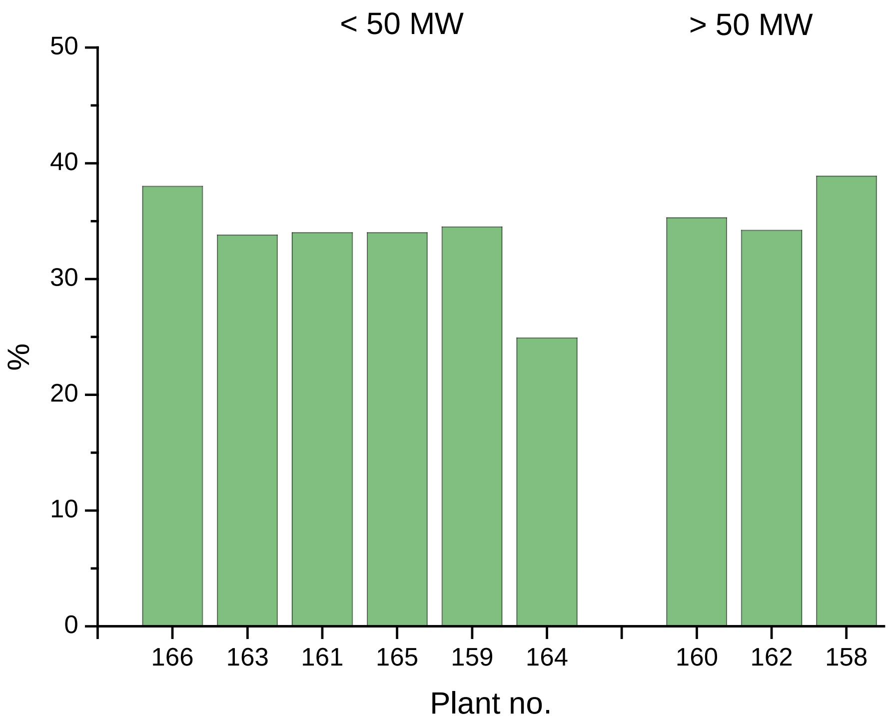

Figure 8: Evaluation level IV, Table a: Efficiencies for the Group "Compressor stations"

Table 53 shows the air emissions for the evaluated compressor stations. Due to the relatively small size of the plants (§ 15 Par. 8 of the 13. BImSchV: < 100 MW, approval under TA Luft), the emissions do not have to be measured continuously. The presented values originate from periodic measurements during the reference year. As full load operation depends strongly on the conditions in the gas grid, they refer to a variety of load cases, including loads of less than 70 % (for which no emission limit is set in the IED). Averaging of the values would therefore cause distortion. A differentiation of the load cases in the groups > 70 % load and < 70 % load is therefore useful, especially as the DLE-technology is only in operation for loads > 70 %.

After conversion of the reference oxygen content, the emission levels of the gas engine (plant no. 166) are in a similar range as those of the reference plants without DLE-technology. The effect of the DLE-technology on NO_x emission values for loads > 70 % can also be seen. Figure 9 and Figure 10 show the NO_x concentrations and Figure 11 and Figure 12 show the CO emissions for this group. All plants comply to the emission limits. Some measurements are out of the permit relevant load range. Details can be taken from the plant specific descriptions.

Table 53: Evaluation level IV, Table b: Air emissions for the Group "Compressor stations"

TRTI in MW_{th}	Plant no.	NO_x			CO		
		Min in mg/Nm^3	Max in mg/Nm^3	Primary measures	Min in mg/Nm3	Max in mg/Nm^3	Secondary measures
< 50	166	260 at 5 % O_2 (= 98 at 15 % O_2)	733 at 5 % O_2 (= 275 at 15 % O_2)	Clean-Burn	230 at 5 % O_2 (= 86 at 15 % O_2)	245 at 5 % O_2 (= 92 at 15 % O_2)	Flue gas catalyst
	163	126	274		16	433	-
	161	> 70%: 19; < 70 %: 22	> 70 %: 32; < 70 %: 24	DLE	> 70 %: < 5; < 70 %: 22	> 70 %: 20; < 70 %: 33	-
	165	> 70 %: 23; < 70 %: 107	> 70 %: 63; < 70 %: 107	DLE	> 70 %: 7; < 70 %: 988	> 70 %: 17; < 70 %: 988	-
	159	132	266	-	< 10	<10	-
	164	44	85	-	23	31	CO catalyst
> 50	160	145	250	-	< 5	119	-
	162	92	310	-	10	35	CO catalyst
	158	> 70 %: 39	> 70 %: 60	DLE	16	16	-

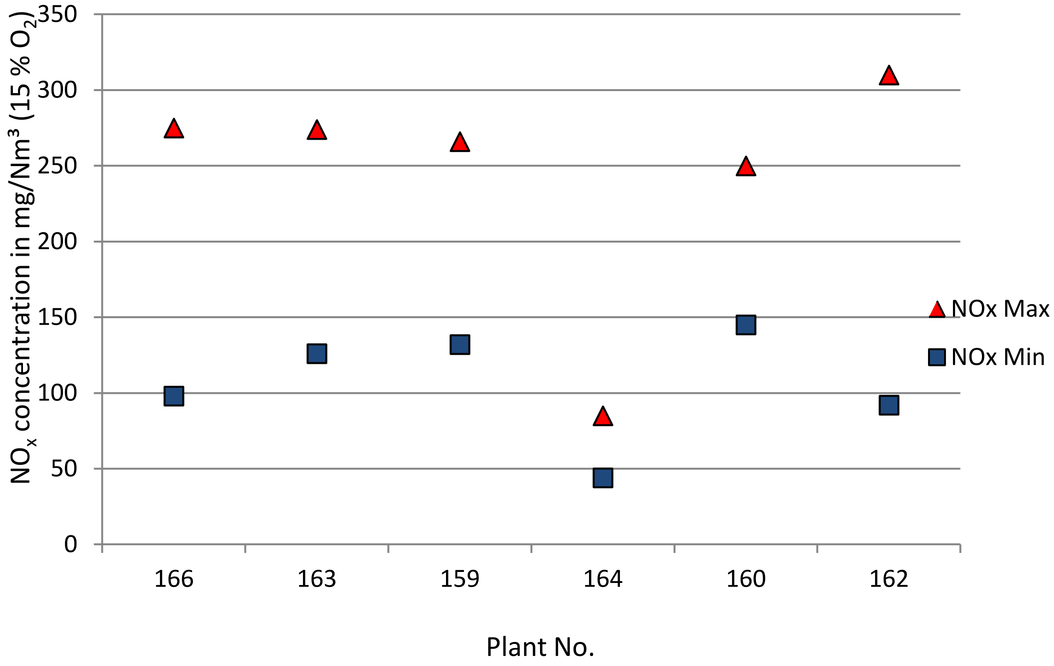

Figure 9: Evaluation level IV, Table b: NO_x emissions for the Group "Compressor stations", compressor stations without DLE-technology (No. 166 = gas engine)

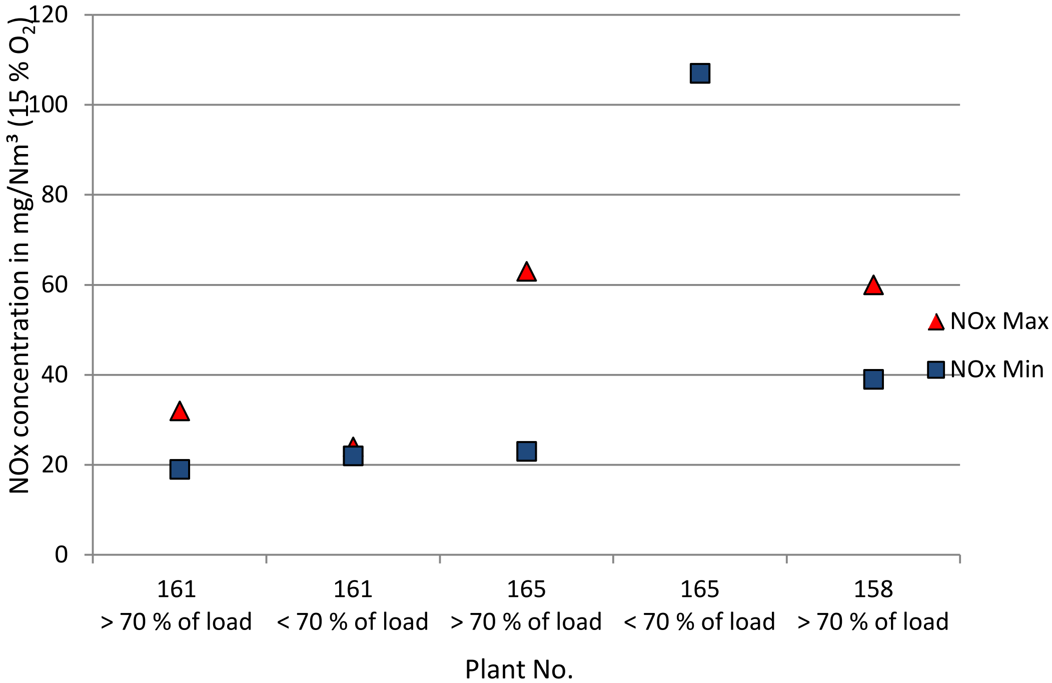

Figure 10: Evaluation level IV, Table b: NO_x emissions for the Group "Compressor stations", compressor stations with DLE-technology, distinguished between load > 70 % and < 70 %

All plants comply to the emission limits. For plants no. 159, 162 and 163 DLE-retrofits are planned to achieve lower emissions. Plant no. 166 will be shut down, a replacement is already installed. Plants no. 160 and 164 will be shut down. It should be noted that the maximal value of plant no. 165 is out of the permit relevant load range.

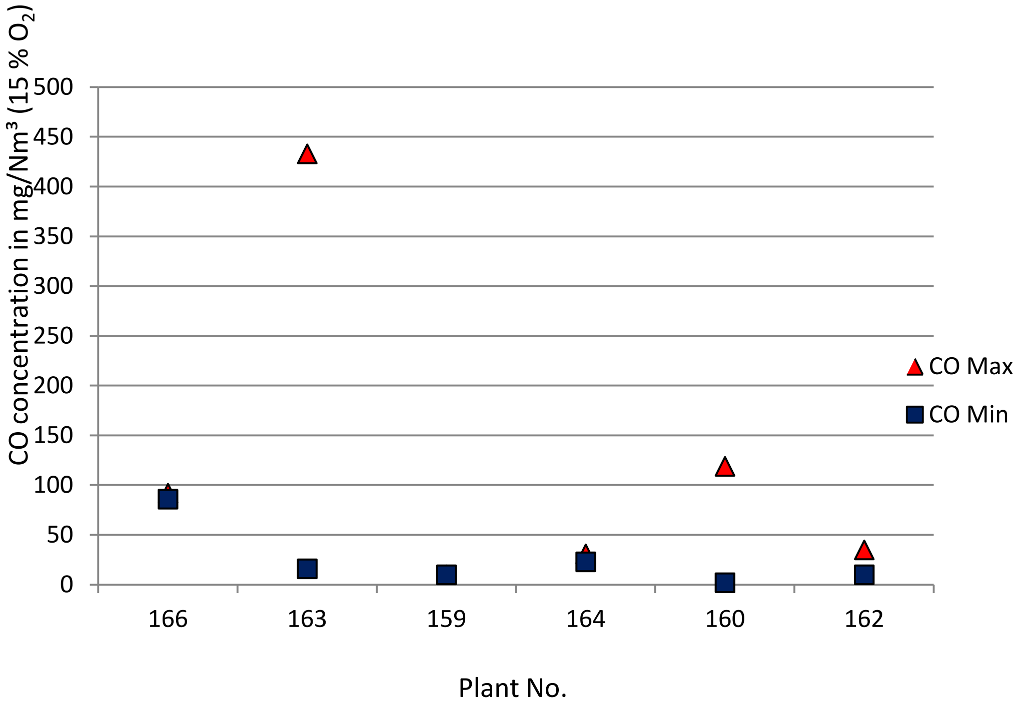

Figure 11: Evaluation level IV, Table b: CO emissions for the Group "Compressor stations", compressor stations without DLE-technology, please note that different load cases are included (Plant no. 166 = gas engine)

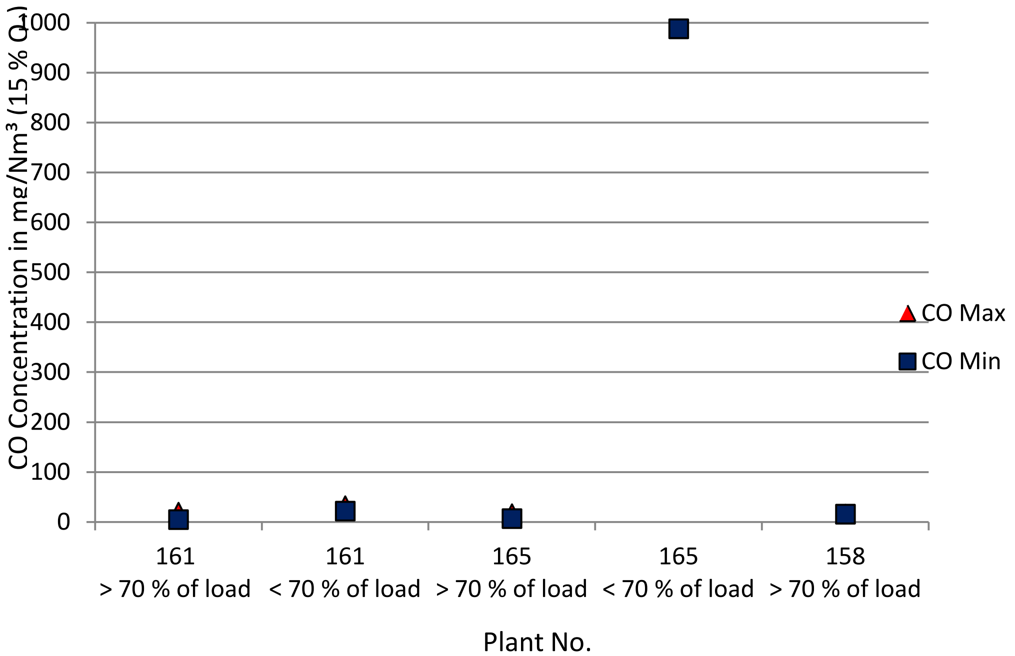

Figure 12: Evaluation level IV, Table b: CO emissions for the Group "Compressor stations", compressor stations with DLE-technology, distinguished between load > 70 % and < 70 %

All CO emission values greater than 100 mg/Nm^3 are out of the permit relevant load range. For plant no. 159, different load cases were considered, all with less than 10 mg/Nm^3 of CO. For plant no. 158, CO was not measured for loads < 70 %; plant no. 158 will be retrofitted with an CO catalyst precautionary.

As no waste water is produced in compressor stations, there is no data available on this topic. Suggestions of BAT were not made in this category.

3.2.2.3 Descriptions of Evaluated Plants or Installations

NG Compressor Station for Medium load, Reference no. 166

Reference no. 166 is a NG-fuelled engine which drives a NG compressor station, which was commissioned in 1985. It is part of a combustion installation with a total rated thermal input of 73 MW_{th}.

The total rated thermal input for reference no. 166 is 21.6 MW_{th}, the gross mechanical power output is 8.2 MW_{mc}, which results in a nominal mechanical efficiency of 38 %.

Table 54 shows values for the fuel energy input and energy output in the reference year 2010.

Table 54: General operating data for reference plant no. 166

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	3.18E+04	-
Total operating time under normal operating conditions	h	1783.7	-
Equivalent full load operating factor	%	83.0	-

Environmental aspects

The air-pollutants NO_x and CO are measured periodically in the flue gas. Table 55 shows values for the measured concentrations and the annual loads. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. The reference oxygen content is 5 %. It should be noted, that the values include OTNOCs. Compared to the other compressor stations, which are using a gas turbine, the emissions are in the same range, if a conversion of the oxygen content is done. The plant is equipped with a flue gas catalyst.

Table 55: Air emissions for reference no. 166

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values Prescribed by competent authority
NO_x	mg/Nm^3	260	-	-	-	-	733	-	Perio.	No	800
	kg/year						13900				
CO	mg/Nm^3	230	-	-	-	-	245	-	Perio.	No	650
	kg/year						1410				

There are no solid residues or waste water emissions.

Special characteristics

The plant is used exclusively as a mechanical drive for a medium load NG compressor. It is planned to shut the plant down.

NG Compressor Station for Peak Load, Reference no. 163

Reference no. 163 is a combined gas turbine and compressor station, which was commissioned in 1985. It is part of a combustion installation with a total rated thermal input of 140 MW_{th}.

The total rated thermal input for reference no. 163 is 26.3 MW_{th}, the gross mechanical power output is 8.9 MW_{mc}, which results in a nominal mechanical efficiency of 33.8 %.

Table 56 shows values for the fuel energy input and energy output in the reference year 2010.

Table 56: General operating data for reference no. 163

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	6.76E+03	-
Total operating time under normal operating conditions	h	436.55	483
Equivalent full load operating factor	%	59.0	-

Environmental aspects

The air-pollutants NO_x and CO are measured periodically in the flue gas. NO_x was measured five times a year, the same is true for CO. Table 57 shows values for the measured concentrations and the annual loads. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. The reference oxygen content is 15 %. It should be noted, that some of the given values are out of permit relevant load range. The emission vlaue of 433 mg CO/Nm^3 does not refer to stationary operation, to which the given emission limit value refers.

Table 57: Air emissions for reference no. 163

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority
NO_x	mg/Nm^3	126	-	-	-	-	274	-	Perio.	No	340
	kg/year	7950									
CO	mg/Nm^3	16	-	-	-	-	433	-	Perio.	No	100
	kg/year	2380									

There are no solid residues or waste water emissions.

Special characteristics

The gas turbine is used exclusively as mechanical drive of a peak load NG compressor. A DLE-combustion chamber retrofit is planned for 2014.

NG Compressor Station for Medium load, Reference no. 161

Reference no. 161 is a combined gas turbine and compressor station, which was commissioned in 1998. It is part of a combustion installation with a total rated thermal input of 66 MW_{th}.

The total rated thermal input for reference no. 161 is 32 MW_{th}, the gross mechanical power output is 10.7 MW_{mc}, which results in a nominal mechanical efficiency of 33.4 %.

Table 58 shows values for the fuel energy input and energy output in the reference year 2010. Five years have been taken into account for the rolling average value (operating time).

Table 58: General operating data for reference no. 161

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	7.60E+04	-
Total operating time under normal operating conditions	h	2781.22	3336
Equivalent full load operating factor	%	85.0	-

Environmental aspects

The air-pollutants NO_x and CO are measured periodically in the flue gas. NO_x was measured five times a year, the same is true for CO. Table 59 and Figure 60 show values for the measured concentrations and the annual loads. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. The reference oxygen content is 15 %. It should be noted, that the values include OTNOCs. The annual load of NO_x was 10660 kg/year, for CO it was 3650 kg/year. The gas turbine is equipped with DLE-technology.

Table 59: Air emissions for reference no. 161 - Loads > 70 %

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority
NO_x	mg/Nm^3	19	-	-	-	-	32	-	Perio.	No	88
CO	mg/Nm^3	<5	-	-	-	-	20	-	Perio.	No	60

Table 60: Air emissions for reference no. 161 - Loads < 70 %

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority
NO_x	mg/Nm³	22	-	-	-	-	24	-	Perio.	No	-
CO	mg/Nm³	22	-	-	-	-	33	-	Perio.	No	-

There are no solid residues or waste water emissions.

Special characteristics

The gas turbine is used exclusively as mechanical drive of a NG compressor.

NG Compressor Station for Emergency Load, Reference no. 165

Reference no. 165 is a combined gas turbine and compressor station, which was commissioned in 2009. It is part of a combustion installation with a total rated thermal input of 150 MW_{th}.

The total rated thermal input for reference no. 165 is 32.9 MW_{th}, the gross mechanical power output is 11.2 MW_{mc}, which results in a nominal mechanical efficiency of 34 %.

Table 61 shows values for the fuel energy input and energy output in the reference year 2010.

Table 61: General operating data for reference no. 165

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	2.19E+02	-
Total operating time under normal operating conditions	h	8.42	-
Equivalent full load operating factor	%	79.0	-

This plant was designed for base load operation. Due to special circumstances in the natural gas network, the plant was only rarely used in the reference year.

Environmental aspects

The air-pollutants NO_x and CO are measured periodically in the flue gas. NO_x was measured five times a year, the same is true for CO. Table 62 and Figure 63 show the emission values. The turbine is equipped with DLE-technology. The reference oxygen content is 15 %. It should be noted, that the values include OTNOCs. The annual load of NO_x was 70 kg/year, for CO it was 90 kg/year.

Table 62: Air emissions for reference no. 165 - Loads > 70 %

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority
NO_x	mg/Nm^3	23	-	-	-	-	63	-	Perio.	No	75
CO	mg/Nm^3	7	-	-	-	-	17	-	Perio.	No	100

Table 63: Air emissions for reference no. 165 - Loads < 70 %

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority
NO_x	mg/Nm^3	107	-	-	-	-	107	-	Perio.	No	-
CO	mg/Nm^3	988	-	-	-	-	988	-	Perio.	No	-

Please note that only one measurement was done below 70 % load.

There are no solid residues or waste water emissions.

Special characteristics

The gas turbine is used exclusively as mechanical drive of a peak load NG compressor.

NG Compressor Station for Medium load, Reference no. 159

Reference no. 159 is a combined gas turbine and compressor station, which was commissioned in 1992. It is part of a combustion installation with a total rated thermal input of 86 MW_{th}.

The total rated thermal input for reference no. 159 is 27.8 MW_{th}, the gross mechanical power output is 9.6 MW_{mc}, which results in a nominal mechanical efficiency of 34.5 %.

Table 64 shows values for the fuel energy input and energy output in the reference year 2010. Five years have been taken into account for the rolling average value (operating time).

Table 64: General operating data for reference no. 159

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	5.62E+04	-
Total operating time under normal operating conditions	h	3168.1	4910
Equivalent full load operating factor	%	64.0	-

Environmental aspects

The air-pollutants NO_x and CO are measured periodically in the flue gas. NO_x was measured four times a year, the same is true for CO. Table 65 shows values for the measured concentrations and the annual loads. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. The reference oxygen content is 15 %. It should be noted, that the values include OTNOCs.

Table 65: Air emissions for reference no. 159

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values Prescribed by competent authority
NO_x	mg/Nm^3	132	-	-	-	-	266	-	Perio.	No	328
	kg/year	6.5E+04									
CO	mg/Nm^3	< 10	-	-	-	-	<10	-	Perio.	No	100
	kg/year	3030									

There are no solid residues or waste water emissions.

Special characteristics

The gas turbine is used exclusively as mechanical drive of a medium load NG compressor. To reduce the air emissions, it is planned to retrofit a DLE-combustion chamber in 2014.

NG Compressor Station for Emergency Load, Reference no. 164

Reference no. 164 is a combined gas turbine and compressor station, which was commissioned in 1974. It is part of a combustion installation with a total rated thermal input of 81 MW_{th}.

The total rated thermal input for reference no. 164 is 42.5 MW_{th}, the gross mechanical power output is 10.6 MW_{mc}, which results in a nominal mechanical efficiency of 24.9 %.

Table 66 shows values for the fuel energy input and energy output in the reference year 2010.

Table 66: General operating data for reference no. 164

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	1.22E+03	-
Total operating time under normal operating conditions	h	21.34	-
Equivalent full load operating factor	%	*	-

* The mechanical useful energy is not measured and can therefore not be stated. Hence, the calculation of utilisation ratios is not possible.

Environmental aspects

The air-pollutants NO_x and CO are measured periodically in the flue gas. NO_x was measured four times a year, CO only once. Table 67 shows values for the measured concentrations and the annual loads. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. The reference oxygen content is 15 %. It should be noted, that the values include OTNOCs. The gas turbine is equipped with a CO catalyst.

Table 67: Air emissions for reference no. 164

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority
NO_x	mg/Nm³	44	-	-	-	-	85	-	Perio.	No	300
	kg/year	370									
CO	mg/Nm³	23	-	-	-	-	31.2	-	Perio.	No	100
	kg/year	60									

There are no solid residues or waste water emissions.

Special characteristics

The gas turbine is used exclusively as mechanical drive of a peak load NG compressor. To reduce CO-emissions, a CO-catalyst is installed.

NG Compressor Station for Medium load, Reference no. 160

Reference no. 160 is a combined gas turbine and compressor station, which was commissioned in 1982. It is part of a combustion installation with a total rated thermal input of 281 MW_{th}.

The total rated thermal input for reference no. 160 is 53.23 MW_{th}, the gross mechanical power output is 18.8 MW_{mc}, which results in a nominal mechanical efficiency of 35.3 %.

Table 68 shows values for the fuel energy input and energy output in the reference year 2010. Five years have been taken into account for the rolling average value (operating time).

Table 68: General operating data for reference no. 160

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	9.72E+04	-
Total operating time under normal operating conditions	h	2658.02	4260
Equivalent full load operating factor	%	69.0	-

Environmental aspects

The air-pollutants NO_x and CO are measured periodically in the flue gas. NO_x was measured twelve times a year, the same is true for CO. Table 69 shows values for the measured concentrations and the annual loads. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. The reference oxygen content is 15 %. It should be noted, that the values include OTNOCs. The CO emission value of 118.8 mg/Nm^3 does not refer to stationary operating conditions.

Table 69: Air emissions for reference no. 160

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority
NO_x	mg/Nm^3	145	-	-	-	-	250	-	Perio.	No	354
	kg/year	1.2E+05									
CO	mg/Nm^3	4.5	-	-	-	-	118.8	-	Perio.	No	100
	kg/year	8940									

There are no solid residues or waste water emissions.

Special characteristics

The gas turbine is used exclusively as mechanical drive of a medium load NG compressor. The plant will be shut down and replaced in 2014.

NG Compressor Station for Peak Load, Reference no. 162

Reference no. 162 is a combined gas turbine and compressor station, which was commissioned in 1985. It is part of a combustion installation with a total rated thermal input of 216 MW_{th}.

The total rated thermal input for reference no. 162 is 62 MW_{th}, the gross mechanical power output is 21.2 MW_{mc}, which results in a nominal mechanical efficiency of 34.2 %.

Table 70 shows values for the fuel energy input and energy output in the reference year 2010.

Table 70: General operating data for reference no. 162

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	2.59E+04	-
Total operating time under normal operating conditions	h	1201.72	-
Equivalent full load operating factor	%	35.0	-

Environmental aspects

The air-pollutants NO_x and CO are measured periodically in the flue gas. NO_x was measured ten times a year, the same is true for CO. Table 71 shows values for the measured concentrations and the annual loads. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. The gas turbine is equipped with a CO catalyst. The reference oxygen content is 15 %. It should be noted, that the values include OTNOCs.

Table 71: Air emissions for reference no. 162

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority
NO_x	mg/Nm³	92	-	-	-	-	310	-	Perio.	No	342
	kg/year	3,19E+04									
CO	mg/Nm³	10	-	-	-	-	35	-	Perio.	No	100
	kg/year	1,15E+04									

There are no solid residues or waste water emissions.

Special characteristics

The gas turbine is used exclusively as mechanical drive of a peak load NG compressor. To reduce the air emissions, a CO-catalyst has been retrofitted. It is further planned to retrofit a DLE-combustion chamber in 2013.

NG Compressor Station for Base Load, Reference no. 158

Reference no. 158 is a combined gas turbine and compressor station, which was commissioned in 2000. It is part of a combustion installation with a total rated thermal input of 340 MW_{th}.

The total rated thermal input for reference no. 158 is 66.5 MW_{th}, the gross mechanical power output is 25.9 MW_{mc}, which results in a nominal mechanical efficiency of 38.9 %.

Table 72 shows values for the fuel energy input and energy output in the reference year 2010. Five years have been taken into account for the rolling average value.

Table 72: General operating data for reference no. 158

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	2.95E+05	-
Total operating time under normal operating conditions	h	5996	5133
Equivalent full load operating factor	%	74.0	-

Environmental aspects

The air-pollutants NO_x and CO are measured periodically in the flue gas. NO_x was measured four times a year, CO only once. Table 73 shows values for the measured concentrations and the annual loads. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. The gas turbine is equipped with DLE-technology. The reference oxygen content is 15 %. A precautionary retrofit of a CO-catalyst is planned.

Table 73: Air emissions for reference no. 158

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm^3	39	-	-	-	-	60	-	Perio.	No	-	100
	kg/year	3.6E+04										
CO	mg/Nm^3	16	-	-	-	-	16	-	Perio.	No	-	100
	kg/year	6E+04										

There are no solid residues or waste water emissions.

Special characteristics

The gas turbine is used exclusively as mechanical drive of a base load NG compressor.

3.2.3 Gas-fired Boilers

3.2.3.1 General Discussion and Explanation of the Technology and the Emission Abatement Measures

Gas-fired boilers are used to convert gaseous fuels of different sources into electricity and thermal useful energy. In LCP boilers, NG is nowadays not used anymore for solely electricity-production, as it can be utilised much more efficient in CCGT plants. Some older NG-fired boilers, however, are still in operation or are kept as emergency capacity. Small plants are also still operated with NG. LCP boilers are using other gases, which are produced as a by-product in other chemical or industrial processes, such as coke oven gas or blast furnace gas. The boilers are usually operated in base load. Emission abatement measures depend on the fuel used. Low-NO_x-burners are almost always used. One of the evaluated plants is in addition to this equipped with a SCR unit for NO_x reduction.

Blast furnace gas-fired boilers are specially designed to meet the available fuel characteristics of the gas-production facility. Sometimes, the permits allow for special operating modes and fuel qualities, which depend on the operation mode of the gas-producing facility. Not all special operating modes are included in the available data, as they did not occur in the reference period.

3.2.3.2 Presentation of the Results (evaluation levels III and IV)

For the group “Gas-fired Boilers” eight questionnaires are available. As can be seen in Table 74, plants no. 114-1 to 114-3 are operated in case of medium load or peak load. They are used to assure district heating and are fired with NG. The other plants are fired with a hydrogen rich gas mixture from industrial processes. The fuel for plant no. 157 originates from a chemical production process while plants no. 144 and 145 are primarily fired with gas from a blast furnace or coke oven. The designs of the individual plants vary therefore and it may be useful to categorise them – in the European context – in more special subgroups.

Table 74: Evaluation level III: Group "Gas-fired Boilers"

TRTI in MW_{th}	Plant no.	TRTI in MW_{th}	Year of commissioning (last retrofit)	Operating mode (according to EIPPCB)	Total operating time under normal conditions	Equivalent full load operating factor	CHP	Fuel	Other
< 100	114-1	64 each	2000 ()	Peak load	1489	55.3	No	NG	Heat production only
	114-2				1317	48.8			
	114-3		2004 ()	Medium load	1561	51.4			
> 100 - 300	157-1	165 each	2010 ()	Base load	7452	36.1	No	75 % hydrogen, 25 % NG	2 identical boilers, heat only
	157-2				6792	37.6			
> 300	145	550	2003	Base load	7871	91.7	Yes	84 % blast furnace gas, 14 % coke oven gas, 1 % NG	-
	144-1	840	1975 ()	Base load	6933	48.3	Yes	67 % blast furnace gas, 22 % coke oven gas, 11 % NG	2 identical boilers, 144-2: ST-retrofit (+13MW)
	144-2	840	1976 (2008)	Base load	7280	53.9	Yes	68 % blast furnace gas, 20 % coke oven gas, 11 % NG	

With the exception of plant no. 114, the plants are operated in base load with high annual hours of operation. Plant no. 157 is used only for heat generation, while plants no. 144 and 145 are used primarily for electricity production but can also provide heat. The fuel utilisation factors, which can be taken from Table 75, of the electricity producing plants is much lower than for plants that are used for heat generation only.

Table 75: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Gas-fired Boilers"

TRTI in MW_{th}	Plant no.	Efficiency (el., gross, nom.) in %	Utilisation ratio			Fuel utilisation factor
			(el., gross) in %	(el., net) in %	(th.) in %	(net) in %
< 100	114-1	-	-	-	94.6	94.6
	114-2	-	-	-	92.4	92.4
	114-3	-	-	-	94.2	94.2
> 100 - 300	157-1	-	-	-	92.0	92.0
	157-2	-	-	-	92.0	92.0
> 300	145	43.8	40.9	38.3	8.1	46.3
	144-1	36.5	40.8	38.0	1.6	39.6
	144-2	38.1	36.7	34.5	1.4	35.9

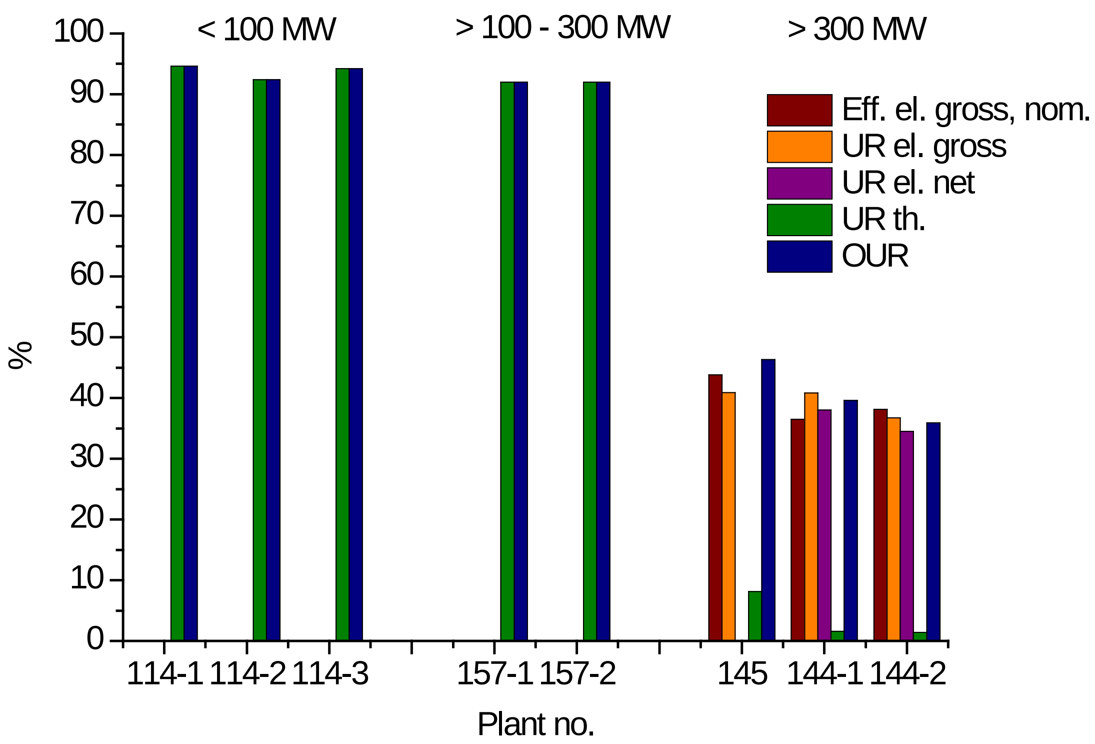

Figure 13: Evaluation level IV, Table a: Efficiencies and utilisation ratios for the Group "Gas-fired Boilers"

Table 76 shows the air emission values of the plants. With the exception of the SCR of plant no. 145, no secondary measures for emission abatement are taken in any of the plants. As stated above, plants no. 144 and 145 were not operated in all possible load stages (according to permission), so that the given values do not describe all possible occurring emission scenarios. The low dust emissions of all plants are due to the exclusive application of gaseous fuels. Plants no. 114 and 157 are fired with gas poor in sulphur, so that no SO_x is emitted. The relatively high CO emissions of plant no. 145 can be attributed to the special regulation of fuel reference (amount and quality of blast furnace gas). The air emissions of the plants are not very comparable, as they use a wide variety of fuels. The air emissions for gas-fired boilers are summarised in Table 77 and the subsequent diagrams.

Table 76: Evaluation level IV, Table b: Air emissions for the Group "Gas-fired Boilers"

TRTI in MW_{th}	Plant no.	NO_x		CO		Dust		SO_x	
		Ø in mg/Nm³	Secondary measures	Ø in mg/Nm³	Secondary measures	Øin mg/Nm³	Secondary measures	Ø in mg/Nm³	Secondary measures
< 100	114-1	85.0	-	6.2	-	0.04	-	-	-
	114-2	91.3	-	2.0	-	0.04	-	-	-
	114-3	76.0	-	1.7	-	0.00	-	-	-
> 100 - 300	157-1	69.6	-	2.0	-	-	-	-	-
	157-2	70.6	-	1.0	-	-	-	-	-
> 300	145	84.1	SCR	22.8	-	2.60	-	114.1	-
	144-1	58.4	-	1.0	-	1.80	-	98.5	-
	144-2	57.3	-	1.1	-	3.30	-	106.7	-

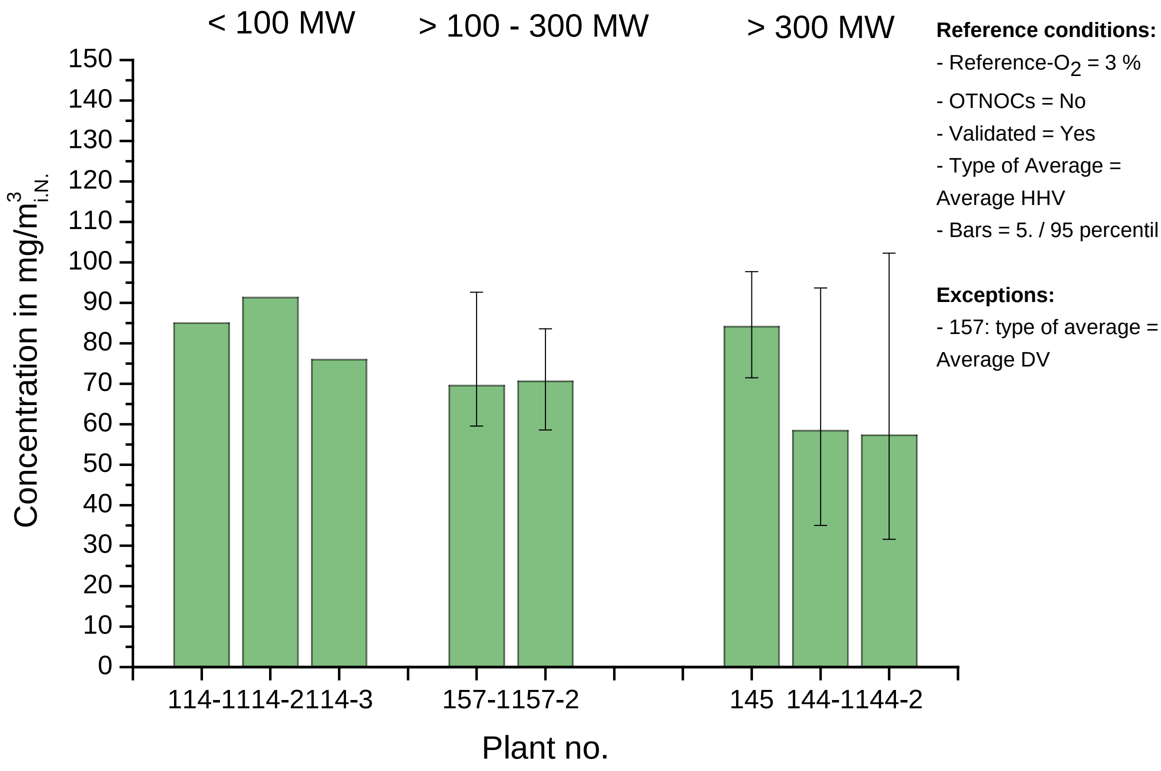

Figure 14: Evaluation level IV, Table b: NO_x emissions for the Group "Gas-fired Boilers"

As can be seen, the annual averages of NO_x emissions for all plants are in the range of 60 to 90 mg/Nm^3. Even plant no. 145, the only plant with secondary abatement measures, is in this range.

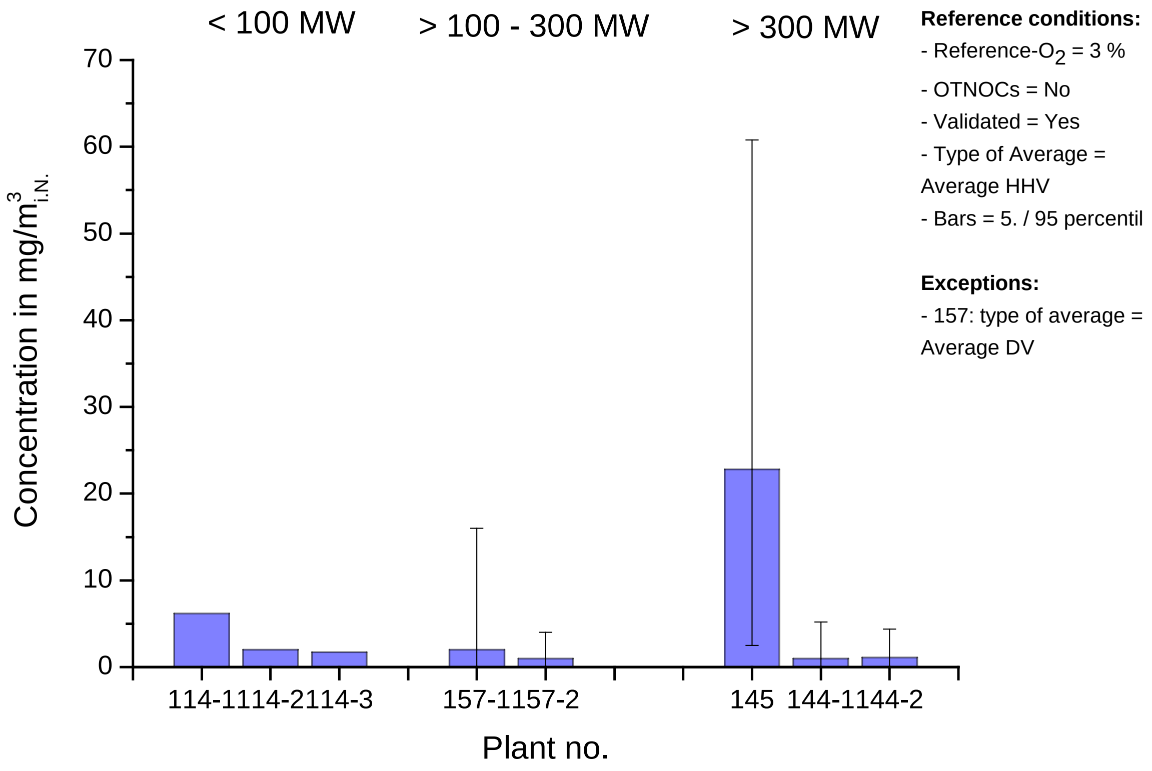

Figure 15: Evaluation level IV, Table b: CO emissions for the Group "Gas-fired Boilers"

The CO concentrations are well below 10 mg/Nm^3 for all plants, but for no. 145. As stated above, the fuel availability for plant no. 145 is fluctuating, which causes the highly volatile emission values. It should be noted, that this presentation of the results has to be seen in close connection to the more detailed data, given in the questionnaires; only this way allows for a comprehensive picture of the emissions and their backgrounds.

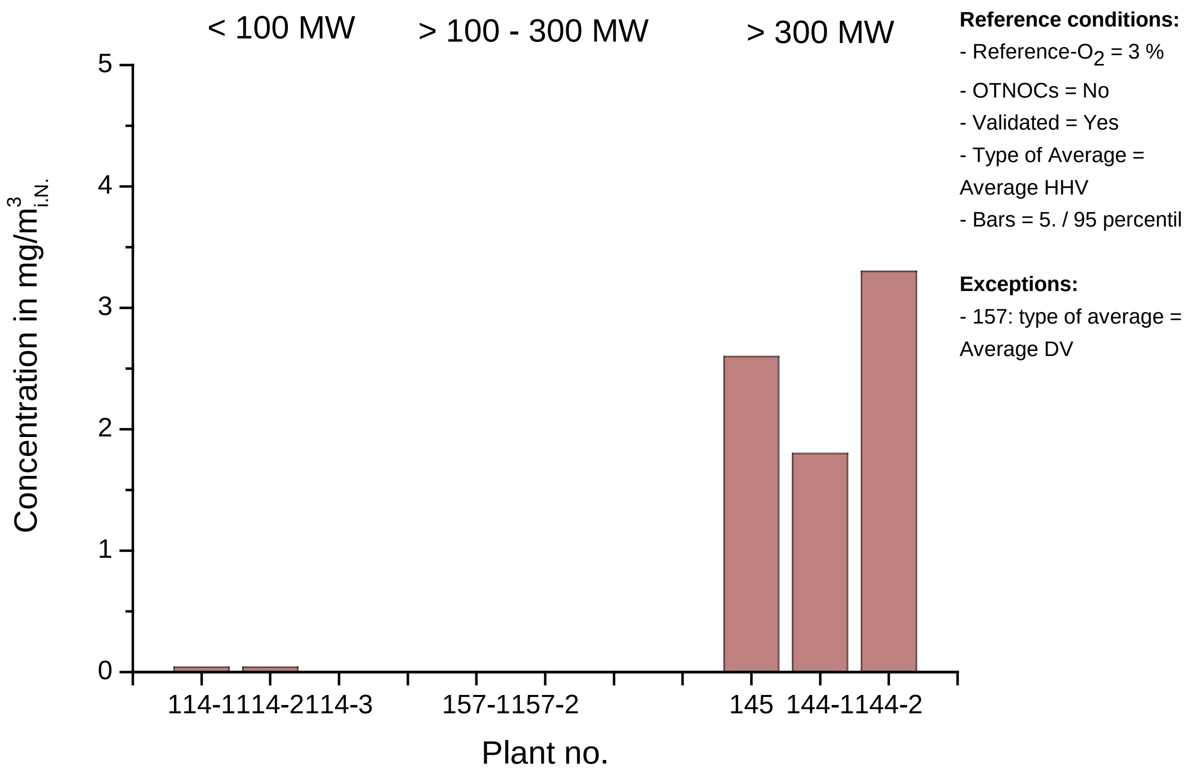

Figure 16: Evaluation level IV, Table b: Dust emissions for the Group "Gas-fired Boilers"

The dust emissions for all plants depend highly on the type of fuel used in the individual plants. Blast furnace gas-fired plants, such as plants no. 144 and 145, do not show significant dust emissions (2 to 4 mg/Nm^3), while plant no. 114 emits almost no dust at all. The dust emissions of plant no. 157 are not measured.

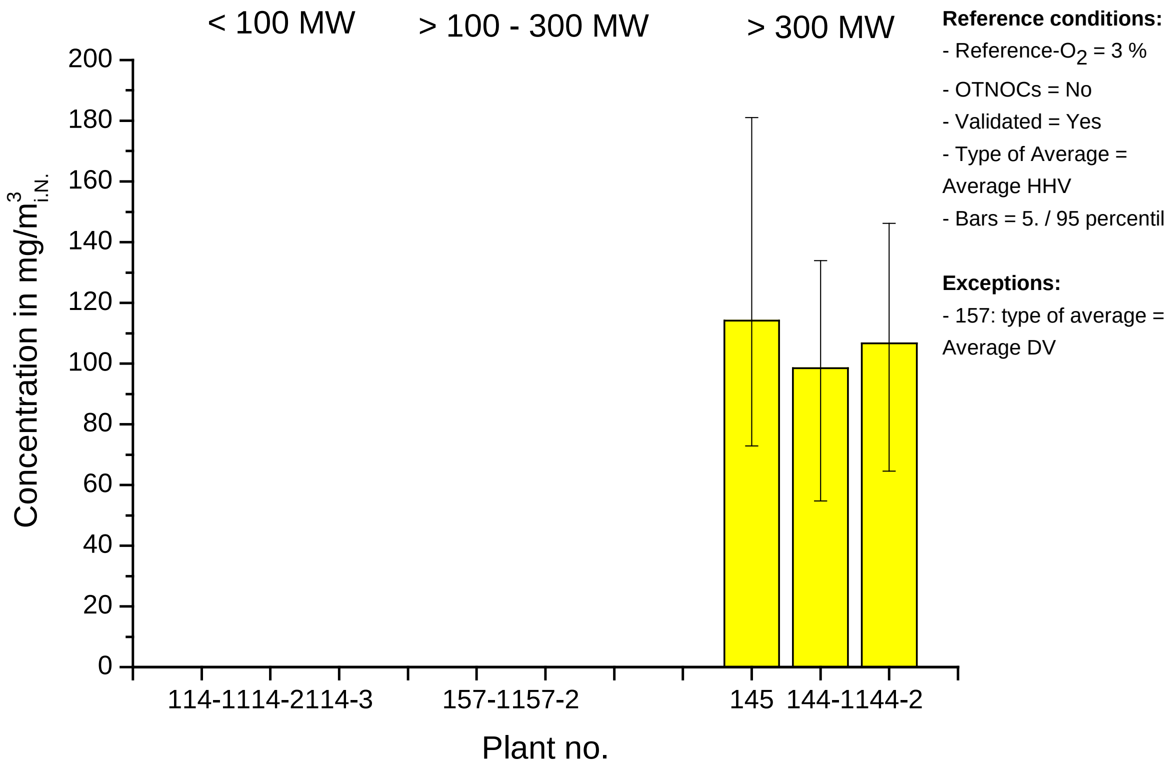

Figure 17: Evaluation level IV, Table b: SO_x emissions for the Group "Gas-fired Boilers"

SO_x emissions are similar to dust emissions: Only blast furnace gas-fired plants (no. 144 and 145) show noticeable emissions of around 100 mg/Nm³. SO_x is not measured at the other plants due to the low amounts of sulphur in the fuel.

The reference conditions for all plants are summarised in Table 77.

Table 77: Reference conditions and exceptions for the Group "Gas-fired Boilers"

Plant no.	Ref. O_2 in %	Includes OTNOCs	Validated	Type of average	Fuel	Other
Reference	3	No	Yes	Average HHV	NG	-
114	-	-	-	-	-	Peak load
144	-	-	-	-	67 % blast furnace gas, 22 % coke oven gas, 11 % NG	2 identical boilers, ST-retrofit
145	-	-	-	-	84 % blast furnace gas, 14 % coke oven gas, 1 % NG	-
157	-	-	No	DV	75 % hydrogen, 25 % NG	2 identical boilers, heat only

Except for plant no. 144, no plant produces waste water that has to be monitored. The details on the waste water production of plant no. 144 can be found in the more detailed plants description (see chapter 3.2.3.3).

For this group, the plants' operators submitted 13 BAT templates. They are summarised in Table 78.

Table 78: Evaluation level IV, Table d: BAT submissions for the Group "Gas-fired Boilers"

TRTI in MW_{th}	Plant no.	No. of templates	Short summary	Technical domain	Level of detail
< 100	114-1	0	-	-	-
	114-2	0	-	-	-
	114-3	0	-	-	-
> 100 - 300	157-1, 157-2	1	Low-NO_x-burner for H_2 und NG	Firing-system	high
> 300	145	6	Fuel pre-treatment	Fuel	medium
			Low-NO_x-burner and SCR	Air emission	medium
			Recirculation of water	Water	medium
			Avoidance of solid residue	Solid residue	medium
			Water pre-treatment	Water	medium
			Low-NO_x-burner	Firing-system	medium
	144-1, 144-2	6	Fuel pre-treatment	Fuel	high
			Low-NO_x-burner	Air emission	medium
			Plant configuration	Whole plant	high
			Recirculation of water	Water	medium
			Avoidance of solid residue	Solid residue	medium
			Utilisation of waste water	Water	medium

3.2.3.3 Descriptions of Evaluated Plants or Installations

Natural Gas-fired Corner Tube Boiler, Reference no. 114

Reference no. 114 consists of three identical NG-fired corner tube boilers, which are used to supply peak load heat for district heating. LFO can also be combusted. The first two boilers were commissioned in 2000, the third boiler in 2004.

The combustion installation is located at a combustion site with a total net electric power output of 1596 MW_{el}. The total rated thermal input of each boiler is 63.5 MW_{th}. The thermal power output (hot water at 20 bar, 150 °C) is 60.0 MW_{th} for each boiler, which leads to a nominal thermal efficiency of 94.9 %.

Table 79, Table 80 and Table 81 show the energy input and output for the reference year as well as the total operating time under normal operating conditions. The reference year for the given values is 2010.

Table 79: General operating data for reference no. 114 – Boiler 1

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	5.23E+04	-
Net heat output – hot water	MWh_{th}	4.95E+04	-
Total operating time under normal operating conditions	h	1489	-
Equivalent full load operating factor	%	55.3	-

Table 80: General operating data for reference no. 114 – Boiler 2

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	4.08E+04	-
Net heat output – hot water	MWh_{th}	3.77E+04	-
Total operating time under normal operating conditions	h	1317	-
Equivalent full load operating factor	%	48.8	-

Table 81: General operating data for reference no. 114 – Boiler 3

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	5.10E+04	-
Net heat output – hot water	MWh_{th}	4.80E+04	-
Total operating time under normal operating conditions	h	1561	-
Equivalent full load operating factor	%	51.4	-

In the reference year, the boilers were operated for about 1500 h each, with an equivalent full load operating factor of about 50 %. The thermal utilisation ratios were 94.6 %, 92.4 % and 94.2 %, respectively.

Environmental aspects

The boilers produce typical air emissions for gaseous fuel-fired power plants. In accordance to the official authorisation, the air pollutants dust, NO_x and CO are continuously measured in the flue gas. Primary measures are taken for emission abatement directly in boilers (low-NO_x-burners).

Table 82, Table 83 and Table 84 show the concentrations and the annual loads for the measured air-pollutants in the flue gas of both gas turbines. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do not include OTNOCs. The reference oxygen content is 3 %.

Table 82: Air emissions for reference no. 114 – Boiler 1

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm^3	67.8	-	84.95	-	-	93.19	HHV	Cont.	Yes	110	-
	kg/year	4428.7										
CO	mg/Nm^3	3.43	-	6.24	-	-	22.29	HHV	Cont.	Yes	50	-
	kg/year	211.9										
Dust	mg/Nm^3	0.02	-	0.04	-	-	0.09	HHV	Cont.	Yes	5	-
	kg/year	1.5										

Table 83: Air emissions for reference no. 114 – Boiler 2

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm^3	81.81	-	91.3	-	-	98.99	HHV	Cont.	Yes	110	-
	kg/year	3647.6										
CO	mg/Nm^3	1.06	-	1.96	-	-	3.23	HHV	Cont.	Yes	50	-
	kg/year	66.1										
Dust	mg/Nm^3	0.02	-	0.04	-	-	0.14	HHV	Cont.	Yes	5	-
	kg/year	1.2										

Table 84: Air emissions for reference no. 114 – Boiler 3

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm³	38.17	-	76.03	-	-	90.15	HHV	Cont.	Yes	110	-
	kg/year	3961.5										
CO	mg/Nm³	0	-	1.74	-	-	10.29	HHV	Cont.	Yes	50	-
	kg/year	70.9										
Dust	mg/Nm³	-	-	-	-	-	0.02	HHV	Cont.	Yes	5	-
	kg/year	-										

There are no waste waters or solid residues produced.

Special characteristics

The boilers are heat-operated flexibly to meet the demand of heat for the district heating. For this reason, short-term load changes are necessary.

Process Gas-fired Boiler for Heat Generation in the Chemical Industry, Reference no. 157

Reference no. 157 consists of two gas-fired boilers, which generate process steam for the chemical industry. Both boilers were commissioned in 2010. The gaseous fuel, which accounts for 75 % of the used fuel in the reference year, originates mainly from other processes in the chemical industry and consists of 96 % hydrogen and 4 % water. In addition the boilers are fired with NG, which amounts to 25 % in the reference year. The steam parameters are 49 bar and 400 $^{\circ}$C.

The boilers are part of a power plant site with a total rated thermal input of 880 MW_{th}. They account for 165 MW_{th} each. The gross heat power output is 153 MW_{th}, so that the nominal gross thermal efficiency is 92.7 %.

Table 85 and Table 86 show values for the fuel energy input and energy output in the reference year 2011 for the two boilers.

Table 85: General operating data for reference no. 157 – boiler 1

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	4.44E+05	-
Gross heat output – steam	MWh_{th}	4.09E+05	-
Net heat output – steam	MWh_{th}	3.95E+05	-
Total operating time under normal operating conditions	h	7452	-
Equivalent full load operating factor	%	36.1	-

Table 86: General operating data for reference no. 157 – boiler 2

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	4.21E+05	-
Gross heat output – steam	MWh_{th}	3.88E+05	-
Net heat output – steam	MWh_{th}	3.74E+05	-
Total operating time under normal operating conditions	h	6792	-
Equivalent full load operating factor	%	37.6	-

The boilers are exclusively used to supply process steam to the chemical industry. The second boiler is redundant to ensure steady supply of process steam. Therefore, the equivalent full load operating factors are only 37.6 % and 36.1 %, respectively. The thermal utilisation ratios are 87.9 % and 88.0 %.

Environmental aspects

The boilers produce typical air emissions for gaseous fuel-fired power plants. There are primary measures taken for emission abatement.

Table 87 and Table 88 show the concentrations and the annual loads for the measured air-pollutants in the flue gas. In accordance to the official authorisation, CO and NO_x were continuously measured. It should be noted, that the presented values do not include OTNOCs. The reference oxygen content is 3 %.

Table 87: Air emissions for reference no. 157 – boiler 1

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm^3	55	61	71	84	87	100	DV	Cont.	No	200	100
	kg/year	27941										
CO	mg/Nm^3	0	0	2	16	21	32	DV	Cont.	No	100-160	50 - 80
	kg/year	627										

Table 88: Air emissions for reference no. 157 – boiler 2

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm^3	55	60	72	85	86	94	DV	Cont.	No	200	100
	kg/year	2.2E+04										
CO	mg/Nm^3	0	0	1	4	7	17	DV	Cont.	No	100 - 160	50 - 80
	kg/year	1138										

There are no solid residues and no wastewater produced in the plant.

Special characteristics

The boilers are operated flexibly to meet the demand of the chemical site. For this reason, short-term load changes are necessary.

To achieve low NOx emissions, the boilers are equipped with low-NO_x-burners. The combustion air is split into primary and secondary air. The secondary air is swirled which leads to internal flue gas recirculation and thus to lower emission values. These low-NOx-burners allow for low emission combustion of hydrogen rich fuels as well as NG and are therefore suggested as BAT by the operator.

Blast Furnace Gas-fired Plant, Reference no. 145

Reference no. 145 consists of a once-through boiler for the generation of electricity and process steam. The main fuel is blast furnace gas, but the fuel mixture also consists of smaller amounts of coke oven gas (depending on the steelworks operation) and NG. The steam is fed into a condensation turbine. The plant was commissioned in 2003. The cooling system uses a forced draught cooling tower. Figure 18 shows a schematic sketch of the plant layout.

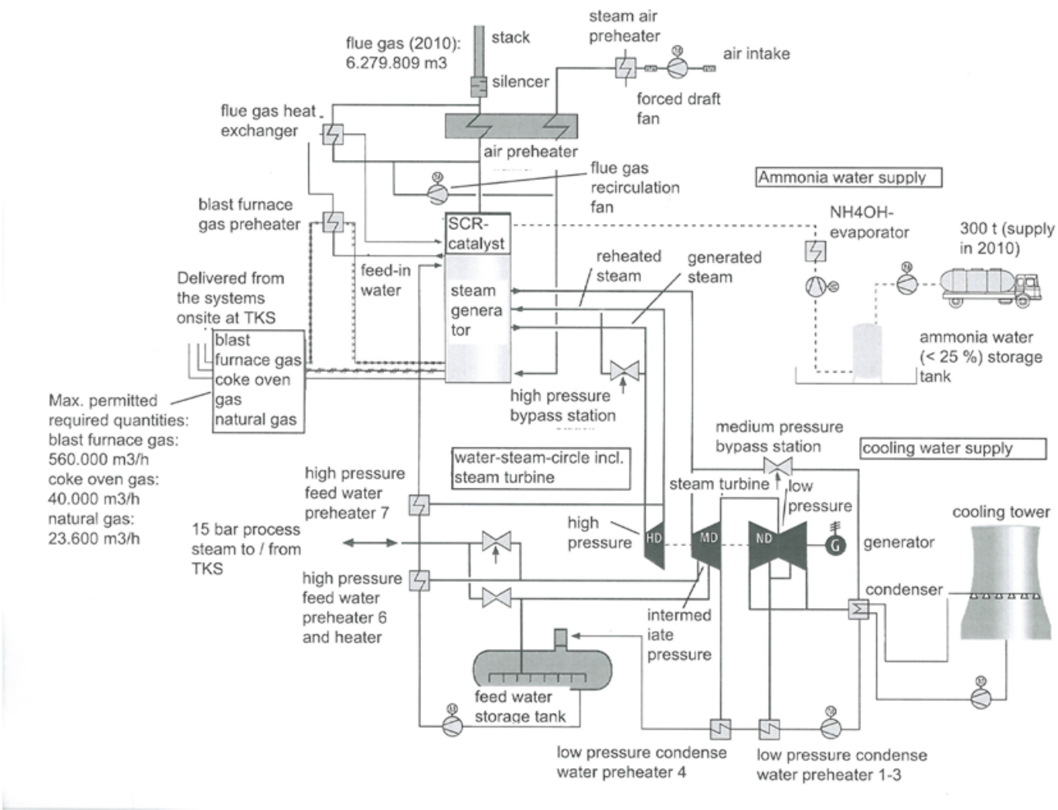

Figure 18: Sketch of the design of reference no. 145

The total rated thermal input of the plant is 550 MW_{th}, the gross electric power output is 240.7 MW_{el}. With this, the nominal gross electrical efficiency is 43.7 %.

Table 89 shows values for the fuel energy input and energy output in the reference year 2010 for both boilers. Five years (2006 – 2010) have been taken into account for the rolling average value.

Table 89: General operating data for reference no. 145

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	3.97E+06	3.84E+06
Gross electric energy output	MWh_{el}	1.62E+06	1.61E+06
Net electric energy output	MWh_{el}	1.52E+06	1.52E+06
Gross heat output – steam	MWh_{th}	3.20E+05	3.16E+05
Net heat output – steam	MWh_{th}	3.20E+05	3.16E+05
Total operating time under normal operating conditions	h	7871	8017
Equivalent full load operating factor	%	92	87

In the reference year, the boiler was operated for about 8000 h with an equivalent full load operating factor of 92 %. The net electrical utilisation ratio was 38.2 %, the thermal utilisation ratio 8.1 %. In 2010, the fuel utilisation factor was 46.3 %.

Environmental aspects

The plant is fired with CO-rich blast furnace gas. The air pollutants SO_x, NO_x and CO are continuously measured in the flue gas. There are primary and secondary measures used for emission abatement. For primary measures low-NO_x-burners are installed as well as a SCR unit (secondary measure) to minimise NO_x emissions by means of ammonia (NH_3). These technologies are suggested as BAT by the operator.

Table 90 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by the competent authority is given. It should be noted, that the presented values are validated and do not include OTNOCs. The reference oxygen content is 3 %.

It is emphasised, that in the reference year 2010 the plant has not been operated in all of the permitted operating conditions (like e.g. special operating hours given by specific constellations on the steel works site concerning the blast furnace operation and conditions at the coke oven battery). The emission behaviour and characteristics do therefore only reflect in extracts the whole emission behaviour of the power plant over an necessarily to be considered longer period.

Table 90: Air emissions for reference no. 145

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h*	d
NO_x	mg/Nm³	10.15	71.51	84.12	97.72	98.75	271.4	HHV	Cont.	Yes	200	100
	kg/year	5.2E+05										
CO	mg/Nm³	0.7	2.51	22.75	60.81	71.34	200.9	HHV	Cont.	Yes	200	100
	kg/year	1.4E+05										
NH_3	mg/Nm³	< 0.2	-	< 0.2	-	-	< 0.2	single measurement	Perio.	Yes	200	3.8
	kg/year	-										
Dust	mg/Nm³	2.3	-	2.6	-	-	3.2	single measurement	Perio.	Yes	-	10
	kg/year	1.6E+04										
SO_x	mg/Nm³	13.43	72.78	114.1	180.5	198.4	362.6	HHV	Cont.	Yes	400	200
	kg/year	7E+05										

* Values obtained in 2010 are based on validated half-hourly values. These values result out of normed values with subtraction of the measurement uncertainty, which has been determined during the calibration process. Normally, the half-hourly emission limit value equates to the double of the daily average emission limit value according to the 13. / 17. BImSchV.

The waste water is treated in the nearby steelworks. This is the reason, why no water emissions do occur at the power plant's site.

There are no solid by-products produced in the plant. The general avoidance of by-products is suggested as BAT by the operator.

Special characteristics

The plant is fired with different gaseous fuels, which are produced in a nearby facility. The gas is pre-treated (e.g. desulphurised) on-site at the production facilities of the steelworks. The burners are designed for low caloric fuels (only small amounts of natural gas necessary), which are suggested as BAT in this context. The NO_x emissions can be safely kept within the emission limit values due to the low-NO_x-burners and the SCR unit. These measures are suggested as BAT by the operator. The plant can be operated flexibly to meet the gas production, which depends on the operation mode of the steelworks. This complementary and optimised operating regime according to the fuel supply is suggested as BAT by the operator.

Blast Furnace Gas-fired Plant, Reference no. 144

Plant no. 144 consists of two identical once-through boilers, which are used for the generation of electricity and heat in form of process steam. The main fuel is blast furnace gas, but the fuel mixture also consists of small amounts of coke oven gas (depending on the steelworks operation) and natural gas. The steam is fed into a condensation turbine. The boilers were commissioned in 1975 and 1976. The later one was retrofitted with a more powerful steam turbine (HD/ND) in 2008. The cooling system comprises two natural draft cooling towers.

The total rated thermal input of each boiler is 840 MW_{th}, the gross electrical power output for boiler 1 is 307 MW_{el} and 320 MW_{el} for boiler 2. With this, the nominal gross electrical efficiencies are 36.5 % (boiler 1) and 38.1 % (boiler 2) respectively.

Table 91 and Table 92 show values for the fuel energy input and energy output in the reference year 2010 for both boilers. Five years (2006 – 2010) have been taken into account for the rolling average value.

Table 91: General operating data for reference no. 144 - boiler 1

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	2.81E+06	-
Gross electric energy output	MWh_{el}	1.15E+06	1.11E+06
Net electric energy output	MWh_{el}	1.07E+06	1.04E+06
Gross heat output – steam	MWh_{th}	4.50E+04	3.76E+04
Net heat output – steam	MWh_{th}	4.50E+04	3.76E+04
Total operating time under normal operating conditions	h	6933	6187
Equivalent full load operating factor	%	48.26	-

Table 92: General operating data for reference no. 144 - boiler 2

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	3.29E+06	-
Gross electric energy output	MWh_{el}	1.21E+06	1.20E+06
Net electric energy output	MWh_{el}	1.14E+06	1.12E+06
Gross heat output – steam	MWh_{th}	4.72E+04	5.47E+04
Net heat output – steam	MWh_{th}	4.72E+04	5.47E+04
Total operating time under normal operating conditions	h	7280	6984
Equivalent full load operating factor	%	53.86	-

In the reference year, the boilers were operated for about 7000 h with an equivalent full load operating factor of around 50 %. The net electrical utilisation ratios are 38.1 % (boiler 1) and 34.6 % (boiler 2). In addition to this, heat (1.6 % and 1.4 %) was delivered to third parties. In 2010 the fuel utilisation factor is 39.7 % for boiler 1 and 36 % for boiler 2.

Environmental aspects

The plant is fired with CO-rich blast furnace gas. The air pollutants SO_x, NO_x and CO are continuously measured in the flue gas. Only primary measures, like low-NO_x-burners in particular are are used for emission abatement. These are suggested in that context as BAT.

Table 93 and Table 94 show the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by the competent authority is given. It should be noted, that the presented values are validated (i.e. standardised values with subtraction of the measurement uncertainty, which has been determined during calibration) and do not include OTNOCs. The reference oxygen content is 3 %.

It is emphasised, that in the reference year 2010 the plant has not been operated in all of the permitted operating conditions (like e.g. special operating hours given by specific constellations on the steel works site concerning the blast furnace operation). The emission behaviour and characteristics do therefore only reflect in extracts the whole emission behaviour of the power plant over a necessarily to be considered longer period.

Table 93: Air emissions for reference no. 144 - Boiler 1

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm³	9.1	35	58.42	93.68	100.55	233	HHV	Cont.	Yes	270	135
	kg/year	2.6E+05										
CO	mg/Nm³	0	0	0.95	5.2	8.9	81.2	HHV	Cont.	Yes	100	50
	kg/year	5584										
Dust	mg/Nm³	0.5	N.A.	1.8	N.A.	N.A.	4.0	single measurement	Perio.	Yes	-	10
	kg/year	7808										
SO_x	mg/Nm³	4.1	54.65	98.45	133.85	142.9	211	HHV	Cont.	Yes	400	200
	kg/year	4.2E+05										

* Values obtained in 2010 are based on validated half-hourly values. These values result out of normed values with subtraction of the measurement uncertainty, which has been determined during the calibration process. Normally, the half-hourly emission limit value equates to the double of the daily average emission limit value according to the 13. / 17. BImSchV.

Table 94: Air emissions for reference no. 144 - Boiler 2

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
NO_x	mg/Nm³	15.3	31.6	57.28	102.3	109.8	162.8	HHV	Cont.	Yes	270	135
	kg/year						2.6E+05					
CO	mg/Nm³	-	-	1.13	4.4	6.8	83.2	HHV	Cont.	Yes	100	50
	kg/year						5653					
Dust	mg/Nm³	1.9	N.A.	3.3	N.A.	N.A.	4.5	single measurement	Perio.	Yes	-	10
	kg/year						14737					
SO_x	mg/Nm³	15.5	64.6	106.7	146.2	155.5	246.6	HHV	Cont.	Yes	400	200
	kg/year						4.6E+05					

* Values obtained in 2010 are based on validated half-HA values. Normally, the half-HA emission limit value equates to the double of the DV emission limit value according to the 13./17. BImSchV.

The waste water from both steam cycles is treated on-site in one WWT facility, before it is discharged into a nearby river. The waste water from the cooling system is not pre-treated before discharge. The water emissions are presented in Table 95.

Table 95: Waste water emissions for reference no. 144

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	1.4E+06	-	-	-	-	-	-
Temp.	(°C)	16.7	20.78	28	-	-	-	-	33
pH		8.52	8.69	8.79	-	-	-	-	6.5 to 9
TSS	(mg/l)	1	5.77	14.8	single measurement	Grab sample	No	10	50
	(kg/year)			8179.58					
COD	(mg/l)	-	-	-	-	-	-	-	30
	(kg/year)			-					
TOC	(mg/l)	3.3	3.82	4.18	single measurement	Grab sample	No	7	90
	(kg/year)			5415.25					
P (total)	(mg/l)	0.08	0.51	1.24	single measurement	Grab sample	No	10	3
	(kg/year)			722.98					

There are no solid by-products produced in the plant. The generally avoidance of by-products is suggested as BAT by the operator.

Special characteristics

The plant is fired with different gaseous fuels (blast furnace and coke oven gas), which are produced in nearby facilities as well as natural gas. The gases from the steelworks are pre-treated (e.g. desulphurised) on-site. The firing system with its gas specific low-NO_x-burner is suitable for all three gas types, which is suggested as BAT by the operator. The plant can be operated flexibly to meet the gas production, which depends on the operation mode of the steelworks. This complementary and optimised operating regime according to the fuel supply is suggested as BAT by the operator.

3.3 Techniques for the Combustion of Liquid Fuels

The installation technology and the emission abatement measures did not change significantly compared to the predecessor report from 2002. Hence, for a detailed description please refer to this report[5].

3.3.1 Presentation of the Results (evaluation levels III and IV)

For the combustion of liquid fuels only two combustion installations were evaluated. Combustion installation no. 115's total rated thermal input is 168 MW_{th}. It consists of six boilers for the generation of hot water for district heating in peak load (500 hours of operation in the reference year). The flue gasses are emitted via two stacks. Combustion installation no. 112 consists of two GT for emergency electricity production. The GT were operated for only five and ten hours, respectively, in the reference year. For this reason, no emissions are measured for combustion installation no. 112. Table 96 gives an overview of the evaluated plants.

Table 96: Evaluation level III: Group "Liquid Fuel-fired Plants"

TRTI in MW_{th}	Plant no.	TRTI in MW_{th}	Year of commissioning (last retrofit)	Operating mode (according to EIPPCB)	Total operating time under normal conditions	Equivalent full load operating factor	CHP	Technology	Other
< 50	115	6 x 28	2004 ()	Peak load (heat)	500	39.7	No	Boiler	6 boilers
> 100 - 300	112-1	119	1980 (2008)	Emergency (elec.)	5	97.2	No	GT	2 GT, no emissions measured
	112-2				10				

Table 97 shows the efficiencies and the utilisation ratios for these plants. Compared to combustion installation no. 112, combustion installation no. 115 shows a higher fuel utilisation factor. This is caused by the fact, that no. 115 is only used for heat generation, while no. 112 is exclusively used for electricity production. As there are only air emissions values for combustion installation no. 115 available, they are not separately shown here, but can be found in the detailed description (see chapter 3.3.2). The reference conditions and exceptions for the evaluation are given in Table 98. There are no water emissions for any of the plants.

[5] Rentz, O. ; Gütlin, K. ; Karl, U.: Erarbeitung der Grundlagen für das BVT-Merkblatt Großfeuerungsanlagen im Rahmen des Informationsaustausches nach Art. 16(2) IVU-Richtlinie, Forschungsbericht 200 46 317 / Deutsch-Französisches Institut Für Umweltforschung Universität Karlsruhe (TH). 2002. – Forschungsbericht

Table 97: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Liquid Fuel-fired Plants"

TRTI in MW_{th}	Plant no.	Efficiency	Utilisation ratio			Fuel utilisation factor
		(el., gross, nom.) in %	(el., gross) in %	(el., net) in %	(th.) in %	(net.) in %
< 50	115	-	-	-	92.1	92.1
> 100-300	112-1	25.2	24.9	24.6	-	24.6
	112-2	25.2	24.8	24.6	-	24.6

Table 98: Reference conditions and exceptions for the Group "Liquid Fuel-fired Plants"

Plant no.	Ref. O_2 in %	Includes OTNOCs	Validated	Type of average	Fuel	Other
Reference	3	No	Yes	Average HHV	LFO	-
115	-	Yes	-	-	-	6 boilers
112	15	-	-	-	-	2 GT, no emissions measured (< 300 h of operation)

For both installations, a BAT template was submitted. They deal with the configuration of the plants and with the handling of peak loads. BAT suggestions for combustion installation no. 115 concern the district heating net, while the suggestions for combustion installation no. 112 consider electrical peak loads. Table 99 gives an overview of the submitted BAT-suggestions.

Table 99: Evaluation level IV, Table d: BAT submissions for the Group "Liquid Fuel-fired Plants"

TRTI in MW_{th}	Plant no.	No. of templates	Short summary	Technical domain	Level of detail
< 50	115	1	Configuration of the whole plant (handling of district heating peak load, Low-NO_x-burners)	Whole plant	Medium
> 100 - 300	112-1, 112-2	1	Configuration of the whole plant (handling of electrical peak load, quick load changes)	Whole plant	Low

3.3.2 Descriptions of Evaluated Plants or Installations

Fire-tube Boiler for Peak Load Heat Production, Reference no. 115

Reference no. 115 is comprised of six identical LFO-fired fire-tube boilers for peak load heat production and to ensure heat input for a neighbouring coal-fired power plant. The boilers are set up in a single building, the flue gases are emitted via two separate stacks. The plant was commissioned in 2004. Generated hot water pressure is 10 bar, the temperature depends on the heat consumption in the district heating and is between 90 °C and 135 °C.

The total rated thermal input of each boiler is 28 MW_{th}, the gross heat power output (hot water) is 26.71 MW_{th}, which leads to a nominal gross thermal efficiency of 93.5 %. Table 100 shows the energy input and output for the reference year as well as the total operating time under normal operating conditions. The reference year for the given values is 2010.

Table 100: General operating data for reference no. 115

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	2.78E+04	-
Gross heat output – hot water	MWh_{th}	2.56E+04	-
Net heat output – hot water	MWh_{th}	2.56E+04	-
Total operating time under normal operating conditions	h	324.1	-
Equivalent full load operating factor	%	51.1	-

The average total operating time under normal operating conditions for all six boilers was 324.1 h in 2010. The equivalent full load operating factor was 51.1 %. The thermal utilisation ratio was 92.1 %.

Environmental aspects

The plant emits low amounts of air pollutants due to the low-emission fuel (LFO). In accordance to the official authorisation, the air pollutants dust and CO are continuously measured in the flue gas. Table 101 shows the concentration and the annual load for the measured air-pollutants. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do include OTNOCs. The reference oxygen content is 3 %.

Table 101: Air emissions for reference no. 115

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm³	0	0.36	0.484	0.67	0.767	2.38	HHV	Cont.	Yes	-	1
	kg/year	-										
NO_x	mg/Nm³	-	-	-	-	-	-	-	Estimated value	Yes	400	200
	kg/year	7000										
CO	mg/Nm³	0	0	1.494	5.553	6.807	134.1	HHV	Cont.	Yes	160	80
	kg/year	170										

Because of the extra light oil used, the low-NO_x-configuration of the burners and the relatively short operating time, NO_x does not need to be measured continuously. The mean NO_x concentration is around 170 mg/Nm^3. Secondary measures for emission abatement are not necessary.

There are neither waste water emissions nor solid residues.

Special characteristics

The plant is only operated when the demand of the district heating is high or when the heat input in other facilities has to be backed up. Due to the low-emission fuel and the low-NO_x-burners, the emissions are overall low. These characteristics of the plant are suggested as BAT by the operator.

Gas Turbine for Emergency Load Electricity Generation, Reference no. 112

Reference no. 112 consists of two identical LFO-fired gas turbines for peak load electricity generation with separate stacks. The installation is located at the same combustion site as combustion installation no. 111. Combustion installation no. 112 was commissioned in 1980 as a CCGT-plant. In 2008, the heat recovery boiler was removed so that the gas turbines are now in solo-operation.

The total rated thermal input of each turbine is 119 MW_{th}, the gross electric power output is 30 MW_{el}, which results in a nominal gross electrical efficiency of 25.2 %.

Table 102 and Table 103 show the energy input and output for the reference year as well as the total operating time under normal operating conditions for both gas turbines. The reference year for the given values is 2010.

Table 102: General operating data for reference no. 112 – GT 1

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	5.78E+02	-
Gross electric energy output	MWh_{el}	1.44E+02	-
Net electric energy output	MWh_{el}	1.42E+02	-
Total operating time under normal operating conditions	h	5	-
Equivalent full load operating factor	%	97.2	-

Table 103: General operating data for reference no. 112 – GT 2

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	1.10E+03	-
Gross electric energy output	MWh_{el}	2.73E+02	-
Net electric energy output	MWh_{el}	2.71E+02	-
Total operating time under normal operating conditions	h	9.5	-
Equivalent full load operating factor	%	97.2	-

The turbines have been in operation for only 5 and 9.5 h. For this time, the turbines were operated at full load. The net electrical utilisation ratio is 24.6 %.

Environmental aspects

The gas turbines are maximally operated for 300 h each year. For this reason, the air emissions are not monitored. For primary NO_x-reduction, the gas turbines are equipped with a water injection.

There are neither solid residues nor waste waters produced at the installation.

Special characteristics

The combustion installation is exclusively used for peak load electricity generation. The average operating time per year is 20 h. The former CCGT-plant was converted to the meet the market conditions and requirements. This operation mode and the configuration of the installation are suggested as BAT by the operator.

3.4 Techniques for the Combustion of Solid Fuels

The combustion of solid fuels is done solely in boilers. Possible firing-technologies are pulverized-fuel firing, CFB firing and grate firing. In Germany, different solid fuels are combusted. They are, according to annex V of the IED, hard coals, lignite (from the Rhenish region, the Lausitz region and the Middle-German region) and biomass fuels. In addition to this, the combustion of co-combustion of solid wastes, meat and bone meal, sewage sludge, waste woods and RDF (all according to annex IV of the IED) is practiced. All evaluated plants are used for the generation of electricity, some in combination with heat generation for district heating.

In this project 35 questionnaires of 25 solid fuel-fired combustion installations are evaluated. They can be categorised, depending on the type of fuel and technology (evaluation level II).

Table 104: Evaluation level II: Categorisation of solid fuel-fired plants

	Hard coal	Lignite	Biomass
Q_{th} in MW	Boiler	Boiler	Boiler
< 100	-	-	5
> 100 - 300	1	1	-
> 300	14	14	-

For the solid fuel-fired plants in Germany predominantly hard coal- and lignite-fired units were submitted (15 questionnaires each). Additionally, data of four installations firing biomass was provided. As shown in the table, most of the hard coal- and lignite-fired units display total rated thermal inputs of more than 300 MW_{th}. As this group is very big, it is useful to create additional subgroups. This approach, which differentiates the plants further by their total rated thermal input, is justified by the following reasons:

The LCP in the EU are designed site- and fuel-specifically. This is especially true for their auxiliary systems, such as FGT, WWT, cooling system and others. For the revision process of the BREF LCP it is therefore necessary to include more detailed information on the individual plant concepts and operation modes. Thus, a first, rough classification of the plants by the total rated thermal input in smaller ranges is useful.

The classification of the lignite and hard coal-fired reference LCP into just two categories with a 300 MW_{th} threshold is not very meaningful, as in this way the advanced state of the art it not taken into account adequately. A new classification system, which classifies LCP with a thermal input of more than 300 MW_{th}, is proposed as follows:

Lignite:
- 300 – 1000 MW_{th}
- 1000 – 2000 MW_{th}
- > 2000 MW_{th}

Hard coal: - 300 – 800 MW_{th}
- 800 – 1600 MW_{th}
- > 1600 MW_{th}

With a new classification of lignite-fired combustion installations and for hard coal-fired plants plant specific characteristics can be taken into consideration much better. Furthermore, the evaluated reference plants were modernised continuously to meet the state of the art. With the aforementioned new classification system, these measures can be taken into account more differentiated. This proposal was popular with the Technical Working Group. In continuation, a further classification by the annual operating time with a threshold of 4000 h was suggested.

The German EEG provides incentives for biomass-fired boilers only to an electrical power output of 20 MW_{el}. For this reason, the thermal rated inputs of all evaluated plants are between 50 and 100 MW_{th}.

Evaluation level III includes the three categories hard coal-, lignite- and biomass-fired plants. Some hard coal- and lignite-fired plants also co-combust biomass fuels, RDF, or gaseous fuels. Due to the small quantities, their influence is only relatively small and not further considered in this report. Other differences among the categories or individual plants can complicate the comparison. The majority of the plants are used for CHP. Three plants are industrial plants, which are operated under special conditions. The particularities of the individual plants can be taken from the more detailed plants descriptions in chapters 3.4.1.3, 3.4.2.3 and 3.4.3.3.

3.4.1 Hard Coal-fired Boilers

3.4.1.1 General Discussion and Explanation of the Technique and the Measures for Emissions Control

In principle, the technologies and measures for emission control did not change compared to the predecessor report from 2002. Hence, for a detailed description please refer to this report[6]. Until 2012, no new hard coal-fired LCPs were commissioned (retrofits and other changes to auxiliary systems are excluded). The newest evaluated boiler was commissioned in 1992. At the moment, new plants are under construction or were commissioned in the very recent past. They are designed for live steam parameters of 300 bar and 600 °C, which will improve the efficiency of the plants. As there is no or no sufficient operation data available, these plants are not included in this report. The majority of the combusted hard coals are imported, while the share of hard coals of German origin decreases.

In 2004, the 13. BImSchV was revised. It now involves new emission limit values for mercury for hard coal-fired LCPs. After a transitional arrangement, the new value is set to 0.03 mg/Nm^3. By the comprehensive application of FGD and SCR/SNCR units, Hg emissions could already be lowered significantly.

§ 15, sect. (1) of the 13. BImSchV (2004) demands a continuous measuring of Hg emissions, but under certain conditions, deviations from this are possible. According to § 15, sect. (9) of the 13. BImSchV the measurement can be done periodically after

[6] RENTZ, O. ; GÜTLIN, K. ; KARL, U.: Erarbeitung der Grundlagen für das BVT-Merkblatt Großfeuerungsanlagen im Rahmen des Informationsaustausches nach Art. 16(2) IVU-Richtlinie, Forschungsbericht 200 46 317 / Deutsch-Französisches Institut Für Umweltforschung Universität Karlsruhe (TH). 2002. – Forschungsbericht

application request, if 50 % of the Hg emissions are below the limit emission values (30 µg/Nm^3 for DV and 50 µg/Nm^3 for HHV). Depending on the hard coal and the FGT equipment, this applies to many German installations.

In addition to Hg emission abatement in a flue gas scrubbing facility, new technologies are tested and already successfully used in a few power plants.

3.4.1.2 Presentation of the Results (evaluation levels III and IV)

Table 105 shows the evaluation level III for the hard coal-fired plants with their most significant characteristics. A total of 13 combustion installations is evaluated in 15 questionnaires. As stated above, the plants are divided by their thermal input into the categories 300 – 800 MW_{th}, 800 – 1600 MW_{th} und > 1600 MW_{th}. According to the standards given by the EIPPCB, all plants are operated in base load with high equivalent full load operating factors. Although the plants were commissioned for the first time 20 to 44 years ago, most of them have been modernised in the last ten years. If for "other" nothing is stated, the concerned plant is a dry-bottom pulverised hard coal firing.

Table 105: Evaluation level III: Group "Hard Coal-fired Boilers"

TRTI in MW_{th}	Plant no.	TRTI in MW_{th}	Year of commissioning (last retrofit)	Operating mode (according to EIPPCB)	Total operating time under normal conditions	Equivalent full load operating factor	CHP	Co-combustion of waste	Other
> 100 - 300	156	207	1992 (2010)	Base load	7884	72.8	Yes	Yes	Chemical plant; 3 different boilers; CFB boiler; 61.4 % hard coal, 25 % NG, remainder: chemical residues
> 300 - 800	134	383	1985 (2001)	Base load	6909	90.9	Yes	No	-
	141	670	1975 (2005)	Base load	6425	85.7	Yes	No	Conversion from oil/gas boiler to hard coal
	146	710	1971 (), 1983 ()	Base load	8696	82.9	Yes	Yes	Chemical plant; 2 diff. boilers with slag-tap-furnace; 89.6 % hard coal, remainder: chemical residues
> 800 - 1600	138	805	1963 (2007)	Base load	5225	64.9	Yes	No	Slag-tap-furnace 91.26 % hard coal, 8.7 % coke oven gas
	124-1	990	1968 ()	Base load	6463	80.5	Yes	No	One of four identical boilers at the site
	139	1278	1989 (2010)	Base load	6189	62.2	Yes	No	92.9 % hard coal, 6.8 % coke oven gas; low-NO_x-burner retrofit planned
	123	1370	1992 (2000, 2010)	Base load	7034	73.5	Yes	Yes	99.6 % hard coal
> 1600	124-2	1860	1985 (2008)	Base load	4346	77.8	No	No	-
	122-1	1870 each	1982 (2009)	Base load	6342	78.1	No	No	2 identical boilers
	122-2		1985 (2009)		6395	78.4			
	131	1870	1976 (2004)	Base load	5721	83.4	No	No	-

TRTI in MW_{th}	Plant no.	TRTI in MW_{th}	Year of commis-sioning (last retrofit)	Operating mode (according to EIPPCB)	Total operating time under normal conditions	Equivalent full load operating factor	CHP	Co-combustion of waste	Other
	142	1900 (inst.)	1984 (1999)	Base load	6749	74.3	No	Yes	GT preceding the boiler
	121	2100	1985 (2009)	Base load	7958	84.5	Yes	Yes	Slag-tap-furnace; 96.4 % hard coal
	132	2150	1987 (1998)	Base load	6836	78.3	No	No	-

Five of the regarded plants are used for the co-combustion of waste. Nine plants are used for CHP. Plants no. 146 and 156 are located at a chemical industry sites, which is why they are mainly heat-operated (process steam) and use chemical residues as fuel. They are for this reason only comparable with the other plants to limited extend. Table 106 shows the efficiencies and utilisation ratios for all regarded plants.

Table 106: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Hard Coal-fired Boilers"

TRTI in MW_{th}	Plant no.	Efficiency	Utilisation ratio			Fuel utilisation factor
		(el., gross, nom.) in %	(el., gross) in %	(el., net) in %	(th.) in %	(net) in %
> 100 - 300	156	17.6	-	9.0	62.6	76.2*
> 300 - 800	134	20.9	20.6	18.7	68.3	87.0
	141	41.8	38.0	34.5	16.0	50.6
	146	34.8	18.1	15.9	64.2	80.0
> 800 - 1600	138	38.5	35.4	31.9	4.7	36.5
	124-1	37.4	34.3	32.4	15.8	48.2
	139	39.1	37.2	32.8	16.8	49.6
	123	40.1	41.7	38.4	2.4	40.8
> 1600	124-2	39.8	38.0	35.5	-	35.5
	122-1	40.7	38.6	36.4	-	36.4
	122-2	40.7	38.9	36.6	-	36.6
	131	44.1	41.2	38.0	-	38.0
	142	40.5	40.7	37.6	-	37.6
	121	39.9	40.0	37.4	0.1	37.5
	132	42.8	41.5	39.4	-	39.4

* this plant provides thermal and mechanical energy, the mechanical utilisation ratio of 4.7 % is already included in the fuel utilisation factor.

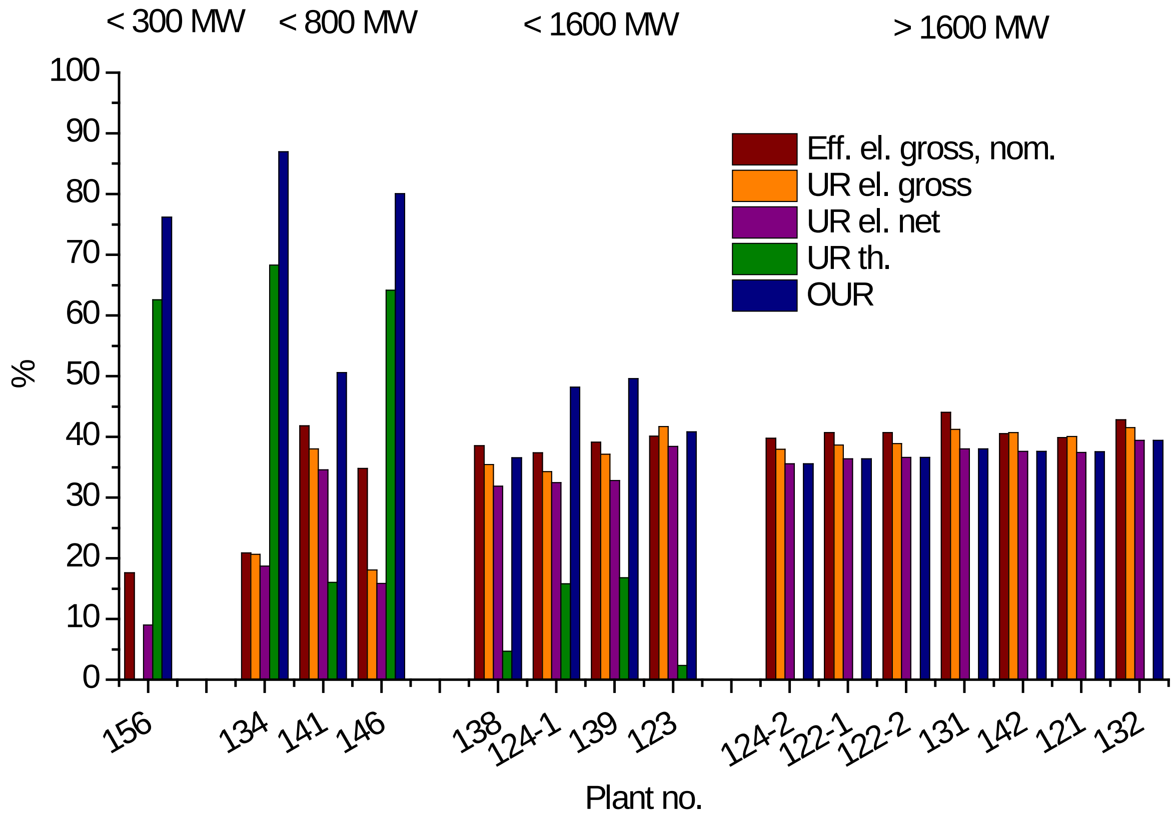

Figure 19: Evaluation level IV, Table a: Efficiencies and utilisation ratios for the Group "Hard Coal-fired Boilers"

It is notable that plants no. 134, 146 and 156 show relatively low nominal gross electrical efficiencies. On the other hand, these plants display high thermal utilisation ratios and thus high fuel utilisation factors. As stated above, comparisons of these plants to other plants are only of limited extend as they are heat-operated. The efficiencies and utilisation ratios of the other plants are in the same value range.

The air emissions, the sulphur content of the fuel and the secondary abatement measures are shown in Table 107. For better comparability of the plants, five significant emissions are shown in diagrams in Figure 20 to Figure 24. It should be noted that there are no secondary abatement measures for Hg and CO emissions. Instead, for Hg, the method to obtain data is given.

Table 107: Evaluation level IV, Table b: Air emissions for the Group "Hard Coal-fired Boilers"

		NO_x		CO	Dust		SO_x				Hg	
TRTI in MW_{th}	Plant no.	Ø in mg/Nm³	Secondary measures	Ø in mg/Nm³	Ø in mg/Nm³	Secondary measures	Ø S-content of coal in %	Ø in mg/Nm³	Secondary measures	Ø SO_x-removal in %	Ø in mg/Nm³	Method to obtain data
> 100 - 300	156	98.3	-	228.1	0.1	Cyclone, fabric filter	0.93	350.9	Dry adsorption	78.2	<0.000	Perio. (4x)
> 300 - 800	134	196.0	SCR	16.3	2.9	ESP	-	48.8	FGD	97.4	<0.000	Perio. (6x)
	141	78.4	SCR	25.2	0.3	ESP	0.71	51.1	FGD	96.1	0.006	Perio. (5x)
	146	178.2	SCR	15.6	11.1	ESP	0.9	107.7	FGD	-	0.004	Perio. (12x)
> 800 - 1600	138	141.6	SCR	2.3	2.6	ESP	1.08	132.9	FGD	92.0	0.004	Cont.
	124-1	201.5	SCR	8.4	8.3	ESP	-	36.3	FGD	97.9	0.004	Perio. (9x)
	139	183.9	SCR	0.2	1.3	ESP	1.08	122.4	FGD	93.3	0.004	Cont.
	123	175.6	SCR	10.1	2.6	ESP	0.69	40.4	FGD	-	0.003	Cont.
> 1600	124-2	214.4	SCR	9.4	4.2	ESP	-	286.8	FGD	83.1	0.003	Perio. (9x)
	122-1	195.2	SCR	1.9	0.6	ESP	0.84	115.3	FGD	91.4	0.002	Cont.
	122-2	196.1	SCR	3.1	2.2	ESP	0.84	123.1	FGD	90.5	0.001	Cont.
	131	168.4	SCR	1.9	8.5	ESP	-	99.3	FGD	87.7	0.002	Cont.
	142	182.6	SCR	1.0	3.5	ESP	-	116.0	FGD	91.7	0.001	Cont.
	121	187.4	SCR	7.6	5.6	ESP	-	82.7	FGD	-	0.001	Cont.

		NO_x		CO	Dust		SO_x				Hg	
	132	182.6	SCR	2.8	4.7	ESP	-	81.2	FGD	91.0	-	-

Figure 20 shows that the annual average of the NO_x emissions is about 200 mg/Nm³ for all plants. Well below this value are plants no. 141 and 156. Plant no. 156 is a CFB boiler, which achieves low NO_x emissions without secondary measures; on the other hand, hard coal makes up for only 61 % of its fuel diet. Plant no. 124-2 shows a peak (500 mg/Nm³) for the 95th percentile, which can be explained by an outage of the SCR facility. As OTNOCs are included in the given values of this particular plant, this peak can be seen in the diagram.

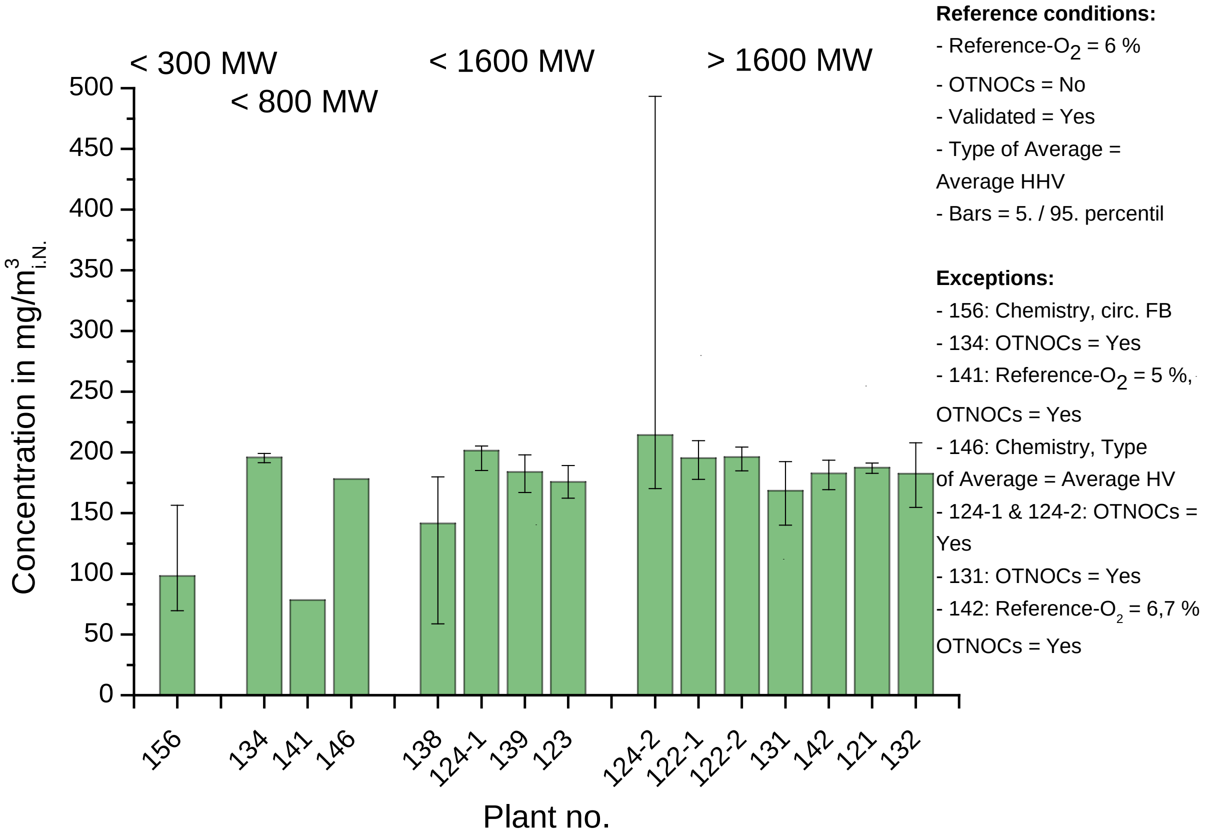

Figure 20: Evaluation level IV, Table b: NO_x emissions for the Group "Hard Coal-fired Boilers"

The CO emissions for all plants are shown in Figure 21. The high CO emissions of plant no. 156 are due to the low combustion temperatures of CFB boilers. The other plants show CO emissions of below 26 mg/Nm³. For plants with a total rated thermal input of more than 800 MW, the maximum is only 10.1 mg/Nm³.

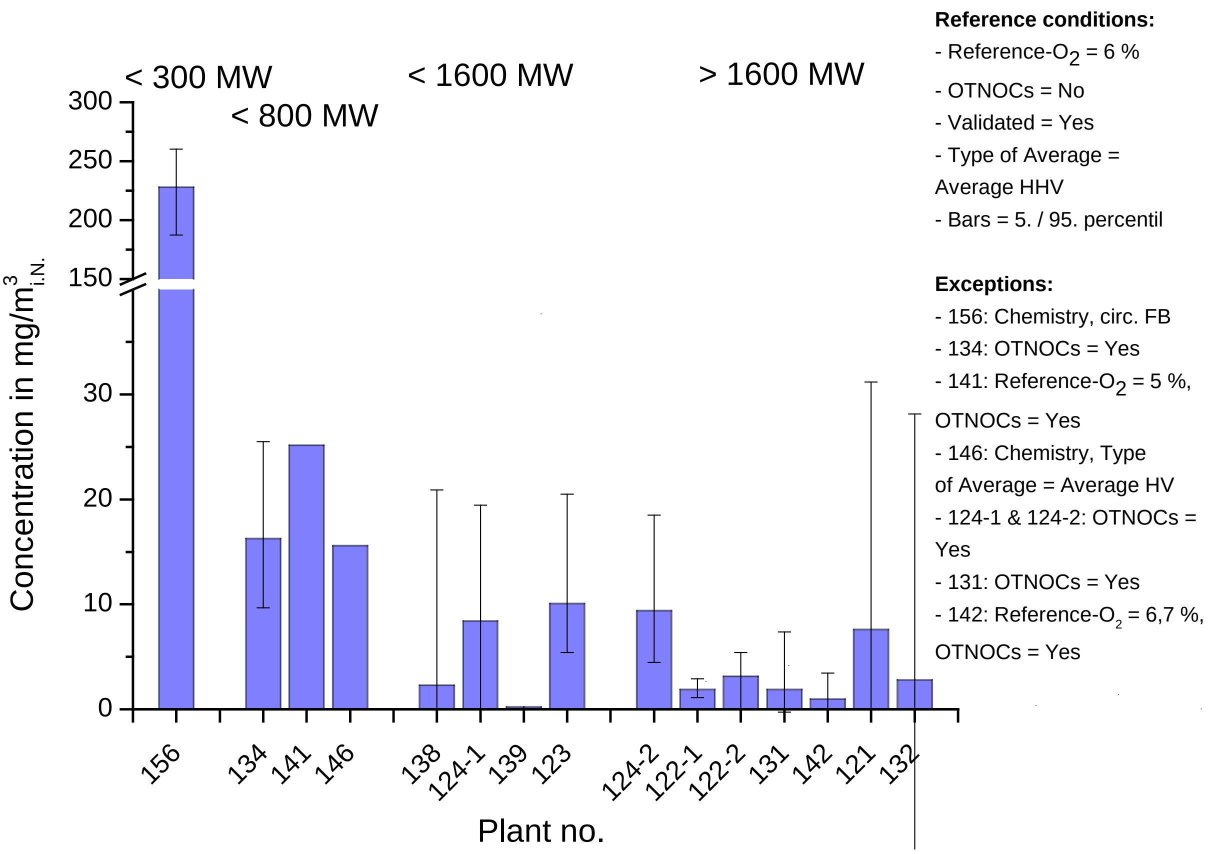

Figure 21: Evaluation level IV, Table b: CO emissions for the Group "Hard Coal-fired Boilers"

The SO_x emissions are shown in Figure 22. As can be seen, the majority of the plants display values of less than 135 mg/Nm^3. Only plants no. 156 and 124-2 exceed this value. For plant no. 124-2 this is due to a short outage of the FGD. Plant no. 156 is not really comparable to the other plants, because of its special fuel and firing-technology. In addition to this, plant no. 156 is the only plant equipped with a dry adsorption instead of a wet FGD. Plant no. 124-2 shows a peak in the 95th percentile which is caused by the FGD-outage. If OTNOCs are not included in the values, the 95th percentile for plant no. 124-2 is only 189 mg/Nm^3. Values for the (rate of) SO_x removal are shown in Figure 23. According to the 13. BImSchV, SO_x removal as well as SO_x emissions are relevant for all coal-fired German plants. The minimal SOx removal is set to at least 85 % for hard coal-fired plants with a TRTI of more than 300 MW_{th}; for CFB boilers with a TRTI of less than 300 MW_{th} it is 75 %. In contrast to the 13. BImSchV, SO_x removal is not directly relevant in the IED.

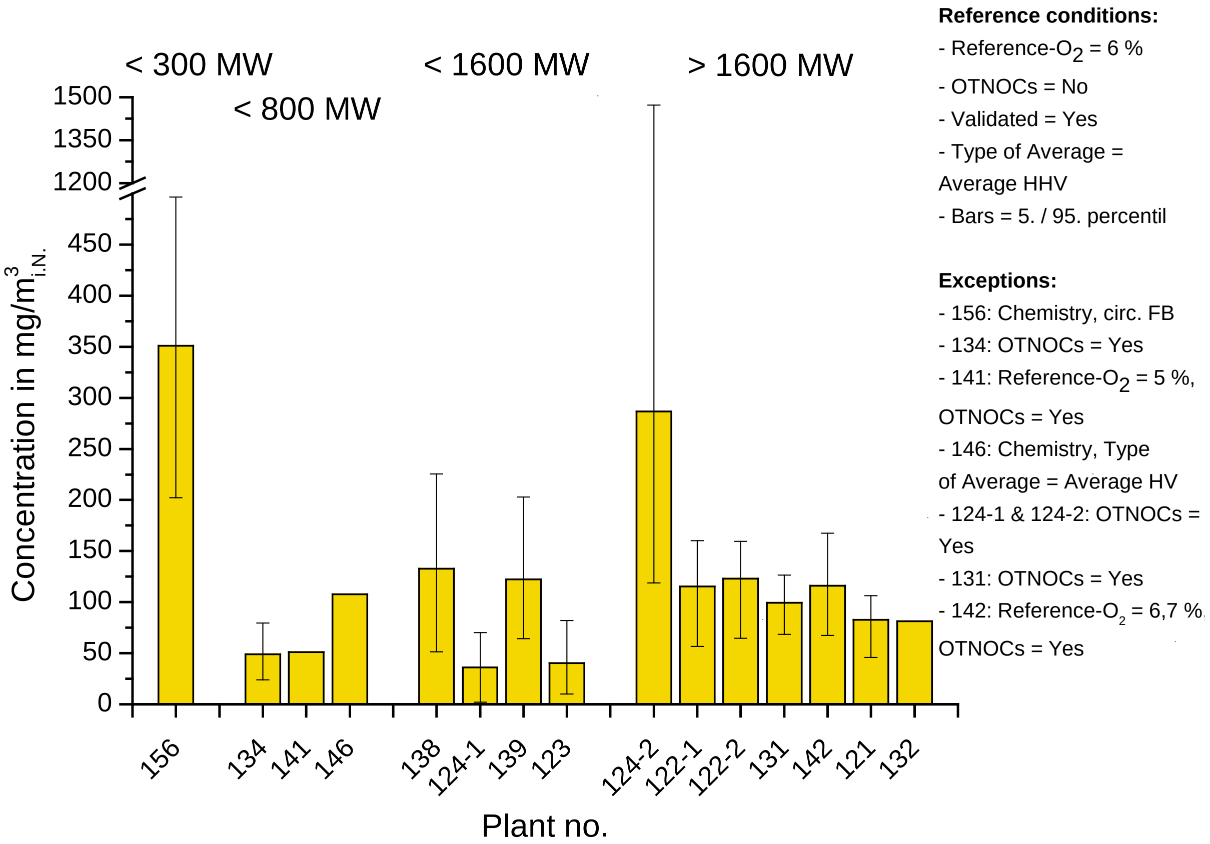

Figure 22: Evaluation level IV, Table b: SO_x emissions for the Group "Hard Coal-fired Boilers"

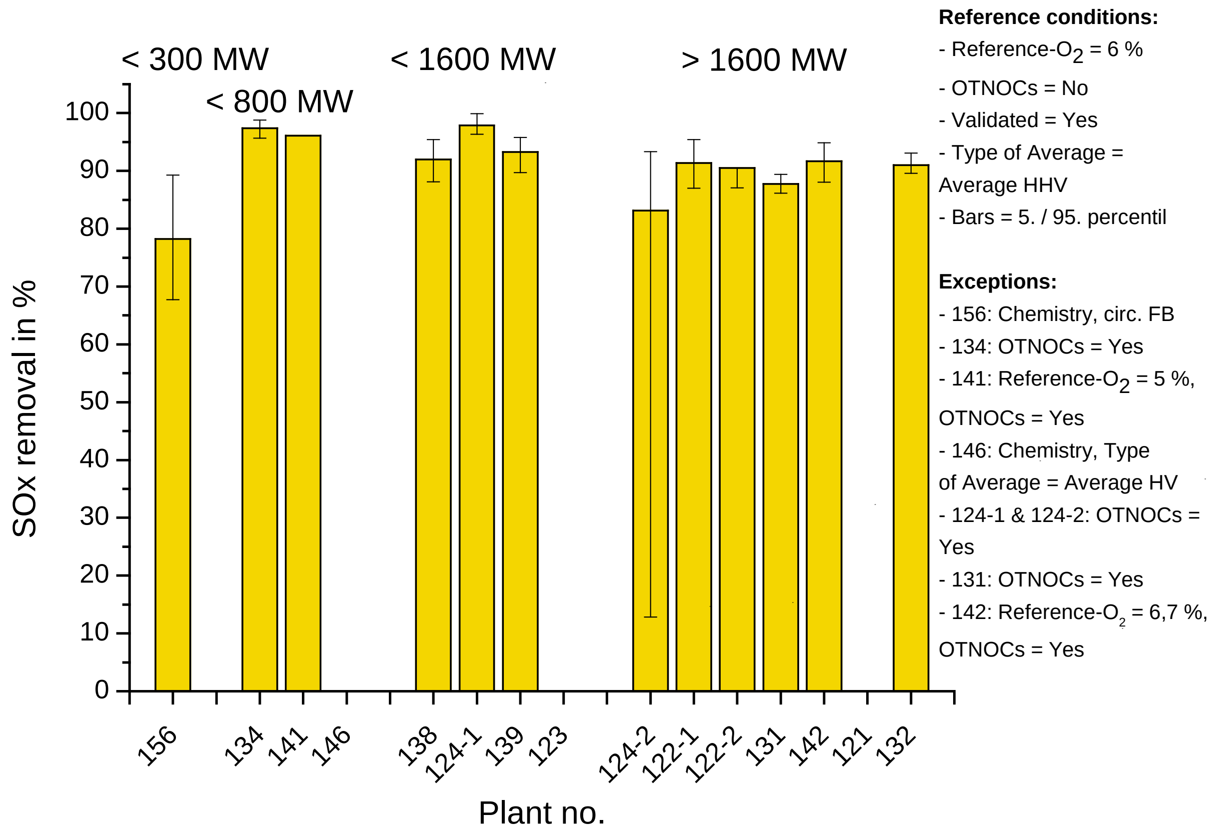

Figure 23: Evaluation level IV, Table b: SO_x removal for the Group "Hard Coal-fired Boilers"

The Hg emissions for all plants are shown in Figure 24. It can be seen that they are less than 6 µg/Nm³ on an annual average basis. At some plants, new technologies for the abatement of Hg emissions are tested; the results of this, however, are not included in the given values.

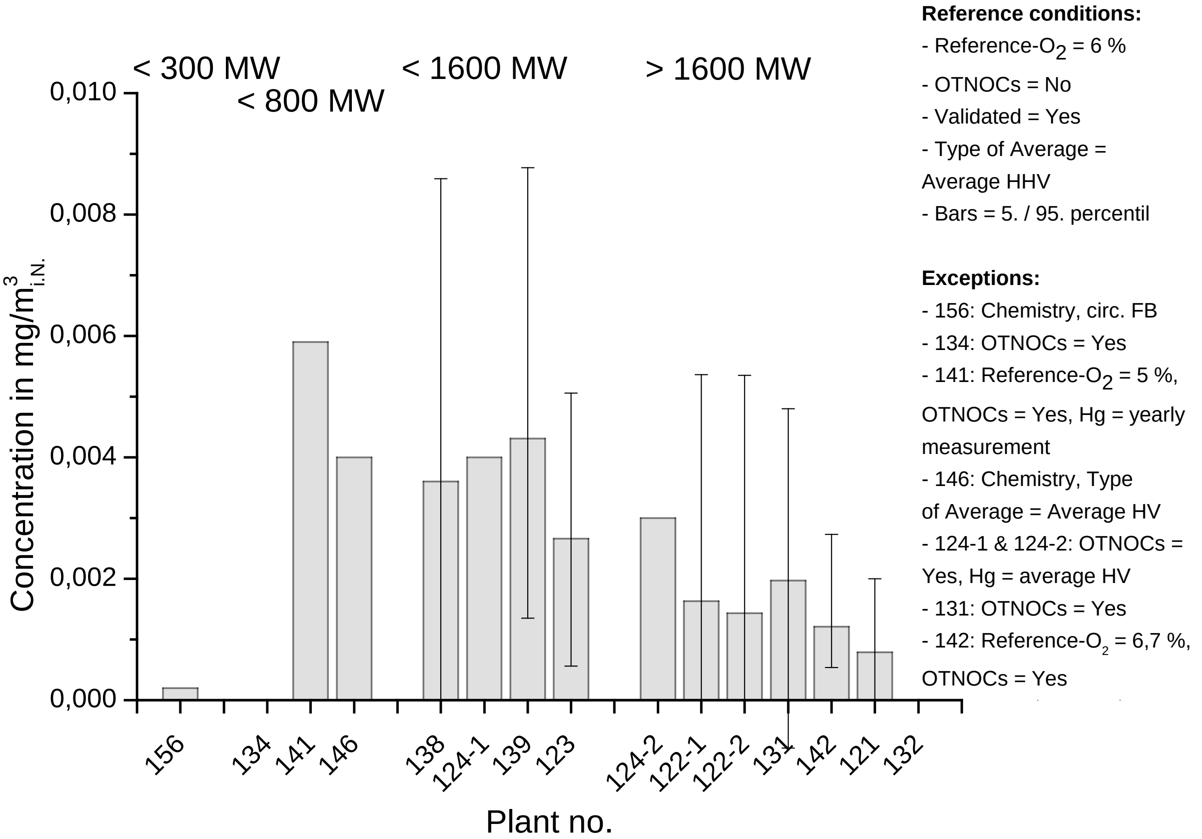

Figure 24: Evaluation level IV, Table b: Hg emissions for the Group "Hard Coal-fired Boilers"

The dust emissions are relatively low. As can be taken from Figure 25, they are (with one exception) below 10 mg/Nm³. Plant no. 146 shows emissions of 11 mg/Nm³. The very low emission values of plant no. 156 are due to the application of fabric filters. Plants no. 141 and 122-1 also display low values, but are equipped with ESP.

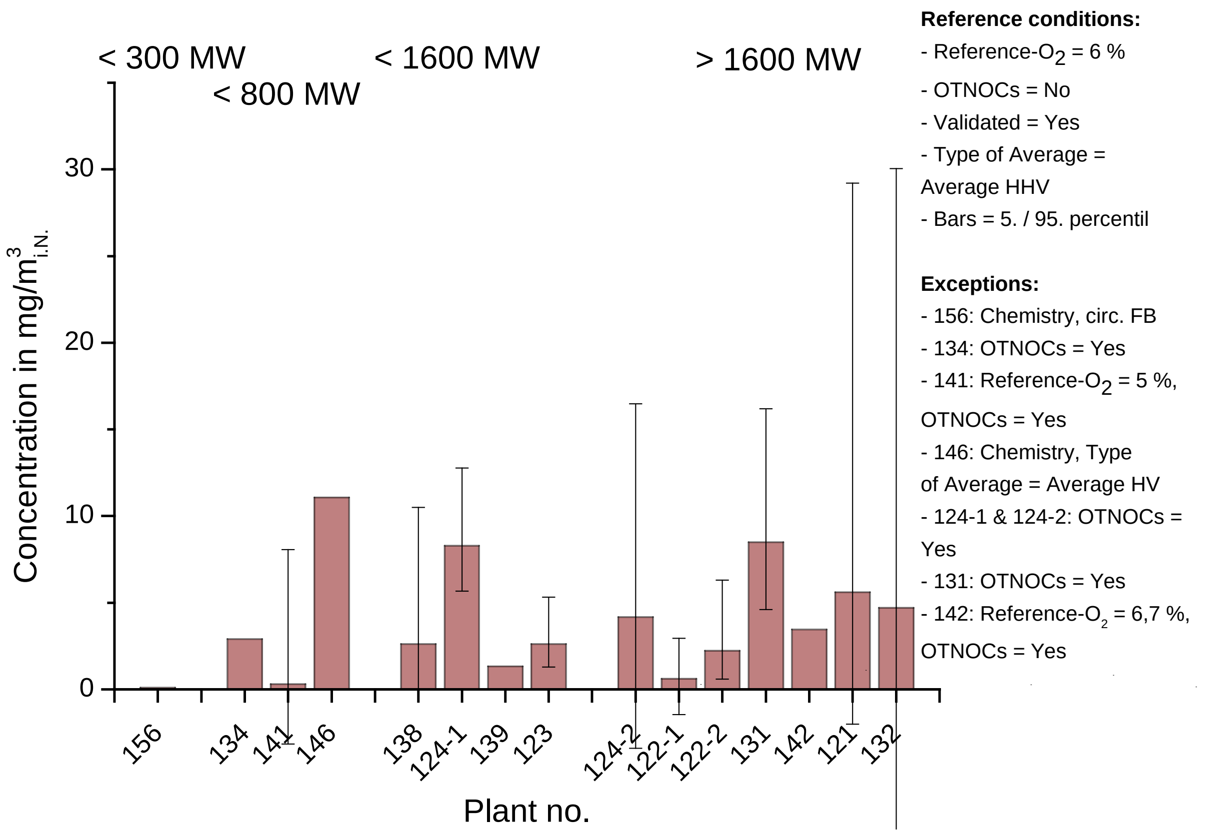

Figure 25: Evaluation level IV, Table b: Dust emissions for the Group "Hard Coal-fired Boilers"

Table 108 summarises the reference conditions and exceptions for hard coal-fired plants.

Table 108: Reference conditions and exceptions for the Group "Hard Coal-fired Boilers"

Plant no.	Ref. O_2 in %	Includes OTNOCs	Vali-dated	Type of average	Fuel	Other
Reference	6	No	Yes	HHV	Hard coal	-
121	-	Yes	-	-	96 % coal, waste co-combustion	Slag-tap-furnace
124	-	Yes	-	-	-	-
131	-	Yes	-	-	-	-
134	-	Yes	-	-	-	-
138	5	-	-	-	91 % coal, 9 % coke oven gas	Slag-tap-furnace
141	5	Yes	-	-	-	Conversion from oil/gas to hard coal
142	6.7	Yes	-	-	-	GT preceding the boiler
146	-	Yes	No	HA	90 % coal, 10 % chemical waste	Chemical plant, 2 diff. boiler
156	-	-	-	-	61.4 % coal, 25 % NG, remainder: chemical waste	Chemical plant; 3 different boilers; CFB boiler; cyclone, fabric filter

Table 109 and Table 110 show the water emissions for the hard coal-fired plants. When comparing the emissions of the different plants, the different possible sources for the waste water streams have to be considered. Waste water originating from the FGD, for example, contains much more sulphate than all other waste waters. For this reason and for better comparability, two tables were created, Table 109, which includes - according to annex 47 of the waste water regulations - all waste waters from FGD and Table 110, which shows all other waste waters in accordance with annex 31 of the waste water regulations.

Table 109: Evaluation level IV, Table c: Water emissions (from the FGD) for the Group "Hard Coal-fired Boilers"

Q_{th} in MW	Plant no.	TOC In mg/l	COD In mg/l	N (total) In mg/l	P (total) In mg/l	Sulphate In mg/l	Fluo-ride In mg/l	Cu in mg/l	Cd in mg/l	Hg in mg/l	Pb in mg/l	Discharge point	Origin of WW
> 300 - 800	134a	18.3	39.5	-	0.1	1850	15	0.01	0.005	0.002	0.02	Environment (T)	FGD
	141	11	-	235	-	1409	147	0.19	0.224	0.151	0.11	River (T)	FGD, water conditioning, cooling system, equipment cleaning
> 800 - 1600	138a	-	-	-	-	1219.0	9.6	0.00	0.000 4	0.004	-	River (T)	FGD
	124-1a	18.3	39.5	-	0.1	1850.0	15.0	0.01	0.005	0.002	0.02	River (T)	FGD
	139a	-	-	-	-	1219.0	9.6	0.00	0.000 4	0.004	-	River (T)	FGD
	123a	16.0	48.0	109.2	-	1468.0	9.5	0.01	0.004	0.002	0.01	River (T)	FGD
> 1600	124-2a	18.3	39.5	-	0.1	1850	15.0	0.01	0.005 0	0.002	0.02	River (T)	FGD, Rain water
	122-1a, 122-2a	-	39.2	-	-	1175	12.3	8.00	-	0.003	0.01	River (T)	FGD
	131a	17.1	-	-	0.1	1620	14.7	0.00	0.0001	0.000	0.00	Sea (T)	FGD
	142a	17.1	-	-	-	-	11.2	-	-	-	-	River (T)	FGD
	121a	-	-	-	-	1290	15.2	-	-	-	-	River (T)	FGD
	132a	3.6	-	37.3	-	-	2.8	0.01	0.0100	0.001	0.02	River (T)	FGD, other

Table 110: Evaluation level IV, Table c: Water emissions (other) for the Group "Hard Coal-fired Boilers"

Q_{th} in MW	Plant no.	TOC In mg/l	COD In mg/l	N (total) In mg/l	P (total) In mg/l	Sulphate In mg/l	Fluoride In mg/l	Cu in mg/l	Cd in mg/l	Hg in mg/l	Pb in mg/l	Discharge point	Origin of WW
> 100 - 300	156	-	-	-	-	-	-	-	-	-	-	River (NT)	Steam system
> 300 - 800	134b	7.4	20.5	-	0.2	308	-	0.04	0.002	0.001	0.02	River (NT)	Steam system, cooling system, rain water
	146a	8.7	-	-	-	-	-	0.04	0	0	0	Environment (NT)	-
	146b	5.3	-	11	-	-	0	0.02	0.0001	0.004	0.01	Environment (NT)	-
	146c	11.3	-	11.6	-	-	0	0.02	0.012	0.004	0	Environment (NT)	-
> 800 - 1600	138b	-	-	-	-	-	-	-	-	-	-	River (T)	cooling system
	124-1b	7.4	20.5	-	0.2	308.0	-	0.04	0.002	0.001	0.02	River (NT)	Steam system, cooling system, rain water
	139b	-	-	-	-	-	-	-	-	-	-	River (NT)	cooling system
	139c	-	-	-	-	-	-	-	-	-	-	River (T)	Steam system
	123b	13.0	39.0	-	0.4	563.0	-	-	-	-	-	River (NT)	cooling system
	123c	5.0	16.0	-	-	-	-	-	-	-	-	River (T)	rain water
1600	124-2b	7.4	20.5	-	0.2	308	-	0.04	0.002	0.001	0.02	River (NT)	Steam system, cooling system, Rain water

Q_{th} in MW	Plant no.	TOC In mg/l	COD In mg/l	N (total) In mg/l	P (total) In mg/l	Sul-phate In mg/l	Fluo-ride In mg/l	Cu in mg/l	Cd in mg/l	Hg in mg/l	Pb in mg/l	Discharge point	Origin of WW
	122-1b, 122-2b	-	19.0	-	0.1	-	-	-	-	-	-	River (NT)	Cooling system
	131b	4.9	-	2.3	0.0	-	-	-	-	-	-	Sea (T)	Water conditioning
	142b	12.1	-	-	-	-	-	-	-	-	-	River (T)	Ash system
	142c	-	-	-	-	-	-	-	-	-	-	River (T)	Cooling system
	142d	10.2	-	14.1	-	-	-	-	-	-	-	River (T)	Other
	121b	-	-	-	-	-	-	-	-	-	-	River (T)	Process water, Rain water
	121c	-	-	-	-	-	-	-	-	-	-	River (T)	Steam system
	121d	-	-	-	-	-	-	-	-	-	-	River (T)	Process water
	132b	-	-	190.7	-	-	-	-	-	-	-	River (T)	Water conditioning

The high number of suggestions made for BAT reflects the higher complexity of hard coal-fired plants in contrast to CCGT plants. In total, 38 templates were submitted. Table 111 gives a brief summary of the suggestions made.

Table 111: Evaluation level IV, Table d: BAT submissions for the Group "Hard Coal-fired Boilers"

TRTI in MW_{th}	Plant no.	No. of templates	Short summary	Technical domain	Level of detail
> 100 - 300	156	1	Co-combustion of liquid subsitute fuel	Fuel pre-treatment	High
> 300 - 800	134	1	Plant configuration (CHP operation)	Whole plant	Medium
	141	1	Plant configuration (conversion from oil boiler to hard coal)	Whole plant	High
	146	1	Plant configuration (integration of CHP, utilisation of chemical gases, low emissions, high efficiency)	Whole plant	Low
> 800 - 1600	138	2	Turbine retrofit (eff. increase)	Whole plant	Low
			SO_3-conditioning	Air emissions	Medium
	124-1	2	Plant configuration (CHP)	Whole plant	Low
			Turbine driven feed water pump	Whole plant	Low
	139	1	SO_3-conditioning	Air emissions	Low
	123	2	Covered coal bunker	Fuel pre-treatment	Medium
			Plant configuration (CHP)	Whole plant	Medium
> 1600	124-2	1	Turbine driven feed water pump	Whole plant	Gering
	122-1, 122-2	2	FGD	Air emissions	Medium
			Flue gas emissions via wet stack	Air emissions	Medium
	131	3	Additional LP turbine	Whole plant	Medium
			Co-combustion of sewage sludge	Brennstoffaufbereitung	Medium
			Discharge of NH_4 rich waste water	Water	Medium
	142	8	Classification of substitute fuels	Fuel pre-treatment	High
			Multistage FGT	Air emissions	Medium
			Utilisation of FGD waste water	Water	Medium
			Reduction of waste water from dust removal	Water	Medium
			Optimised ash quality	Solid residues	Medium
			Reduction of cooling water consumption	Water	Medium

TRTI in MW_{th}	Plant no.	No. of templates	Short summary	Technical domain	Level of detail
			Utilisation of flue gas from GT	Firing system	Medium
			Process simulation	Process control	Medium
> 1600	121	11	Drying in bowl mill	Fuel pre-treatment	Medium
			Magnetic separator	Fuel pre-treatment	Medium
			Multistage FGT	Air emissions	Medium
			Chemical/physical WWT	Water	Low
			Recycling of WW in slag-tap Firing	Water	Low
			Optimised gypsum quality	Solid residues	Low
			Production of granulate material for road construction	Solid residues	Low
			Optimised water quality	Water	Low
			Slag-tap Firing	Firing system	Low
			Optimised process operation	Whole plant	Low
			Plant configuration	Whole plant	Low
	132	2	Turbine driven feed water pump	Whole plant	Medium
			Combined discharge and recirculation cooling tower	Water	Medium

3.4.1.3 Descriptions of Evaluated Plants or Installations

Circulating Fluidised Bed Combustion, Reference no. 156

Reference no. 156 uses a circulating fluidised bed (CFB) combustion for steam generation (System Circifluid). The steam is primarily used to operate turbo compressors in the chemical industry and secondarily for electricity generation. The plant consists of a natural circulation boiler, which is in operation since 1992. The main fuel is hard coal. In addition to this, NG, liquid waste and process gases from the chemical industry can be incinerated in the CFB boiler. The cooling system for the solid residues is a closed loop. The generated live steam (130 bar and 540 °C) is fed into a backpressure turbine, where it is expanded. Steam can be extracted and delivered to other plants at CHEMPARK at 110 bar, 16 bar and 6 bar and corresponding temperatures.

The plant was modernised in the last 10 years. The cyclone precipitator as well as the super heater and the air preheating were renewed. In addition to this, the evaporator heating surfaces were increased in size and the feeding system for inert materials and limestone to the CFB boiler was altered.

The plant represents a part of a combustion site. It accounts for 105 MW_{th} of the total rated thermal input of the location, which is 207 MW_{th}.

Table 112 shows the energy input and output for the reference year as well as the total operating time under normal operating conditions. It should be noted that the given values refer to the whole combustion site and not the single regarded plant. The reference year for the given values is 2010. Three years have been taken into account for the rolling average value.

Table 112: General operating data for reference no. 156

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	1.19E+06	1.18E+06
Gross electric energy output	MWh_{el}	-	-
Net electric energy output	MWh_{el}	1.07E+05	1.11E+05
Net heat output – steam	MWh_{th}	7.1E+05	7.21E+05
Net heat output – hot water	MWh_{th}	3.4E+04	33323.4
Mechanical energy output	MWh_{mc}	5.6E+04	52254.2
Total operating time under normal operating conditions	h	7884	7814
Equivalent full load operating factor	%	72.8	73.0

In the reference year, the plant was operated for almost 7900 h with an equivalent full load operating factor of 72.8 %. The net electrical utilisation ratio is 9 %. With a thermal utilisation ratio of 62.5 % and a net mechanical utilisation ratio of 4.7 % the fuel utilisation factor is 76.2 %. From the rolling average values a net electrical utilisation ratio of 9.4 % can be calculated as well as a thermal utilisation ratio of 64 % and a net mechanical utilisation ratio of 4.4 %, which lead to a fuel utilisation factor of 77.8 %. The total operating time under normal operating conditions for the rolling average value is greater than 7800 h with an equivalent full load operating factor of 73 %.

Environmental aspects

The plant produces typical air and water emissions for hard coal-fired power plants as well as corresponding amounts of solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x and CO are continuously measured in the flue gas. In addition to this, the Hg-emissions are periodically measured. There are primary and secondary measures taken for emission abatement. Primary measures are air staging, recirculation of flue gas and ash as well as low-NO_x-burners. Figure 26 shows a schematic diagram of the FGT process.

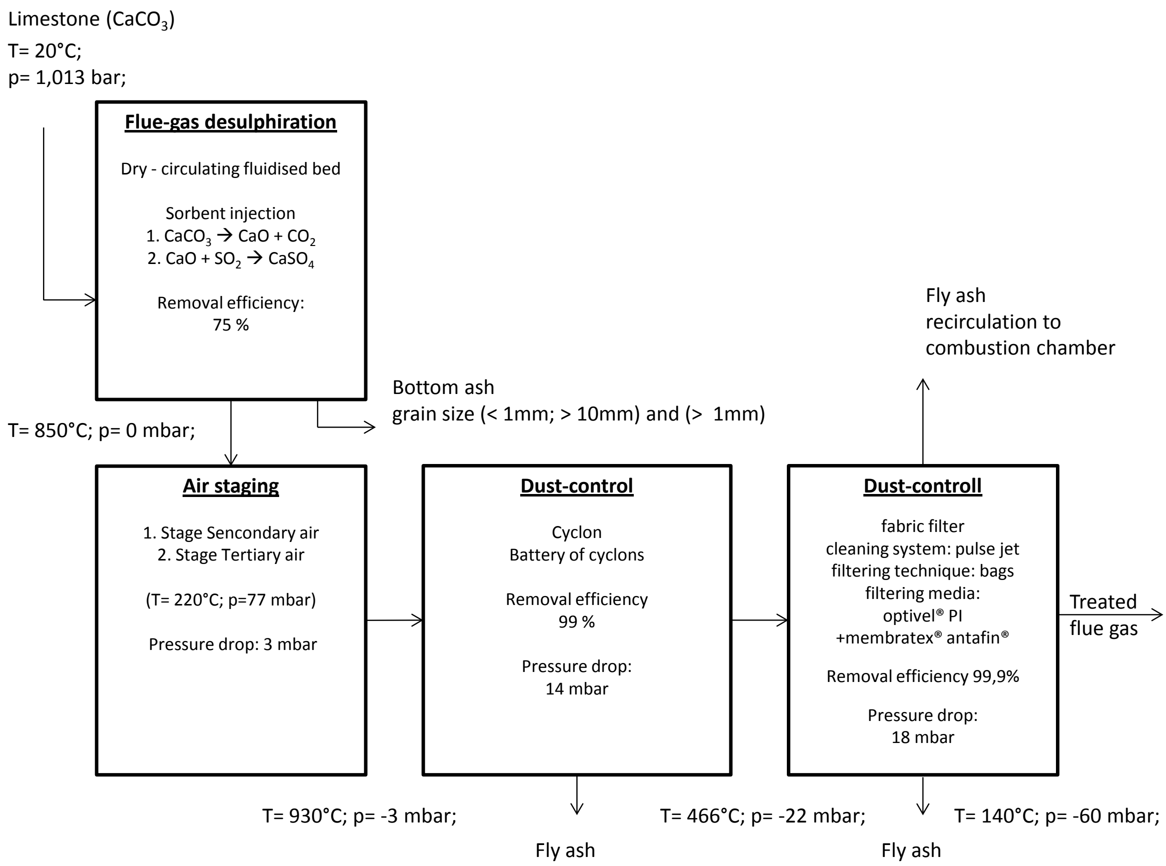

Figure 26: Schematic diagram of the FGT process for reference no. 156

$CaCO_3$ is added into the CFB boiler for desulphurisation purposes. Dust emissions are reduced in a two-stage dust-control system. The first stage consists of two parallel cyclones, by which 99 % of dust are separated from the flue gas. In the subsequent fabric filter the flue gas is further cleaned, so that 99.9 % of dust can be removed.

Table 113 shows the concentration and the annual load for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated, but do not include OTNOCs. The reference oxygen content is 6 %.

Table 113: Air emissions for reference no. 156

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm³	0.1		0.1		1	48.4	HHV	Cont.	Yes	100	50
	kg/year						112					
SO_x	mg/Nm³	9	202.18	350.9	496.8	525	923	HHV	Cont.	Yes	800	400
	kg/year						3.9E+05					
SO_x remo val	(%)	52.7	67.7	78.2	89.3	91.4	99.4	HHV	Cont.	Yes	-	-
NO_x	mg/Nm³	27.6	69.7	98.3	156.3	168	312	HHV	Cont.	Yes	800	400
	kg/year						1.1E+05					
CO	mg/Nm³	42.4	187.44	228.1	260.2	267	592	HHV	Cont.	Yes	500	250
	kg/year						2.6E+05					
Hg	mg/Nm³	1E-04	-	2E-04	-	-	0	-	Perio.	No	-	-
	kg/year						-					

Whenever daily or half-hourly emission limit values are exceeded, the competent authority is informed.

The waste water (mainly from the drum-desludging) is cooled with cold water to a temperature of 30 °C before being emitted into the environment. The water emissions are shown in Table 114.

Table 114: Water emissions for reference no. 156

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values rescribed by competent authority
Flow	(m^3/year)	-	14628	-	-	-	-	-	-
Temp.	(°C)	-	< 30	-	-	-	-	-	-
pH		9.55	9.75	9.87	-	-	-	-	-

Table 115 shows the solid residues (by-products). Fly ash makes up the largest part of the by-products. The residues can be used for the restoration of open cast mines, quarries and pits.

Table 115: Solid residues for reference no. 156

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Bottom ash	Combustion process	10 01 01	1939.5	Reclamation/restoration of open cast mines, quarries and pits	-
Fly ash	Combustion process	10 01 02	11857.5	Reclamation/restoration of open cast mines, quarries and pits	-

Special characteristics

The co-combustion of substitute fuels (liquid hydrocarbons) in the CFB is proposed for BAT. The maximum allowed share of substitute fuel in the total mass input of the boiler amounts to 25 %.

The substitute fuel is a distillation residue of the chemical industry and gets injected in the first draught of the hard coal-fired atmospheric CFB boiler. The substitute fuel can only be pumped in the heated state above 100°C. Atmospheric emissions of volatile heavy metals are not affected by the co-combustion of substitute fuel. The increase in heavy metal content in the ashes is insignificant and the quality of the by-products (fly ash, bottom ash) is virtually unchanged. As the ash content of substitute fuel is lower than that of coal and as the fuel mass input decreases due to co-combustion, the amount of fly ash also decreases due to co-combustion.

Pulverised Coal Firing, Reference no. 134

Reference no. 134 is a pulverised coal-fired power plant for the generation of electricity, process steam and district heat. The plant was commissioned in 1985 and is heat-operated. The fuel is mainly pulverised hard coal with moderate amounts of volatile matter. In addition to this, HFO and propane (for start-up) can be incinerated in small amounts.

The boiler is a once-through boiler, which feeds an extraction/back-pressure steam turbine. The live steam parameters are 246 bar and 540 °C, the reheater steam parameters are 51 bar and 537 °C. The steam is condensed in district heating preheaters and also used for the heating of make-up water as well as for the heating of cold condensate from nearby power plants. Hot water is produced at max. 25 bar/120 °C. In addition to this, process steam can be extracted for neighbouring industry facilities.

The unit is part of a plant site with a total rated thermal input of 6337 MW_{th}. It accounts for 383 MW_{th}. The nominal gross electric power output is 80 MW_{el} with an additional heat power output of 270 MW_{th}.

Table 116 shows values for the fuel energy input and energy output in the reference year 2010.

Table 116: General operating data for reference no. 134

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	2.40E+06	-
Gross electric energy output	MWh_{el}	4.96E+05	-
Net electric energy output	MWh_{el}	4.49E+05	-
Gross heat output – steam	MWh_{th}	1.21E+06	-
Net heat output – steam	MWh_{th}	1.21E+06	-
Gross heat output – hot water	MWh_{th}	4.27E+05	-
Net heat output – hot water	MWh_{th}	4.27E+05	-
Total operating time under normal operating conditions	h	6909	-
Equivalent full load operating factor	%	91	-

In the reference year, the plant was operated for almost 7000 h with an equivalent full load operating factor of 91 %. The net electrical utilisation ratio is 18.7 %, the thermal utilisation ratio is 68.4 %, which results in a fuel utilisation factor of 87.1 %.

Environmental aspects

The plant produces typical air and water emissions for hard coal-fired power plants and corresponding amounts of solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x and CO are continuously measured in the flue gas. In addition to this, other pollutant emissions are periodically measured. There are primary and secondary measures taken for emission abatement. Primary measures are air grading as well as low-NO_x-burners. Figure 27 shows a schematic diagram of the FGT process (secondary measures).

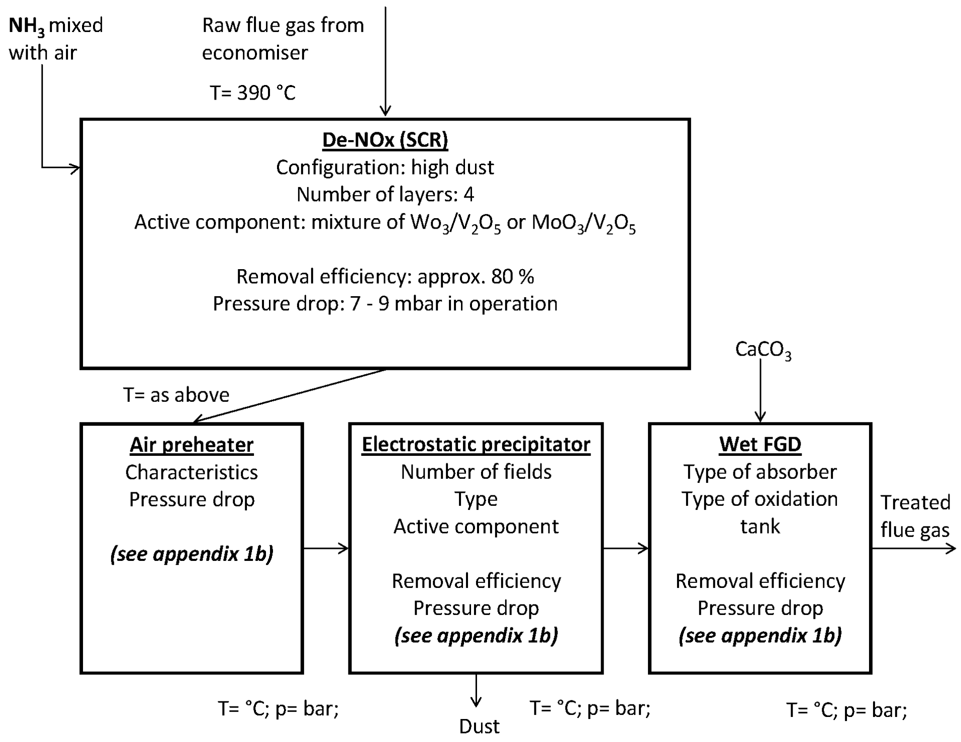

Figure 27: Schematic diagram of the FGT process for reference no. 134

The first stage of the FGT process is the SCR unit, in which NO_x is reduced by NH_3. The flue gas is then cooled (air heater), before dust is removed in the ESP. SO_x is removed in the wet FGD, where it reacts with $Ca(OH)_2$ to form gypsum. The treated flue gas is emitted via a stack.

Table 117 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do include OTNOCs. The reference oxygen content is 6 %.

Table 117: Air emissions for reference no. 134

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm³	0	1.63	2.9	6.04	6.54	17.78	HHV	Cont.	Yes	40	20
	kg/year	9000										
SO_x	mg/Nm³	0	24.03	48.84	79.43	83.8	1894.8	HHV	Cont.	Yes	370	185
	kg/year	1.7E+05										
SO_x removal	(%)	1.65	95.66	97.4	98.79	98.85	100	HHV	Cont.	Yes	85	-
NO_x	mg/Nm³	0	191.53	195.97	199.05	199.8	685.51	HHV	Cont.	Yes	400	200
	kg/year	6E+05										
CO	mg/Nm³	0	9.66	16.27	25.51	27.78	164.7	HHV	Cont.	Yes	200	100
	kg/year	3.2E+04										
Hg	mg/Nm³	-	-	0.004	-	-	0.0063	HHV	Perio	Yes	0.03	0.05
	kg/year	-										
Cd+Tl	mg/Nm³	-	-	0	-	-	0.0022	HA	Perio	Yes	0.05	-
	kg/year	-										
Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V	mg/Nm³	-	-	5E-05	-	-	0.0215	HA	Perio	Yes	0.05	-
	kg/year	-										
PCDD/PCDF	ng/Nm³	-	-	0	-	-	0.0008	HA	Perio	Yes	0.08	-
	kg/year	-										

Taking into account the legal and regulatory provisions, some of the waste water is discharged directly into a river (cooling water). Other waste waters, especially waste water from the FGD, are pre-treated on site as can be seen in Figure 28. It should be noted, that there is one water treatment facility for the whole combustion site. The water emissions for the different waste water streams are shown in Table 118 and Table 119.

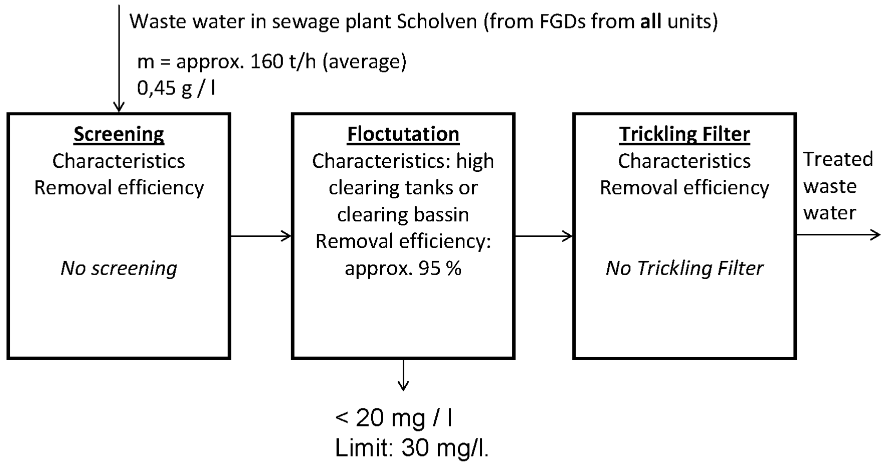

Figure 28: Schematic diagram of the WWT process for reference no. 134

Table 118: Water emissions for reference no. 134 - after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	6E+05	-	-	-	-	-	-
Temp.	(°C)	11	-	30	-	-	-	-	-
pH		8.6	-	9.1	-	-	-	-	-
TDS	(mg/l)	1	-	27	-	Grab sample	-	-	-
	(kg/year)			-					
COD	(mg/l)	26	-	53	-	Grab sample	-	-	-
	(kg/year)			-					
Cd	(mg/l)	0.005	-	0.005	-	Grab sample	-	-	0.05
	(kg/year)			-					
Pb	(mg/l)	0.02	-	0.02	-	Grab sample	-	-	0.1
	(kg/year)			-					
Cr	(mg/l)	0.013	-	0.04	-	Grab sample	-	-	0.5
	(kg/year)			-					
Cu	(mg/l)	0.01	-	0.017	-	Grab sample	-	-	0.5
	(kg/year)			-					
Zn	(mg/l)	0.01	-	0.024	-	Grab sample	-	-	1
	(kg/year)			-					
Ni	(mg/l)	0.01	-	0.027	-	Grab sample	-	-	0.5
	(kg/year)			-					
AOX	(mg/l)	0.07	-	0.64	-	Grab sample	-	-	-
	(kg/year)			-					
P (total)	(mg/l)	0.05	-	0.05	-	Grab sample	-	-	-
	(kg/year)			-					

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
TOC	(mg/l)	12.6	-	24	-	Grab sample	-	-	-
	(kg/year)			-					
Cl^-	(mg/l)	2700	-	4200	-	Grab sample	-	-	-
	(kg/year)			-					
SO_4^{2-}	(mg/l)	1500	-	2200	-	Grab sample	-	-	-
	(kg/year)			-					
Hg	(mg/l)	0.001	-	0.002	-	Grab sample	-	-	0.03
	(kg/year)			-					

Table 119: Water emissions for reference no. 134 - non-treated waste water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	9E+04	-	-	-	-	-	-
Temp.	(°C)	14.1	-	22.7	-	-	-	-	< 30
pH		8.1	-	8.5	-	-	-	-	7 to 9.5
TDS	(mg/l)	1	-	44	-	Grab sample	-	12	50
	(kg/year)			-					
COD	(mg/l)	15	-	26	-	Grab sample	-	12	50
	(kg/year)			-					
Cd	(mg/l)	0.002	-	0.002	-	Grab sample	-	12	0.002
	(kg/year)			-					
Pb	(mg/l)	0.02	-	0.02	-	Grab sample	-	-	0.04
	(kg/year)			-					
Cr	(mg/l)	0.01	-	0.01	-	Grab sample	-	-	0.04
	(kg/year)			-					
Cu	(mg/l)	0.012	-	0.059	-	Grab sample	-	-	0.08
	(kg/year)			-					
Zn	(mg/l)	0.015	-	0.27	-	Grab sample	-	-	1
	(kg/year)			-					
Ni	(mg/l)	0.01	-	0.01	-	Grab sample	-	-	-
	(kg/year)			-					
AOX	(mg/l)	0.03	-	0.07	-	Grab sample	-	12	0.08
	(kg/year)			-					
P (total)	(mg/l)	0.08	-	0.4	-	Grab sample	-	-	0.6
	(kg/year)			-					
TOC	(mg/l)	5.1	-	9.7	-	Grab sample	-	12	20
	(kg/year)			-					

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Cl^-	(mg/l)	83	-	229	-	Grab sample	-	12	600
	(kg/year)	-							
SO_4^{2-}	(mg/l)	150	-	466	-	Grab sample	-	12	1000
	(kg/year)	-							
Hg	(mg/l)	0.001	-	0.001	-	Grab sample	-	12	-
	(kg/year)	-							
NH_3-N	(mg/l)	1	-	1	-	Grab sample	-	12	-
	(kg/year)	-							
As	(mg/l)	0.002	-	0.003	-	Grab sample	-	12	0.1
	(kg/year)	-							
V	(mg/l)	0.01	-	0.012	-	Grab sample	-	-	4
	(kg/year)	-							

Table 120 shows the solid residues (by-products). Fly ash makes up the largest part of by-products. The by-products can be utilised in the construction material industry and for road building. The gypsum from the wet FGD is processed in a nearby plaster facility.

Table 120: Solid residues for reference no. 134

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Fly ash (minimum analytic figures)	Flue-gas treatment facilities	-	31000	-	concrete additive, cement substitution
Bottom ash (minimum analytic figures)	Combustion process	-	9000	-	concrete blocks, road construction, filling application
Gypsum (minimum analytic figures)	Flue-gas treatment facilities	-	17000	-	plaster board, projection plaster

Special characteristics

In this plant the feed-water pump is directly driven by the main steam turbine. The plant is a CHP plant, which is beneficial for the fuel efficiency. The heat-operated plant provides process steam at different pressures. This configuration is suggested as BAT by the operator.

Pulverised Coal Firing, Reference no. 141

Reference no. 141 is a pulverised coal-fired power plant for the generation of electricity and district heat. It was originally commissioned in 1975 as a gas- and oil-fired facility, but retrofitted for hard coal with moderate amounts of volatile matter in 2005. The boiler is a once-through boiler, which feeds a steam turbine. The live steam parameters are 180 bar and 530 °C, the reheater steam parameters are 20 bar and 530 °C. Steam can be extracted from the turbine to provide district heating. The cooling system is a once-through cooling.

The plant is a part of a power plant site with a total rated thermal input of 3865 MW_{th}. It accounts for 670 MW_{th}. The gross electric power output is 280 MW_{el} with an additional gross heat power output of 192 MW_{th}.

Table 121 shows values for the fuel energy input and energy output in the reference year 2010. Five years have been taken into account for the rolling average value.

Table 121: General operating data for reference no. 141

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	3.69E+06	3.67E+06
Gross electric energy output	MWh_{el}	1.40E+06	1.42E+06
Net electric energy output	MWh_{el}	1.27E+06	1.29E+06
Gross heat output – hot water	MWh_{th}	6.03E+05	524966.5
Net heat output – hot water	MWh_{th}	5.91E+05	514673.0
Total operating time under normal operating conditions	h	6424.8	6251.4
Equivalent full load operating factor	%	85.7	88.0

In the reference year, the plant was operated for more than 6400 h. The equivalent full load operating factor is 86 %. The net electrical utilisation ratio is 34.4 %. With a thermal utilisation ratio of 16 % the fuel utilisation factor is 50.4 %. For the rolling average value a net electrical utilisation ratio of 35.1 % can be calculated as well as a thermal utilisation ratio of 14 %, which lead to a fuel utilisation factor of 49.1 %. The total operating time for the rolling average value is about 6250 h with an equivalent full load operating factor of 88 %.

Environmental aspects

The plant produces typical air and water emissions for hard coal-fired power plants and corresponding amounts of solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x and CO are continuously measured in the flue gas. In addition to this, other pollutant emissions are periodically measured. There are primary and secondary measures taken for emission abatement. Primary measures are air grading as well as low-NO_x-burners. Figure 29 shows a schematic diagram of the FGT process.

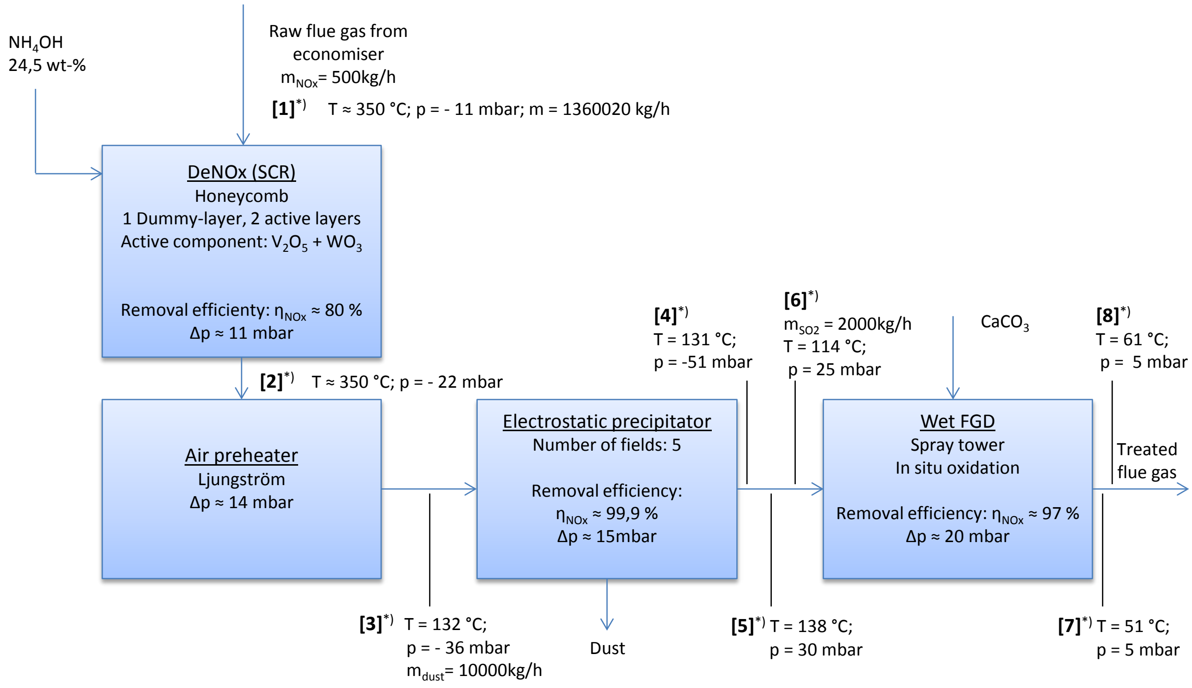

Figure 29: Schematic diagram of the FGT process for reference no. 141

The first stage of the FGT process is the SCR unit, in which NO_x is reduced by NH_3. The flue gas is then cooled (air heater), before dust is removed in the ESP. SO_x is removed in the wet FGD, where it reacts with $CaCO_3$ to form gypsum. The treated flue gas is then emitted.

Table 122 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are not validated and do include OTNOCs. The reference oxygen content is 6 %.

Table 122: Air emissions for reference no. 141

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	0.07	-	1	-	-	12.73	HHV	Cont.	No	20	-
	kg/year	3700										
SOx	mg/Nm^3	0.01	-	67	-	-	305.42	HHV	Cont.	No	100	-
	kg/year	3.6E+05										
SOx removal	(%)	-	-	96.1	-	-	-	HHV	Cont.	No	95	-
NOx	mg/Nm^3	51.1	-	85	-	-	465.81	HHV	Cont.	No	100	-
	kg/year	4E+05										
CO	mg/Nm^3	0	-	26	-	-	205.55	HHV	Cont.	No	200	-
	kg/year	1.2 E+05										
HCl	mg/Nm^3	-	-	0.5	-	-	-	-	Perio.	No	20	-
	kg/year	2300										
HF	mg/Nm^3	-	-	0.1	-	-	-	-	Perio.	No	3	-
	kg/year	600										
Hg	mg/Nm^3	-	-	0.0059	-	-	-	-	Perio.	-	0.03	-
	kg/year	27.874										
CH4	mg/Nm^3	-	-	0.002	-	-	-	-	Estimated value	-	-	-
	kg/year	9300										
NMVOC	mg/Nm^3	-	-	1.128	-	-	-	-	Estimated value	-	-	-
	kg/year	5321										
Cd	mg/Nm^3	-	-	2E-06	-	-	-	-	Estimated value	-	0.05	-
	kg/year	0.01										
Ti	mg/Nm^3	-	-	5.5E-06	-	-	-	-	Estimated value	-	0.05	-
	kg/year	0.026										
Cd+Tl	mg/Nm^3	-	-	7.6E-06	-	-	-	-	Estimated value	-	0.05	-
	kg/year	0.036										

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum		Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
Sb	mg/Nm³	-	-	7.2E-06	-	-	-		-	Perio.	-	0.5	-
	kg/year						0.034						
As	mg/Nm³	-	-	0.0034	-	-	-		-	Perio.	-	0.05	-
	kg/year						15.834						
Pb	mg/Nm³	-	-	0.0002	-	-	-		-	Perio.	-	0.5	-
	kg/year						1.011						
Cr	mg/Nm³	-	-	9.5E-05		-	-	-	-	Perio.	-	0.05	-
	kg/year						0.449						
Co	mg/Nm³	-	-	3.3E-05		-	-	-	-	Perio.	-	0.05	-
	kg/year						0.157						
Cu	mg/Nm³	-	-	7.7E-05		-	-	-	-	Perio.	-	0.5	-
	kg/year						0.362						
Mn	mg/Nm³	-	-	8.3E-04		-	-	-	-	Perio.	-	0.5	-
	kg/year						3.938						
Ni	mg/Nm³	-	-	6.6E-05		-	-	-	-	Perio.	-	0.5	-
	kg/year						0.312						
V	mg/Nm³	-	-	1.7E-04		-	-	-	-	Perio.	-	0.5	-
	kg/year						0.783						
Other *	mg/Nm³	-	-	0.0049		-	-	-	-	Perio.	-	0.5	-
	kg/year						22.88						
Zn	mg/Nm³	-	-	1.2E-04		-	-	-	-	Perio.	-	-	-
	kg/year						0.586						
PCDD/ PCDF	(ng I-TEQ/Nm³ dry, reference oxygen)	-	-	0.0017		-	-	-	-	Perio.	-	0.1	-
	kg/year						8E-06						

*: Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V

The waste water is pre-treated on site in a common facility, before it is discharged. The water emissions are shown in Table 123.

Table 123: Water emissions for reference no. 141 - after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	25000	28830	30000	-	-	-	-	-
Temp.	(°C)	28	34	40	-	-	-	-	-
pH		8.9	9.2	9.6	-	-	-	-	-
TSS	(mg/l)	73	7498	12000	-	Grab sample	-	52	30
	(kg/year)			-					
Cd	(mg/l)	0.037	0.224	0.51	-	Grab sample	-	12	-
	(kg/year)			-					
Pb	(mg/l)	0.08	0.107	0.32	-	Grab sample	-	-	0.05
	(kg/year)			-					
Cr	(mg/l)	0.027	0.112	0.2	-	Grab sample	-	-	0.1
	(kg/year)			-					
Cu	(mg/l)	0.03	0.194	0.46	-	Grab sample	-	12	0.1
	(kg/year)			-					
Zn	(mg/l)	0.29	1.387	2.1	-	Grab sample	-	12	1
	(kg/year)			-					
Ni	(mg/l)	0.164	0.322	0.5	-	Grab sample	-	12	0.1
	(kg/year)			-					
TOC	(mg/l)	1	11	22	-	Grab sample	-	52	20
	(kg/year)			-					
Cl^-	(mg/l)	83	-	229	-	Grab sample	-	12	600
	(kg/year)			-					
SO_4^{2-}	(mg/l)	1130	1409	1700	-	Grab	-	52	20000

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
	(kg/year)					sample			
Hg	(mg/l)	0.005	0.151	0.243	-	Grab sample	-	12	0.01
	(kg/year)			-					
NH_3-N	(mg/l)	0.4	2	9.7	-	Grab sample	-	104	10
	(kg/year)			-					
As	(mg/l)	0.02	0.615	2.02	-	Grab sample	-	12	-
	(kg/year)			-					
F^-	(mg/l)	4.7	147	472	-	Grab sample	-	52	30
	(kg/year)			-					
S^{2-}	(mg/l)	0.02	0.08	0.51	-	Grab sample	-	52	0.13
	(kg/year)			-					
SO_3^{2-}	(mg/l)	0.5	2.5	5	-	Grab sample	-	52	20
	(kg/year)			-					
N (total)	(mg/l)	42.5	235	556.5	-	Grab sample	-	104	-
	(kg/year)			-					
NO_2^-/NO_3^-	(mg/l)	0.0007	0.001	0.0039	-	Grab sample	-	104	-
	(kg/year)			-					
Cd+Tl	(mg/l)	0.037	0.224	0.51	-	Grab sample	-	12	-
	(kg/year)			-					
Other*	(mg/l)	0.321	1.35	3.5	-	Grab sample	-	12	-
	(kg/year)			-					

*: Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V

Table 124 shows the solid residues (by-products). Fly ash makes up the largest part of by-products. The by-products can be utilised in the construction material industry. The gypsum from the wet FGD can be processed in the plasterboard industry. Sludges from the FGD WWT have to be disposed.

Table 124: Solid residues for reference no. 141

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Fly ash	Flue-gas treatment facilities	EN-450	3.4E+04	Utilisation - Construction industry	concrete
Bottom ash	Combustion process	-	1.4E+04	Utilisation - Construction industry	stones
Gypsum	Chemical product handling and storage facilities	eurogypsum	1.5E+04	Utilisation - Construction industry	gypsum plates
SO_2 scrubber waste	Flue-gas treatment facilities	-	14.6	Utilisation - Underground mining	waste

Special characteristics

The plant was originally fired with oil and gas. It was converted into a pulverised coal-fired plant in 2005. Three mills, the ash removal and the economiser were installed. The convective heating surfaces were modified. These reconstructive measures are shown in Figure 30 and are suggested as BAT by the operator.

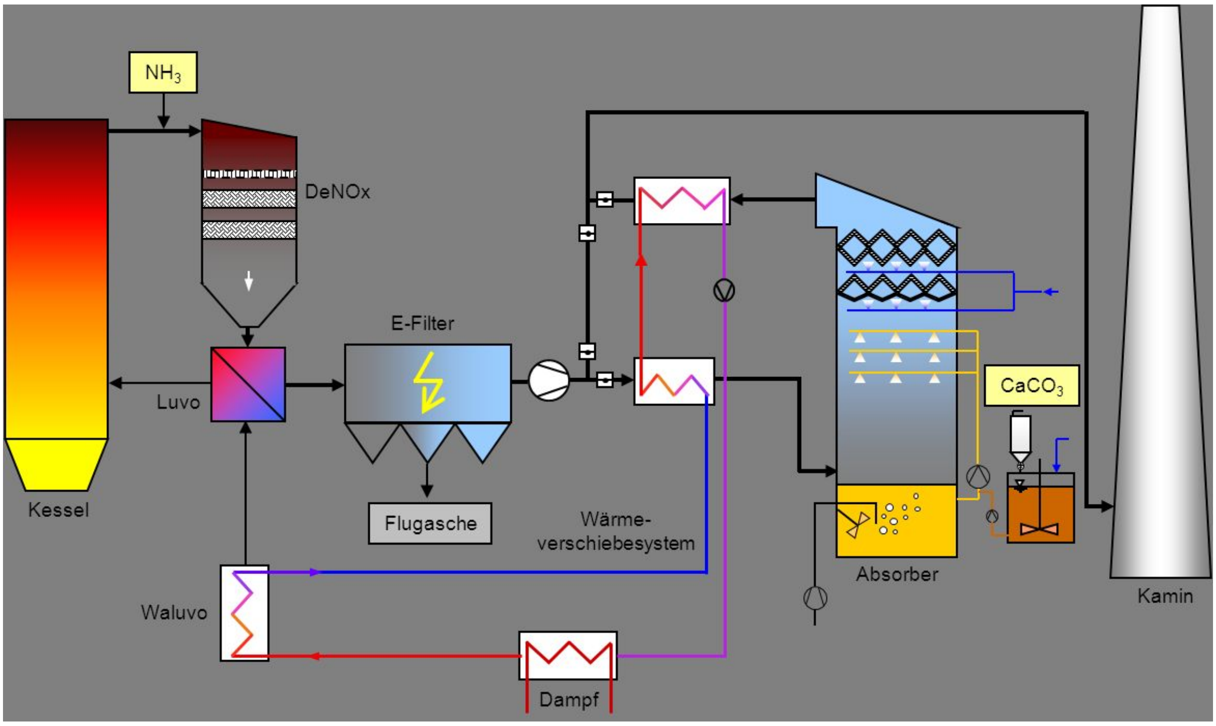

Figure 30: Retrofitted FGT for reference no. 141

Pulverised Coal Firing, Reference no. 146

Reference no. 146 is a pulverised coal-fired power plant for the generation of electricity and process steam for the chemical industry. The plant consists of two once-through boilers, which were commissioned in 1971 (Unit 1) and 1983 (Unit 2), respectively. The fuel is mainly hard coal, but small amounts of heavy crude oil, NG, liquid and solid wastes and process gases from a nearby chemical facility can be combusted as well.

The boiler of Unit 1 feeds an extraction/condensation steam turbine, from which 75 % of the steam are extracted before the low pressure turbine to be used as process steam in a nearby chemical facility. The live steam parameters are 175 bar and 530 °C, the reheater steam parameters are 22 bar and 350 °C.

The boiler of Unit 2 feeds an extraction/back-pressure steam turbine. The live steam parameters are 250 bar and 580 °C, the reheater steam parameters are 22 bar and 350 °C. The cooling system uses a natural draught cooling tower as well as a mechanical draught cooling tower.

The plants are part of a power plant site with a total rated thermal input of 1600°MW_{th}. They account for 327 MW_{th} (Unit 1) and 383 MW_{th} (Unit 2), respectively. The gross electric power output of K1 is 112°MW_{el} with an additional gross heat power output of 200 MW_{th}. The gross electric power output of K2 is 135°MW_{el} with an additional gross heat power output of 253 MW_{th}.

Table 125 shows values for the fuel energy input and energy output in the reference year 2010. Five years have been taken into account for the rolling average value.

Table 125: General operating data for reference no. 146

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	5.12E+06	5.38E+06
Gross electric energy output	MWh_{el}	9.25E+05	9.74E+05
Net electric energy output	MWh_{el}	8.12E+05	8.60E+05
Gross heat output – steam	MWh_{th}	3.72E+06	3.91E+06
Net heat output – steam	MWh_{th}	3.29E+06	3.37E+06
Total operating time under normal operating conditions	h	8696.0	8631.0
Equivalent full load operating factor	%	83.0	88.0

In the reference year, the plant was operated for almost 8700 h. The equivalent full load operating factor is 83 %. The net electrical utilisation ratio is 15.8 %. With a thermal utilisation ratio of 64.2 % the fuel utilisation factor is 80 %. For the rolling average value a net electrical utilisation ratio of 16 % can be calculated as well as a thermal utilisation ratio of 62.7 %, which lead to a fuel utilisation factor of 78.7 %. The total operating time for the rolling average value is about 8600 h with an equivalent full load operating factor of 88 %.

Environmental aspects

The plant produces typical air and water emissions for hard coal-fired power plant and corresponding amounts of solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x and CO are continuously measured in the flue gas. In addition to this, other pollutant emissions are periodically measured. There are primary and secondary measures taken for emission abatement.

The first stage of the FGT process is the dust-removal in the ESP. SO_x is removed in the wet FGD. After re-heating NO_x is reduced by NH_3 in the SCR unit. The treated flue gas is then emitted.

Table 126 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are not validated and do include OTNOCs. The reference oxygen content is 6 %.

Table 126: Air emissions for reference no. 146

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority d**
Dust	mg/Nm³	-	-	11.0754	-	-	-	HA	Cont.	No	20 (150 for OTNOCs)
	kg/year	3.5E+04									
SOx	mg/Nm³	-	-	107.659	-	-	-	HA	Cont.	No	180
	kg/year	4.2E+05									
NOx	mg/Nm³	-	-	178.199	-	-	-	HA	Cont.	No	205
	kg/year	1.3E+06									
CO	mg/Nm³	-	-	15.6111	-	-	-	HA	Cont.	No	155
	kg/year	5.4E+04									
HCl	mg/Nm³	-	-	0.6	-	-	-	HA	Perio.	No	20
	kg/year	2049									
HF	mg/Nm³	-	-	0.15	-	-	-	HA	Perio.	No	1
	kg/year	489									
Hg	mg/Nm³	-	-	0.0043	-	-	-	HA	Perio.	No	0.03
	kg/year	14.533									
NH3	mg/Nm³	-	-	-	-	-	-	-	Perio.	No	-
	kg/year	2.7E+05									
TOC	mg/Nm³	-	-	4.5	-	-	-	HA	Perio.	No	10
	kg/year	15601									
Cd	mg/Nm³	-	-	0.0033	-	-	-	HA	Perio.	No	-
	kg/year	10.754									
Ti	mg/Nm³	-	-	0.0033	-	-	-	HA	Perio.	No	-
	kg/year	10.754									
Cd+Tl	mg/Nm³	-	-	0.006	-	-	-	HA	Perio.	No	0.05
	kg/year	21.5									

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority
Sb	mg/Nm³	-	-	0.0033	-	-	-	HA	Perio.	No	-
	kg/year	10.754									
As	mg/Nm³	-	-	0.0043	-	-	-	HA	Perio.	No	-
	kg/year	13.704									
Pb	mg/Nm³	-	-	0.0044	-	-	-	HA	Perio.	No	-
	kg/year	14.445									
Cr	mg/Nm³	-	-	0.0053	-	-	-	HA	Perio.	No	-
	kg/year	16.801									
Co	mg/Nm³	-	-	0.0033	-	-	-	HA	Perio.	No	-
	kg/year	10.754									
Cu	mg/Nm³	-	-	0.0063	-	-	-	HA	Perio.	No	-
	kg/year	-									
Mn	mg/Nm³	-	-	0.0307	-	-	-	HA	Perio.	No	-
	kg/year	114.639									
Ni	mg/Nm³	-	-	0.0037	-	-	-	HA	Perio.	No	-
	kg/year	11.728									
V	mg/Nm³	-	-	0.006	-	-	-	HA	Perio.	No	-
	kg/year	19.562									
Other *	mg/Nm³	-	-	0.0673	-	-	-	HA	Perio.	No	0.5
	kg/year	245									
Sn	mg/Nm³	-	-	0.0033	-	-	-	-	Perio.	-	-
	kg/year	10.754									
PCDD / PCDF	ng/Nm³	-	-	0.0045	-	-	-	-	Perio.	-	0.1
	kg/year	1.4E-05									

*: Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V

**: Emission limit values for periodically measured values refer to the associated sampling time

Most of the waste water is treated in a treatment facility of a nearby chemical plant. The waste water from the FGD is pre-treated on site before being discharged. The water emissions are shown in Table 127, Table 128 and Table 129.

Table 127: Water emissions for reference no. 146 - Unit 1

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	7.3E+05	-	-	-	-	-	-
TOC	(mg/l)	-	8.74	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Cl^-	(mg/l)	-	150	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Hg	(mg/l)	-	0	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Cd	(mg/l)	-	0	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Pb	(mg/l)	-	0	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Cu	(mg/l)	-	0.037	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Zn	(mg/l)	-	0	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Ni	(mg/l)	-	0.058	-	HA	Composite sample	-	-	-
	(kg/year)			-					
AOX	(mg/l)	-	0.015	-	HA	Composite sample	-	-	-
	(kg/year)			-					

Table 128: Water emissions for reference no. 146 - Unit 2

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	6.3E+05	-	-	-	-	-	-
TOC	(mg/l)	-	5.3	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Cl^-	(mg/l)	-	200	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Hg	(mg/l)	-	0.0041	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Cd	(mg/l)	-	0.0001	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Pb	(mg/l)	-	0.01	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Cu	(mg/l)	-	0.017	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Zn	(mg/l)	-	0.046	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Ni	(mg/l)	-	0	-	HA	Composite sample	-	-	-
	(kg/year)			-					
AOX	(mg/l)	-	0.0047	-	HA	Composite sample	-	-	-
	(kg/year)			-					
F^-	(mg/l)	-	0	-	HA	Composite sample	-	-	-
	(kg/year)			-					
N (total)	(mg/l)	-	11	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Cr	(mg/l)	-	0	-	-	Composite sample	-	-	-
	(kg/year)			-					

Table 129: Water emissions for reference no. 146 - pre-treated waste water from FGD

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	3.1E+04	-	-	-	-	-	-
TOC	(mg/l)	-	11.33	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Cl^-	(mg/l)	-	1.1E+04	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Hg	(mg/l)	-	0.0039	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Cd	(mg/l)	-	0.0117	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Pb	(mg/l)	-	0	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Cu	(mg/l)	-	0.015	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Zn	(mg/l)	-	0	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Ni	(mg/l)	-	0.01	-	HA	Composite sample	-	-	-
	(kg/year)			-					
AOX	(mg/l)	-	0.006	-	HA	Composite sample	-	-	-
	(kg/year)			-					
F^-	(mg/l)	-	0	-	HA	Composite sample	-	-	-
	(kg/year)			-					
N (total)	(mg/l)	-	11.58	-	HA	Composite sample	-	-	-
	(kg/year)			-					
Cr	(mg/l)	-	0.012	-	HA	Composite sample	-	-	-
	(kg/year)			-					

Table 130 shows the solid residues (by-products). Boiler slag makes up the largest part of by-products. The by-products can be utilised in the construction material industry.

Table 130: Solid residues for reference no. 146

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Boiler slag	Combustion process	-	9.6E+04	Utilisation - others	-
Gypsum	Flue-gas treatment facilities	-	2.9E+04	Utilisation - Construction industry	-
Sludge	WWT facilities	-	528	-	-

Special characteristics

By the combination of chemical production and steam/power generation, the overall energy efficiency can be improved. The liquid and gaseous residues from the chemical production can be combusted in the plant. Modified burners are installed for the different fuels. The WWT is done in a central facility. This configuration is suggested as BAT by the operator.

Slag-tap Boiler, Reference no. 138

Reference no. 138 is a slag-tap boiler for the generation of electricity and hot water for district heating. It was commissioned in 1963 and modernised in 2002 and 2007. The main fuel is pulverised hard coal with moderate amounts of volatile matter. In addition to this, coke oven gas can be combusted. The slag is removed in molten state. The plant consists of a once-through boiler (with forced circulation at low loads), which feeds an extraction/condensation steam turbine. The live steam parameters are 190 bar and 530 °C, the reheater steam parameters are 28.4 bar and 530 °C. Steam can be extracted from the turbine to provide heat for district heating. The condenser cooling system uses three open mechanical draught cooling towers.

The plant is located at a combustion site with a total rated thermal input of 2083 MW_{th}. Combustion installation no. 139 is also located at this site. The total rated thermal input for reference no. 138 is 805 MW_{th}, the gross electric power output is 310 MW_{el} and the thermal power output (hot water) is 130 MW_{th}.

Table 131 shows values for the fuel energy input and energy output in the reference year 2010. Five years (2006 – 2010) have been taken into account for the rolling average value.

Table 131: General operating data for reference no. 138

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	2.73E+06	2.94E+06
Gross electric energy output	MWh_{el}	9.67E+05	1.05E+06
Net electric energy output	MWh_{el}	8.69E+05	9.47E+05
Net heat output – hot water	MWh_{th}	1.28E+05	77281.0
Total operating time under normal operating conditions	h	5225.0	5138.0
Equivalent full load operating factor	%	65	71.0

In the reference year, the plant was operated for about 5200 h with an equivalent full load operating factor of 65 %. The net electrical utilisation ratio is 38.2 %. With a thermal utilisation ratio of 4.7 % the fuel utilisation factor is 42.9 %. With the rolling average values a net electrical utilisation ratio of 32.2 % can be calculated as well as a thermal utilisation ratio of 2.6 %, which lead to a fuel utilisation factor of 34.8 %. The total operating time for the rolling average value is about 5100 h with an equivalent full load operating factor of 71 %.

Environmental aspects

The plant produces typical air and water emissions for hard coal-fired power plants as well as corresponding solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x, CO and Hg are continuously measured in the flue gas. There are primary and secondary measures taken for emission abatement. Primary measures are air staging as well as low-NO_x-burners. Figure 31 shows a schematic diagram of the FGT process (secondary measures).

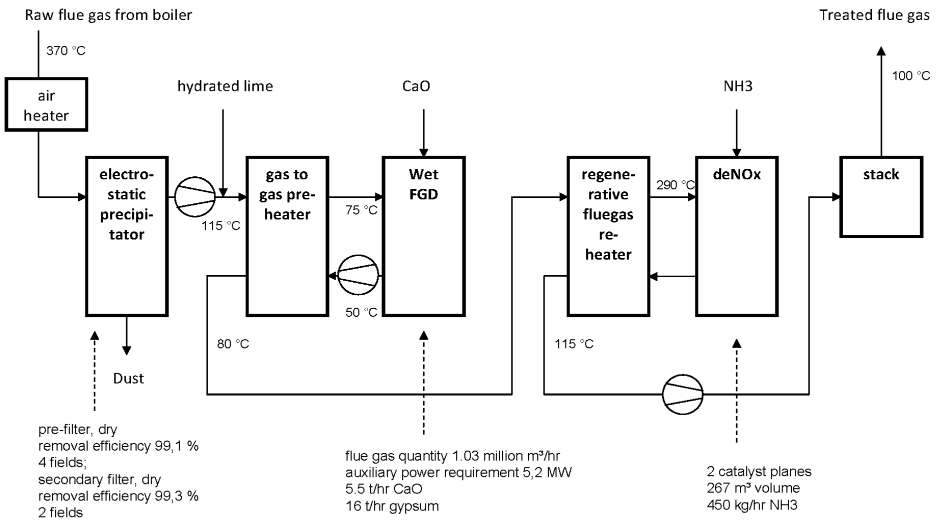

Figure 31: Schematic diagram of the FGT process for reference no. 138

The first stages of the FGT process are the cooling of the air in the air-heater and the removal of fly ash and dust in the ESP. The separation efficiency is improved by the addition of SO_3 prior to the ESP. Hydrated lime is then added to the flue gas, before it is cooled in a gas to gas heater. Subsequently, SO_x is removed in the wet FGD, where it reacts with CaO. After the FGD, the flue gas is reheated in the regenerative gas to gas heater. NO_x is reduced in a SCR unit, using NH_3. Again, the flue gas is first cooled and then reheated after the SCR. The flue gas is then emitted via a stack.

Table 132 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do not include OTNOCs. The reference oxygen content is 6 %.

Table 132: Air emissions for reference no. 138

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm³	0	0	2.61	7.1	8	10	HHV	Cont.	Yes	100	50
	kg/year	8917										
SO_x	mg/Nm³	0	51.3	132.9	225.7	240	342	HHV	Cont.	Yes	800	400
	kg/year	5.2 E+05										
SO_x re-moval	(%)	80.8	88.1	91.98	95.43	95.95	99.47	HHV	Cont.	No	85	-
NO_x	mg/Nm³	0.19	58.8	141.6	179.8	182.4	202.4	HHV	Cont.	Yes	400	200
	kg/year	5.9E+05										
CO	mg/Nm³	0	0	2.3	20.9	28.3	49.4	HHV	Cont.	Yes	500	250
	kg/year	7281.93										
Hg	mg/Nm³	0	0	0.0036	0.0086	0.0092	0.019	HHV	Cont.	Yes	0.05	0.03
	kg/year	-										

Figure 32 shows a schematic diagram of the WWT process. Taking account of the legal and regulatory provisions, the waste water from the cooling system is discharged directly into a river. Another waste water stream originates from the FGD, in which pre-treated river water is used. The waste water is then cleaned in the WWT (WWT) facility, before it is discharged into the river. The water emissions for the occurring waste water streams are shown in Table 133 and Table 134.

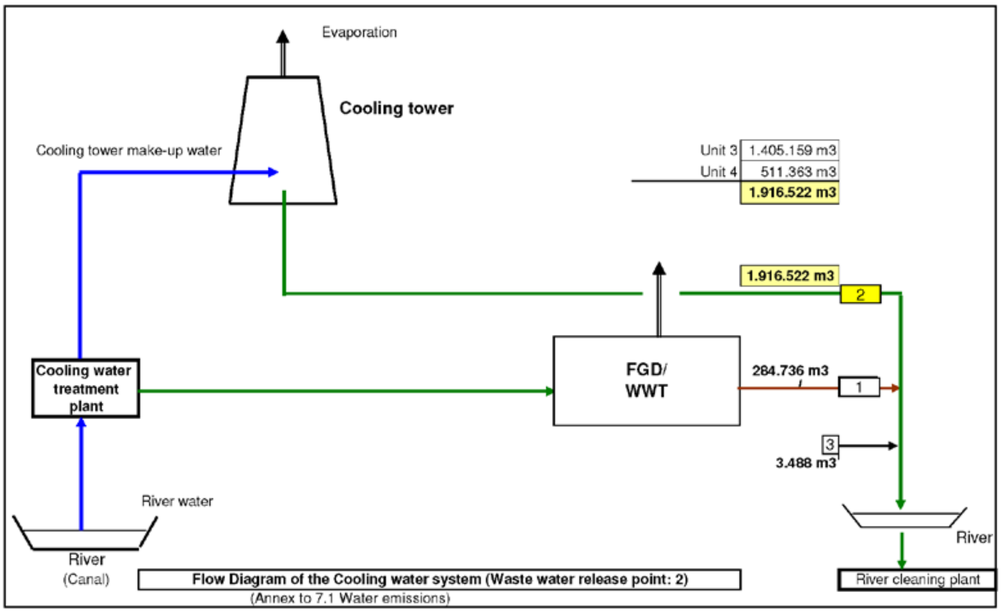

Figure 32: Schematic diagram of the WWT process for reference no. 138

Table 133: Water emissions for reference no. 138 - after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	29	31	33	-	-	-	-	-
Temp	(°C)	17.6	23.1	29.7	-	-	-	-	-
pH		6.5	8	8.6	-	-	-	-	-
TSS	(mg/l)	2	6	22	HA	Grab sample	-	16	30
	(kg/year)			610					
F^-	(mg/l)	5	9.6	22	HA	Grab sample	-	16	30
	(kg/year)			976					
S^{2-}	(mg/l)	-	-	-	-	Grab sample	-	16	0.2
	(kg/year)			-					
SO_3^{2-}	(mg/l)	-	-	-	-	Grab sample	-	16	20
	(kg/year)			-					
SO_4^{2-}	(mg/l)	1080	1219	1370	HA	Grab sample	-	16	2000
	(kg/year)			1.2E+05					
Cd	(mg/l)	0.00025	0.0004	0.0021	HA	Grab sample	-	16	0.05
	(kg/year)			0.04					
Hg	(mg/l)	0.0011	0.0044	0.0095	HA	Grab sample	-	16	0.03
	(kg/year)			0.45					
Pb	(mg/l)	-	-	-	HA	Grab sample	-	16	0.1
	(kg/year)			-					
Cr	(mg/l)	0.0025	0.014	0.028	HA	Grab sample	-	16	0.5
	(kg/year)			1.42					
Cu	(mg/l)	0.0025	0.003	0.006	HA	Grab	-	16	0.5

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
	(kg/year)			0.30		sample			
Ni	(mg/l)	0.0025	0.0063	0.015	HA	Grab sample	-	16	0.5
	(kg/year)			0.64					
Zn	(mg/l)	0.0025	0.02	0.14	HA	Grab sample	-	16	1
	(kg/year)			2.03					

Table 134: Water emissions for reference no. 138 - non-treated waste water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	29	31	33	-	-	-	-	225 m^3/ 0.5 h
Temp.	(°C)	17.6	23.1	29.7	-	-	-	-	30° C; in exceptional case 35° (max.)
pH		6.5	8	8.6	-	-	-	-	6.5 to 9.5
AOX	(mg/l)	0.012	0.023	0.038	HA	Grab sample	-	6	limit value 0.15 mg/l only after impact proportioning with microbicidal active substances
	(kg/year)			12					

Table 135 shows the solid residues (by-products). The biggest amount of solid residues is made up of boiler slag, which can be utilised as blasting grid. Fly ash can be recirculated into the boiler, where it is incorporated into the boiler slag, or can be utilised in the construction material industry. The gypsum can also be reused (e.g. in the plaster board industry).

Table 135: Solid residues for reference no. 138

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Fly ash	Combustion process	-	335	Utilisation - others	construction material, landfill
Boiler slag	Combustion process	-	5.3E+04	Utilisation - others	blasting grid
Gypsum	Flue-gas treatment facilities	-	1.7E+04	Utilisation - Construction industry	gypsum industry, e. g. plaster boards

Special characteristics

The plant was extensively modernised in the past. Among other things, a new start-up steam generator was installed as well as a new reverse osmosis unit. Also, the heat exchanger for the district heating was renewed.

The replacement of hp-turbine-rotor, hp-inner case and all hp-blades with up to date technology is suggested as BAT by the operator. By this, the net electrical efficiency of the plant was increased by 0.8 %-points. Thus, the operating costs are reduced and the life-time of the turbine is extended.

The dust removal in the ESP, which is enhanced by the conditioning of the flue gas with SO_3, is also suggested as BAT by the operator.

Pulverised Coal Firing, Reference no. 124

Reference no. 124 consists of two power units of different size, which are located at the same combustion site. While power unit F is only used for the generation of electricity, unit B produces heat and electricity. Unit B was commissioned in 1968, unit F in 1985. The feed-water pump of unit F was modernised in 2008. Both units are fired with pulverised hard coal with moderate amounts of volatile matter. In addition to this, heavy crude oil, pellets from a neighbouring chemical plant, petroleum coke and propane (for start-up) can be incinerated in small amounts. The boilers of both units are once-through boilers, which feed a single steam turbine each. The live steam parameters for unit B are 212 bar and 537 °C, the reheater steam parameters are 60 bar and 535 °C. For unit F, the live steam parameters are 230 bar, 538 °C. The cooling system uses a natural draught cooling tower. Make up water is taken from a lake or well. Figure 33 shows a sketch of the plant layout.

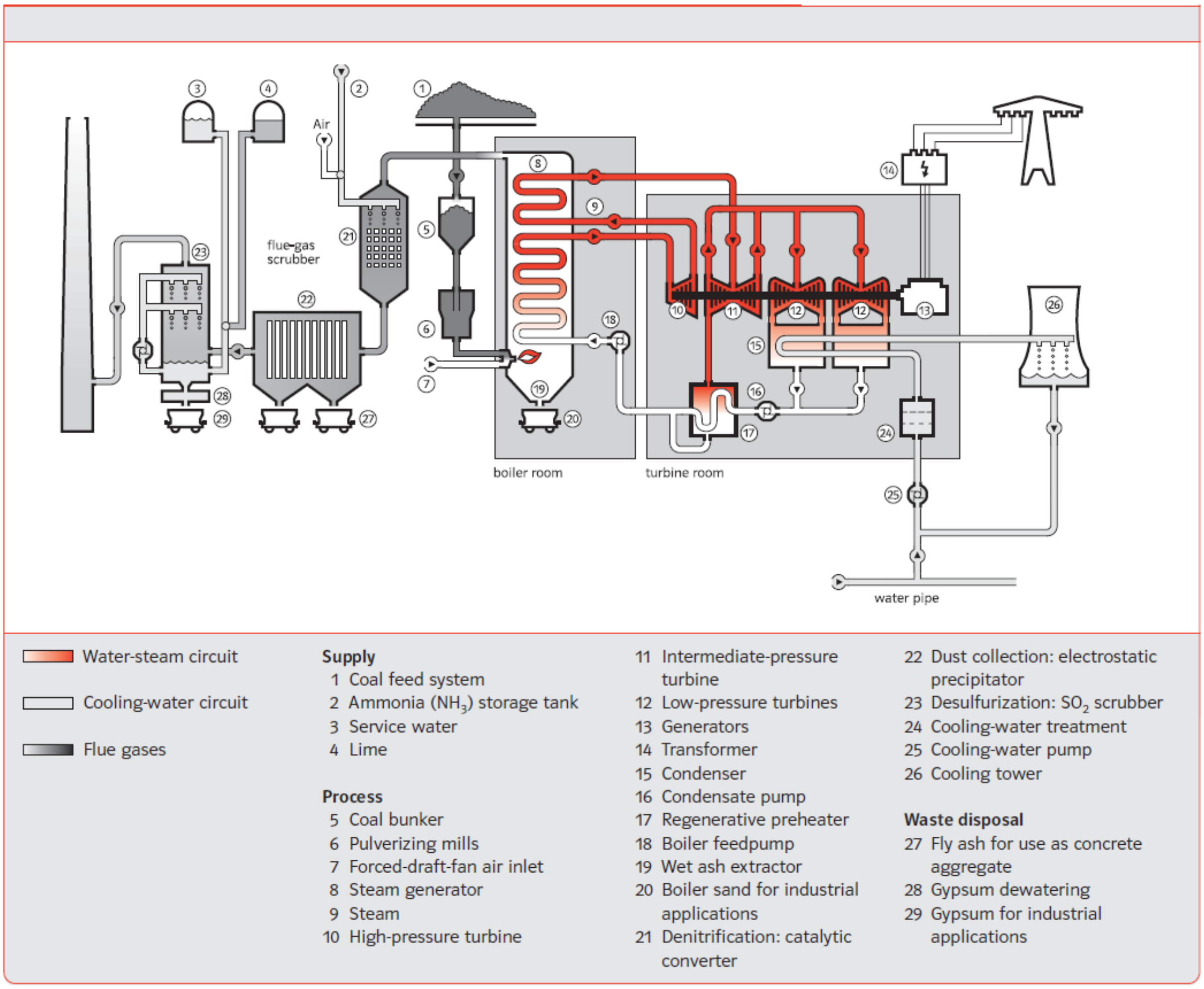

Figure 33: Sketch of the design of reference no. 124

The two units are part of a plant site with a total rated thermal input of 6337 MW_{th}. They account for 990 MW_{th} (unit B) and 1860 MW_{th} (unit F). The gross electric power output of unit B is 370 MW_{el} with an additional gross heat power output of 160 MW_{th}. The gross electric power output of unit F is 740 MW_{el}, with a nominal gross electrical efficiency of 39.8%.

Table 136 and Table 137 show values for the fuel energy input and energy output in the reference year 2010 for the two units.

Table 136: General operating data for reference no. 124 – Unit B

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	5.15E+06	-
Gross electric energy output	MWh_{el}	1.77E+06	-
Net electric energy output	MWh_{el}	1.67E+06	-
Gross heat output – steam	MWh_{th}	3.21E+05	-
Net heat output – steam	MWh_{th}	3.21E+05	-
Gross heat output – hot water	MWh_{th}	4.91E+05	-
Net heat output – hot water	MWh_{th}	4.91E+05	-
Total operating time under normal operating conditions	h	6463.0	-
Equivalent full load operating factor	%	80	-

Table 137: General operating data for reference no. 124 – Unit F

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	6.29E+06	-
Gross electric energy output	MWh_{el}	2.39E+06	-
Net electric energy output	MWh_{el}	2.24E+06	-
Total operating time under normal operating conditions	h	4346	-
Equivalent full load operating factor	%	78	-

While unit B was operated for almost 6500 h in the reference year, unit F was operated for more than 4300 h. The equivalent full load operating factor is about 80 % in both cases. The net electrical utilisation ratio for unit B is 32.4 %, the thermal utilisation ratio is 15.7 % and thus the fuel utilisation factor adds up to 48.1 %. For unit F the fuel utilisation factor is 35.6 %.

Environmental aspects

The plant produces typical air and water emissions for hard coal-fired power plant and corresponding amounts of solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x and CO are continuously measured in the flue gas. In addition to this, other pollutant emissions are periodically measured. There are primary and secondary measures taken for emission abatement. Primary measures are air grading as well as low-NO_x-burners. Figure 34 shows a schematic diagram of the FGT process (secondary measures), which is identical for both plants.

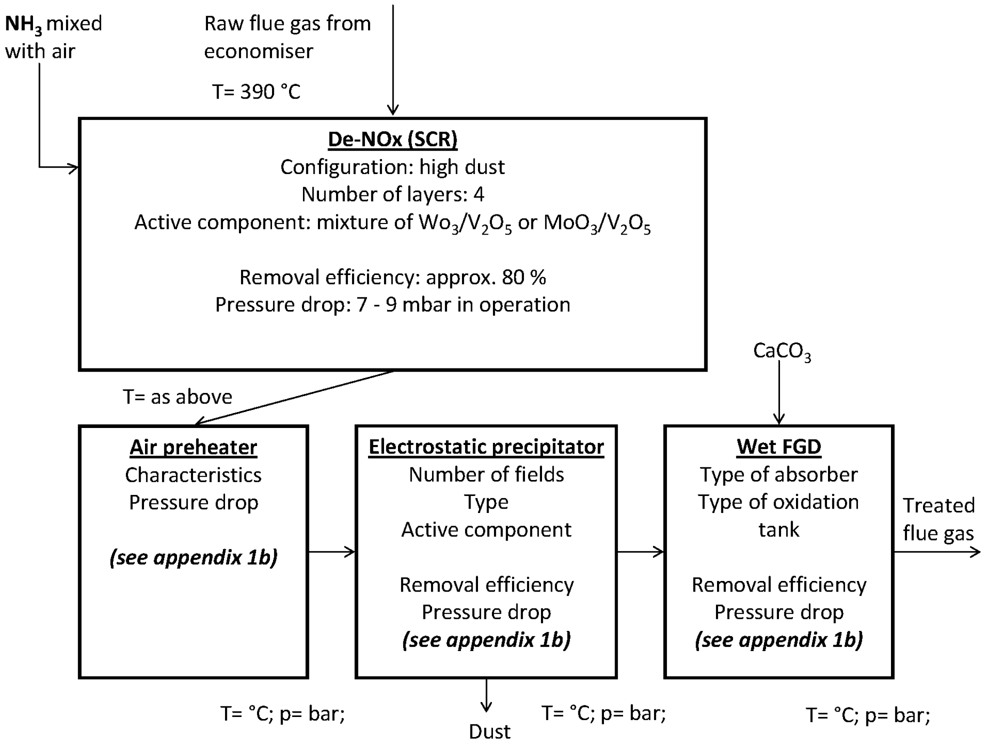

Figure 34: Schematic diagram of the FGT process for reference no. 124

The first stage of the FGT process is the SCR unit, in which NO_x is reduced by NH_3. The flue gas is then cooled (air heater), before dust is removed in the ESP. SO_x is removed in the wet FGD, where it reacts with $CaCO_3$ to form gypsum. The treated flue gas is emitted via a stack.

Table 138 and Table 139 show the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do include OTNOCs. The reference oxygen content is 6 %.

Table 138: Air emissions for reference no. 124 – Unit B

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority 1/2 h	Emission limit values prescribed by competent authority d
Dust	mg/Nm^3	0	6.59	8.28	11.1	12.04	26.27	HHV	Cont.	Yes	40	20
	kg/year						6.5E+04					
SO_x	mg/Nm^3	0	2.22	36.31	70.03	80.12	1619.8	HHV	Cont.	Yes	400	200
	kg/year						7E+05					
SO_x removal	(%)	0	96.36	97.89	99.91	100	100	HHV	Cont.	Yes	85	-
NO_x	mg/Nm^3	0	185.18	201.51	205.36	211.89	874.41	HHV	Cont.	Yes	400	200
	kg/year						1.3E+06					
CO	mg/Nm^3	0	0	8.44	19.44	21.76	90.61	HHV	Cont.	Yes	400	200
	kg/year						2.9E+04					
HCl	mg/Nm^3	-	-	0.5	-	-	0.7	HA	Perio.	Yes	60	10
	kg/year						-					
HF	mg/Nm^3	-	-	0.74	-	-	0.95	HA	Perio.	Yes	4	1
	kg/year						-					
Hg	mg/Nm^3	-	-	0.0039	-	-	0.0063	HA	Perio.	Yes	0.3	0.5
	kg/year						-					
Other *	mg/Nm^3	-		0.0047	-	-	0.0072	HA	Perio.	Yes	0.5	-
	kg/year						-					
PCDD/PCDF	ng/Nm^3	-	-	0.0002	-	-	0.0003	HA	Perio.	Yes	0.08	-
	kg/year						-					

*: Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V

Table 139: Air emissions for reference no. 124 – Unit F

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	0	2.54	4.17	8.26	9.52	64.69	HHV	Cont.	Yes	40	20
	kg/year	1.3E+05										
SO_x	mg/Nm^3	0	118.68	286.79	1472.59	1590.95	2656.15	HHV	Cont.	Yes	400	200
	kg/year	1.3E+06										
SO_x removal	(%)	0	12.86	83.11	93.31	94.14	100	HHV	Cont.	Yes	85	-
NO_x	mg/Nm^3	0	170.26	214.37	493.17	649.47	957.74	HHV	Cont.	Yes	400	200
	kg/year	1.5E+06										
CO	mg/Nm^3	0	4.45	9.41	18.5	22.11	148.23	HHV	Cont.	Yes	400	200
	kg/year	8E+04										
HCl	mg/Nm^3	-	-	5.9	-	-	9.1	HA	Perio.	Yes	-	no limit
	kg/year	-										
HF	mg/Nm^3	-	-	2.1	-	-	2.46	HA	Perio.	Yes	-	-
	kg/year	-										
Hg	mg/Nm^3	-	-	0.0032	-	-	0.0039	HA	Perio.	Yes	0.03	0.05
	kg/year	-										
Cd+Tl	mg/Nm^3	-	-	0.0028	-	-	0.0032	HA	Perio.	Yes	0.05	-
	kg/year	-										
Other*	mg/Nm^3	-	-	0.0141	-	-	0.0182	HA	Perio.	Yes	0.5	-
	kg/year	-										
PCDD/PCDF	ng/Nm^3	-	-	0.0001	-	-	0.0015	HA	Perio.	Yes	0.08	-
	kg/year	-										

*: Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V

Figure 35 shows a schematic diagram of the WWT process. Taking account of the legal and regulatory provisions, some of the waste water is discharged directly into a river. The water emissions for the different waste water streams are shown in Table 140 andTable 141. It must be said, that there is one water treatment facility for the whole combustion site, so that other waste water streams are also included in the presented values.

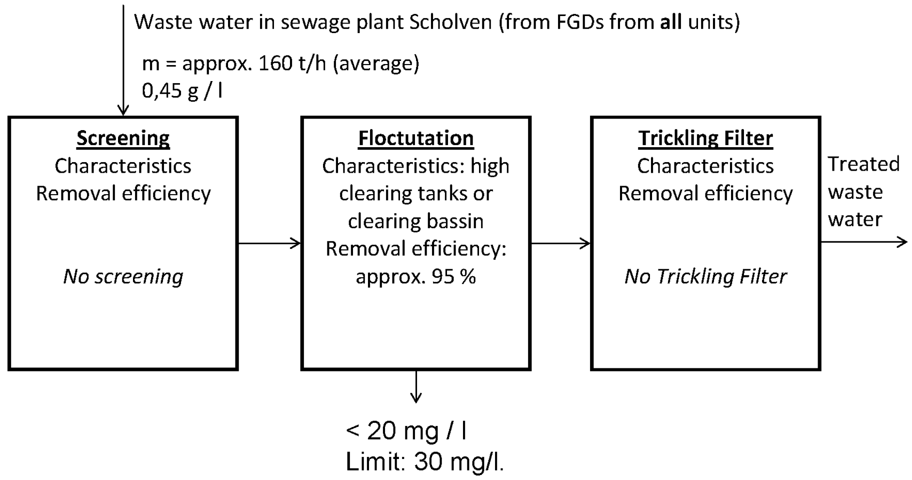

Figure 35: Schematic diagram of the WWT process for reference no. 124

Table 140: Water emissions for reference no. 124 - after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	2.8E+5	-	-	-	-	-	-
Temp.	(°C)	11	-	30	-	-	-	-	-
pH		8.6	-	9.1	-	-	-	-	-
TDS	(mg/l)	1	-	27	-	Grab sample	-	-	-
	(kg/year)			-					
COD	(mg/l)	26		53	-	Grab sample	-	-	-
	(kg/year)			-					
TOC	(mg/l)	12.6	-	24	-	Grab sample	-	-	-
	(kg/year)			-					
Cl^-	(mg/l)	2700	-	4200	-	Grab sample	-	-	-
	(kg/year)			-					
SO_4^{2-}	(mg/l)	1500	-	2200	-	Grab sample	-	-	-
	(kg/year)			-					
F^-	(mg/l)	6	-	24	-	Grab sample	-	-	-
	(kg/year)			-					
S^{2-}	(mg/l)	0.05	-	0.05	-	Grab sample	-	-	0.2
	(kg/year)			-					
NO_2^-/NO_3^-	(mg/l)	39.06	-	75.37	-	Grab sample	-	-	-
	(kg/year)			-					
Cd	(mg/l)	0.005		0.005	-	Grab sample	-	-	0.05
	(kg/year)								
P (total)	(mg/l)	0.05	-	0.05	-	Grab sample	-	-	-
	(kg/year)			-					
Pb	(mg/l)	0.02	-	0.02	-	Grab	-	-	0.1

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
	(kg/year)			-		sample			
Cr	(mg/l)	0.013	-	0.04	-	Grab sample	-	-	0.5
	(kg/year)			-					
Cu	(mg/l)	0.01	-	0.017	-	Grab sample	-	-	0.5
	(kg/year)			-					
Zn	(mg/l)	0.01	-	0.024	-	Grab sample	-	-	1
	(kg/year)			-					
Ni	(mg/l)	0.01	-	0.027	-	Grab sample	-	-	0.5
	(kg/year)			-					
Hg	(mg/l)	0.001	-	0.002	-	Grab sample	-	-	0.03
	(kg/year)			-					
AOX	(mg/l)	0.07	-	0.64	-	Composite sample	-	-	-
	(kg/year)			-					

Table 141: Water emissions for reference no. 124 - non-treated waste water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	1.3E+5	-	-	-	-	-	-
Temp.	(°C)	14.1	-	22.7	-	-	-	-	< 30
pH		8.1	-	8.5	-	-	-	-	7.5 to 9
TDS	(mg/l)	1	-	44	-	Grab sample	-	12	50
	(kg/year)	-							
COD	(mg/l)	15	-	26	-	Grab sample	-	12	50
	(kg/year)	-							
TOC	(mg/l)	5.1	-	9.7	-	Grab sample	-	12	20
	(kg/year)	-							
Cl^-	(mg/l)	83	-	229	-	Grab sample	-	12	600
	(kg/year)	-							
SO_4^{2-}	(mg/l)	150	-	466	-	Grab sample	-	12	1000
	(kg/year)	-							
NH_3-N	(mg/l)	1	-	1	-	Grab sample	-	12	-
	(kg/year)	-							
NO_2^- /NO_3^-	(mg/l)	4.71	-	12.75	-	Grab sample	-	12	20
	(kg/year)	-							
P (total)	(mg/l)	0.08	-	0.4	-	Grab sample	-	12	0.6
	(kg/year)	-							
Cd	(mg/l)	0.002	-	0.002	-	Grab sample	-	12	0.002
	(kg/year)	-							
Hg	(mg/l)	0.001	-	0.001	-	Grab sample	-	12	-
	(kg/year)	-							

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
As	(mg/l)	0.002	-	0.003	-	Grab sample	-	12	0.1
	(kg/year)			-					
Pb	(mg/l)	0.02	-	0.02	-	Grab sample	-	12	0.04
	(kg/year)			-					
Cr	(mg/l)	0.01	-	0.01	-	Grab sample	-	12	0.04
	(kg/year)			-					
Cu	(mg/l)	0.012	-	0.059	-	Grab sample	-	12	0.08
	(kg/year)			-					
Ni	(mg/l)	0.01	-	0.01	-	Grab sample	-	12	-
	(kg/year)			-					
V	(mg/l)	0.01	-	0.012	-	Grab sample	-	-	4
	(kg/year)			-					
Zn	(mg/l)	0.015	-	0.27	-	Grab sample	-	12	1
	(kg/year)			-					
AOX	(mg/l)	0.03	-	0.07	-	Grab sample	-	12	0.08
	(kg/year)			-					

Table 142 and Table 143 show the solid residues (by-products). Due to the different sulphur content of the coals and other plant specific characteristics, the amount of gypsum makes up the largest part of by-products from unit B, while for unit F it is the fly ash.

The residues can be utilised in the concrete- and road construction industry. The gypsum from the wet FGD is processed in a nearby plasterboard facility.

Table 142: Solid residues for reference no. 124 – Unit B

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Fly ash (minimum analytic figures)	Flue-gas treatment facilities	-	3.4E+04	-	concrete additive, cement substitution
Bottom ash (minimum analytic figures)	Combustion process	-	1.5E+04	-	concrete blocks, road construction, filling application
Gypsum (minimum analytic figures)	Flue-gas treatment facilities	-	6.3E+04	-	plaster board, projection plaster

Table 143: Solid residues for reference no. 124 –Unit F

Description	Source	Code	Generation during reference year	Final destination	For utilisation, specify the activity the material is used in
Fly ash (minimum analytic figures)	Flue-gas treatment facilities	-	9.8E+04	-	concrete additive, cement substitution
Bottom ash (minimum analytic figures)	Combustion process	-	1.1E+04	-	concrete blocks, road construction, filling application
Gypsum (minimum analytic figures)	Flue-gas treatment facilities	-	3E+04	-	plaster board, projection plaster

Special characteristics

In both units, the feed-water pump is driven by a separate steam turbine. This leads to an increase in the efficiency of the plant, especially at high loads. Plant B serves as a CHP plant, which results in a higher fuel efficiency. Both technologies are suggested as BAT by the operator.

Pulverised Coal Firing, Reference no. 139

Reference no. 139 is a pulverised coal-fired power plant for the generation of electricity and hot water for district heating. It was commissioned in 1989 and modernised between 2010 and 2013. The main fuel is hard coal with high amounts of volatile matter. In addition to this, coke oven gas can be combusted. The plant consists of a once-through boiler (with forced circulation at low loads), which feeds an extraction/condensation turbine. The live steam parameters are 264 bar and 535 °C, the reheater steam parameters are 65.4 bar and 541 °C. Steam can be extracted from the turbine to provide heat for district heating. The cooling system uses a natural draught cooling tower.

The plant is located at a combustion site with a total rated thermal input of 2083 MW_{th}. Combustion installation no. 138 is also located at this site. The total rated thermal input for reference no. 139 is 1278 MW_{th}, the gross electric power output is 500 MW_{el} and the thermal power output (hot water) is 550 MW_{th}.

Table 144 shows values for the fuel energy input and energy output in the reference year 2010. Five years have been taken into account for the rolling average values.

Table 144: General operating data for reference no. 139

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	4.92E+06	5.77E+06
Gross electric energy output	MWh_{el}	1.83E+06	2.22E+06
Net electric energy output	MWh_{el}	1.62E+06	1.97E+06
Net heat output – hot water	MWh_{th}	8.25E+05	735602.0
Total operating time under normal operating conditions	h	6189	6537
Equivalent full load operating factor	%	62	69.0

In the reference year, the plant was operated for about 6200 h with an equivalent full load operating factor of 62 %. The net electrical utilisation ratio is 32.9 %. With a thermal utilisation ratio of 16.7 % the fuel utilisation factor is 49.6 %. With the rolling average values a net electrical utilisation ratio of 34.1 % can be calculated as well as a thermal utilisation ratio of 12.7 %, which lead to a fuel utilisation factor of 46.8 %. The total operating time for the rolling average value is about 6500 h with an equivalent full load operating factor of 69 %.

Environmental aspects

The plant produces typical air and water emissions for hard coal-fired power plants as well as corresponding solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x, CO and Hg are continuously measured in the flue gas. There are primary and secondary measures taken for emission abatement. Primary measures are air staging as well as low-NO_x-burners. Figure 36 shows a schematic diagram of the FGT process (secondary measures).

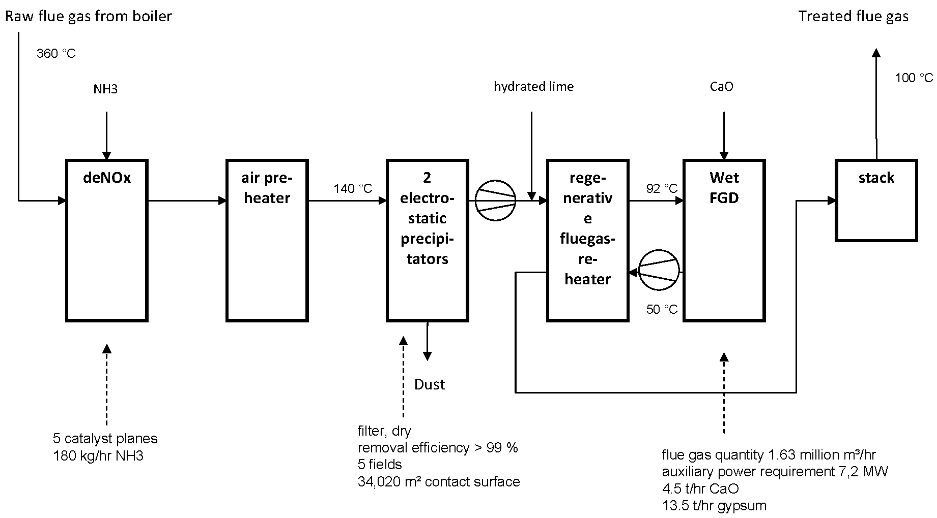

Figure 36: Schematic diagram of the FGT process for reference no. 139

The first stage of the FGT process is the SCR unit, in which NO_x is reduced by NH_3. The flue gas is then cooled (air heater), before dust is removed in the ESP. SO_x is removed in the wet FGD, where it reacts with lime to form gypsum. The treated flue gas is reheated and emitted via a stack.

Table 145 shows the concentration and the annual load for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that most of the presented values are validated and do not include OTNOCs. The reference oxygen content is 6 %.

Table 145: Air emissions for reference no. 139

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm³	0	0	1.34	4.05	4.45	9.4	HHV	Cont.	Yes	60	20
	kg/year	8475										
SO_x	mg/Nm³	23.2	64.3	122.39	203	215.76	287.7	HHV	Cont.	Yes	600	300
	kg/year	8.3E+05										
SO_x removal	(%)	0	89.7	93.27	95.77	95.97	97.91	HHV	Cont.	No	85	-
NO_x	mg/Nm³	0	167	183.85	197.86	200.93	244.5	HHV	Cont.	Yes	400	200
	kg/year	1.2E+06										
CO	mg/Nm³	0	0	0.22	0	0	47.45	HHV	Cont.	Yes	500	250
	kg/year	1281.83										
Hg	mg/Nm³	0	0	0.0043	0.0088	0.0102	0.036	HHV	Cont.	Yes	0.05	0.03
	kg/year	25										

Figure 37 shows a schematic diagram of the WWT process. Taking account of the legal and regulatory provisions, the waste water from the cooling system is discharged directly into a river. Another waste water stream originates from the FGD, in which pre-treated river water is used. The waste water is then cleaned in the WWT (WWT) facility, before it is discharged into the river. The water emissions for the occurring waste water streams are shown in Table 146 and Table 147.

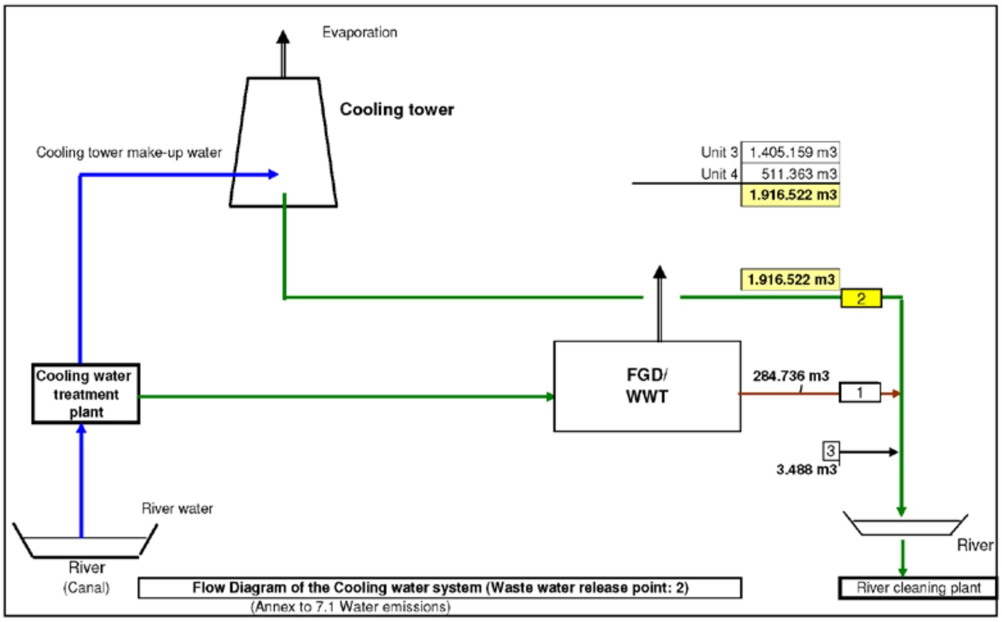

Figure 37: Schematic diagram of the WWT process for reference no. 139

Table 146: Water emissions for reference no. 139 - after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	51	55	60	-	-	-	-	63.65 m^3/0.5 h
Temp.	(°C)	17.6	23.1	29.7	-	-	-	-	30° C; in exceptional case 35° (max)
pH		6.5	8	8.6	-	-	-	-	6.5 to 9.5
TSS	(mg/l)	2	6	22	HA	Grab sample	-	16	30
	(kg/year)	1099							
F^-	(mg/l)	5	9.6	22	HA	Grab sample	-	16	30
	(kg/year)	1758							

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
S^{2-}	(mg/l)	-	-	-	-	Grab sample	-	16	0.2
	(kg/year)			-					
SO_3^{2-}	(mg/l)	-	-	-	-	Grab sample	-	16	20
	(kg/year)			-					
SO_4^{2-}	(mg/l)	1080	1219	1370	HA	Grab sample	-	16	2000
	(kg/year)			2.2E+05					
Cd	(mg/l)	0.0003	0.0004	0.0021	HA	Grab sample	-	16	0.05
	(kg/year)			0.07					
Hg	(mg/l)	0.0011	0.0044	0.0095	HA	Grab sample	-	16	0.03
	(kg/year)			0.81					
Pb	(mg/l)	-	-	-	HA	Grab sample	-	16	0.1
	(kg/year)			-					
Cr	(mg/l)	0.0025	0.014	0.028	HA	Grab sample	-	16	0.5
	(kg/year)			2.56					
Cu	(mg/l)	0.0025	0.003	0.006	HA	Grab sample	-	16	0.5
	(kg/year)			0.55					
Ni	(mg/l)	0.0025	0.0063	0.015	HA	Grab sample	-	16	0.5
	(kg/year)			1.15					
Zn	(mg/l)	0.0025	0.02	0.14	HA	Grab sample	-	16	1
	(kg/year)			3.66					

Table 147: Water emissions for reference no. 139 - non-treated waste water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	70	143	180	-	-	-	-	100 m^3/0.5 h
Temp.	(°C)	25	31	36	-	-	-	-	-
pH		7.6	7.8	8	-	-	-	-	6.5 to 9.5
TSS	(mg/l)	41	48	58	HA	Grab sample	-	3	limit value 50 mg/l related to regeneration waste water from the demineralisation with ion exchanger
	(kg/year)			167					
AOX	(mg/l)	0.057	0.074	0.096	DV	Grab sample	-	3	limit value 0, 5 mg/l related to regeneration waste water from condensate polishing, limit value 1.0 mg/l from demineralisation
	(kg/year)			0.258					

Table 148 shows the solid residues (by-products). Fly ash, which can be utilised in the construction material industry, makes up the largest amount of solid residues. The produced gypsum is sold to the plaster board industry. Residual sludges from the cooling water make-up water treatment are used as fertiliser for agricultural purposes.

Table 148: Solid residues for reference no. 139

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Fly ash, dry	Combustion process	EN 450	7.4E+04	Utilisation - Construction industry	concrete and cement
Fly ash, wet	Combustion process	EN 450	3521	Temporary stockpile	finally: concrete and cement after drying
Fly ash	Combustion process		3047	Utilisation - others	construction material, landfill
Gypsum	Flue-gas treatment facilities		3.2E+04	Utilisation - Construction industry	gypsum industry, e. g. plaster boards
Bottom ash	Combustion process		1.5E+04	Utilisation - others	e. g. construction, bricks, underground
Cooling tower make-up water treatment sludge	Raw water treatment facilities		3494	Utilisation - others	fertiliser/agriculture
FGD WWT sludge	WWT facilities		2374		disposed as waste

Special characteristics

The plant was extensively modernised in the past. Among other things, new low-NO_x-burners have been installed. The hp-turbine-rotor was renewed, which led to a higher overall efficiency of the plant.

The dust removal in the ESP, which is enhanced by the conditioning of the flue gas with SO_3, is suggested as BAT by the operator.

Pulverised Coal Firing, Reference no. 123

Reference no. 123 is a pulverised coal-fired power plant for electricity generation, which was commissioned in 1992. The plant is located at a combustion site, whose total rated thermal input in the reference year was 5140 MW_{th}. The now installed total rated thermal input is smaller, as some combustion plants have been shut down recently. The main fuel is hard coal with moderate amounts of volatile matter. In addition to this, de-watered sewage sludge can be co-combusted. The boiler is a once-through boiler. The live steam parameters are 262 bar and 545 °C, the reheater steam parameters are 54 bar and 562 °C. The cooling system uses a natural draught cooling tower. Water losses are compensated for by additional river water. Furthermore, heat can be used for district heating. Figure 38 shows a sketch of the plant layout.

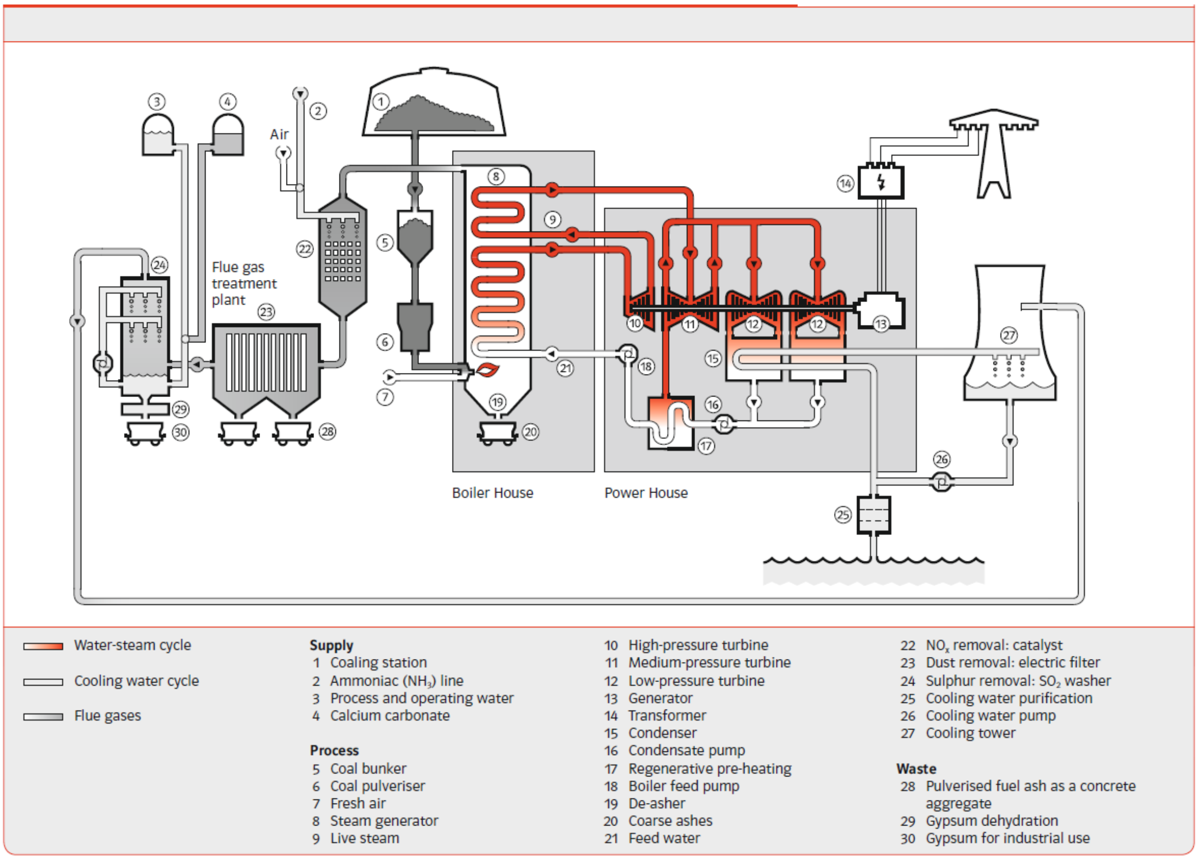

Figure 38: Sketch of the design of reference no. 123

The total rated thermal input of the plant is 1370 MW_{th}, the gross electric power output is 550 MW_{el}. In addition a maximal thermal power output of 300 MW_{th} can be produced.

Table 149 shows the energy input and output for the reference year as well as the total operating time under normal operating conditions. The reference year for the given values is 2010. Five years have been taken into account for the rolling average value.

Table 149: General operating data for reference no. 123

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	7.08E+06	7.25E+06
Gross electric energy output	MWh_{el}	2.95E+06	3.07E+06
Net electric energy output	MWh_{el}	2.72E+06	2.83E+06
Gross heat output – hot water	MWh_{th}	1.66E+05	1.45E+05
Net heat output – hot water	MWh_{th}	1.66E+05	1.45E+05
Total operating time under normal operating conditions	h	7034.2	-
Equivalent full load operating factor	%	74	-

In the reference year, the plant was operated for more than 7000 h. The equivalent full load operating factor is 74 %. The net electrical utilisation ratio is 38.4 %. With a thermal utilisation ratio of 2.4 % the fuel utilisation factor is 40.8 %. For the rolling average value a net electrical utilisation ratio of 39 % can be calculated as well as a thermal utilisation ratio of 2 %, which lead to a fuel utilisation factor of 41 %.

Environmental aspects

The plant produces typical air and water emissions for hard coal-fired power plants as well as corresponding solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x, CO, HCl, NH_3, TOC and Hg are continuously measured in the flue gas. In addition to this, other pollutant emissions are periodically measured. There are primary and secondary measures taken for emission abatement. Primary measures are air staging and low-NO_x-burners, which have been retrofitted in 2010. For the combustion of sewage sludge, separate burners are installed. Figure 39 shows a schematic diagram of the FGT facility (secondary measures).

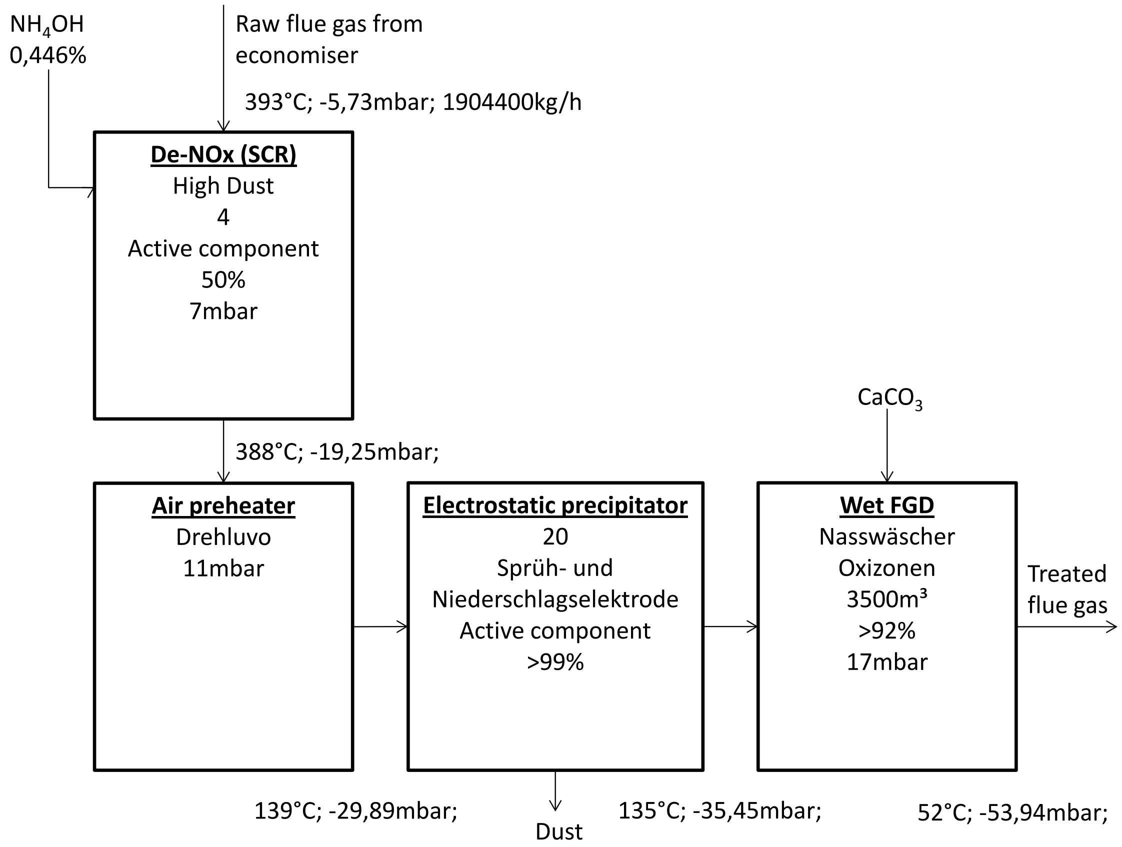

Figure 39: Schematic diagram of the FGT process for reference no. 123

The first stage of the FGT process is the SCR unit, in which NO_x is reduced by using NH_3. The flue gas is then cooled (air heater), before dust is removed in the ESP. SO_x is removed in the wet FGD, where it reacts with $CaCO_3$ to form gypsum. The treated flue gas is emitted via the cooling tower.

Table 150 shows the concentration and the annual load for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated, but do not include OTNOCs. The reference oxygen content is 6 %.

Table 150: Air emissions for reference no. 123

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	0.0135	0	2.62	10.52	12	21.25	HHV	Cont.	Yes	15	-
	kg/year	2.4E+04										
SO_x	mg/Nm^3	0.336	10.06	40.36	81.99	88	201.11	HHV	Cont.	Yes	178	-
	kg/year	3.6E+05										
NO_x	mg/Nm^3	36.2	162.14	175.59	189.3	191.97	405.62	HHV	Cont.	Yes	200	-
	kg/year	1.5E+06										
CO	mg/Nm^3	3.17	5.4	10.07	20.51	24.33	173.5	HHV	Cont.	Yes	178	-
	kg/year	8.7E+04										
HCl	mg/Nm^3	0.0865	0.18	0.55	0.82	0.86	4.28	HHV	Cont.	Yes	20	-
	kg/year	4501.58										
HF	mg/Nm^3	-	-	0.074	-	-	-	-	Perio.	Yes	1	-
	kg/year	617.866										
Hg	mg/Nm^3	0.0007	0.0006	0.0027	0.0051	0.0057	0.0331	HHV	Cont.	Yes	0.03	-
	kg/year	22.12										
NH_3	mg/Nm^3	0.087	0	0.02	0.14	0.17	0.5	HHV	Cont.	Yes	2	-
	kg/year	197.16										
TOC	mg/Nm^3	0.13	0	0.32	0.65	0.68	4.44	HHV	Cont.	Yes	10	-
	kg/year	2562.04										
Cd+Tl	mg/Nm^3	-	-	0.0008	-	-	-	-	Perio.	No	0.05	-
	kg/year	6.63										
Other*	mg/Nm^3	-	-	0.0288	-	-	NA	HHV	Perio.	-	0.5	-

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
	kg/year						239.8					
PCD D/P CDF	ng TEQ/Nm^3	-	-	0.004	-	-	-	HHV	Perio.	Yes	0.01	-
	kg/year						3.4E-05					

*other: Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V

Figure 40 shows a schematic diagram of the WWT process. Taking account of the legal and regulatory provisions, some of the waste water is discharged directly into a river. The water emissions for the three occurring waste water streams are shown in Table 151, Table 152 and Table 153. It must be said, that there is one water treatment facility for the whole combustion site, so that other waste water streams are also included in the presented values.

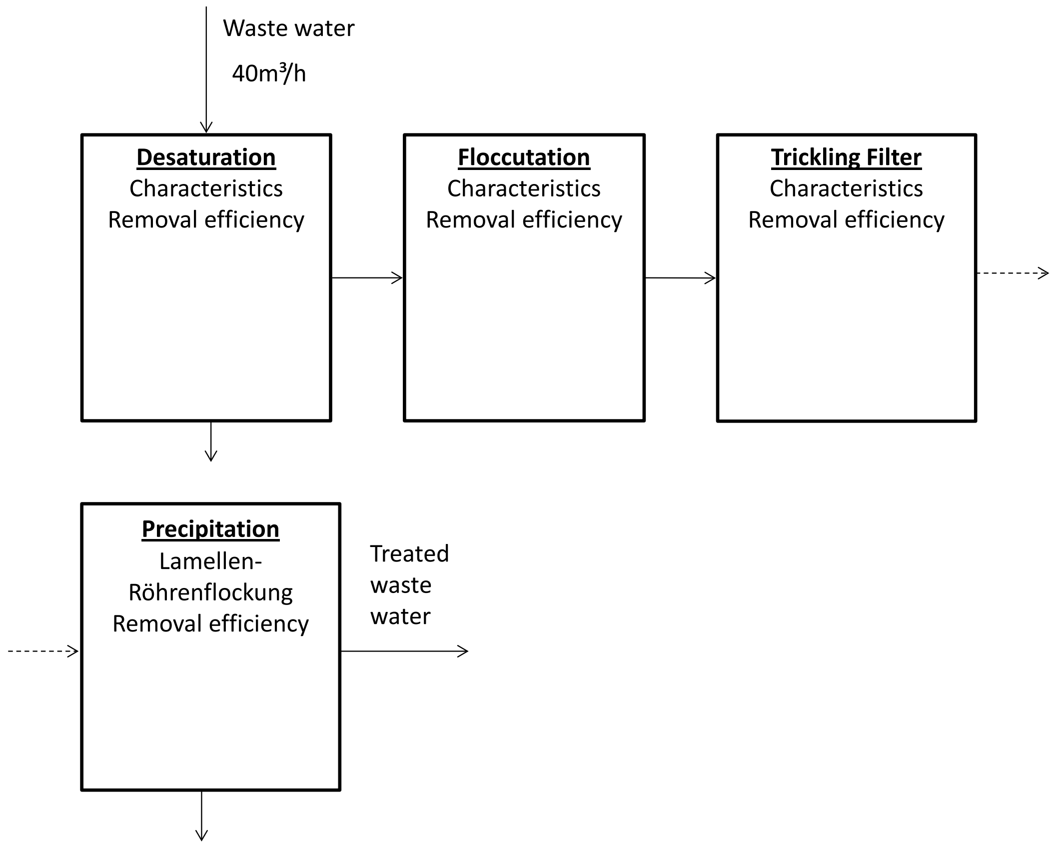

Figure 40: Schematic diagram of the WWT process for reference no. 123

Table 151: Water emissions for reference no. 123 - after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	1.5E+5	1.7E+5	1.8E+5	-	-	-	-	2.5E+05
Temp.	(°C)	32.7	36.4	40	-	-	-	-	-
pH		8.69	8.9	9.17	-	-	-	-	-
TSS	(mg/l)	8	13	20	-	Grab sample	Yes	50	
	(kg/year)			2008					
COD	(mg/l)	32	48	57	-	Grab sample	Yes	50	80
	(kg/year)			7414					
TOC	(mg/l)	10	16	19	-	Grab sample	Yes	50	
	(kg/year)			2471					
Cl^-	(mg/l)	1400	1680	2190	-	Grab sample	Yes	50	
	(kg/year)			2.6E+05					
F^-	(mg/l)	7.8	9.5	11.8	-	Grab sample	Yes	50	30
	(kg/year)			1467					
SO_4^{2-}	(mg/l)	1031	1468	1690	-	Grab sample	Yes	50	2000
	(kg/year)			2.3E+05					
N (total)	(mg/l)	81.65	109.2	143.9	-	Grab sample	Yes	50	
	(kg/year)			1.7E+04					
NH_3-N	(mg/l)	0.77	2.26	8.94	-	Grab sample	Yes	50	25
	(kg/year)			349.1					
Cd	(mg/l)	0.001	0.004	0.009	-	Grab sample	Yes	50	0.03
	(kg/year)			0.618					
Ti	(mg/l)	0.013	0.018	0.03	-	Grab sample	Yes	50	
	(kg/year)			2.78					
Cd+Tl	(mg/l)	0.015	0.022	0.033	-	Grab sample	Yes	50	
	(kg/year)			3.4					
Hg	(mg/l)	0.001	0.002	0.008	-	Grab		50	0.03

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
	(kg/year)			0.309		sample	Ye		
As	(mg/l)	0.002	0.004	0.007	-	Grab sample	Yes	50	
	(kg/year)			0.618					
Pb	(mg/l)	0.005	0.005	0.01	-	Grab sample	Yes	50	0.06
	(kg/year)			0.772					
Cr	(mg/l)	0.007	0.011	0.02	-	Grab sample	Yes	50	0.3
	(kg/year)			1.7					
Cu	(mg/l)	0.01	0.011	0.014	-	Grab sample	Yes	50	0.3
	(kg/year)			1.7					
Ni	(mg/l)	0.01	0.01	0.01	-	Grab sample	Yes	50	0.3
	(kg/year)			1.54					
Zn	(mg/l)	0.02	0.035	0.065	-	Grab sample	Yes	50	0.06
	(kg/year)			5.41					
PCDD/ PCDF	(ng TE/l)	0.01	0.014	0.026	-	Grab sample	Yes	4	
	(kg/year)			2.16					

Table 152: Water emissions for reference no. 123 - non-treated waste water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	1.2E+5	1.5E+5	1.9E+5	-	-	-	-	1.4E+06
Temp.	(°C)	-	-	-	-	-	-	-	-
pH		-	-	-	-	-	-	-	

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
COD	(mg/l)	31	39	60	-	Grab sample	Yes	50	
	(kg/year)			0					
TOC	(mg/l)	10	13	20	-	Grab sample	Yes	50	
	(kg/year)			0					
Total Hydro-carbon content	(mg/l)	116	153	262	-	Grab sample	Yes	250	
	(kg/year)			0					
Cl^-	(mg/l)	256	305	429	-	Grab sample	Yes	250	
	(kg/year)			7882					
SO_4^{2-}	(mg/l)	438	563	661	-	Grab sample	Yes	250	
	(kg/year)			1.1E+04					
P (total)	(mg/l)	0.28	0.35	0.46	-	Grab sample	Yes	50	0.5
	(kg/year)			0					
AOX	(mg/l)	0.04	0.051	0.07	-	Grab sample	Yes	12	
	(kg/year)			0.00					

Table 153: Water emissions for reference no. 123 - surface runoff

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	-	-	-	-	-	-	1.9E+5
Temp.	(°C)	16.6	25.9	33.2	-	-	-	-	-
pH		7.9	8.2	8.4	-	-	-	-	
COD	(mg/l)	15	16	23	-	Grab sample	Yes	50	
	(kg/year)	-							
TOC	(mg/l)	5	5	8	-	Grab sample	Yes	50	
	(kg/year)	-							
Oil and grease	(mg/l)	0.1	0.1	0.2	-	Grab sample	Yes	50	
	(kg/year)	-							

Table 154 shows the solid residues (by-products). The biggest amount of solid residues is made up of fly ash, bottom ash and gypsum. These by-products can be used in the construction industry.

Table 154: Solid residues for reference no. 123

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Fly ash (minimum analytic figures)	Flue-gas treatment facilities	10 01 02	9.8E+04	Utilisation - Construction industry	concrete additive, cement substitution
Bottom ash (minimum analytic figures)	Combustion process	10 01 15	2.1E+04	Utilisation - Construction industry	concrete blocks, road construction, filling application
Gypsum (minimum analytic figures)	Flue-gas treatment facilities	10 01 07	3.8E+04	Utilisation - Construction industry	plaster board, projection plaster
FGD-sludge (analytic figures from 2009 - average)	WWT facilities	10 01 05	6596	-	filling application

Special characteristics

The coal stockpile of plant 123 is a closed-system, so that dust and noise emissions can be minimised. In addition to this, CHP results in higher fuel efficiency. Both technologies are suggested as BAT by the operator.

Pulverised Coal Firing, Reference no. 122

Reference no. 122 is a pulverised coal-fired power plant for electricity generation, which was commissioned in 1992. The plant was retrofitted with a new FGD and a new wet stack in 2005. In 2009, modifications to the milling system were done to adjust them for a broader variety of imported hard coals. The plant is fired solely with hard coal with high amounts of volatile matter. The plant consists of two identical once-through boilers (with forced circulation in part load), which feed a single condensation steam turbine each. The live steam parameters are 186 bar and 530 °C, the reheater steam parameters are 38 bar and 530 °C. The cooling system uses a natural draught cooling tower. Water losses are compensated for by additional river water and ground water.

The total rated thermal input for each boiler is 1870 MW_{th}, the gross electric power output is 7610 MW_{el} (for each turbine), which leads to a nominal gross electrical efficiency of 39 %.

Table 155 and Table 156 show the energy input and output for the reference year as well as the total operating time under normal operating conditions. The reference year for the given values is 2010. Five years have been taken into account for the rolling average value.

Table 155: General operating data for reference no. 122 – Boiler 1

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	9.26E+06	9.53E+06
Gross electric energy output	MWh_{el}	3.58E+06	3.71E+06
Net electric energy output	MWh_{el}	3.37E+06	3.49E+06
Total operating time under normal operating conditions	h	6342.0	6345.0
Equivalent full load operating factor	%	78	80

Table 156: General operating data for reference no. 122 – Boiler 2

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	9.37E+06	8.97E+06
Gross electric energy output	MWh_{el}	3.65E+06	3.49E+06
Net electric energy output	MWh_{el}	3.43E+06	3.29E+06
Total operating time under normal operating conditions	h	6395.0	6030.0
Equivalent full load operating factor	%	78	80

In the reference year, the plant was operated for about 6400 h. The equivalent full load operating factors are 78 % (for both boilers). The net electrical utilisation ratios are 36.4 % and 36.6 %, respectively. From the rolling average values, net electrical utilisation ratios of 36.6 % and 36.7 % can be calculated. The boilers were operated for 6000 h and 6300 h, with equivalent full load operating factors of 80 %.

The modernisations made to the plant (new FGD, new stack and modified milling capacity, different measures for a higher electrical efficiency) are suggested as BAT by the operator.

Environmental aspects

The plant produces typical air and water emissions for hard coal-fired power plants as well as corresponding solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x, CO and Hg are continuously measured in the flue gas. There are primary and secondary measures taken for emission abatement. Primary measures are air staging and low-NO_x-burners. Figure 41 shows a schematic diagram of the FGT facility (secondary measures).

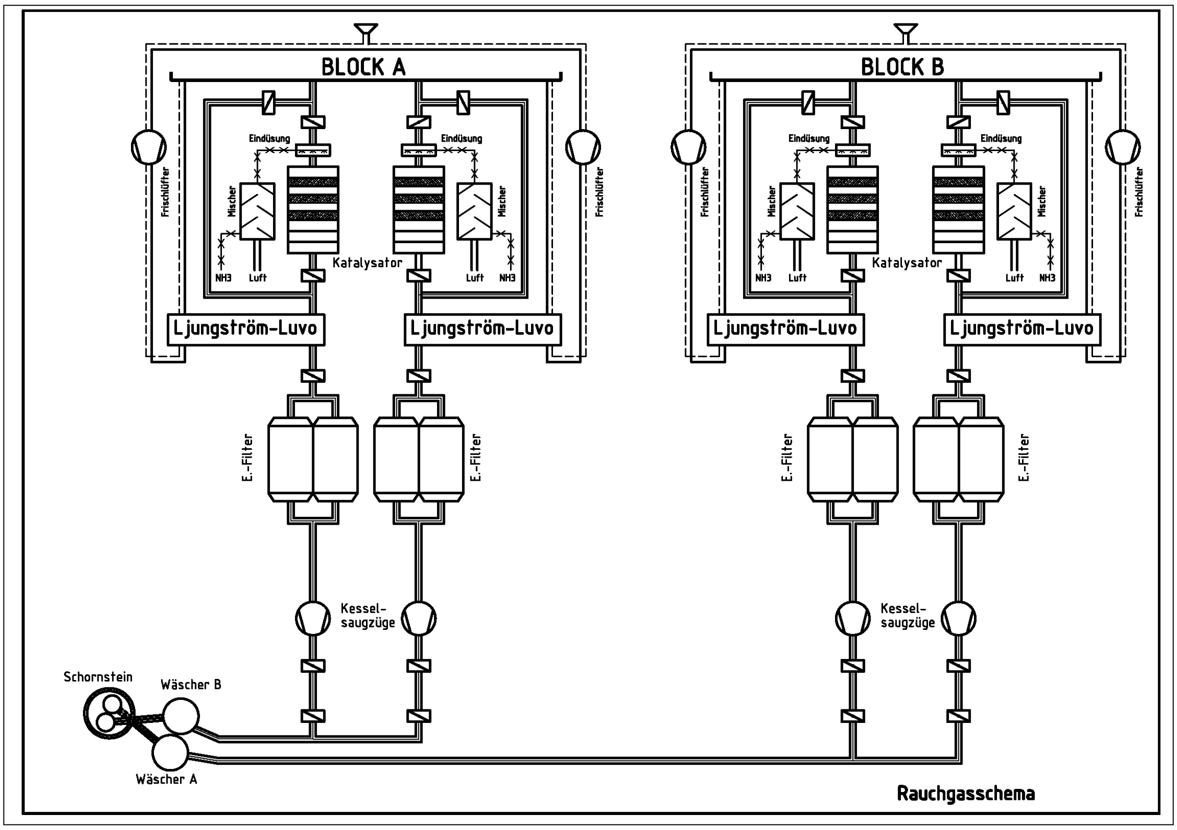

Figure 41: Schematic diagram of the FGT process for reference no. 122

The first stage of the FGT process is the SCR unit, in which NO_x is reduced by using NH_3. The flue gas is then cooled (air heater), before dust is removed in the ESP. SO_x is removed in the wet FGD, where it reacts with $CaCO_3$ to form gypsum. The treated flue emitted via a wet stack. The FGD and the subsequent emission via a wet stack are suggested as BAT by the operator.

Table 157 and Table 158 show the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated. While the values for the concentrations do include OTNOCs, the values for the annual loads do not include OTNOCs. The reference oxygen content is 6 %.

Table 157: Air emissions for reference no. 122 – Boiler 1

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values Prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	0	0	0.6179	2.38	2.77	21.18	HHV	Cont.	Yes	60	20
	kg/year	7235										
SO_x	mg/Nm^3	0	56.6	115.31	160.23	162.675	208.38	HHV	Cont.	Yes	400	200
	kg/year	1.4E+06										
SO_x removal	(%)	41.7	87	91.38	95.4	95.8	98.8	HHV	Cont.	No	85	-
NO_x	mg/Nm^3	67	177.92	195.23	209.54	215.62	677.05	HHV	Cont.	Yes	400	200
	kg/year	2.3E+06										
CO	mg/Nm^3	0.99	1.12	1.8853	2.8975	4.02	112.54	HHV	Cont.	Yes	400	200
	kg/year	2.2E+04										
	kg/year	-										
Hg	mg/Nm^3	0	0	0.0016	0.0054	0.0066	0.047	HHV	Cont.	Yes	-	0.03
	kg/year	-										

Table 158: Air emissions for reference no. 122 – Boiler 2

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	0	0.15	2.22	4.56	4.85	58.18	HHV	Cont.	Yes	60	20
	kg/year						2.6E+04					
SO_x	mg/Nm^3	18.14	64.74	123.06	159.5	162.99	309.3	HHV	Cont.	Yes	400	200
	kg/year						1.5E+06					
SO_x re-mo-val	(%)	33.9	87.1	90.53	90.5	94.7	98.4	HHV	Cont.	No	85	-
NO_x	mg/Nm^3	60.28	184.69	196.06	204.49	207.67	616.38	HHV	Cont.	Yes	400	200
	kg/year						2.4E+06					
CO	mg/Nm^3	0	0.03	3.13	5.397	6.6	494.1	HHV	Cont.	Yes	400	200
	kg/year						3.7E+04					
	kg/year						-					
Hg	mg/Nm^3	0	0	0.0014	0.0054	0.0064	0.047	HHV	Cont.	Yes	-	0.03
	kg/year						-					

Figure 42 shows a schematic diagram of the WWT process. Taking account of the legal and regulatory provisions, some of the waste water from the cooling system is discharged directly into a river. Another part of the cooling water is filtered and reused in the FGD and the WWT (WWT) facility. Some of the treated waste water is recycled in the cooling system, the rest is discharged into a river. The water emissions for the occurring waste water streams are shown in Table 159 and Table 160.

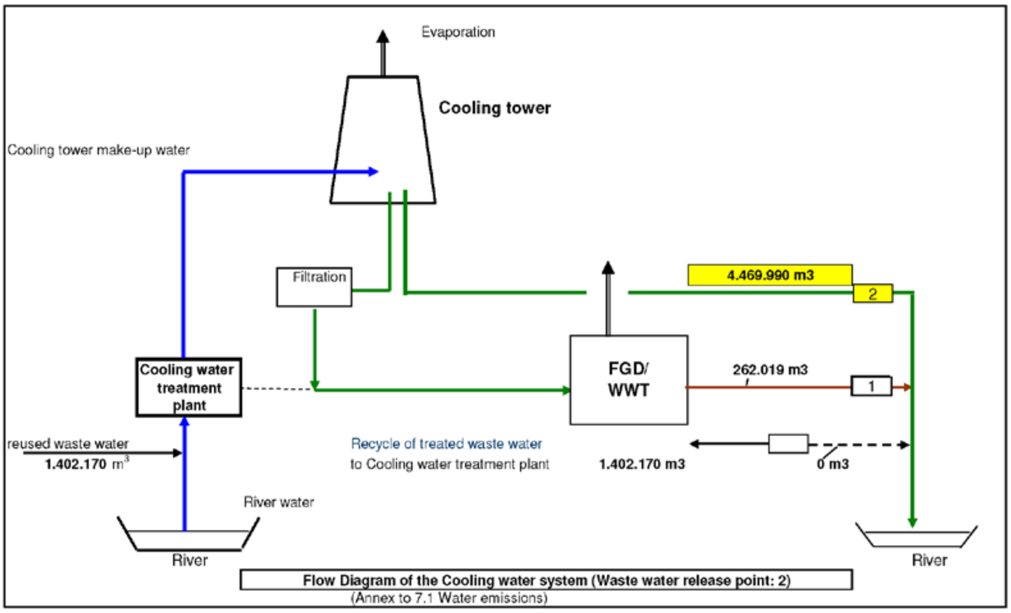

Figure 42: Schematic diagram of the WWT process for reference no. 122

Table 159: Water emissions for reference no. 122 - after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	8	31.9	53.8	-	-	-	-	-
Temp.	(°C)	35.6	38.6	43.2	-	-	-	-	-
pH		8.2	8.9	9.3	-	-	-	-	6.5 to 10
TSS	(mg/l)	8	10.5	18	HA	Grab sample	-	19	30
	(kg/year)			1384					
COD	(mg/l)	35	39.2	75	HA	Grab sample	-	19	80 mg/l (using limestone: 150 mg/l)
	(kg/year)			5166					
F^-	(mg/l)	10	12.3	17	HA	Grab sample	-	15	30
	(kg/year)			1621					
S^{2-}	(mg/l)	-	-	-	HA	Grab sample	-	19	0.2
	(kg/year)			-					
SO_3^{2-}	(mg/l)	-	-	-	HA	Grab sample	-	19	20
	(kg/year)			-					
SO_4^{2-}	(mg/l)	1040	1175	1220	HA	Grab sample	-	19	2000
	(kg/year)			1.5E+05					
Cd	(mg/l)	-	-	-	HA	Grab sample	-	36	0.05
	(kg/year)			-					
Hg	(mg/l)	0.0002	0.0034	0.027	HA	Grab sample	-	36	0.03
	(kg/year)			0.45					
Pb	(mg/l)	0.005	0.0054	0.014	HA	Grab sample	-	39	0.1
	(kg/year)			0.7					
Cr	(mg/l)	0.005	0.021	0.056	HA	Grab sample	-	38	0.5
	(kg/year)			2.8					

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Cu	(mg/l)	5	8	16	HA	Composite sample	-	39	0.5
	(kg/year)	1054.3							
Ni	(mg/l)	0.0025	0.0026	0.008	HA	Grab sample	-	20	0.5
	(kg/year)								
Zn	(mg/l)	0.0025	0.0037	0.012	HA	Grab sample	-	16	1
	(kg/year)	0.5							

Table 160: Water emissions for reference no. 122 - non-treated waste water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	95.6	304.8	503	-	-	-	-	-
Temp.	(°C)	16.6	22.7	29	-	-	-	-	-
pH		6.7	8.2	8.7	-	-	-	-	-
COD	(mg/l)	14	19	23	HA	Grab sample	-	16	45
	(kg/year)	4.3E+04							
P (total)	(mg/l)	0.09	0.13	0.21	HA	Grab sample	-	16	1.5
	(kg/year)	292							
AOX	(mg/l)	0.011	0.02	0.028	HA	Grab sample	-	-	0.15
	(kg/year)	45							

Table 161 shows the solid residues (by-products). The biggest amount of solid residues is made up of fly ash, bottom ash and gypsum. These by-products can be used in the construction industry. Residual sludges from the cooling water make-up water treatment are used as fertiliser for agricultural purposes.

Table 161: Solid residues for reference no. 122

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Fly ash (EN 450), dry	Combustion process	EN 450	1.7E+05	Utilisation - Construction industry	concrete and cement
Fly ash (EN 450), wet 3)	Combustion process	EN 450	2.6E+04	Temporary stockpile	finally: concrete and cement after drying
Bottom ash	Combustion process	-	1.2E+04	Utilisation - others	e. g. construction, bricks, underground
Gypsum	Flue-gas treatment facilities	gypsum quality	1E+05	Utilisation - Construction industry	gypsum industry, e. g. plaster boards
Cooling tower make-up water treatment sludge	Raw WWT facilities	-	9402	Utilisation - others	fertiliser/agriculture
FGD WWT sludge	WWT facilities	-	6676.8	-	disposed as waste

Special characteristics

The wet FGD and the emission of the flue gas via a wet stack are suggested as BAT by the operator.

Pulverised Coal Firing, Reference no. 131

Reference no. 131 is a pulverised coal-fired power plant for electricity generation. The plant was commissioned in 1976 and continuously revised, for the last time in 2004. The fuel is mainly hard coal, but also small shares of heavy crude oil and petroleum coke can be co-combusted. The boilers is a once-through boiler, which feeds a steam turbine. The live steam parameters are 188 bar and 530 °C, the reheater steam parameters are 39 bar and 530 °C. The condenser is sea water cooled. Figure 43 shows a sketch of the plant layout.

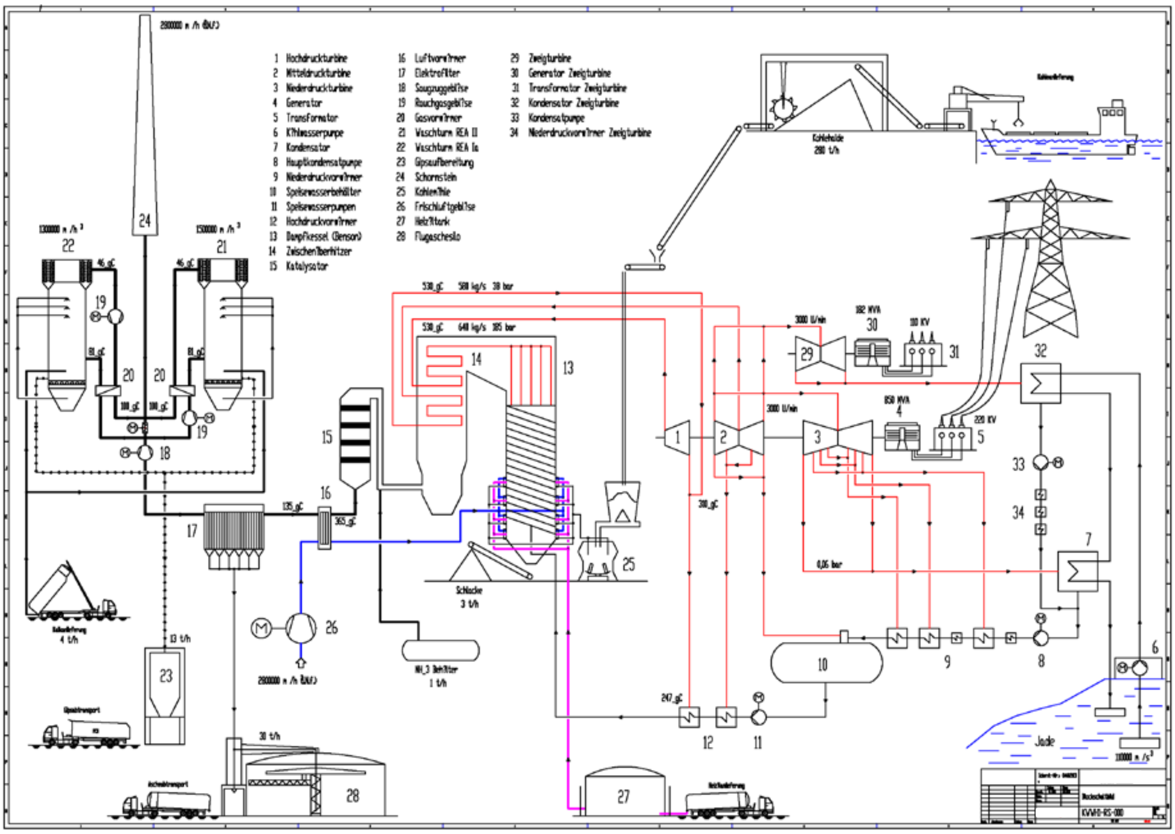

Figure 43: Sketch of the design of reference no. 131

The total rated thermal input of the plant is 1870 MW_{th}, the gross electric power output is 824 MW_{el}. The nominal gross electrical efficiency is 44 %.

Table 162 shows values for the fuel energy input and energy output in the reference year 2010. Five years have been taken into account for the rolling average value.

Table 162: General operating data for reference no. 131

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	8.92E+06	1.02E+07
Gross electric energy output	MWh_{el}	3.68E+06	4.09E+06
Net electric energy output	MWh_{el}	3.39E+06	3.78E+06
Total operating time under normal operating conditions	h	5720.9	6277.0
Equivalent full load operating factor	%	83	87

In the reference year, the plant was operated for about 5700 h with an equivalent full load operating factor of 83 %. The net electrical utilisation ratio is 38 %. For the rolling average value a net electrical utilisation ratio of 37 % can be calculated. The total operating time under normal operating conditions for the rolling average value is almost 6300 h with an equivalent full load operating factor of 87 %.

Environmental aspects

The plant produces typical air and water emissions for hard coal-fired power plant as well as corresponding solid residues. In accordance to the official authorisation, the air pollutants dust, SO_X, NO_X, CO, HCl, HF, TOC and Hg are continuously measured in the flue gas. In addition to this, other pollutant emissions are periodically measured. There are primary and secondary measures taken for emission abatement. Primary measures are air grading as well as low-NO_X-burners. Figure 44 shows a schematic diagram of the FGT process (secondary measures).

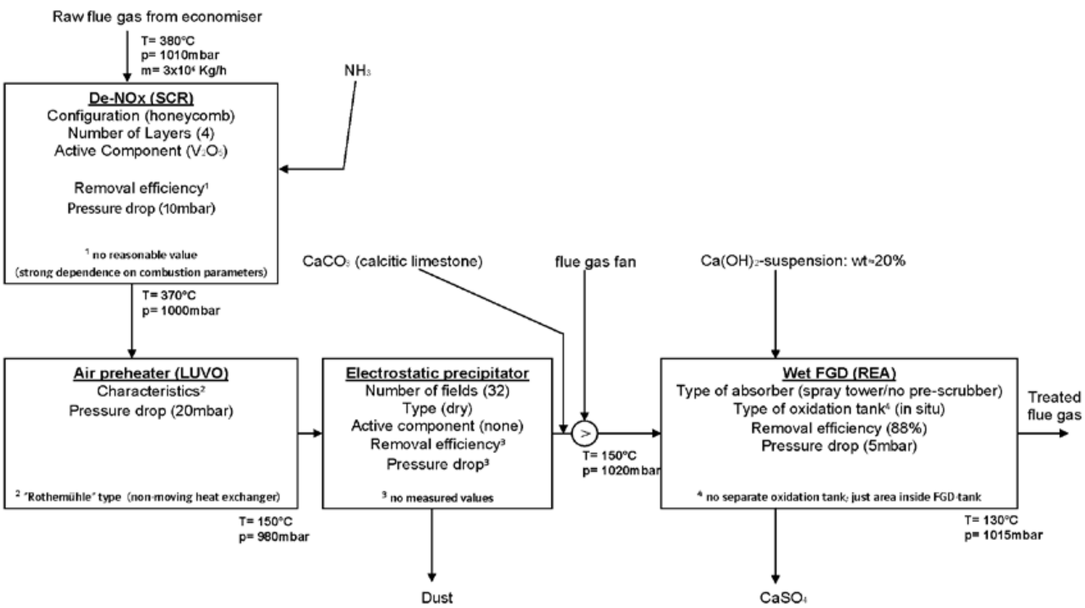

Figure 44: Schematic diagram of the FGT process for reference no. 131

The first stage of the FGT process is the SCR unit, in which NO_x is reduced by NH_3. The flue gas is then cooled (air heater), before dust is removed in the ESP. SO_x is removed in the wet FGD, where it reacts with $Ca(OH)_2$ to form gypsum. The treated flue gas is emitted via a stack.

Table 163 shows the concentration and the annual load for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are not validated and do include OTNOCs. The reference oxygen content is 6 %.

Table 163: Air emissions for reference no. 131

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm³	1.53	4.4	11.96	24.26	26.44	84.65	HHV	Cont.	No	20	60
	kg/year						1.4E+05					
SO_x	mg/Nm³	22.74	93.09	124.01	151.05	154.37	250.14	HHV	Cont.	No	300	600
	kg/year						1.4E+06					
SO_x removal	(%)	70.39	86.13	87.72	89.43	89.92	100	HHV	Cont.	No	85	
NO_x	mg/Nm³	8.08	151.13	179.39	203.45	211.4	889.56	HHV	Cont.	No	200	400
	kg/year						2E+06					
CO	mg/Nm³	0	0.29	2.47	7.96	9.96	107.85	HHV	Cont.	No	250	500
	kg/year						2.6E+04					
HCl	mg/Nm³	2.17	2.48	3.05	4.39	4.72	7.45	HHV	Cont.	No	100	200
	kg/year						32780					
HF	mg/Nm³	0.01	4.98	7.21	9.74	10.15	16.75	HHV	Cont.	No	15	30
	kg/year						7.8E+04					
Hg	mg/Nm³	1E-05	2E-05	0.0028	0.0056	0.0062	0.0184	HHV	Cont.	No	-	-
	kg/year						29.9					
TOC	mg/Nm³	0	0.01	0.54	1.13	1.31	4.01	HHV	Cont.	No	6	3
	kg/year						-					
Cd+Tl	mg/Nm³	-	-	-	-	-	0.0013	HA	Perio.	Yes	0.01	-
	kg/year						-					
Other*	mg/Nm³	-	-	0.0125	-	-	0.0143	HA	Perio.	Yes	0.1	-
	kg/year						-					

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
PCDD / PCDF	ng/Nm³	-	-	0.0007	-	-	0.0007	HA	Perio.	Yes	0.02	-
	kg/year	-										

*other: Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V

The cooling water is not treated. Other waste water streams, especially waste water from the FGD, are treated in a central water treatment facility (see Figure 45). The water emissions for the different waste water streams are shown in Table 164 and Table 165.

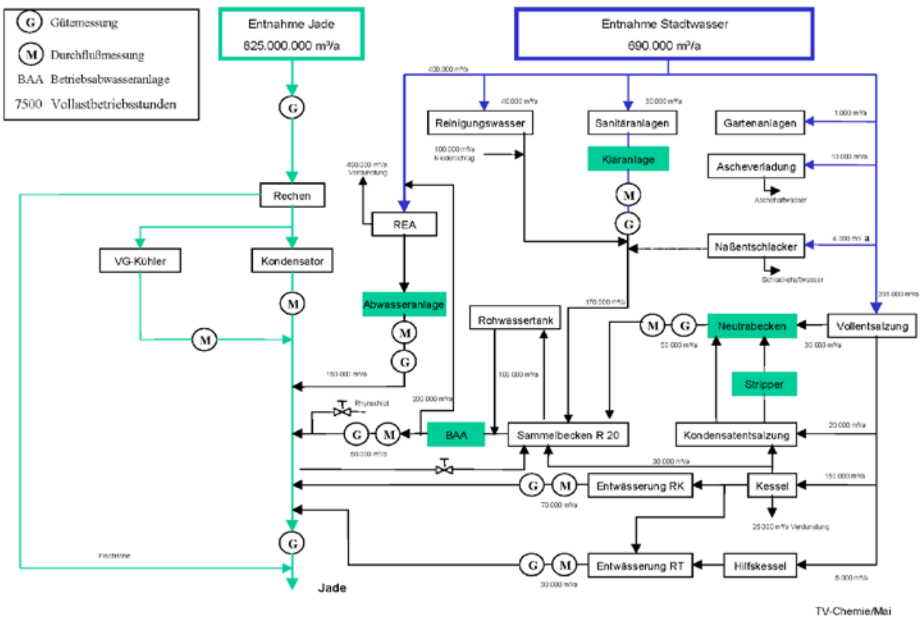

Figure 45: Schematic diagram of the WWT process for reference no. 131

Table 164: Water emissions for reference no. 131 - after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	56400	-	-	-	-	-	-
Temp.	(°C)	-	36.6	-	-	-	-	44	-
pH		-	9.7	-	-	-	-	44	-
TSS	(mg/l)	-	7	-	-	Grab sample	-	44	30
	(kg/year)			-					
TOC	(mg/l)	-	17.1	-	-	Grab sample	-	44	-
	(kg/year)			-					
Cl^-	(mg/l)	-	3340	-	-	Grab sample	-	44	-
	(kg/year)			-					
F^-	(mg/l)	-	14.7	-	-	Grab sample	-	44	30
	(kg/year)			-					
S^{2-}	(mg/l)	-	0.03	-	-	Grab sample	-	12	-
	(kg/year)			-					
SO_3^{2-}	(mg/l)	-	1.6	-	-	Grab sample	-	12	20
	(kg/year)			-					
SO_4^{2-}	(mg/l)	-	1620	-	-	Grab sample	-	44	2000
	(kg/year)			-					
NO_2^-/NO_3^-	(mg/l)	-	75	-	-	Grab sample	-	44	-
	(kg/year)			-					
NH_3-N	(mg/l)	-	1.3	-	-	Grab sample	-	44	10
	(kg/year)			-					
P (total)	(mg/l)	-	0.08	-	-	Grab sample	-	12	2
	(kg/year)			-					
Cd	(mg/l)	-	0.0001	-	-	Grab sample	-	5	0.0125
	(kg/year)			-					

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Hg	(mg/l)	-	0.0003	-	-	Grab sample	-	44	0.0075
	(kg/year)	-							
Pb	(mg/l)	-	0.004	-	-	Grab sample	-	5	0.05
	(kg/year)	-							
Cr	(mg/l)	-	0.039	-	-	Grab sample	-	5	-
	(kg/year)	-							
Cu	(mg/l)	-	0.001	-	-	Grab sample	-	5	0.1
	(kg/year)	-							
Ni	(mg/l)	-	0.003	-	-	Grab sample	-	5	0.05
	(kg/year)	-							
Zn	(mg/l)	-	0.011	-	-	Grab sample	-	5	1
	(kg/year)	-							
AOX	(mg/l)	-	0.028	-	-	Grab sample	-	12	1
	(kg/year)	-							

Table 165: Water emissions for reference no. 131 - non-treated waste water

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	8.4E+04	-	-	-	-	-	-
Temp.	(°C)	-	14.8	-	-	-	-	-	-
pH		-	7.8	-	-	-	-	-	-

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
TSS	(mg/l)	-	3.5	-	-	Grab sample	-	46	30
	(kg/year)	-							
TOC	(mg/l)	-	4.9	-	-	Grab sample	-	46	-
	(kg/year)	-							
N (total)	(mg/l)		1.75		-	Grab sample	-	6	-
	(kg/year)								
NH_3-N	(mg/l)	-	0.3	-	-	Grab sample	-	46	10
	(kg/year)	-							
P (total)	(mg/l)	-	0.046	-	-	Grab sample	-	6	2
	(kg/year)	-							
AOX	(mg/l)	-	0.052	-	-	Grab sample	-	46	0.3
	(kg/year)	-							

Table 166 shows the solid residues (by-products). Gypsum and fly ash make up the largest part of by-products and are utilised in the cement industry. Other by-products can be used for the restoration of open cast mines, quarries and pits.

Table 166: Solid residues for reference no. 131

Description	Source	Code	Gene-ration in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Gypsum	Flue-gas treatment facilities	10 01 05	5.3E+04	Utilisation - Construction industry	Cement industry
Fly Ash	Combustion process	10 01 01 10 01 02	9.8E+04	Utilisation - Construction industry	Cement industry
Boiler sand	Combustion process	10 01 01	1.5E+04	Utilisation - Construction industry	Road construction
Sludge (Cooling tower raw water treatment)	Raw water treatment facilities	19 90 03	4530	Reclamation/restoration of open cast mines, quarries and pits	Recycling of raw materials
Sludge (FGD WWT)	WWT facilities	10 01 07	1021	Reclamation/restoration of open cast mines, quarries and pits	Recycling of raw materials

Special characteristics

The plant was comprehensively upgraded in the past. Among other things, the minimal load was reduced and the load ramp was optimised. An additional branch turbine, which is only operated at loads higher than 50 %, was installed, to increase the electrical output of the plant by 42 MW. Different fuels like petroleum coke and sewage sludge have been co-combusted. The plant is also equipped with a pilot facility for CO_2 capture. The waste water, which contains NH_4, is discharged into a municipal sewerage, instead of being rectificated with high energy input. These techniques are suggested as BAT by the operator.

Pulverised Coal Firing in Combination with a Topping Gas Turbine, Reference no. 142

Reference no. 142 is used for the generation of electricity. The pulverised coal-fired boiler is equipped with a topping gas turbine. The hot, oxygen-rich flue gas from the gas turbine is fed into the boiler. The plant was commissioned in 1984 and retrofitted in 1999 (ND-Turbine). The main fuel is hard coal with medium content of volatile matter. In addition to this, production-specific commercial wastes (BPG) and substitute fuel of municipal wastes (SBS) can be co-combusted. For start-up and for auxiliary firing, NG is used. The gas turbine is fired with NG only.

Due to the gas turbine, the plant can accomplish short-term load changes and thus react to the fluctuating electricity demand. The plant consists of a once-through boiler, which feeds steam into a condensation turbine. The live steam parameters are 186 bar and 530 °C. The reheater steam parameters are 40 bar and 530 °C. The cooling system uses a natural draught cooling tower.

The plant is located at a combustion site with a total rated thermal input of 5100 MW_{th}. The total rated thermal input of the combustion installation no. 142 is 1900 MW_{th}, of which 372 MW_{th} are accounted for by the gas turbine and 1528 MW_{th} by the coal-fired boiler. The gross electric power output of the gas turbine is 112 MW_{el}, with a nominal gross electrical efficiency of 30.1 %. The gross electric power output of the steam turbine is 658 MW_{el}, so that the nominal gross electrical efficiency of the whole plant adds up to 43.0 %.

Table 167 shows values for the fuel energy input and energy output in the reference year 2010. Five years (2006 – 2010) have been taken into account for the rolling average value.

Table 167: General operating data for reference no. 142

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	9.80E+06	1.02E+07
Gross electric energy output	MWh_{el}	3.99E+06	4.18E+06
Net electric energy output	MWh_{el}	3.69E+06	3.86E+06
Total operating time under normal operating conditions	h	6749	6922.0
Equivalent full load operating factor	%	76	77

In the reference year, the plant was operated for about 6750 h with an equivalent full load operating factor of 76.0 %. The net electrical utilisation ratio is 37.7 %. For the rolling average value a net electrical utilisation ratio of 37.8 % can be calculated. The total operating time under normal operating conditions for the rolling average value is with around 6900 h and with an equivalent full load operating factor of 77 % only slightly higher than in the reference year. It has to be noted, that - in the reference year as well as in the rolling average value - the gas turbine was operated for roughly 2400 h with an equivalent full load operating factor of less than 30 %.

Environmental aspects

The plant releases typical air and water emissions for hard coal-fired power plants as well as produces corresponding solid by-products. The air pollutants dust, SO_x, NO_x, CO and Hg are continuously measured in the flue gas. In addition to these parameters, HCl and HF are measured periodically. There are primary and secondary measures used for emission abatement. Primary measures are air staging as well as implemented low-NO_x-burners. Figure 46 shows a schematic diagram of the FGT process (secondary measures).

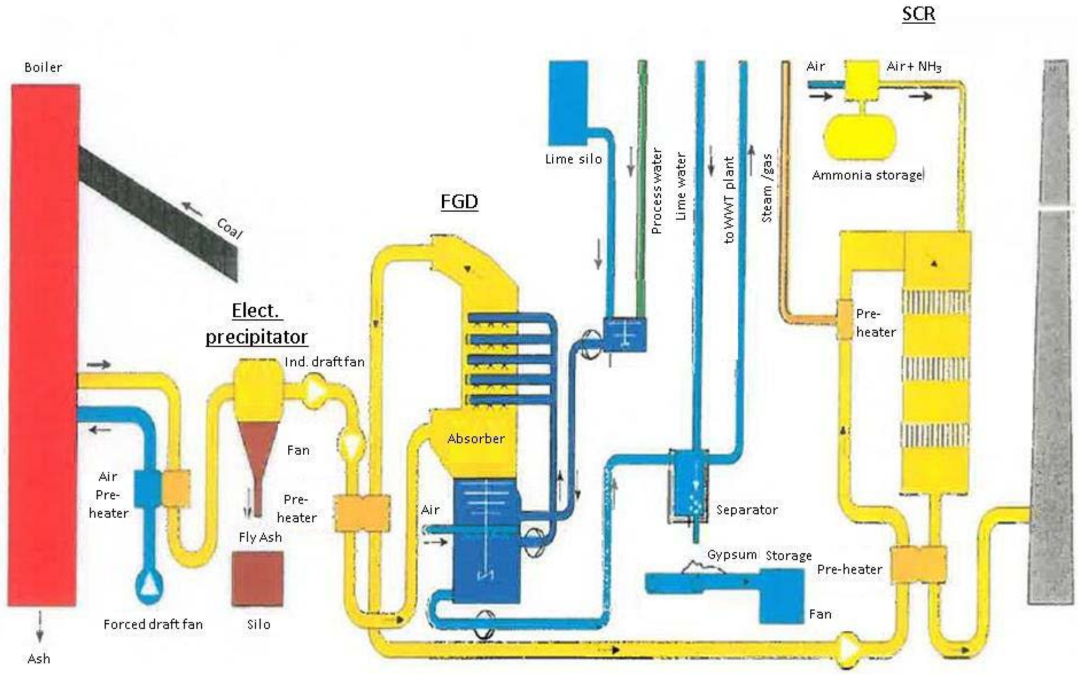

Figure 46: Schematic diagram of the FGT process for reference no. 142

The first stage of the flue gas treatment process is the preheating of the inlet air followed by the removal of fly ash and dust in the electrostatic precipitator (ESP). SO_x are then removed in the wet flue gas desulphurization (FGD), where they react with $CaCO_3$ to form gypsum. Finally, the flue gas is reheated, before NO_x is converted to nitrogen and water in a selective catalytic reduction (SCR) unit, using ammonia (NH_3). The treated flue gas is then released via stack.

Table 168 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by the competent authority is given. It should be noted, that the presented concentration values are validated (i.e. standardised values with subtraction of the measurement uncertainty, which has been determined during calibration) and do include OTNOCs, while the values for the annual loads do include OTNOCs. The reference oxygen content is 6 %.

It is emphasised, that the plant's emission data for the reference year 2010 characteristically depends from the percentage of the co-combustion of surrogate fuels. The emission behaviour and characteristics do only reflect in extracts the whole emission behaviour of the power plant over a necessarily to be considered longer period.

Table 168: Air emissions for reference no. 142

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h*	d
Dust	mg/Nm³	0	0	3.45	11.21	13.2	71.84	HHV	Cont.	Yes	-	20
	kg/year	3.8E+04										
SO_x	mg/Nm³	16.1	67	116	167.51	176	290.7	HHV	Cont.	Yes	-	180
	kg/year	1.2E+06										
SO_x re-moval	(%)	85	88	91.68	94.84	95.1	97.44	HHV	Cont.	Yes	-	85
NO_x	mg/Nm³	112	169	182.6	193.59	198	400.3	HHV	Cont.	Yes	-	200
	kg/year	1.9E+06										
CO	mg/Nm³	0	0	0.97	3.45	6	242.1	HHV	Cont.	Yes	-	220
	kg/year	8190										
HCl	mg/Nm³	-	-	4.98	-	-	-	HHV	Perio.	Yes	-	20
	kg/year	5E+04										
HF	mg/Nm³	-	-	0.82	-	-	-	HHV	Perio.	Yes	-	10
	kg/year	8186										
Hg	mg/Nm³	0	0	0.001	0.0027	0	0.006	HHV	Cont.	Yes	-	0
	kg/year	11.51										

* Values obtained in 2010 are based on validated half-hourly values. These values result out of normed values with subtraction of the measurement uncertainty, which has been determined during the calibration process. Normally, the half-hourly emission limit value equates to the double of the daily average emission limit value according to the 13. / 17. BImSchV.

Waste water is treated on-site, before being discharged into nearby surface water. The waste water originates from the cooling system, the FGD, the ash system and the biological pre-treatment. The water emissions of the different streams are presented in Table 169, Table 170, Table 171 and Table 172.

Table 169: Water emissions for reference no. 142 - after WWT (from FGD)

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	2E+05	-	-	-	-	-	-
Temp.	(°C)	-	-	30	-	-	-	-	-
pH		6.5	-	9	-	-	-	-	-
TOC	(mg/l)	-	17.325	-	-	Grab sample	-	4	20
	(kg/year)	-							
F^-	(mg/l)	-	11.2	-	-	Grab sample	-	4	30
	(kg/year)	1117.7							

Table 170: Water emissions for reference no. 142 - after WWT (from ash system)

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	5.9E+05	-	-	-	-	-	-
Temp	(°C)	-	-	30	-	-	-	-	-
pH		6.5	-	9	-	-	-	-	-
TOC	(mg/l)	-	12.3	-	-	Grab sample	-	4	DV emission limit value: 50 mg/l
	(kg/year)	-							

Table 171: Water emissions for reference no. 142 - after WWT (from cooling system)

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	9E+05	-	-	-	-	-	-
Temp.	(°C)	-	-	30	-	-	-	-	-
pH		6.5	-	9	-	-	-	-	-

Table 172: Water emissions for reference no. 142 - after WWT (from biological pre-treatment)

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	9881	-	-	-	-	-	-
Temp.	(°C)	-	-	30	-	-	-	-	-
pH		6.5	-	9	-	-	-	-	-
TOC	mg/l	-	10.35	-		Grab sample	No	4	DV emission limit value: 150 mg/l (4 out of 5 + 100%)
	kg/year	102.27							
N (total)	mg/l	-	14.6	-		Grab sample	No	4	DV emission limit value: 50 mg/l (4 out of 5 + 100%)
	kg/year	144.26							

Table 173 shows the solid by-products (e.g. gypsum, ash and sand). Fly ash makes up the largest part of the solid by-products. The ash and the gypsum as well as the boiler sand can be utilised in the construction material industry. Sludges from the waste water treatment processes are disposed or recycled.

Table 173: Solid residues for reference no. 142

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Gypsum	Flue-gas treatment facilities	10 01 05	5.30E+04	Utilisation - Construction industry	Cement industry
Fly Ash	Combustion process	10 01 01 10 01 02	9.76E+04	Utilisation - Construction industry	Cement industry
Boiler sand	Combustion process	10 01 01	1.51E+04	Utilisation - Construction industry	Road construction
Sludge (Cooling tower raw water treatment)	Raw water treatment facilities	19 90 03	4.53E+03	Reclamation/restoration of open cast mines, quarries and pits	Recycling of raw materials
Sludge (FGD WWT)	WWT facilities	10 01 07	1.02E+03	Reclamation/restoration of open cast mines, quarries and pits	Recycling of raw materials

Special characteristics

Prior to incineration, unwanted substances are separated from the substitute fuels (BPG/SBS) by metal separators and classifiers. This technology is suggested as BAT by the operator.

The plant's flue gas cleaning system is very efficient. The FGD consists of three absorbers, each equipped with five scrubber levels. The FGD as well as the SCR unit are supplemented by gas pre-heaters (regenerative or vapor run), which cool down the flue gases before they enter the unit and heat them up before they exit. The gas pre-heaters are fitted with sensor-controlled sealing gap regulators in order to reduce flue gas slippage. This is therefore suggested as BAT by the operator.

The waste water stream from the FGD is treated in a specially designed facility. Ash quality will be improved and waste water (incl. so far contained CSB emissions) will be avoided by the retrofit of a dry de-ashing with afterburning in future. These process optimisations connected to the dry de-ashing systems are therefore suggested as BAT by the operator.

The cooling water is conditioned (decarbonisation with quicklime powder), which results in a reduced water consumption. Additionally, the waste water from the cooling system is reused in the FGD and therewith the total water consumption is reduced further.

The plant uses a process quality optimisation system in order to identify improvement potential and to optimise the plant operation mode. This technology is suggested as BAT by the operator.

The combination of the excess heat use of the topping gas turbine with a hard-coal fired dry de-ashed boiler is suggested as BAT by the operator.

Slag-tap Boiler, Reference no. 121

Reference no. 121 is a slag-tap boiler for electricity generation, which was commissioned in 1985. Additionally, heat for local heating and the nearby coal mine is provided. The boiler consists of a slag-tap furnace with 32 combined oil- and coal-burners, which are located at the ceiling of the furnace. The furnace temperature of slag-tap firings is higher than the melting temperature of the slag, so that the slag is removed in molten state. The fuel is mainly anthracite coal (90 % in 2010), which is extracted from the nearby coal mine. This coal is characterised by a high hardness and a low content of volatiles, which results in a lower flammability. The slag-tap firing is specially designed to meet the requirements (high temperatures) for the combustion of this fuel. In this context, the technology as in the present case (including the fly ash recirculation) is suggested as BAT by the operator. Other fuels, like bituminous coal, sewage sludge and meat and bone meal can be co-combusted. For start-up and as auxiliary firing, heavy crude oil is used. The live steam parameters are 194 bar and 540 °C, the steam parameters for the mid-pressure turbine are 33.4 bar and 540 °C and 6 bar and 320 °C for the low-pressure turbine. The cooling system is a circulating system with natural draft cooling tower. Make-up water is taken from a nearby channel. Figure 47 shows a sketch of the plant layout.

The plant was retrofitted and modernised by plenty of measures in the last 5 years. The turbines, the condenser, the cooling water cycle, the generator-cooling system and the flue gas treatment facilities were retrofitted or renewed. These optimisation measures are therefore suggested as BAT by the operator.

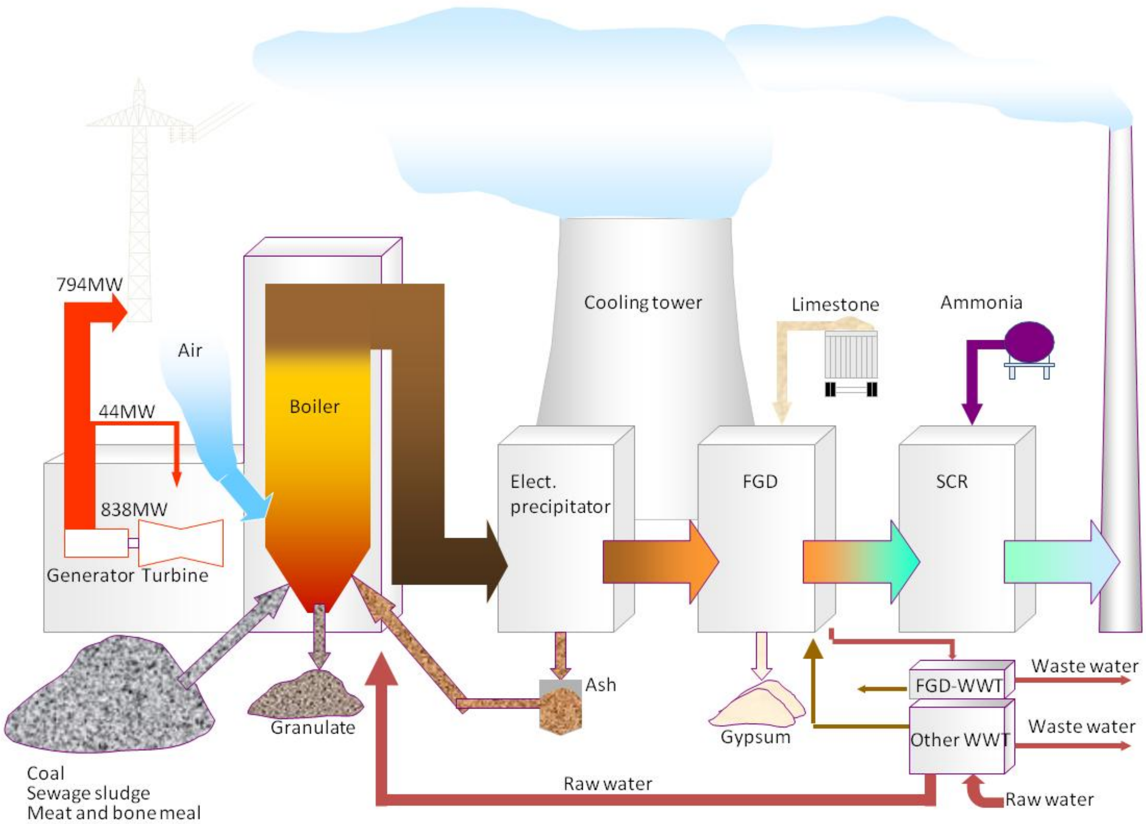

Figure 47: Sketch of the design of reference no. 121

The total rated thermal input of the plant is 2100 MW_{th}, the gross electric power output is 838 MW_{el}. The nominal gross electrical efficiency is 39.9 %.

Table 174 shows values for the fuel energy input and energy output in the reference year 2010. Five years (2006 – 2010) have been taken into account for the rolling average value.

Table 174: General operating data for reference no. 121

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	1.41E+07	1.23E+07
Gross electric energy output	MWh_{el}	5.65E+06	4.77E+06
Net electric energy output	MWh_{el}	5.29E+06	4.46E+06
Gross heat output – steam	MWh_{th}	1.21E+04	4.08E+04
Net heat output – steam	MWh_{th}	0	2.87E+04
Total operating time under normal operating conditions	h	7958	7383
Equivalent full load operating factor	%	84.5	79.6

In the reference year, the plant was operated for about 8000 h with an equivalent full load operating factor of 84.5 %, respectively 79.6 % for the fire-year average. The net electrical utilisation ratio is 37.5 %. For the rolling average value a net electrical utilisation ratio of 36.3 % can be calculated. The total operating time under normal operating conditions for the rolling average value is about 7400 h with an equivalent full load operating factor of 79.6 %.

Environmental aspects

The plant releases typical air and water emissions for hard coal-fired power plants as well as produces corresponding solid by-products. The air pollutants dust, SO_x, NO_x, CO and Hg are continuously measured in the flue gas. In addition to these parameters, HCl and HF are periodically measured. There are primary and secondary measures used for emission abatement. Primary measures are air staging as well as implemented low-NO_x-burners.

The first stage of the flue gas treatment process is the preheating of the inlet air followed by the removal of fly ash and dust in the electrostatic precipitator (ESP). The dust is recirculated into the furnace. SO_x are then removed in the wet flue gas desulphurisation (FGD), where they react with $CaCO_3$ to form gypsum, which is mainly used as valorised by-product in the cement industry. Finally, the flue gas is reheated, before NO_x is converted to nitrogen and water in a selective catalytic reduction unit (SCR), using ammonia (NH_3). The flue gas is then released via stack. The flue gas treatment facility in its whole is suggested as BAT by the operator.

Table 175 shows the concentrations and the annual loads for the measured air pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by the competent authority is given. It should be noted, that the presented concentration values are validated (i.e. standardised values with subtraction of the measurement uncertainty, which has been determined during calibration) and do not include OTNOCs, while the values for the annual loads do include OTNOCs. The reference oxygen content is 6 %.

It is emphasised, that the plant's emission data for the reference year 2010 characteristically depends from the percentage of the co-combustion of surrogate fuels.

The emission behaviour and characteristics do only reflect in extracts the whole emission behaviour of the power plant over a necessarily to be considered longer period.

Table 175: Air emissions for reference no. 121

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h*	d
Dust	mg/Nm^3	0	1.7	5.6	13.3	15.6	82.8	HHV	Cont.	Yes	-	20
	kg/year	9.4E+04										
SO_x	mg/Nm^3	19.5	45.8	82.7	106.3	111.3	335.8	HHV	Cont.	Yes	-	180
	kg/year	1.4E+06										
SO_x removal	(%)	-	-	96.1	-	-	-	HHV	-	-	-	85
NO_x	mg/Nm^3	10.5	182.8	187.4	191.3	193	1353	HHV	Cont.	Yes	-	200
	kg/year	3.1E+06										
CO	mg/Nm^3	0	0	7.6	31.2	39.8	371.4	HHV	Cont.	Yes	-	220
	kg/year	1.2E+05										
HCl	mg/Nm^3	-	-	0.97	-	-	-	HHV	Perio.	Yes	-	20
	kg/year	1.8E+04										
HF	mg/Nm^3	-	-	1.35	-	-	-	HHV	Perio.	Yes	-	10
	kg/year	2.5E+04										
Hg	mg/Nm^3	0	0	0.0008	0.002	0.002	0.052	HHV	Cont.	Yes	-	0.03
	kg/year	12.97										

* Values obtained in 2010 are based on validated half-hourly values. These values result out of normed values with subtraction of the measurement uncertainty, which has been determined during the calibration process. Normally, the half-hourly emission limit value equates to the double of the daily average emission limit value according to the 13. / 17. BImSchV.

The waste water from the plant is pre-treated on-site, before it is discharged. The waste water can be divided into the following four groups: waste water from the FGD, sanitary waste water, neutralized water from the water conditioning facility and other waste waters (surface runoff and process waters). The waste water streams show different characteristics. The water emissions are presented in Table 176, Table 177 , Table 178 and Table 179, a flow-sheet has been attached to the questionnaire as well. The cleaning of the waste water from the FGD and the recycling of used water (from the water conditioning) are suggested as BAT by the operator. In addition to this, the fresh water consumption could be reduced in two ways: in-situ improvements to the cooling water quality allowed for less additional raw water in the cooling cycle (decarbonising); waste water from the cooling system can be reused in the FGD and the granulate circuit. Both approaches along with the internal cooling tower make-up water treatment facilities and sludge utilisation are therefore also suggested as BAT by the operator.

Table 176: Water emissions for reference no. 121 - after WWT (FGD)

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	2.6E+05	-	-	-	-	-	-
Temp.	(°C)	-	-	30	-	-	-	-	-
pH		6.5	-	9	-	-	-	-	-
TSS	(mg/l)	2.4	9.9	38.5	Daily average	Grab sample	-	12	threshold value: 30 mg/l for 95% of all measurements. Up to 45 mg/l for 5% of remaining measurements.
	(kg/year)	2577							
F^-	(mg/l)	7.7	15.2	23	-	Grab sample	-	4	30
	(kg/year)	3966							
SO_3^{2-}	(mg/l)	0.4	4.8	13	-	Grab sample	-	4	20
	(kg/year)	1249							
SO_4^{2-}	(mg/l)	1051	1290	1480	-	Grab sample	-	4	2000
	(kg/year)	3.4E+05							

Table 177: Water emissions for reference no. 121 - after WWT (other waste waters)

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	5.4E+05	-	-	-	-	-	-
Temp.	(°C)	-	-	30	-	-	-	-	-
pH		6.5	8	9	-	-	-	-	-
TSS	(mg/l)	3.3	6.6	12.5	-	Grab sample	-	4	30
	(kg/year)	3536							

Table 178: Water emissions for reference no. 121 - after WWT (neutralised water)

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	1.8E+04	-	-	-	-	-	-
Temp.	(°C)	-	-	30	-	-	-	-	-
pH		6.5	7.3	9	-	-	-	-	-

Table 179: Water emissions for reference no. 121 - after WWT (sanitary waters)

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	6484	-	-	-	-	-	-
Temp.	(°C)	-	-	30	-	-	-	-	-
pH		6.5	-	9	-	-	-	-	-
BOD_5	(mg/l)	1.1	3.7	9	-	Grab sample	No	4	20
	(kg/year)			24					

Table 180 shows the solid by-products (e.g. gypsum, sludge and ashes). Granulate material (ash) and gypsum make up the largest part of the by-products. The optimisation of the gypsum quality (FGD prewashing and centrifugal dewatering) as well as the utilisation of the granulate material are suggested as BAT by the operator.

Table 180: Solid residues for reference no. 121

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Granulate Material (Ash)	Combustion process	100101	1.56E+05	Utilisation - others	Road construction
Gypsum	Flue-gas treatment facilities	100105	7.23E+04	Utilisation - others	Cement industry
Slag	Combustion process	100114	1.49E+02	Reclamation/restoration of open cast mines, quarries and pits	Recycling of raw materials
Dust	Flue-gas treatment facilities	100116	1.77E+02	Reclamation/restoration of open cast mines, quarries and pits	Recycling of raw materials
Cooling Tower Water treatment facilities' sludge	Raw water treatment facilities	199003	1.19E+02	Utilisation - others	Agriculture
FGD-Sludge	WWT facilities	100107	7.70E+03	Reclamation/restoration of open cast mines, quarries and pits	Recycling of raw materials

Special characteristics

Due to the unique and site-specific main fuel, a specially designed conveying system and air-recirculation system are integrated in the fuel pre-treatment and handling system. In addition to this, a magnetic metal removal is installed. This is suggested as BAT by the operator.

The plant uses a process quality optimisation system in order to identify improvement potential and to optimise the plant operation mode. This technology is suggested as BAT as well.

Pulverised Coal Firing, Reference no. 132

Reference no. 132 is a pulverised coal-fired power plant for electricity generation. The plant was commissioned in 1987 and revised in 1998. The fuel is mainly hard coal, but petroleum coke can be co-combusted (max. share 10 %). Oil and Refused Derived Fuel (RDF) are only used for the start-up.

The boiler is a once-through boiler with low load forced circulation, which feeds a steam turbine. The live steam parameters are 210 bar and 544°C, the reheater steam parameters are 45 bar and 544 °C. The cooling system uses a cooling tower. It can be operated as open once-through cooling system with cooling tower or as closed circulation with cooling tower. Figure 48 shows a sketch of the plant layout.

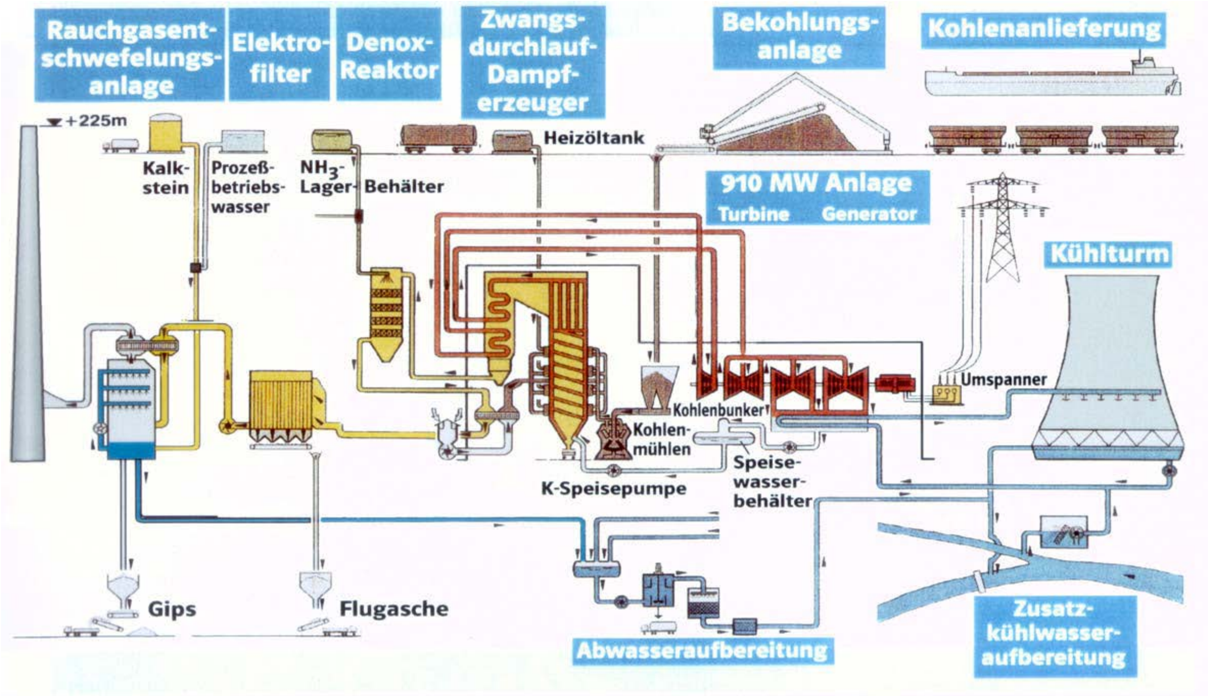

Figure 48: Sketch of the design of reference no. 132

The total rated thermal input of the plant is 2150 MW_{th}, the gross electric power output is 920 MW_{el}. The nominal gross electrical efficiency is 42.8 %.

Table 181 shows values for the fuel energy input and energy output in the reference year 2010. Five years have been taken into account for the rolling average value.

Table 181: General operating data for reference no. 132

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	1.15E+07	1.07E+07
Gross electric energy output	MWh_{el}	4.78E+06	4.39E+06
Net electric energy output	MWh_{el}	4.54E+06	4.16E+06
Total operating time under normal operating conditions	h	6836	6163.6
Equivalent full load operating factor	%	78	81

In the reference year, the plant was operated for about 6800 h with an equivalent full load operating factor of 78 %. The net electrical utilisation ratio is 39.5 %. For the rolling average value a net electrical utilisation ratio of 38.9 % can be calculated. The total operating time under normal operating conditions for the rolling average value is about 6100 h with an equivalent full load operating factor of 81 %.

Environmental aspects

The plant produces typical air and water emissions for hard coal-fired power plants as - well as corresponding solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x, CO, HCl, HF and NH_3 are continuously measured in the flue gas. There are primary and secondary measures taken for emission abatement. Primary measures are air staging as well as low-NO_x-burners. Figure 49 shows a schematic diagram of the FGT process (secondary measures).

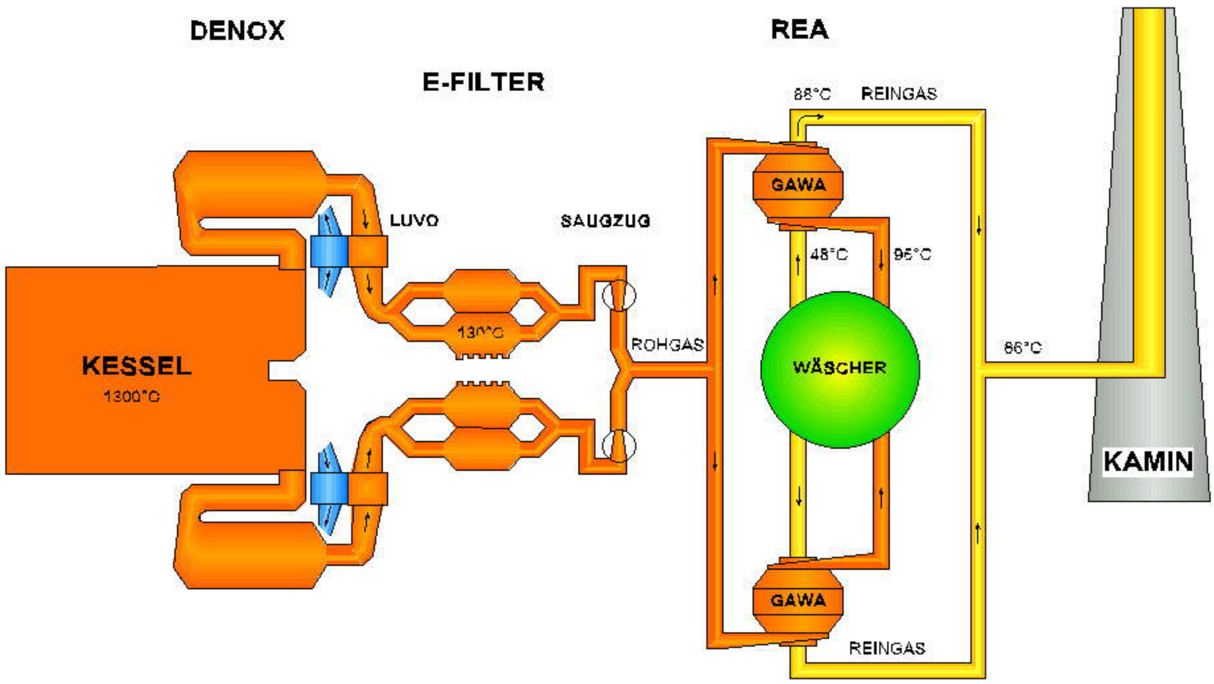

Figure 49: Schematic diagramm of the FGT process for reference no. 132

The first stage of the FGT process is the SCR unit, in which NO_x is reduced by using NH_3. The flue gas is then cooled (air heater), before dust is removed in the ESP. SO_x is removed in the wet FGD, where it reacts with $CaCO_3$ to form gypsum. The treated flue gas is reheated and emitted via a stack.

Table 182 shows the concentration and the annual load for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do not include OTNOCs. The reference oxygen content is 6 %.

Table 182: Air emissions for reference no. 132

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	3.2	-	4.7	-	-	7.3	HHV	Cont.	Yes	40	20
	kg/year	8.7E+04										
SO_x	mg/Nm^3	33.4	-	81.2	-	-	106.2	HHV	Cont.	Yes	400	200
	kg/year	1.4E+05										
SO_x removal	(%)	-	-	91	-	-	-	HHV	Cont.	Yes	-	88
NO$_x$	mg/Nm^3	168.8	-	182.6	-	-	191.2	HHV	Cont.	Yes	400	200
	kg/year	2.9E+05										
CO	mg/Nm^3	1.7	-	2.8	-	-	3.6	HHV	Cont.	Yes	76	38
	kg/year	5.2E+04										
HCl	mg/Nm^3	-	-	2.17	-	-	-	HHV	Cont.	Yes	-	-
	kg/year	3.9E+04										
HF	mg/Nm^3	2.64	-	3.24	-	-	3.86	HHV	Cont.	Yes	20	10
	kg/year	5.6E+04										
Hg	mg/Nm^3	-	-	-	-	-	-	-	-	-	-	-
	kg/year	-										
NH_3	mg/Nm^3	0	-	0.1	-	-	0.4	HHV	Cont.	Yes	4	2
	kg/year	1326										

Waste water is discharged from the WWT facility on the one hand and from the neutralisation pond on the other. The water emissions are presented in Table 183 and Table 184.

Table 183: Water emissions for reference no. 132 - after WWT

		Minimum	Average	Maximum	Type ofa verage	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	1.2 E+05	-	-	-	-	-	-
Temp.	(°C)	-	50	-	-	-	-	-	50
pH		-	7.5	-	-	-	-	-	-
TDS	(mg/l)	-	2	-	-	Grab sample	-	6	20
	(kg/year)			-					
TOC	(mg/l)	-	3.61	-	-	Grab sample	-	6	13
	(kg/year)			-					
F^-	(mg/l)	-	2.8	-	-	Grab sample	-	6	10
	(kg/year)			-					
SO_3^{2-}	(mg/l)	-	0.22	-	-	Grab sample	-	-	20
	(kg/year)			-					
N (total)	(mg/l)	-	37.3	-	-	Grab sample	-	6	45
	(kg/year)			-					
NH_3-N	(mg/l)	-	0.95	-	-	Grab sample	-	6	10
	(kg/year)			-					
Cd	(mg/l)	-	0.01	-	-	Grab sample	-	6	0.015
	(kg/year)			-					
Hg	(mg/l)	-	0.0005	-	-	Grab sample	-	6	0.015
	(kg/year)			-					
Pb	(mg/l)	-	0.015	-	-	Grab sample	-	6	0.03
	(kg/year)			-					
Cr	(mg/l)	-	0.01	-	-	Grab sample	-	6	0.1

		Minimum	Average	Maximum	Type ofa verage	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
	(kg/year)			-					
Cu	(mg/l)	-	0.01	-	-	Grab sample	-	6	0.1
	(kg/year)			-					
Ni	(mg/l)	-	0.01	-	-	Grab sample	-	6	0.1
	(kg/year)			-					
Zn	(mg/l)	-	0.02	-	-	Grab sample	-	6	0.3
	(kg/year)			-					

Table 184: Water emissions for reference no. 132 - neutralisation pond

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	1.2E+04	-	-	-	-	-	-
Temp.	(°C)	-	20	-	-	-	-	-	20
pH		-	7.4	-	-	-	-	-	-
TDS	(mg/l)	-	25.4	-	-	Grab sample	-	6	50
	(kg/year)			-					
N (total)	(mg/l)	-	190.7	-	-	Grab sample	-	6	150

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
	(kg/year)			-					
As	(mg/l)	-	0.03	-	-	Grab sample	-	6	0.1
	(kg/year)			-					
AOX	(mg/l)	-	0.357	-	-	Grab sample	-	6	1
	(kg/year)			-					

Table 185 shows the solid residues (by-products). Fly ash makes up the largest part of the by-products. The by-products can be utilised in the construction material industry and the road building.

Table 185: Solid residues for reference no. 132

Description	Source	Code	Generation in t during reference year	Final destinat ion	For utilisation, specify the activity the material is used in
Fly ash (minimum analytic figures)	Flue-gas treatment facilities	-	1.6E+05	-	concrete additive, cement substitution
Bottom ash (minimum analytic figures)	Combustion process	-	2.2E+04	-	concrete blocks, road construction, filling application
Gypsum (minimumanalyticfigures)	Flue-gas treatment facilities	-	3.4E+04	-	plasterboard, projection plaster
FGD-sludge (analytic figures from 2009)	WWT facilities	-	1685	-	Filling application

Special characteristics

The plant was comprehensively upgraded in the past. Among other things, the minimal load was reduced and the load ramp was optimised. A FGD facility was installed. In 2005 the plant was further modernised, which allowed for an elevation of the super heater and reheater steam parameters. The feed-water pump is turbine driven.

Depending on the weather conditions, the cooling system can be adjusted. The amount of circulated water (cooling tower) can be raised, so that the amount of extracted river water is reduced.

These techniques are suggested as BAT by the operator.

3.4.2 Lignite-fired Boilers

3.4.2.1 General Discussion and Explanation of the Technology and the Emission Abatement Measures

In principle, the technologies and measures for emission control did not change compared to the predecessor report from 2002. Hence, for a detailed description please refer to this report[7]. Until 2010, no new lignite-fired LCPs were commissioned (industrial plants excluded). The newest evaluated boiler was commissioned in 2003. At the moment, new plants are under construction, in the commissioning phase, or were commissioned in the very recent past. They are designed for live steam parameters of 300 bar and 600 °C, which will improve the efficiency of the plants. As there is no operation data available, these plants are not included in this report.

Concerning the revision of the 13. BImSchV and the associated Hg emissions regulations, lignite-fired plants are treated the same as hard coal-fired ones. Please refer to chapter 3.4.1 for more information.

Lignite is a indigenous fuel in Germany and is normally, due to its relatively low calorific value, combusted in a plant near the mining area. The four German lignite fields are the Rhenish, the Middle German, the Lusatian and the Helmstedtian area. The composition of the lignite from these places can vary significantly. The most important characteristics are water content, heating value and sulphur content. Especially the sulphur content of the fuel influences the SO_x emissions. As can be seen from Table 188, the sulphur content in one are can be three times as high as in others. It can be said, that - in general - Rhenish lignite is low in sulphur, while lignite from the eastern areas of Germany is richer. For some plants that fire high sulphur, indigenous fuels, a special regulation is defined in the 13. BImSchV, which allows for elevated SO_x emission limit values under the condition that the SO_x removal is enhanced. For example: Plants with a TRTI of more than 300 MW_{th}, which fire high sulphur indigenous fuels, can be authorised for emission limit values of 400 mg/Nm^3 (in contrast to the normally valid value of 200 mg/Nm^3). At the same time, a SO_x removal of 95 % is then required (in contrast to the normally valid 85 %). For this reason, the here presented lignite-fired reference plants can show higher emission values when compared to the solid fuel-fired plants.

Other than with hard coals, NO_x emissions of lignite-fired plants can be dealt with solely with the help of primary abatement measures. Low-NO_x-burners and air staging are common, so that emission values of less than 200 mg/Nm^3 are achievable. A distinction must be made between new plants, already built with these measures and plants retrofitted with the according equipment. New built plants generally achieve lower emission values.

[7] RENTZ, O. ; GÜTLIN, K. ; KARL, U.: Erarbeitung der Grundlagen für das BVT-Merkblatt Großfeuerungsanlagen im Rahmen des Informationsaustausches nach Art. 16(2) IVU-Richtlinie, Forschungsbericht 200 46 317 / Deutsch-Französisches Institut Für Umweltforschung Universität Karlsruhe (TH). 2002. – Forschungsbericht

3.4.2.2 Presentation of the Results (evaluation levels III and IV)

For lignite-fired LCP eight combustion installations were evaluated. As some of these consist of multiple combustion plants, a total of 15 questionnaires was submitted. The combustion installation no. 128/129 consists of twelve boilers, of which eight are used for co-combustion of waste (no. 128-1 to 128-4). The remaining four boilers are not used for waste incineration and have therefore been named separately (no. 129-1 and 129-2). This is the reason for nine combustion installation numbers although there are only eight combustion installations evaluated.

Table 186 shows the evaluation level III for lignite-fired plants with their most significant characteristics with respect to the aforementioned classification by the thermal input (300 - 1000 MW_{th}, 1000 - 2000 MW_{th} and > 2000 MW_{th}). If for "other" nothing is stated, the concerned plant is a dry-bottom pulverised lignite firing. According to the standards given by the EIPPCB, all plants (except for plant no. 109) are operated in base load with high equivalent full load operating factors of more than 75 %. Plant no. 109 is used in the sugar industry and therefore operated seasonally, which is the cause for the low operating hours (4872 h). In contrast to all other plants, plant no. 109 uses not raw lignite, but lignite briquettes in a grate firing.

Table 186: Evaluation level III: Group "Lignite-fired Boilers"

TRTI in MW_{th}	Plant no.	TRTI in MW_{th}	Year of commissioning (last retrofit)	Operating mode (according to EIPPCB)	Total operating time under normal conditions	Equivalent full load operating factor	CHP	Co-combustion of waste	Other
> 100 - 300	109	115	2004 (2011)	Base load	4872	81.7	Yes	No	Industrial grate Firing; seasonal operation
> 300 - 1000	137	855	1972 (2007)	Base load	6720	76.7	No	No	-
> 1000 - 2000	128-1	Je 1524	1981 (1991)	Base load	6561	83.5	Yes	Yes	2 identical boilers each; 96.6 % lignite
	128-2		1982 (1993)		7736	82.5			2 identical boilers each; 96.6 % lignite
	128-3		1983 (1992)		8587	84.3			2 identical boilers each; 97.8 % lignite
	128-4		1985 (1993)		8404	85.4			2 identical boilers each; 97.8 % lignite
	129-1		1987 (1994)		7700	85.4		No	2 identical boilers
	129-2		1988 (1994)		7346	85.0			
	130	1702	1975 (2011)	Base load	7345	83.4	No	No	-
> 2000	127-1	Je 2100	1998 ()	Base load	8145	91.2	Yes	Yes	2 identical boilers; 98.1 % lignite
	127-2				6312	90.8			2 identical boilers; 98.4 % lignite
	116	2306	2003 (2007)	Base load	6973	97.5	No	No	-
	117-1	Je 2465	2001 ()	Base load	8306	80.8	Yes	Yes	2 identical boilers; 98.5 % lignite
	117-2		2002 ()		7921	80.7			
	133	2512	1995/96 ()	Base load	6634	79.9	Yes	No	1 of 2 identical boilers, railway-electricity

It can be seen, that 15 of the combustion plants are co-combusting waste and that all but three plants are used for CHP. For lack of heat sinks, the extracted heat is rather small when compared to the total rated thermal input. Plant no. 109 makes an exception of this. The plants with total rated thermal input of more than 2000 MW_{th} are in average younger than plants between 1000 and 2000 MW_{th}. This is reflected in the efficiencies, as can be seen in Table 187. The larger the amount of extracted heat, the larger is the deviation from the calculated (calorific) efficiency in the questionnaire from the nominal value.

Table 187: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Lignite-fired Boilers"

TRTI in MW_{th}	Plant no.	Efficiency	Utilisation ratio			Fuel utilisation factor
		(el., gross, nom.) in %	(el., gross) in %	(el., net) in %	(th.) in %	(net) in %
> 100 - 300	109	22.6	19.4	18.1	67.8	85.9
> 300 - 1000	137	36.0	35.6	33.2	-	33.2
> 1000 - 2000	128-1	35.4	37.9	34.8	1.0	35.9
	128-2	35.4	38.1	35.1	1.4	36.5
	128-3	35.4	37.5	34.7	1.1	35.8
	128-4	35.4	37.9	35.2	0.6	35.8
	129-1	35.4	37.0	34.2	0.5	34.7
	129-2	35.4	36.9	34.0	0.8	34.9
	130	37.7	36.4	33.7	-	33.7
> 2000	127-1	38.1	40.1	37.5	8.6	46.2
	127-2	38.1	40.1	37.6	6.4	44.1
	116	43.1	44.2	41.6	-	41.6
	117-1	37.3	43.5	41.1	3.2	44.3
	117-2	37.3	43.1	40.8	3.1	43.9
	133	39.8	38.5	34.4	7.6	42.0

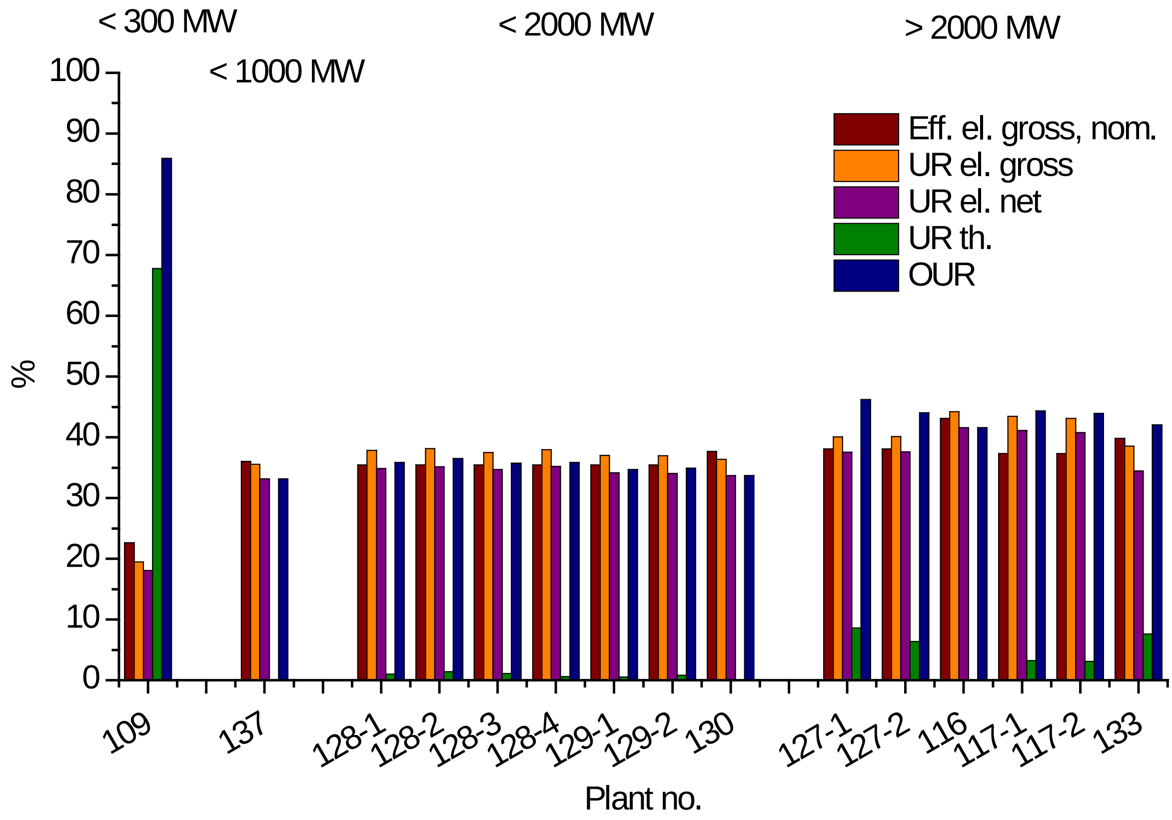

Figure 50: Evaluation level IV, Table a: Efficiencies and utilisation ratios for the Group "Lignite-fired Boilers"

The air emissions, the sulphur content of the fuel and secondary measures are shown in Table 188. In addition to this, the mining area is indicated (BK = Briquette, L = Lusatia, MD = Middle Germany, RH = Rhineland). It can be seen, that (e.g. for the Lusatian area) lignites from the same mining area can show significant differences in sulphur content. It should be noted, that plant no. 109 is the only plant with secondary NO_x abatement measures and the only plant with cyclone and fabric filter instead of an ESP. This is due to the fact that for grate Firings no primary measures can be taken for emission abatement. Additionally, the plant is equipped with a dry absorption FGD. It should further be noted that there are no secondary abatement measures for Hg and CO emissions. Instead, for Hg, the method to obtain data is given.

Table 188: Evaluation level IV, Table b: Air emissions for the Group "Lignite-fired Boilers"

TRTI in MW_{th}	Plant no.	NO_x		CO	Dust		SO_x				Hg	
		Ø in mg/Nm³	Secondary measures	Ø in mg/Nm³	Ø in mg/Nm³	Secondary measures	Ø S-content of coal in %	Ø in mg/Nm³	Secondary measures	Ø SO_x-removal in %	Ø in mg/Nm³	Method to obtain data
> 100 - 300	109	169.1	SNCR	95.1	5.7	Cyclone, fabric filter	0.35 (BK)	79.7	Dry adsorption	85.0	-	-
> 300	137	195.6	-	148.1	11.5	ESP	0.9 (RH)	14.9	FGD	98.7	0.003	estimated
> 1000 - 2000	128-1	194.2	-	96.2	7.3	ESP	1.1 (L)	191.6	FGD	96.1	0.009	Perio. (9x)
	128-2	195.0	-	115.0	6.5	ESP	1.1 (L)	210.0	FGD	95.7	0.009	Perio. (9x)
	128-3	194.0	-	150.1	7.6	ESP	1.1 (L)	222.2	FGD	95.7	0.009	Perio. (9x)
	128-4	190.7	-	151.4	6.1	ESP	1.1 (L)	229.6	FGD	95.6	0.009	Perio. (9x)
	129-1	189.3	-	179.0	6.6	ESP	1.1 (L)	235.1	FGD	95.7	0.009	Perio. (9x)
	129-2	192.7	-	168.0	7.1	ESP	1.1 (L)	236.1	FGD	95.7	0.009	Perio. (9x)
	130	193.1	-	75.0	2.7	ESP	0.9 (RH)	64.0	FGD	97.0	0.003	estimated
> 2000	127-1	120.3	-	53.4	1.6	ESP	0.71 (L)	220.0	FGD	95.4	0.007	Perio. (9x)
	127-2	120.9	-	26.8	1.3	ESP	0.71 (L)	199.7	FGD	95.5	0.007	Perio. (9x)
	116	168.2	-	0.8	0.8	ESP	0.9 (RH)	76.6	FGD	94.4	0.005	estimated
	117-1	171.4	-	11.8	3.1	ESP	1.6 (MD)	296.7	FGD	95.6	0.015	Cont.
	117-2	162.2	-	23.2	2.8	ESP	1.6 (MD)	302.0	FGD	95.4	0.018	Cont.
	133	168.4	-	19.4	4.6	ESP	1.77 (MD)	215.1	FGD	97.6	0.014	Cont.

As can be seen in Figure 51, which shows the NOx emissions, plants with a total rated thermal input of 300 to 2000 MW_{th} emit about 200 mg/Nm^3 of NO_x. They have been retrofitted with primary abatement measures. Newer, larger plants, which were already designed with primary abatement measures, show NO_x concentrations of 120 - 171 mg/Nm^3. The wide concentration range is due to the fact, that NO_x-reducing primary measures are limited by high temperature corrosion caused by sulphur.

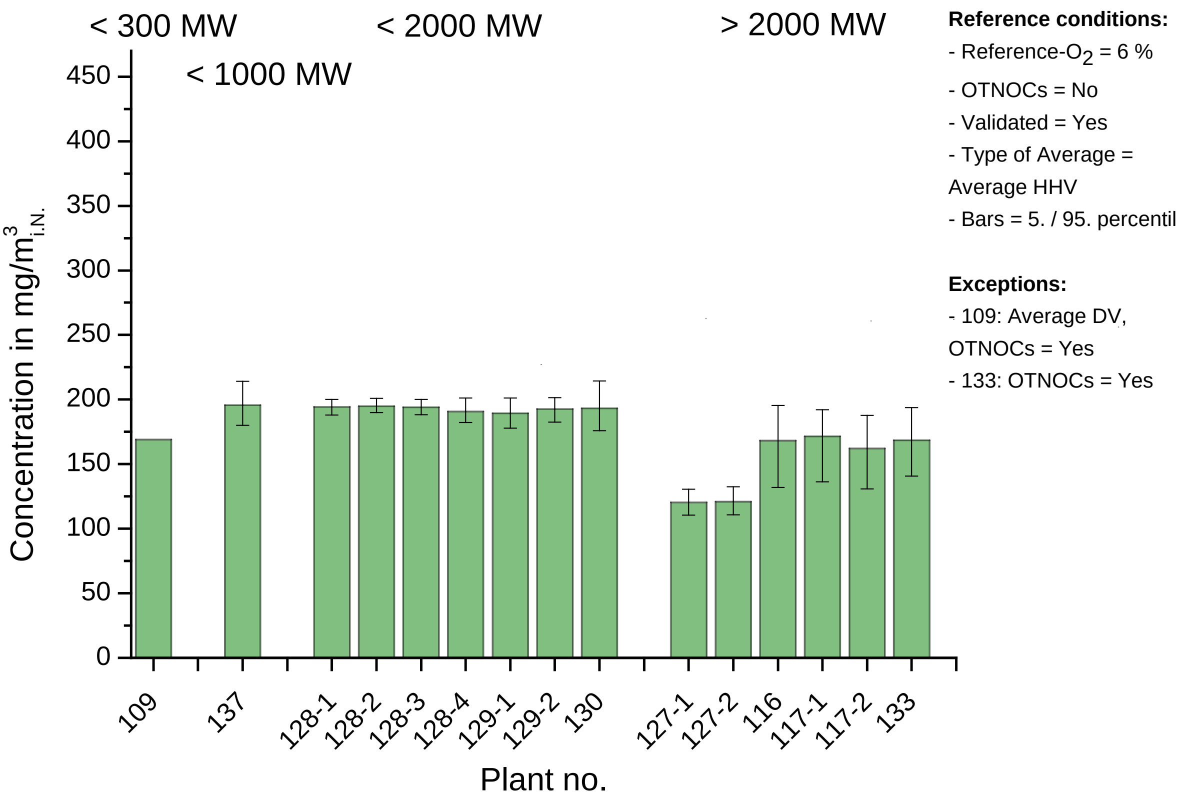

Figure 51: Evaluation level IV, Table b: NO_x emissions for the Group "Lignite-fired Boilers"

The distribution of CO emissions, shown in Figure 52, is similar to that of NO_x. The larger, newer plants show lower values, because primary measures were already included in their furnace design. The cross section of the furnace of older plants is relatively small, thus preventing good burnout. Plant no. 116 shows CO emissions of only 0.8 mg/Nm^3.

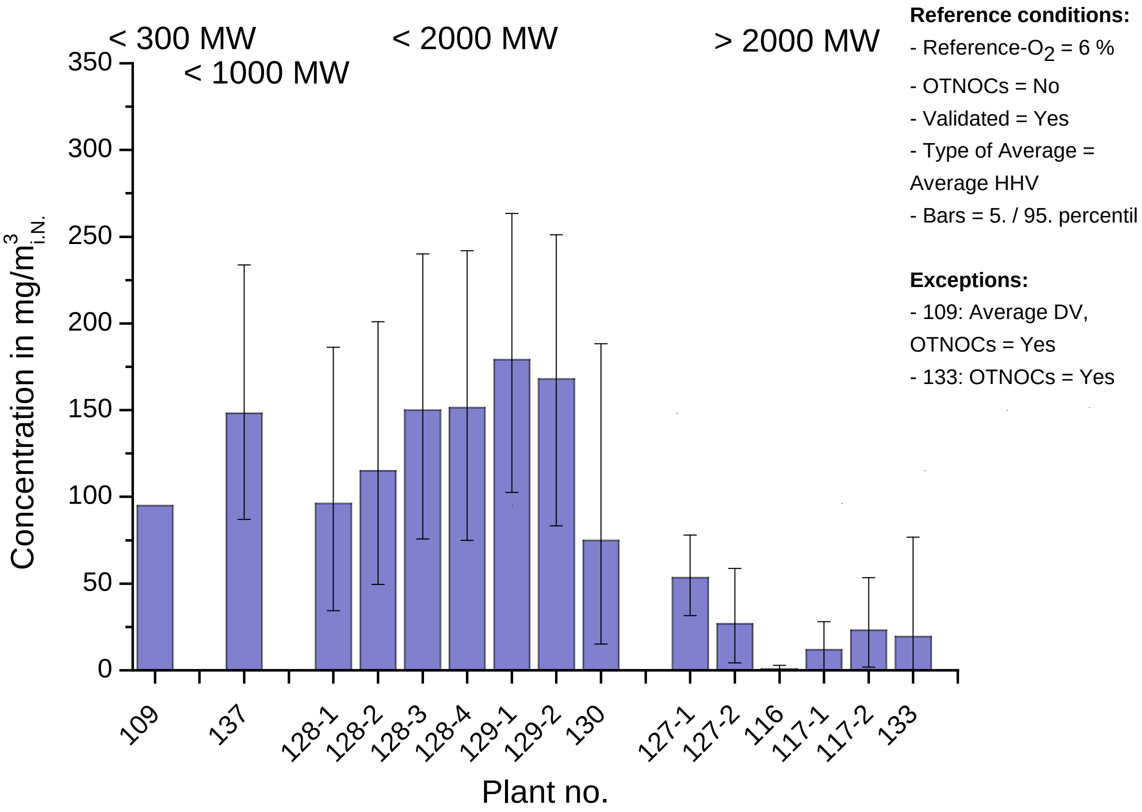

Figure 52: Evaluation level IV, Table b: CO emissions for the Group "Lignite-fired Boilers"

As can be seen in Figure 53, the dust emissions of newer plants are also lower than those of older plants. The overall emission value level is low. With exception of plant no. 137, all plants show values of well below 10 mg/Nm^3. Plant no. 137 is the oldest plant and was retrofitted.

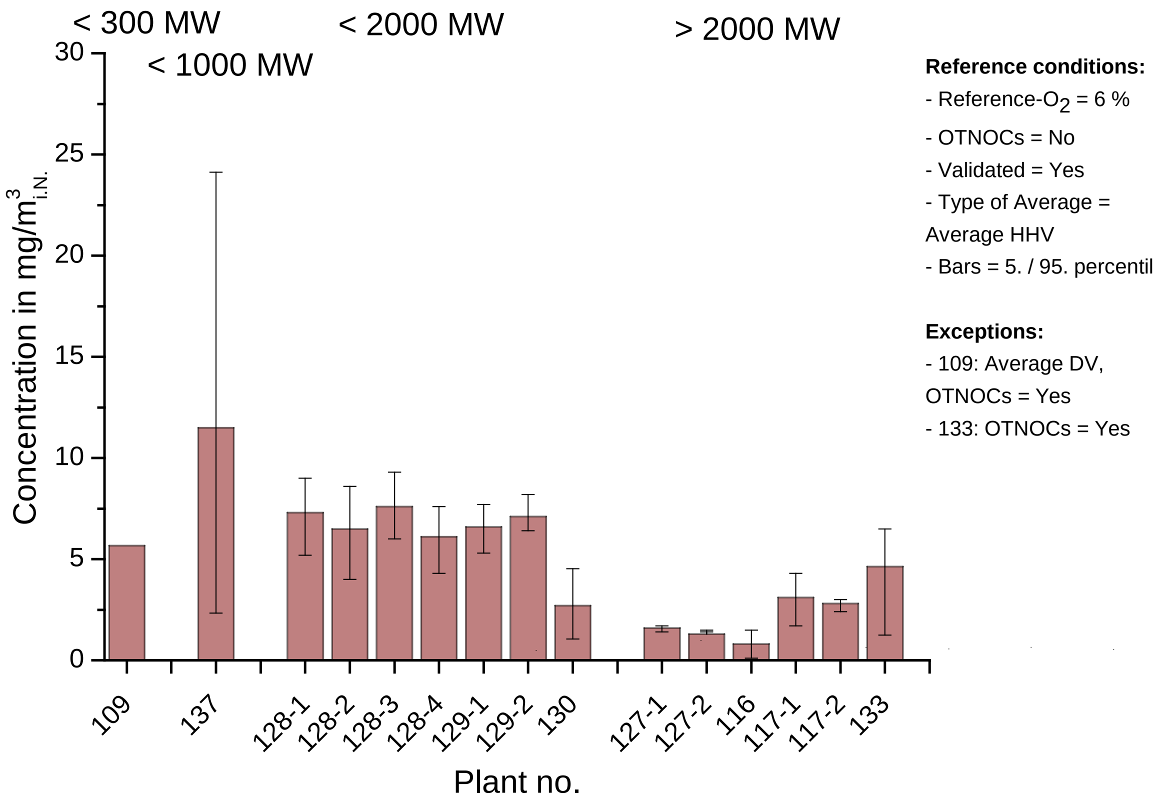

Figure 53: Evaluation level IV, Table b: Dust emissions for the Group "Lignite-fired Boilers"

The tendency of larger plants having lower emissions cannot be approved by the SO_x emissions. The influence of the lignite mining area and thus the sulphur content of the fuel is predominantly. As can be seen in Figure 54, most plants show emissions of more than 200 mg/Nm^3 on an annual average basis. Plants no. 109, 116, 127, 128/129, 130 and 137 combust lignite with medium sulphur content. This causes, with the exception of plant no. 127 and 128/129, low SO_x emissions. Figure 55 shows the SO_x removal. Plants no. 130, 133 and 137 display values of above the required 95 %, which all other raw lignite-fired plants achieve.

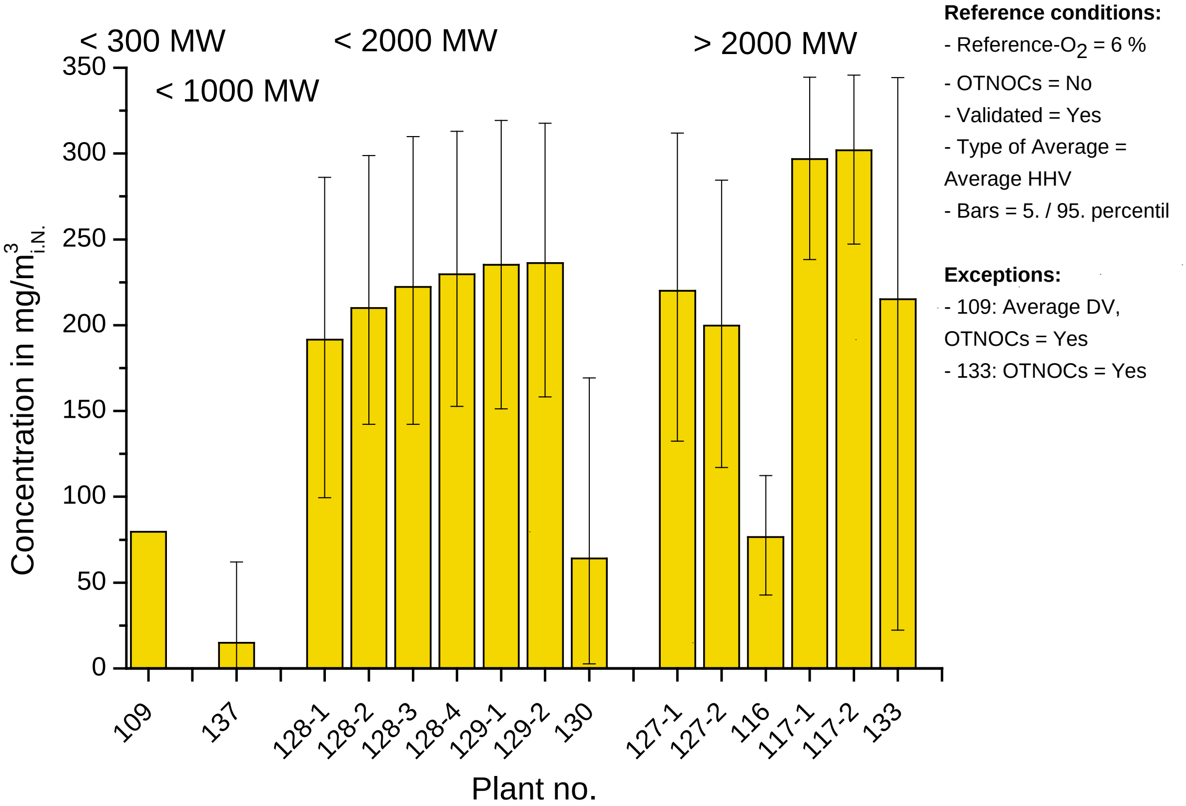

Figure 54: Evaluation level IV, Table b: SO_x emissions for the Group "Lignite-fired Boilers"

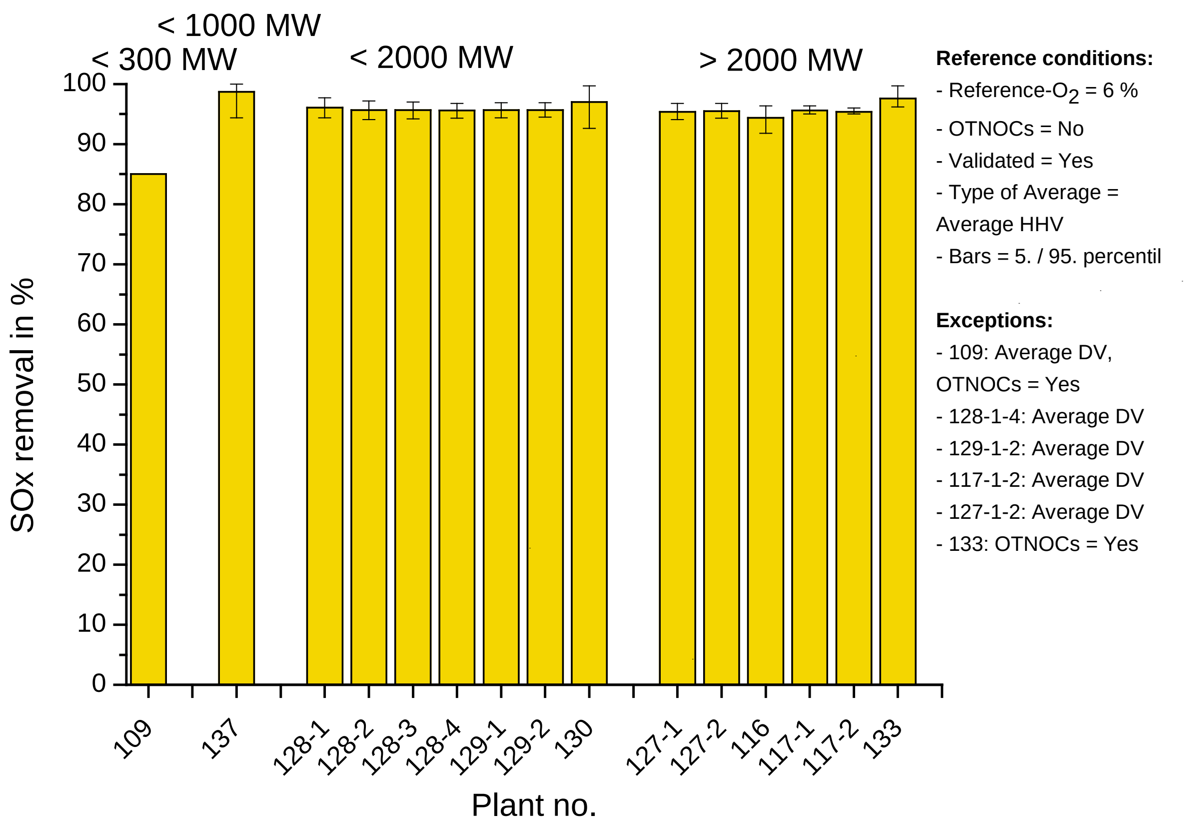

Figure 55: Evaluation level IV, Table b: SO_x removal for the Group "Lignite-fired Boilers"

For plants firing Lausatian or Middle German lignite the permit emission value for SO_x is between 300 and 400 mg/Nm^3 on a daily average basis. In addition to this, usually a SO_x removal of 95 % on a daily average basis is required. This is true for all evaluated plants but no. 109 and 116. The SO_x removal is only required, if the individually carried out proportionality assessment allows for it.

The Hg emissions of lignite-fired plants are shown in Figure 56. The emissions of all evaluated plants is about 10 µg/Nm^3 on an average basis and thus about three times as high as for the evaluated hard coal-fired plants.

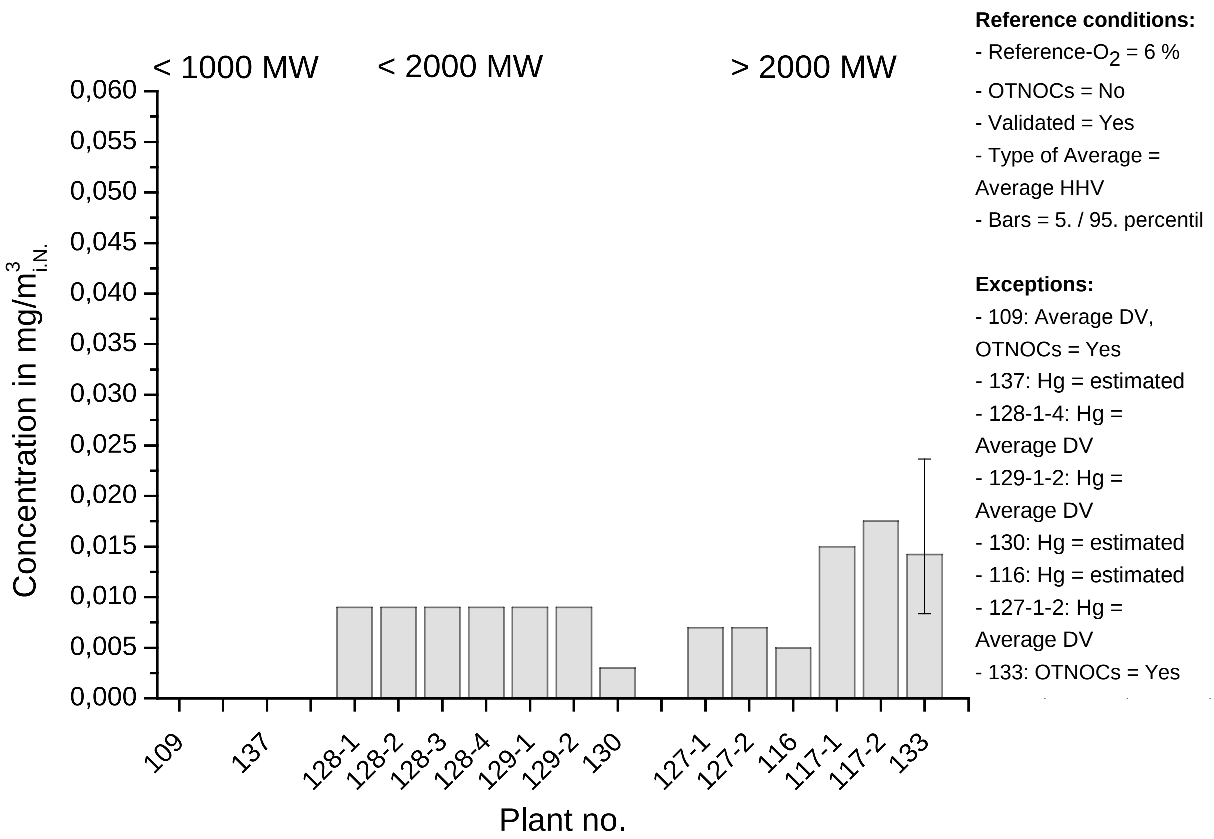

Figure 56: Evaluation level IV, Table b: Hg emissions for the Group "Lignite-fired Boilers"

Table 189 shows the reference conditions and exceptions for lignite-fired plants.

Table 189: Reference conditions and exceptions for the Group "Lignite-fired Boilers"

Plant no.	Ref. O_2 in %	Includes OTNOCs	Validated	Type of average	Fuel	Other
Reference	6	No	Yes	HHV	Lignite	-
109	-	Yes	-	DA	96 % coal, co-combustion of waste	Industrial plant, seasonal operation, cyclone, fabric filter, dry FGD
117	-	-	-	-	1.5 % co-combustion of waste	-
127	-	-	-	-	2 % co-combustion of waste	-
128	-	-	-	-	3 % co-combustion of waste	-
133	-	Yes	-	-	-	Railway electricity

Table 190 shows the water emissions for lignite-fired plants. Compared to the other groups in this report, it has to be noted that the type of WW is varying widely and that the quality of the raw water is also of importance. Plant no. 133 shows a deviation from the other plants, as it is the only plant that discharges waste water from the FGD. In all other reference plants, the waste water from the FGD is used for slope stabilisation in open cast mines together with the ashes. In the effluent of the FGD-WWT of plant no. 133, pollutants, defined in appendix 47 D of the waste water regulations (Fluoride, Cu, Cd, Hg and Pb), are measured. However, not all these values are given by the operator for the sake of clarity. The values given in the here presented table refer to the common discharge point at which all occurring waste water streams are discharged. The concentrations of pollutants originating from the FGD are therefore rather small, as the FGD waste water has been diluted by other waste waters, and are therefore not comparable to the stated emission values for hard coal-fired boilers.

Table 190: Evaluation level IV, Table c: Water emissions for the Group "Lignite-fired Boilers"

Q_{th} in MW	Plant no.	TOC in mg/l	COD in mg/l	N (total) in mg/l	P (total) in mg/l	Sul-phate in mg/l	Fluo-ride in mg/l	Cu in mg/l	Cd in mg/l	Hg in mg/l	Pb in mg/l	Discharge point	Origin of WW
> 100 - 300	109	-	-	-	-	-	-	-	-	-	-	-	-
> 300 - 1000	137	2.9	9.0	1.9	0.03	-	-	-	-	-	-	River (T)	Ash treatment
> 1000 - 2000	128-1a, 128-2a, 128-3a. 128-4a.	6.5	-	-	0.21	-	-	-	-	-	-	River (NT)	Cooling system
	128-1b, 128-2b, 128-3b. 128-4b.	7.7	-	1.1	0.06	-	-	-	-	-	-	River (T)	Steam system, Surface runoff, Other
	130	3.1	9.0	2.4	0.05	-	-	-	-	-	-	River (T)	Ash treatment
> 2000	127-1a, 127-2a	8.1	-	2.7	0.18	1397	-	-	-	-	-	River (T)	Cooling system, Water conditioning, Equipment cleaning, Surface runoff
	127-1b, 127-2b	-	-	-	-	-	-	-	-	-	-	Off-site WWT (NT)	Wasseraufbereitung, Steam system, Other
	116	3.7	-	1.1	0.18	242	-	-	-	-	-	River (T)	Ash treatment
	117-1a, 117-2a	12.2	31.1	14.2	0.20	-	-	-	-	-	-	River (T)	Water conditioning, Cooling system, Equipment cleaning
	117-1b, 117-2b	-	-	-	-	-	-	-	-	-	-	Sewerage (NT)	Water conditioning, Other
	133	10.0	45.0	-	-	1290	5.0	0.020	0.005	0.0002	0.10	River (T)	FGD, Steam system, Cooling system

A total of 40 templates was submitted for BAT for lignite-fired boilers. They deal with several technical domains and vary in their level of detail. They are summarised in Table 191. More detailed information can be found in the individual plant descripitions.

Table 191: Evaluation level IV, Table d: BAT submissions for the Group "Lignite-fired Boilers"

TRTI in MW_{th}	Plant no.	No. of templates	Short summary	Technical domain	Level of detail
> 100 - 300	109	1	Dry FGT	Air emissions	Low
> 300 - 1000	137	11	Coal crushing	Fuel pre-treatment	Medium
			Separation of impurities	Fuel pre-treatment	Medium
			Wet FGD	Air emissions	Medium
			Flue gas emission via cooling tower	Air emissions	Medium
			WWT facility	Water	Medium
			Recycling of WW	Water	Medium
			Utilisation of gypsum	Solid residues	Low
			Utilisation of pulpwood	Solid residues	Low
			Decarbonisation (reduced water consumption)	Water	Low
			Low-NO_x combustion (air staging)	Combustion	Medium
			Low-NO_x combustion (burners)	Combustion	Medium
> 1000 - 2000	128-1, 128-2, 128-3, 128-4, 129-1, 129-2	3	ESP	Air emissions	Low
			Wet FGD	Air emissions	High
			Low-NO_x combustion	Combustion	Medium
	130	10	Coal crushing	Fuel pre-treatment	Medium
			Separation of impurities	Fuel pre-treatment	Medium
			Wet FGD	Air emissions	Medium
			Flue gas emission via cooling tower	Air emissions	Medium
			WWT (process water)	Water	Medium

TRTI in MW_{th}	Plant no.	No. of templates	Short summary	Technical domain	Level of detail
			Recycling of WW	Water	Medium
			Utilisation of gypsum	Solid residues	Low
			Utilisation of pulpwood	Solid residues	Low
			Decarbonisation (reduced water consumption)	Water	Low
			Low-NO_x combustion (air staging)	Combustion	Medium
			Utilisation of pulpwood	Solid residues	Low
			Decarbonisation (reduced water consumption)	Water	Low
			Low-NO_x combustion (air staging)	Combustion	Medium
> 2000	127-1, 127-2	3	ESP	Air emissions	Low
			Wet FGD	Air emissions	High
			Low-NO_x combustion	Combustion	Medium
	116	7	Coal crushing	Fuel pre-treatment	Medium
			Separation of impurities	Fuel pre-treatment	Medium
			Wet FGD	Air emissions	Medium
			Flue gas emission via cooling tower	Air emissions	Medium
			Utilisation of gypsum	Solid residues	Low
			Decarbonisation (reduced water consumption)	Water	Low
			Low-NO_x combustion (air staging)	Combustion	Medium
	117-1, 117-2	3	ESP	Air emissions	Low
			Wet FGD	Air emissions	High
			Low-NO_x combustion	Combustion	Medium
	133	2	Turbine for railway electricity	Turbine	Medium
			CHP operation	Whole plant	Medium

3.4.2.3 Descriptions of Evaluated Plants or Installations

Grate Firing, Reference no. 109

Reference no. 109 is a grate firing with dry ash removal for the generation of electricity and process steam for sugar industry, which was commissioned in 2004. The plant consists of a natural circulation boiler with travelling grate firing. The main fuel is lignite (3” lignite briquettes). In addition to this, NG can be combusted for start-up as well as LFO for auxiliary firing. The live steam parameters are 85 bar and 520 °C. The steam is fed into a back-pressure turbine with a nominal gross electric power output of 26 MW_{el}. The plant has no cooling system, because it is heat-operated. The entire exhaust steam is fed into an industrial process and delivered back as condensate. Up to 130 t/h of 3.5 bar steam can be delivered.

The total rated thermal input of the plant is 115°MW_{th}. The nominal gross electric power output is 26°MW_{el} and the maximal gross heat power output of 75.8 MW_{th}.

Table 192 shows values for the fuel energy input and energy output in the reference year 2009. Five years have been taken into account for the rolling average value.

Table 192: General operating data for reference no. 109

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	4.58E+05	3.40E+05
Gross electric energy output	MWh_{el}	8.90E+04	6.49E+04
Net electric energy output	MWh_{el}	8.27E+04	6.03E+04
Gross heat output – steam	MWh_{th}	3.10E+05	2.38E+05
Net heat output – steam	MWh_{th}	3.10E+05	2.38E+05
Total operating time under normal operating conditions	h	4872	3666
Equivalent full load operating factor	%	81.7	80.7

The plant shows a relatively small total operating time, which can be explained by the heat-operated mode. The industrial plant, to which the process steam is delivered, is in operation for 160 days per year. The equivalent full load operating factor is about 81 %. The net electrical utilisation ratio is 18.1 % (reference year) and 17.7 % (rolling average value), respectively. With a thermal utilisation ratio of 67.8 % (reference year) and 70.0 % (rolling average value), the fuel utilisation factor is 85.9 % (reference year) and 87.7 % (rolling average value).

Environmental aspects

The plant produces typical air and water emissions for lignite-fired power plants as well as corresponding amounts of solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x and CO are continuously measured in the flue gas. There are primary and secondary measures taken for emission abatement. The main primary measure is the air staging.

The first stage of the FGT process is the SNCR unit. NO_x is reduced by using urea, which is soluted and sprayed into the passing flue gas (via 8 nozzles in 2 layers). The flue gas is then fed into two gas cyclone separators, where dust is removed. The flue gas is then mixed with $Ca(OH)_2$. After a residence time of 11 seconds, the reaction products and the leftover Ca(OH)2 as well as fine dust are removed in a fabric filter.

Table 193 shows the concentration and the annual load for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated, but do include OTNOCs. The reference oxygen content is 6 %.

Table 193: Air emissions for reference no. 109

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	0.16	-	5.67	-	-	306	DV	Cont.	Yes	40	20
	kg/year	1633.51										
SO_x	mg/Nm^3	18.02	-	79.72	-	-	117.2	DV	Cont.	Yes	400	200
	kg/year	3.7E+04										
SO_x removal	(%)	-	-	85	-	-	-	DV	Cont.	Yes	-	-
NO_x	mg/Nm^3	99.61		169.1			206.5	DV	Cont.	Yes	400	200
	kg/year	8.1E+04										
CO	mg/Nm^3	41.7	-	95.06	-	-	164.3	DV	Cont.	Yes	400	200
	kg/year	4.7E+04										

No waste water is produced in the process. All of the used water is recycled after reconditioning in a demineralisation.

Table 194 shows the solid residues (by-products). Fly ash and grate ash make up the largest part of the by-products. The residues can be used for the restoration of open cast mines, quarries and pits. Because of the dry desulphurisation, no gypsum is produced.

Table 194: Solid residues for reference no. 109

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Grate ash	Flue-gas treatment facilities	100101	4.18E+03	Reclamation/restoration of open cast mines, quarries and pits	-
Fly ash	Combustion process	100102	2.71E+03	Reclamation/restoration of open cast mines, quarries and pits	-

Special characteristics

The plant is operated to meet the required amounts of process steam. As the industrial facility, which the steam is delivered to, is in operation for only 160 day per year, this is also true for the described plant.

The FGT with dry chemical adsorption and subsequent removal of the solid components in a fabric filter is suggested as BAT by the operator.

Pulverised Coal Firing, Reference no. 137

Reference no. 137 is a pulverised coal-fired power plant for electricity generation, which was commissioned in 1972. The plant consists of a once-through boiler, extensive flue gas treatment facilities and a cooling tower, through which the flue gas is released. The main fuel is Rhenish lignite. For start-up and for auxiliary firing, light fuel oil is used. The live steam parameters are 175 bar and 530 °C, the reheater steam parameters are 33 bar and 530 °C. The extraction/condensation steam turbine has a gross electrical power output of 308 MW_{el}. The cooling system is a circulation cooling with a natural draft cooling tower. Make-up water is taken from surface waters and from the pumping stations of the nearby open-cast mining pit. Figure 57 shows a schematic sketch of the plant layout.

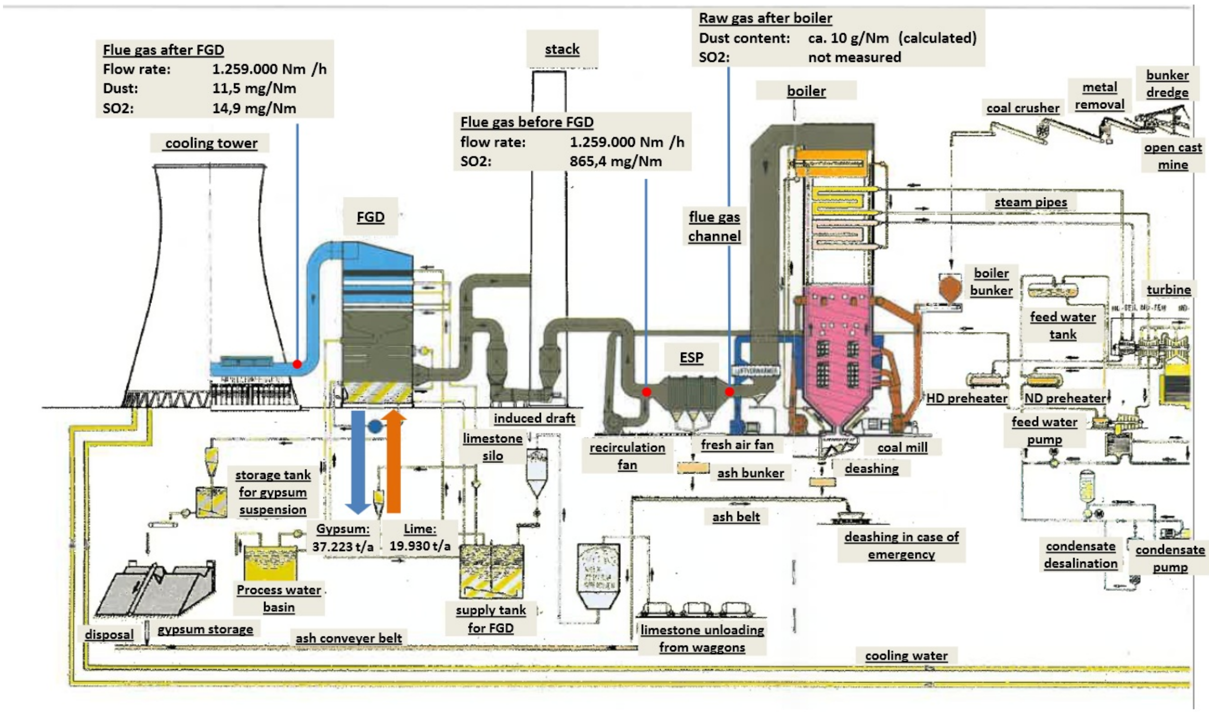

Figure 57: Sketch of the design of reference no. 137

The plant is located at a combustion site with a total rated thermal input of 5974 MW_{th}. Combustion installation no. 130 is also part of this combustion site. The total rated thermal input of the combustion installation no. 137 is 855 MW_{th}, the gross electric power output is 308 MW_{el}. The nominal gross electrical efficiency is 36.0 %.

Table 195 shows values for the fuel energy input and energy output in the reference year 2010. Five years (2006 – 2010) have been taken into account for the rolling average value.

Table 195: General operating data for reference no. 137

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	5.82E+06	6.15E+06
Gross electric energy output	MWh_{el}	2.07E+06	2.16E+06
Net electric energy output	MWh_{el}	1.93E+06	2.01E+06
Total operating time under normal operating conditions	h	6720	6942
Equivalent full load operating factor	%	76.7	79.2

In the reference year, the plant was operated for about 6700 h with an equivalent full load operating factor of 76.7 %. The net electrical utilisation ratio is 33.0 %. For the rolling average value a net electrical utilisation ratio of 33.0 % can be calculated. The total operating time under normal operating conditions for the rolling average value is almost 7000 h with an equivalent full load operating factor of 79.2 %.

Environmental aspects

The plant releases typical air and water emissions for lignite-fired power plants as well as produces corresponding solid by-products like gypsum and ashes. The air pollutants dust, SO_x, NO_x and CO are continuously measured in the flue gas. There are primary and secondary measures to ensure an emission abatement. Primary measures are air staging as well as the implemented low-NO_x-burners. Beyond that, no further NO_x reduction measures are necessary to comply with the emission limit values set in the permit.

The first stage of the flue gas treatment process is the preheating of the inlet air followed by the removal of fly ash and dust in the Electrostatic Precipitator (ESP). SO_x are then removed in the wet Flue Gas Desulphurization (FGD), where they react with $CaCO_3$ to form gypsum, which is mainly used as valorised by-product in the construction industry. The treated flue gas is reheated and then released via the cooling tower.

Table 196 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by the competent authority is given. It should be noted, that the presented values are validated and do include OTNOCs. The reference oxygen content is 6 %.

Table 196: Air emissions for reference no. 137

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority 1/2 h	Emission limit values prescribed by competent authority d
Dust	mg/Nm^3	0	2.34	11.5	24.12	25.92	51.66	HHV	Cont.	Yes	160	80
	kg/year	9.7E+04										
SO_x	mg/Nm^3	0	0	14.9	62.11	84.13	417.8	HHV	Cont.	Yes	800	400
	kg/year	1.3E+05										
SO_x removal	(%)	100	100	98.7	94.41	93.06	83.03	HHV	Cont.	Yes	-	85
NO_x	mg/Nm^3	103.4	180	195.6	214.2	219.5	483.8	HHV	Cont.	Yes	400	200
	kg/year	1.6E+06										
CO	mg/Nm^3	44.6	86.95	148.1	233.8	251.7	482.4	HHV	Cont.	Yes	500	250
	kg/year	1.2E+06										
Hg	mg/Nm^3	-	-	0.003	-	-	-	-	Estimated value	-	-	-
	kg/year	25.2										

Values obtained in 2010 are based on validated half-hourly values. These values result out of normed values with subtraction of the measurement uncertainty, which has been determined during the calibration process. Normally, the half-hourly emission limit value equates to the double of the daily average emission limit value according to the 13. / 17. BImSchV.

Waste water is treated on-site, before being discharged into nearby surface water. The waste water originates mainly from the cooling system, the FGD and the steam cycle. The water emissions are presented in Table 197.

Table 197: Water emissions for reference no. 137 - after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	9.4E+05	-	-	-	-	-	2000 m^3/0.5h
Temp.	(°C)	12.5	22.2	32.1	-	-	-	-	-
pH		8	8.3	8.6	-	-	-	-	6 - 9.3
TSS	(mg/l)	2	5.6	14.4	-	Grab sample	No	12	30
	(kg/year)			5223					
P (total)	(mg/l)	0.03	0.05	0.09	-	Grab sample	No	12	0.1
	(kg/year)			46					
AOX	(mg/l)	0.01	0.015	0.026	-	Grab sample	No	12	100 ↔g/l
	(kg/year)			14					
TOC	(mg/l)	1.74	3.06	4.29	-	Grab sample	No	12	30
	(kg/year)			2859					
COD	(mg/l)	5	9	16	-	Grab sample	No	12	20
	(kg/year)			8598					
Cl^-	(mg/l)	63	109	179	-	Grab sample	No	12	-
	(kg/year)			1E+05					
SO_4^{2-}	(mg/l)	114	163	239	-	Grab sample	No	12	-
	(kg/year)			1.5E+05					
N (total)	(mg/l)	0.96	2.37	5.3	-	Grab sample	No	12	6
	(kg/year)			2214					
NO_2^- /NO_3^-	(mg/l)	0.001	0.004	0.009	-	Grab sample	No	11	-
	(kg/year)			4					
NH_3-N	(mg/l)	0.4	0.4	0.4	-	Grab sample	No	-	-
	(kg/year)			374					

Table 198 shows the solid by-products (gypsum, boiler and fly ash). The by-products can be utilised in the construction material industry and for the restoration of open cast mines, quarries and pits. The separated pulp wood (fibred woody lignite) is generally thermally used. In that context, this is suggested as BAT by the operator.

Table 198: Solid by-products for reference no. 137

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Gypsum	Flue-gas treatment facilities	10 01 05	3.70E+04	Utilisation - Construction industry	Construction materials industry
Gypsum	Flue-gas treatment facilities	10 01 05	2.13E+02	Reclamation/restoration of open cast mines, quarries and pits	Opencast mining
Boiler and fly ash	Combustion process	10 01 01	9.84E+04	Reclamation/restoration of open cast mines, quarries and pits	Opencast mining
Pulpwood	Fuel pre-treatment facilities	-	1.30E+03	Utilisation - others	Thermal combustion in specific combustion plants

Special characteristics

Air grading and low-NO_x-burners are installed for the reduction of NO_x emissions. Due to the reducing atmosphere near the burners and the addition of burn-out air downstream in the furnace, no secondary abatement measures have to be taken. This technology is suggested as BAT by the operator.

The wet FGD, in which SOx is chemically bound to limestone under the formation of gypsum, is also suggested as BAT by the operator.

Due to the release of the flue gas via the cooling tower, a reheating of the flue gas after the FGD does not become necessary. The FGD process followed by the release through the cooling tower are also suggested as BAT by the operator.

The plant's mills pulverise the lignite to grain sizes of 0 – 80 mm, before the fuel is stored in the coal bunkers. Preceding the milling process, iron and other unwanted substances (stones, pulpwood) are removed fully automatically. Both technologies are therefore suggested as BAT by the operator.

The gypsum, which is produced in the FGD, is purified to remove ash particles and other contaminations. By this, the amount of gypsum that has to be disposed is minimized, so that the largest part of the gypsum can be used as a valorised by-product in the construction industry. This purifying technology is suggested as BAT by the operator.

The fresh water conditioning facility produces $CaCO_3$ as a by-product (decarbonisation). The lime can then be used in the wet FGD. This technology is suggested as BAT by the operator.

Some amounts of the produced waste water can be recycled in the process. This leads to a reduction of the amount of needed fresh water. This configuration is also suggested as BAT by the operator.

Pulverised Coal Firing, Reference no 128/129

Reference no. 128/129 is a power station used for the generation of electricity and heat for district heating, which was commissioned between 1982 and 1988. It consists of six combustion plants (three identical pairs A+B, C+D, E+F), each made up of two boilers (12 boilers altogether). Each boiler has its own flue gas treatment facilities. The common cooling system for each pair of identical plants is made up of three cooling towers, via which the flue gas is emitted. The main fuel is pulverized lignite from the nearby open cast mines. In addition to this, high caloric waste is co-combusted in plants A - D (combustion installation no. 128) up to a heat input of 3 %. Plants E and F (combustion installation no. 129) are exclusively lignite-fired. The live steam parameters for all units are 172 bar and 535 °C, the reheater steam parameters are 42 bar and 540 °C. Each unit feeds an extraction/condensation steam turbine with a gross electrical power output of 500 MW_{el}. Pre-treated groundwater from the drains of the nearby open cast mines is used as make-up water.

The total rated thermal input of all twelve boilers combined is 9144 MW_{th}. The nominal gross electrical power output is 3000 MW_{el}. The maximal gross electrical power output is 3240 MW_{el} (exclusively operated in condensation mode). The maximal gross electrical efficiency is 35.4 % (average for all units, no CHP).

Steam at 5 bar/125 °C can be extracted from the turbines to provide heat for district heating. With this, the maximal thermal power output is 348 MW_{th} (58 MW_{th} for each boiler).

Table 199 shows values for the fuel energy input and energy output in the reference year 2010. The presented values belong to unit A, the values for units B - F are similar. Five years have been taken into account for the rolling average value.

Table 199: General operating data for reference no. 128/129 – Unit A

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	8.35E+06	9.62E+06
Gross electric energy output	MWh_{el}	3.16E+06	3.57E+06
Net electric energy output	MWh_{el}	2.91E+06	3.30E+06
Gross heat output – hot water	MWh_{th}	8.87E+04	7.87E+04
Net heat output – hot water	MWh_{th}	8.55E+04	7.52E+04
Total operating time under normal operating conditions	h	6561	7566
Equivalent full load operating factor	%	83.5	83.4

In the past, unit A was operated for 6500 h to 7500 h per year with an equivalent full load operating factor of about 83.5 %. The net electrical utilisation ratio in the reference year is 34.8 % with an additional thermal utilisation ratio of 0.8 %, leading to a fuel utilisation factor of 35.9 %. With the rolling average values a net electrical utilisation ratio of 34.3 % can be calculated as well as a thermal utilisation ratio of 1.1 %, leading to a fuel utilisation factor of 35.1 %.

Environmental aspects

The plant produces typical air and water emissions for lignite-fired power plants as well as corresponding solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x, CO and directly at the boilers A1 and C1 also Hg are continuously measured in the flue gas. In addition to this, due to the co-combustion of high caloric waste, the pollutants HCl, HF, TOC, Hg, Cd+TI, Sb+As+Pb+Co+Cr+Cu+Mn+Ni+V+Sn as well as PCDD/PCDF are measured periodically in the plants A-D (plant no. 128). There are primary and secondary measures taken for emission abatement. Retrofitted primary measures are air staging as well as low-NO_x-burners. With this, no further NO_x-reduction is necessary to comply with the emission limit values.

The first stage of the flue gas treatment (secondary measures) after the air-heater is the three-stage Electrostatic Precipitator (ESP), in which dust is separated. SO_x is removed in the retrofitted wet Flue Gas Desulphurisation (FGD), where it reacts with milled and in water solved lime stone to form marketable gypsum.

Table 200 shows the concentration and the annual load for the measured air-pollutants in the flue gas for Unit A (the values for the other units are similar). In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values for the concentrations are validated and that values in mg/Nm^3 do not include OTNOCs. The reference oxygen content is 6 %.

Table 200: Air emissions for reference no. 128/129 – Unit A

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	3.3	5.2	7.3	9	9.3	20.2	HHV	Cont.	Yes	30	10
	kg/year	9.6E+04										
SO_x	mg/Nm^3	18.8	99.4	191.6	286.2	301.5	448.6	HHV	Cont.	Yes	738	369
	kg/year	2.5E+06										
SO_x removal	(%)	90.9	94.4	96.1	97.7	97.9	99.5	DV	Cont.	Yes	-	95
NO_x	mg/Nm^3	140.6	187.9	194.2	200	201.6	309.1	HHV	Cont.	Yes	400	200
	kg/year	2.6E+06										
CO	mg/Nm^3	10	34.4	96.2	186.3	202.8	369.1	HHV	Cont.	Yes	466	233
	kg/year	1.3E+06										
HCl	mg/Nm^3	0.8	-	1	-	-	1.7	DV	Perio.	No	-	20
	kg/year	-										
HF	mg/Nm^3	-	-	-	-	-	0.2	DV	Perio.	No	-	1
	kg/year	-										
Hg	mg/Nm^3	0.009	-	0.009	-	-	0.011	DV	Perio.	No	0.05	0.03
	kg/year	-										
Cd+Tl	mg/Nm^3	-	-	-	-	-	2E-04	DV	Perio.	No	-	0.01
	kg/year	-										
Other*	mg/Nm^3	0.03	-	0.038	-	-	0.048	DV	Perio.	No	-	0.5
	kg/year	-										
PCDD/PCDF	ng/Nm^3	0.001	-	0.001	-	-	0.001	DV	Perio.	No	-	**
	kg/year	-										

*other: Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V

**0.05 ng I-TEQ/Nm^3 DV

Several waste water streams are produced in the combustion installation. They are treated in a common on-site facility (including neutralisation and sedimentation ponds), before being directly discharged into a river. A more detailed flow sheet for the WWT process is attached to the questionnaire. The waste water from the cooling system is not treated and directly discharged. The water emissions for this stream are given in Table 201. The water emissions for the treated waste water are shown in Table 202.

Table 201: Water emissions for reference no. 128/129 – non-treated waste water for Units A to F

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	3.9E+06	-	-	-	-	-	-
Temp.	(°C)	-	19.8	-	-	-	-	-	-
pH		7.7	8.3	8.6	-	-	-	-	6 - 9
TSS	(mg/l)	1	2.63	14.6	-	Composite sample	-	12	15
	(kg/year)	-							
TOC	(mg/l)	3.4	6.5	9.3	-	Composite sample	-	12	30
	(kg/year)	-							
P (total)	(mg/l)	0.09	0.21	0.31	-	Composite sample	-	12	0.5
	(kg/year)								

Table 202: Water emissions for reference no. 128/129 –treated waste water for Units A to F

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)		4.2E+06		-	-	-	-	-
Temp.	(°C)				-	-	-	-	-
pH		7.7	8.7	9.2	-	-	-	-	6 - 9.5
TSS	(mg/l)	1.2	5.4	16.8	-	Composite sample	-	12	20
	(kg/year)			-					
TOC	(mg/l)	5.6	7.7	10.1	-	Composite sample	-	12	40
	(kg/year)			-					
P (total)	(mg/l)	0.02	0.06	0.088	-	Composite sample	-	12	0.2
	(kg/year)			-					
N (total)	(mg/l)	0.26	1.1	2.5	-	Grab sample	-	12	5
	(kg/year)			-					
AOX	(mg/l)	0.03	0.1	0.1	-	Grab sample	-	12	0.1
	(kg/year)			-					

Table 203 shows the solid residues (by-products) for Unit A. Again, the presented values are similar to those of the other units. Gypsum, fly ash and bottom ash make up the largest part of the solid residues. They are utilized in the construction material industry and the ashes partly also for the refilling of open cast mines.

Table 203: Solid residues for reference no. 128/129 – Unit A

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Fly ash	Flue-gas treatment facilities	-	3.35E+05	Utilisation - others	landfill
Bottom ash	Combustion process	-	1.22E+05	Utilisation - others	landfill
Gypsum	Flue-gas treatment facilities	-	1.93E+05	Utilisation - Construction industry	-

Special characteristics

The separation efficiency of the ESP is 99.92 %. With this, the emission values are well below limit, which is why the technology is suggested as BAT by the operator.

The wet FGD uses lime stone, which is brought into contact with the flue gas. The lime stone reacts with more than 95 % of the SO_2 to form marketable gypsum, which is utilized in the industry. In addition to this, 90 % of HCl and HF are separated. This FGD configuration was retrofitted in this plants and is especially therefore suggested as BAT by the operator.

NO_x emissions are reduced with air staging and low-NO_x-burners. No further reduction of NO_x emissions is necessary. This technology was retrofitted in this plants and is especially therefore suggested as BAT by the operator.

Pulverised Coal Firing, Reference no. 130

Reference no. 130 is a pulverised coal-fired power plant for electricity generation, which was commissioned in 1975. The plant consists of a once-through boiler, extensive flue gas treatment facilities and a cooling tower, through which the flue gas is released. The main fuel is Rhenish lignite. For start-up and for auxiliary firing, light fuel oil is used. The live steam parameters are 175 bar and 530 °C, the reheater steam parameters are 34 bar and 530 °C. The extraction/condensation steam turbine has a gross electrical power output of 641 MW_{el}. The cooling system is a circulation cooling with a natural draft cooling tower. Make-up water is taken from surface waters and from the pumping stations of the nearby open-cast mining pit. Figure 58 shows a schematic sketch of the plant layout.

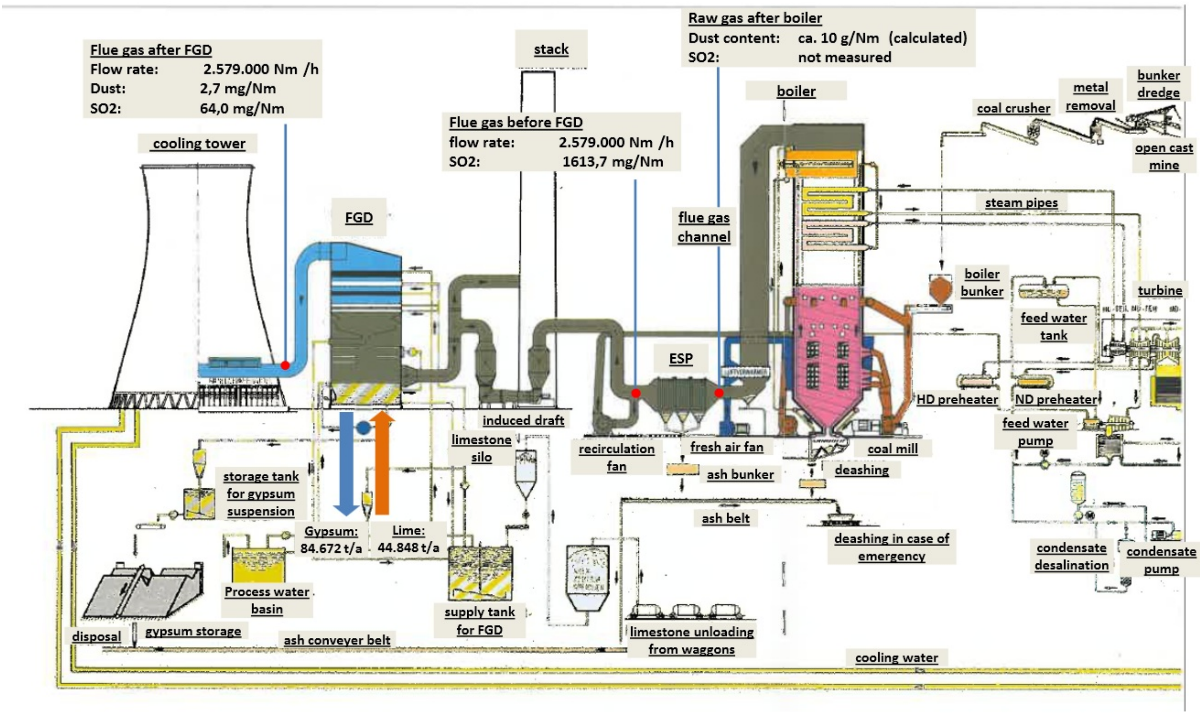

Figure 58: Sketch of the design of reference no. 130

The plant is located at a combustion site with a total rated thermal input of 5974 MW_{th}. Combustion installation no. 137 is also part of this combustion site. The total rated thermal input of the combustion installation no. 130 is 1702 MW_{th}, the gross electric power output is 641 MW_{el}. The nominal gross electrical efficiency is 37.7 %.

Table 204 shows values for the fuel energy input and energy output in the reference year 2010. Five years (2006 – 2010) have been taken into account for the rolling average value.

Table 204: General operating data for reference no. 130

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	1.29E+07	1.24E+07
Gross electric energy output	MWh_{el}	4.71E+06	4.48E+06
Net electric energy output	MWh_{el}	4.36E+06	4.14E+06
Total operating time under normal operating conditions	h	7345	7003
Equivalent full load operating factor	%	83.8	79.9

In the reference year, the plant was operated for about 7350 h with an equivalent full load operating factor of 83.8 %. The net electrical utilisation ratio is 33.5 %. For the rolling average value a net electrical utilisation ratio of 33.5 % can be calculated. The total operating time under normal operating conditions for the rolling average value is almost 7000 h with an equivalent full load operating factor of 79.9 %.

Environmental aspects

The plant releases typical air and water emissions for lignite-fired power plants as well as produces corresponding solid by-products like gypsum and ashes. The air pollutants dust, SO_x, NO_x and CO are continuously measured in the flue gas. There are primary and secondary measures to ensure an emission abatement. Primary measures are air staging as well as the implemented low-NO_x-burners. Beyond that, no further NO_x reduction measures are necessary to comply with the emission limit values set in the permit.

The first stage of the flue gas treatment process is the preheating of the inlet air followed by the removal of fly ash and dust in the Electrostatic Precipitator (ESP). SO_x are then removed in the wet Flue Gas Desulphurization (FGD), where they react with $CaCO_3$ to form gypsum, which is mainly used as valorised by-product in the construction industry. The treated flue gas is reheated and then released via the cooling tower.

Table 205 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by the competent authority are given. It should be noted, that the presented values are validated and do include OTNOCs. The reference oxygen content is 6 %.

Table 205: Air emissions for reference no. 130

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h*	d
Dust	mg/Nm³	0.24	1.06	2.7	4.52	4.82	15.32	HHV	Cont.	Yes	160	80
	kg/year	5E+04										
SO_x	mg/Nm³	0	2.67	64	169.2	197.5	409.2	HHV	Cont.	Yes	800	400
	kg/year	1.2E+06										
SO_x removal	(%)	100	99.71	97	92.61	91.67	83.79	HHV	Cont.	Yes	-	85
NO_x	mg/Nm³	133.73	175.8	193.1	214.3	221.1	370	HHV	Cont.	Yes	400	200
	kg/year	3.6E+06										
CO	mg/Nm³	0	15.1	75	188.2	210.7	436.7	HHV	Cont.	Yes	500	250
	kg/year	1.4E+06										
Hg	mg/Nm³	-	-	0.003	-	-	-	-	Estimated value	-	-	-
	kg/year	55.98										

* Values obtained in 2010 are based on validated half-hourly values. These values result out of normed values with subtraction of the measurement uncertainty, which has been determined during the calibration process. Normally, the half-hourly emission limit value equates to the double of the daily average emission limit value according to the 13. / 17. BImSchV.

Waste water is treated on-site, before being discharged into nearby surface water. The waste water originates mainly from the cooling system, the FGD and the steam cycle. The water emissions are presented in Table 206.

Table 206: Water emissions for reference no. 130 - after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	2.1E+06	-	-	-	-	-	2000 m^3/0.5h
Temp.	(°C)	12.5	22.2	32.1	-	-	-	-	-
pH		8	8.3	8.6	-	-	-	-	6 - 9.3
TSS	(mg/l)	2	5.6	14.4	-	Grab sample	No	12	30
	(kg/year)			1.2E+04					
P (total)	(mg/l)	0.03	0.05	0.09	-	Grab sample	No	12	0.1
	(kg/year)			104					
AOX	(mg/l)	0.01	0.015	0.026	-	Grab sample	No	12	100 ↔g/l
	(kg/year)			31					
TOC	(mg/l)	1.74	3.06	4.29	-	Grab sample	No	12	5
	(kg/year)			6504					
COD	(mg/l)	5	9	16	-	Grab sample	No	12	20
	(kg/year)			2E+04					
Cl^-	(mg/l)	63	109	179	-	Grab sample	No	12	-
	(kg/year)			2.3E+05					
SO_4^{2-}	(mg/l)	114	163	239	-	Grab sample	No	12	-
	(kg/year)			3.5E+05					
N (total)	(mg/l)	0.96	2.37	5.3	-	Grab sample	No	12	6
	(kg/year)			5036					
NO_2^-/NO_3^-	(mg/l)	0.001	0.004	0.009	-	Grab sample	No	11	-
	(kg/year)			8					
NH_3-N	(mg/l)	0.4	0.4	0.4	-	Grab sample	No	-	-

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
	(kg/year)			852					

Table 207 shows the solid by-products (gypsum, boiler and fly ash. These by-products can be utilised in the construction material industry and for the restoration of open cast mines, quarries and pits. The separated pulp wood (fibred woody lignite) is generally thermally used. In that context, this is suggested as BAT by the operator.

Table 207: Solid by-products for reference no. 130

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Gypsum	Flue-gas treatment facilities	10 01 05	8.42E+04	Utilisation - Construction industry	Construction materials industry
Gypsum	Flue-gas treatment facilities	10 01 05	4.84E+02	Reclamation/restoration of open cast mines, quarries and pits	Open cast mining
Boiler and fly ash	Combustion process	10 01 01	2.24E+05	Reclamation/restoration of open cast mines, quarries and pits	Open cast mining
Pulpwood	Fuel pre-treatment facilities	-	2.89E+03	Utilisation - others	Thermal combustion in specific combustion plants

Special characteristics

Air grading and low-NO_x-burners are installed for the reduction of NO_x emissions. Due to the reducing atmosphere near the burners and the addition of burn-out air downstream in the furnace, no secondary abatement measures have to be taken. This technology is suggested as BAT by the operator.

The wet FGD, in which SOx is chemically bound to limestone under the formation of gypsum, is also suggested as BAT by the operator.

Due to the release of the flue gas via the cooling tower, a reheating of the flue gas after the FGD does not become necessary. The FGD process followed by the release through the cooling tower are also suggested as BAT by the operator.

The plant's mills pulverize the lignite to grain sizes of 0 – 80 mm, before the fuel is stored in the coal bunkers. Preceding the milling process, iron and other unwanted substances (stones, pulpwood) are removed fully automatically. Both technologies are therefore suggested as BAT by the operator.

The gypsum, which is produced in the FGD, is purified to remove ash particles and other contaminations. By this, the amount of gypsum that has to be disposed is minimized, so that the largest part of the gypsum can be used as a valorised by-product in the construction industry. This purifying technology is suggested as BAT by the operator.

Some amounts of the produced waste water can be recycled in the process. This leads to a reduction of the amount of needed fresh water. This configuration is also suggested as BAT by the operator.

Pulverised Coal Firing, Reference no. 127

Reference no. 127 is a dry bottom pulverized coal-fired power plant for the generation of electricity and heat (process heat and district heating), which was commissioned in 1998. The combustion installation consists of two identical once-through boilers, which feed an extraction/condensation turbine with a gross electrical power output of 800 MW_{el} each. The main fuel is lignite from nearby open cast mines. In addition to this, different fuels (residues from paper industry, high caloric secondary fuel from household waste and others) can be co-combusted in small amounts (<2 % on a heat input basis). The live steam parameters are 268 bar and 547 °C, the reheater steam parameters are 55 bar and 565 °C. Each condenser is cooled with a closed wet circuit using a natural draught cooling tower. The flue gases of each boiler are treated in its own flue gas treatment facilities, before being emitted via the cooling tower. For the production of make-up water pre-treated groundwater from a nearby lignite open cast mine is used.

The total rated thermal input of both boilers combined is 4200 MW_{th}. The gross electrical power output of 1600 MW_{el} (exclusively operated in condensation mode) can be achieved with a total rated thermal input of 3990 MW_{th}. With this, the nominal net electrical efficiency is 40.1 %. Steam at 36 bar/155 °C and 14 bar/130 °C can be extracted from the turbines to provide steam for industrial users and hot water for district heating in some towns. With this, the thermal power output is 361 MW_{th} for each turbine, which leads to a nominal net overall utilization ratio of 46.2 %.

Table 208 shows values for the fuel energy input and energy output in the reference year 2010. The presented values belong to unit A, the values for unit B are very similar to these. Five years have been taken into account for the rolling average value.

Table 208: General operating data for reference no. 127 – Unit A

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	1.56E+07	1.46E+07
Gross electric energy output	MWh_{el}	6.25E+06	5.92E+06
Net electric energy output	MWh_{el}	5.86E+06	5.36E+06
Gross heat output – steam	MWh_{th}	1.12E+06	8.05E+05
Net heat output – steam	MWh_{th}	1.12E+06	8.05E+05
Gross heat output – hot water	MWh_{th}	2.58E+05	2.16E+05
Net heat output – hot water	MWh_{th}	2.27E+05	1.90E+05
Total operating time under normal operating conditions	h	8145	7783
Equivalent full load operating factor	%	91.2	89.2

In the past, the plant was operated almost continuously with an equivalent full load operating factor of about 90 %. The net electrical utilization ratio in the reference year is 37.5 % with an additional thermal utilization ratio of 8.6 %, leading to a net overall utilization ratio of 46.1 %. With the rolling average values a net electrical utilization ratio of 36.7 % can be calculated as well as a thermal utilization ratio of 5.6 %, leading to a net overall utilization ratio of 42.3 %.

Environmental aspects

The plant produces typical air and water emissions for lignite-fired power plants as well as corresponding solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x and CO are continuously measured in the flue gas. In addition to this, other pollutants (Hg, HCl, HF, TOC, Cd+TI, Sb+As+Pb+Co+Cr+Cu+Mn+Ni+V+Sn as well as PCDD/PCDF) are measured periodically. There are primary and secondary measures taken for emission abatement. Primary measures are air staging as well as low-NO_x-burners. With this, no further NO_x-reduction is necessary to comply with the emission limit values.

The first stage of the flue gas treatment (secondary measures) after the air-heater is the four-stage Electrostatic Precipitator (ESP), in which dust is separated. SO_x is removed in the wet Flue Gas Desulphurisation (FGD), where it reacts with lime stone to form marketable gypsum.

Table 209 shows the concentration and the annual load for the measured air-pollutants in the flue gas for Unit A (the values for Unit B are similar). In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do not include OTNOCs. The oxygen content at the measuring point is 3.5 %. The conversion of the values to the reference oxygen content of 6 % is not allowed.

Table 209: Air emissions for reference no. 127 – Unit A

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	1.1	1.4	1.6	1.7	1.7	3	HHV	Cont.	Yes	30	10
	kg/year	2.8E+04										
SO_x	mg/Nm^3	50	132.4	220	311.9	328.6	673.4	HHV	Cont.	Yes	720	360
	kg/year	4E+06										
SO_x removal	(%)	73.2	94.1	95.4	96.8	97.1	99.9	DV	Cont.	Yes	-	95
NO_x	mg/Nm^3	50.8	110.4	120.3	130.5	132.1	144.4	HHV	Cont.	Yes	400	200
	kg/year	2.5E+06										
CO	mg/Nm^3	1.3	31.6	53.4	78	85.1	440.5	HHV	Cont.	Yes	458	229
	kg/year	1.2E+06										
HCl	mg/Nm^3	0.7	-	1	-	-	1.7	DV	Perio.	No	-	9
	kg/year	-										
HF	mg/Nm^3	-	-	-	-	-	0.7	DV	Perio.	No	-	3
	kg/year	-										
Hg	mg/Nm^3	0.0042	-	0.007	-	-	0.009	DV	Perio.	No	0.05	0.03
	kg/year	-										
TOC	mg/Nm^3	2	-	2.7	-	-	3.6	DV	Perio.	No	-	10
	kg/year	-										
Cd+Tl	mg/Nm^3	0.0001	-	0.001	-	-	0.002	DV	Perio.	No	-	0.01
	kg/year	-										
other *	mg/Nm^3	0.0083	-	0.024	-	-	0.039	DV	Perio.	No	-	0.2
	kg/year	-										

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
PCDD /PCDF	ng/Nm^3	0.0053	-	0.006	-	-	0.007	DV	Perio.	No	-	0.02 ng TEQ / Nm^3 DV
	kg/year						-					

*: Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V+Sn

The waste water, which is produced in the cooling system, the equipment cleaning and in the raw water treatment facility of the plant, is discharged directly into a river after being cleaned in a common on-site waste water pre-treatment facility. The water emissions for this stream are shown in Table 210.

Table 210: Water emissions for reference no. 127 – Unit A

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow Unit A + B	(m^3/year)	-	5.2E+06	-	-	-	-	-	-
Temp.	(°C)	19.3	23.1	28.7	-	-	-	-	-
pH		8.25	8.48	8.63	-	-	-	-	-
TSS	(mg/l)	1.3	3.8	7.8	HA	Grab sample	No	12	30
	(kg/year)			-					
P (total)	(mg/l)	0.14	0.18	0.26	HA	Grab sample	No	12	0.3
	(kg/year)			-					
AOX	(mg/l)	0.03	0.04	0.07	HA	Grab sample	No	12	0.1
	(kg/year)			-					
TOC	(mg/l)	5.96	8.11	11.7	HA	Grab sample	No	12	5
	(kg/year)			-					
Cl^-	(mg/l)	45.7	62.84	79.4	HA	Grab sample	No	12	-
	(kg/year)			-					
SO_4^{2-}	(mg/l)	896	1397	1820	HA	Grab sample	No	12	-
	(kg/year)			-					
N (total)	(mg/l)	1.6	2.74	3.74	HA	Grab sample	No	12	5
	(kg/year)			-					
COD	(mg/l)	12	18.1	28	HA	Grab sample	No	-	30
	(kg/year)			-					

Other waste waters, partly pre-treated, are treated off-site.

Table 211 shows the solid residues (by-products). Gypsum, fly ash and bottom ash make up the largest part of the solid residues. They can be utilized in the construction material industry and for the refilling of open cast mines.

Table 211: Solid residues for reference no. 127 – Unit A

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Fly ash	Flue-gas treatment facilities	-	3.32E+05	Utilisation – others	slope stabilisation
Bottom ash	Combustion process	-	3.78E+04	Utilisation – others	slope stabilisation
Gypsum	Flue-gas treatment facilities	-	2.27E+05	Utilisation – Construction industry	-

Special characteristics

The separation efficiency of the 4-stage ESP is 99.95 % (from 30 g/m^3 to 15 mg/m^3). With this, the emission values are well below the limit, which is why the technology is suggested as BAT by the operator.

The wet FGD uses milled lime stone ($CaCO_3$) solved in water, which is brought into contact with the flue gas. The calcium reacts with more than 95 % of the SO_2 to form marketable gypsum. This FGD configuration is suggested as BAT by the operator.

NO_x emissions are reduced with air staging and low-NO_x-burners. No further reduction of NO_x emissions is necessary. This technology is suggested as BAT by the operator.

Pulverised Coal Firing, Reference no. 116

Reference no. 116 is a pulverised coal-fired power plant for electricity generation which was commissioned in 2003. The plant consists of a once-through boiler, extensive FGT facilities and a cooling tower, through which the flue gas is released. The main fuel is Rhenish lignite. For start-up, LFO is used. The live steam parameters are 275 bar and 580 °C, the reheater steam parameters are 60 bar and 600 °C. The condensation steam turbine has a gross electric power output of 994 MW_{el}. The cooling system is a circulation cooling with a natural draught cooling tower. Make-up water is taken from surface waters, rainwater basins as well as the pumping stations of the nearby open-cast mining pit. Figure 59 shows a schematic sketch of the plant layout.

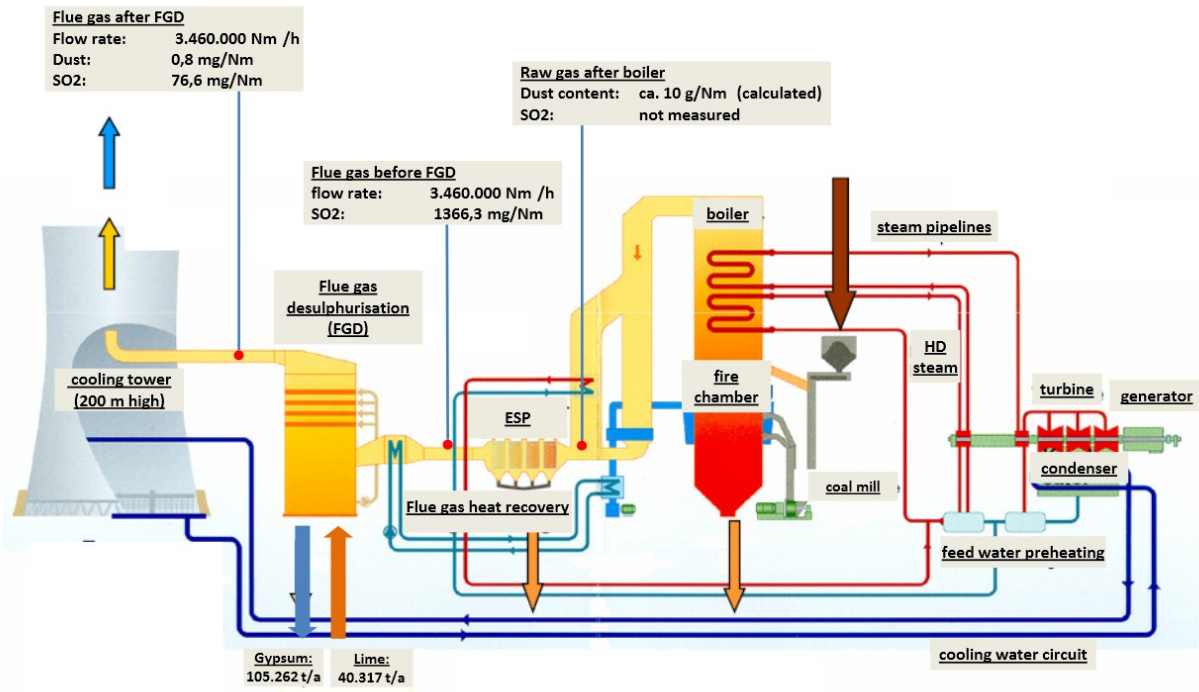

Figure 59: Sketch of the design of reference no. 116

The total rated thermal input of the plant is 2306 MW_{th}, the gross electric power output is 994 MW_{el}. The nominal gross electrical efficiency is 43.1 %. In addition to this, process steam and steam for district heating can be extracted.

Table 212 shows values for the fuel energy input and energy output in the reference year 2010. Five years (2006 – 2010) have been taken into account for the rolling average value.

Table 212: General operating data for reference no. 116

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	1.57E+07	1.64E+07
Gross electric energy output	MWh_{el}	6.93E+06	7.21E+06
Net electric energy output	MWh_{el}	6.52E+06	6.81E+06
Total operating time under normal operating conditions	h	6973	7359
Equivalent full load operating factor	%	79.6	84.0

In the reference year, the plant was operated for about 7000 h with an equivalent full load operating factor of 79.6 %. The net electrical utilisation ratio is 42 %. For the rolling average value a net electrical utilisation ratio of 41.5 % can be calculated. The total operating time under normal operating conditions for the rolling average value is almost 7400 h with an equivalent full load operating factor of 84 %.

Environmental aspects

The plant releases typical air and water emissions for lignite-fired power plants as well as produces corresponding solid by-products like gypsum and ashes. The air pollutants dust, SO_x, NO_x and CO are continuously measured in the flue gas. There are primary and secondary measures taken to ensure an emission abatement. Primary measures are air staging as well as implemented low-NO_x-burners. Beyond that, no further NO_x reduction measures is necessary to comply with the emission limit values set in the permit.

The first stage of the FGT process is the preheating of the inlet air, followed by the removal of fly ash and dust in the ESP. SO_x are then removed in the wet FGD, where they react with $CaCO_3$ to form gypsum, which is mainly used as valorised by-product in the construction industry. The treated flue gas is reheated and then released via the cooling tower.

Table 213 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by the competent authority are given. It should be noted, that the presented values are validated (i.e. standardised values with subtraction of the measurement uncertainty, which has been determined during calibration) and do not include OTNOCs. The reference oxygen content is 6 %.

Table 213: Air emissions for reference no. 116

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority 1/2 h*	Emission limit values prescribed by competent authority d
Dust	mg/Nm^3	0	0.1	0.8	1.5	1.5	2.6	HHV	Cont.	Yes	60	20
	kg/year	1.8E+04										
SO_x	mg/Nm^3	9.7	42.8	76.6	112.3	117.8	291.3	HHV	Cont.	Yes	600	300
	kg/year	1.7E+06										
SO_x re-moval	(%)	86.4	91.8	94.4	96.4	96.7	100	HHV	Cont.	Yes	-	85
NO_x	mg/Nm^3	79.1	131.9	168.2	195.3	198.9	261.1	HHV	Cont.	Yes	400	200
	kg/year	3.8E+06										
CO	mg/Nm^3	0	0	0.8	2.8	7.3	470.9	HHV	Cont.	Yes	500	250
	kg/year	1.8E+04										
Hg	mg/Nm^3	-	-	0.005	-	-	-	-	Esti-mated value	-	-	-
	kg/year	112.9										

* Values obtained in 2010 are based on validated half-hourly values. These values result out of normed values with subtraction of the measurement uncertainty, which has been determined during the calibration process. Normally, the half-hourly emission limit value equates to the double of the daily average emission limit value according to the 13. / 17. BImSchV.

Waste water is treated on-site, before being discharged into nearby surface water. The water emissions are presented in Table 214. A more detailed flow sheet is attached to the questionnaire.

Table 214: Water emissions for reference no. 116 - after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	2.3E+06	-	-	-	-	-	2000 m^3/0.5h
Temp.	(°C)	16	19	27	-	-	-	-	-
pH		8.1	8.5	8.8	-	-	-	-	6 - 9.3
TSS	(mg/l)	1	8	35	-	Grab sample	No	12	30
	(kg/year)	1.7E+04							
P (total)	(mg/l)	0.1	0.2	0.3	-	Grab sample	No	12	0.1
	(kg/year)	385.06							
AOX	(mg/l)	<0.020	0.029	0.037	-	Grab sample	No	12	100 ↔g/l
	(kg/year)	64.34							
TOC	(mg/l)	3.16	3.9	4.5	-	Grab sample	No	12	5
	(kg/year)	8332.73							
Cl^-	(mg/l)	160	322	460	-	Grab sample	No	12	-
	(kg/year)	677.45							
SO_4^{2-}	(mg/l)	163	244	415	-	Grab sample	No	12	-
	(kg/year)	551.5							
N (total)	(mg/l)	1.2	1.63	2.16	-	Grab sample	No	12	6
	(kg/year)	3354.76							
NH_3-N	(mg/l)	0.1	0.2	0.3	-	Grab sample	No	-	-
	(kg/year)	385.06							
TKN	(mg/l)	<0.15	0.12	0.37	-	Grab sample	No	-	-
	(kg/year)	167.2							

Table 215 shows the solid by-products (gypsum, boiler and fly ash). These by-products can be utilised in the construction material industry and for the restoration of open cast mines, quarries and pits.

Table 215: Solid by-products for reference no. 116

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Gypsum	Flue-gas treatment facilities	10 01 05	9.47E+04	Utilisation - Construction industry	Construction materials industry
Gypsum	Flue-gas treatment facilities	10 01 01	1.05E+04	Reclamation / restoration of open cast mines, quarries and pits	Open cast mining
Boiler and fly ash	Combustion process	10 01 01	2.87E+05	Reclamation / restoration of open cast mines, quarries and pits	Open cast mining

Special characteristics

The plant's mills pulverise the lignite to grain sizes of 0 – 80 mm, before the fuel is stored in the coal bunker. Preceding the milling process, metal and other unwanted substances are removed fully automatically. Both technologies are therefore suggested as BAT by the operator.

Due to the release of the flue gas via the cooling tower, a reheating of the flue gas after the FGD does not become necessary. The FGD process followed by the release through the cooling tower are also suggested as BAT by the operator.

The gypsum, which is produced in the FGD, is purified to remove ash particles and other contaminations. By this, the amount of gypsum that has to be disposed is minimised, so that the largest part of the gypsum can be used as a valorised by-product in the construction industry. This purifying technology is suggested as BAT by the operator.

The fresh water conditioning facility produces $CaCO_3$ as a by-product (decarbonisation). The lime can then be used in the wet FGD. This technology is suggested as BAT by the operator.

The air grading for the reduction of NO_x is suggested as BAT as well.

Pulverised Coal Firing, Reference no. 117

Reference no. 117 is a dry bottom pulverized-coal fired power plant for the generation of electricity and heat for district heating, which was commissioned in 2001. The plant consists of two identical once-through boilers. The main fuel is lignite from a nearby surface mine. In addition to this, sewage sludge can be co-combusted (1.5 % on a thermal basis). The live steam parameters are 267.5 bar and 554 °C, the reheater steam parameters are 53.2 bar and 583 °C. Each boiler feeds a single extraction/condensation steam turbine with a gross electrical power output of 920 MW_{el}. The cooling system for each condenser uses a single natural draught wet cooling tower (closed circuit). Make-up water is taken from a nearby reservoir.

The total rated thermal input of both boilers combined is 4930 MW_{th}. The gross electrical power output of 1840 MW_{el} (exclusively operated in condensation mode) can be achieved with a total rated thermal input of 4230 MW_{th}. With this, the nominal net electrical efficiency is 43.5 %. Steam at 18.5 bar and 120 °C can be extracted from the turbines to provide heat for district heating. With this, the thermal power output (hot water) is 220 MW_{th} for each turbine.

Table 216 shows values for the fuel energy input and energy output in the reference year 2010. The presented values belong to unit R, the values for unit S are similar to these. Five years have been taken into account for the rolling average value.

Table 216: General operating data for reference no. 117 – Unit R

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	1.65E+07	1.57E+07
Gross electric energy output	MWh_{el}	7.19E+06	6.79E+06
Net electric energy output	MWh_{el}	6.81E+06	6.42E+06
Gross heat output – steam	MWh_{th}	0.00E+00	0.00E+00
Net heat output – steam	MWh_{th}	0.00E+00	0.00E+00
Gross heat output – hot water	MWh_{th}	5.41E+05	4.42E+05
Net heat output – hot water	MWh_{th}	5.33E+05	4.35E+05
Total operating time under normal operating conditions	h	8306	7960
Equivalent full load operating factor	%	80.8	79.8

In the past, the plant was operated almost continuously with an equivalent full load operating factor of 80 %. Load reductions were only necessary to account for the feed-in of electricity from wind power facilities. The low energy demand allows for a net electrical utilisation ratio of more than 41 %. With the additional thermal utilisation of the steam for district heating, the fuel utilisation factor is about 44 %.

Environmental aspects

The plant produces typical air and water emissions for lignite-fired power plants as well as corresponding solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x, CO and Hg (since 2011) are continuously measured in the flue gas. In addition to this, other pollutants (HCl, HF, TOC, Cd+TI, Sb+As+Pb+Co+Cr+Cu+Mn+Ni+V+Sn as well as PCDD/PCDF) are measured periodically. There are primary and secondary measures taken for emission abatement. Primary measures are air staging as well as low-NO_x-burners. With this, no further NO_x-reduction is necessary to comply with the emission limit values.

The first stage of the flue gas treatment (secondary measures) after the air-heater is the Electrostatic Precipitator (ESP), in which dust is separated. SO_x is removed in the wet Flue Gas Desulphurisation (FGD), where it reacts with lime to form marketable gypsum.

Table 217 shows the concentration and the annual load for the measured air-pollutants in the flue gas for Unit R (the values for Unit S are similar). In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do not include OTNOCs. The oxygen content at the measuring point is 4.5 %. Except for NO_x emissions, the conversion of the values to the reference oxygen content of 6 % is not allowed.

Table 217: Air emissions for reference no. 117 - Unit R

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	1.4	1.7	3.1	4.3	4.3	5	HHV	Cont.	Yes	30	20
	kg/year	7.6E+04										
SO_x	mg/Nm^3	61.5	238.2	296.7	344.5	350	556.6	HHV	Cont.	Yes	750	375
	kg/year	7.2E+06										
SO_x removal	(%)	94.6	95	95.6	96.4	96.6	99.1	DV	Cont.	Yes	-	95
NO_x	mg/Nm^3	100.2	136.4	171.4	192.1	194	315	HHV	Cont.	Yes	400	200
	kg/year	4.7E+06										
CO	mg/Nm^3	5	5.5	11.8	28	31.9	224.5	HHV	Cont.	Yes	440	220
	kg/year	2.9E+05										
HCl	mg/Nm^3	0.5		1.35			3.4	DV	Perio.	No	-	20
	kg/year											
HF	mg/Nm^3						0.6	DV	Perio.	No	-	1
	kg/year											
Hg	mg/Nm^3	0.0016	0.003	0.015	0.022	0.025	0.052	DV	Perio.	No	0.05	0.03
	kg/year											
TOC	mg/Nm^3	1		2.3			4.2	DV	Perio.	No	-	10
	kg/year											
Cd+Tl	mg/Nm^3	0.001		0.002			0.005	DV	Perio.	No	-	0.05
	kg/year											
other *	mg/Nm^3	0.072		0.141			0.331	DV	Perio.	No	-	0.5
	kg/year											

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
PCDD / PCDF	ng/Nm^3	0.0012		0.002			0.002	DV	Perio.	No	-	0.1 ng I-TEQ / Nm^3 DV
	kg/year											

*: Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V

The waste water, which is produced in the plant, is pre-treated on-site and discharged into a river. The water emissions are shown in Table 218. Some of the waste water (from the FGD), is mixed with ash to form a slope stabilisator for the refilling of open cast mines. The sanitary waste water (44000 m^3/a) is treaded off-site and is therefore not monitored.

Table 218: Water emissions for reference no. 117 – Unit R

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	1.5E+06	-	-	-	-	-	-
Temp.	(°C)	15	21.1	32.3	-	-	-	-	< 31
pH		6.8	7.7	8.1	-	-	-	-	< 8.5
TDS	(mg/l)	2	8.2	23	HA	Grab sample	No	12	-
	(kg/year)	-							
P (total)	(mg/l)	0.1	0.2	0.5	HA	Grab sample	No	12	0.8
	(kg/year)	-							
TOC	(mg/l)	6.2	12.2	20	HA	Grab sample	No	12	-
	(kg/year)	-							
N (total)	(mg/l)	4	14.2	23.2	HA	Grab sample	No	12	30
	(kg/year)								
COD	(mg/l)	10	31.1	50	HA	Grab sample	No	-	-
	(kg/year)	-							
Total Hydro-carbon Content	(mg/l)	0.2	0.3	0.5	HA	Grab sample	No	-	-
	(kg/year)								
TSS	(mg/l)	-	-	-	-	-	-	-	30
	(kg/year)	-							

Table 219 shows the solid residues (by-products). Gypsum, fly ash and bottom ash make up the largest part of the solid residues. They can be utilised in the construction material industry and for the refill of open cast mines.

Table 219: Solid residues for reference no. 117 – Unit R

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Fly ash	Flue-gas treatment facilities	-	2.21E+05	Utilisation – others	slope stabilisation
bottom ash	Combustion process	-	6.76E+04	Utilisation – others	slope stabilisation
gypsum	Flue-gas treatment facilities	-	4.44E+05	Utilisation – Construction industry	-

Special characteristics

The separation efficiency of the 4-stage ESP is 99.95 %. With this, the emission values are well below the emission limit, which is why the technology is suggested as BAT by the operator.

The wet FGD uses hydrated quick lime (CaO), which is brought into contact with the flue gas. The calcium reacts with more than 95 % of the SO_2 to form marketable gypsum. This FGD configuration is suggested as BAT by the operator.

NO_x emissions are reduced with air staging and low-NO_x-burners. No further reduction of NO_x emissions is necessary. This is suggested as BAT by the operator.

Pulverised Coal Firing, Reference no. 133

Reference no. 133 is a pulverised coal-fired power plant for electricity generation (public grid, neighbouring chemical plant and railway grid) as well as for heat generation. The plant was commissioned in 1995/96. The fuel is solely lignite from a opencast mining 40 km away. For start-up and for auxiliary firing, LFO or recycled oil is used.

The boiler consists of two once-through boilers with tangential firing and a mutual stack. The live steam parameters are 265 bar and 544°C, the reheater steam parameters are 70 bar and 560 °C. Each boiler feeds an extraction/condensation steam turbine with a nominal gross electric power output of 450 MW_{el} for the public electricity network. In addition to this, both boilers feed a common turbine, which drives a 16.67 Hz-Railway generator with a nominal gross electric power output of 110 MW_{el}.

The cooling system uses a natural draught cooling tower. Make up water is taken from a river. Figure 60 shows a sketch of the plant layout.

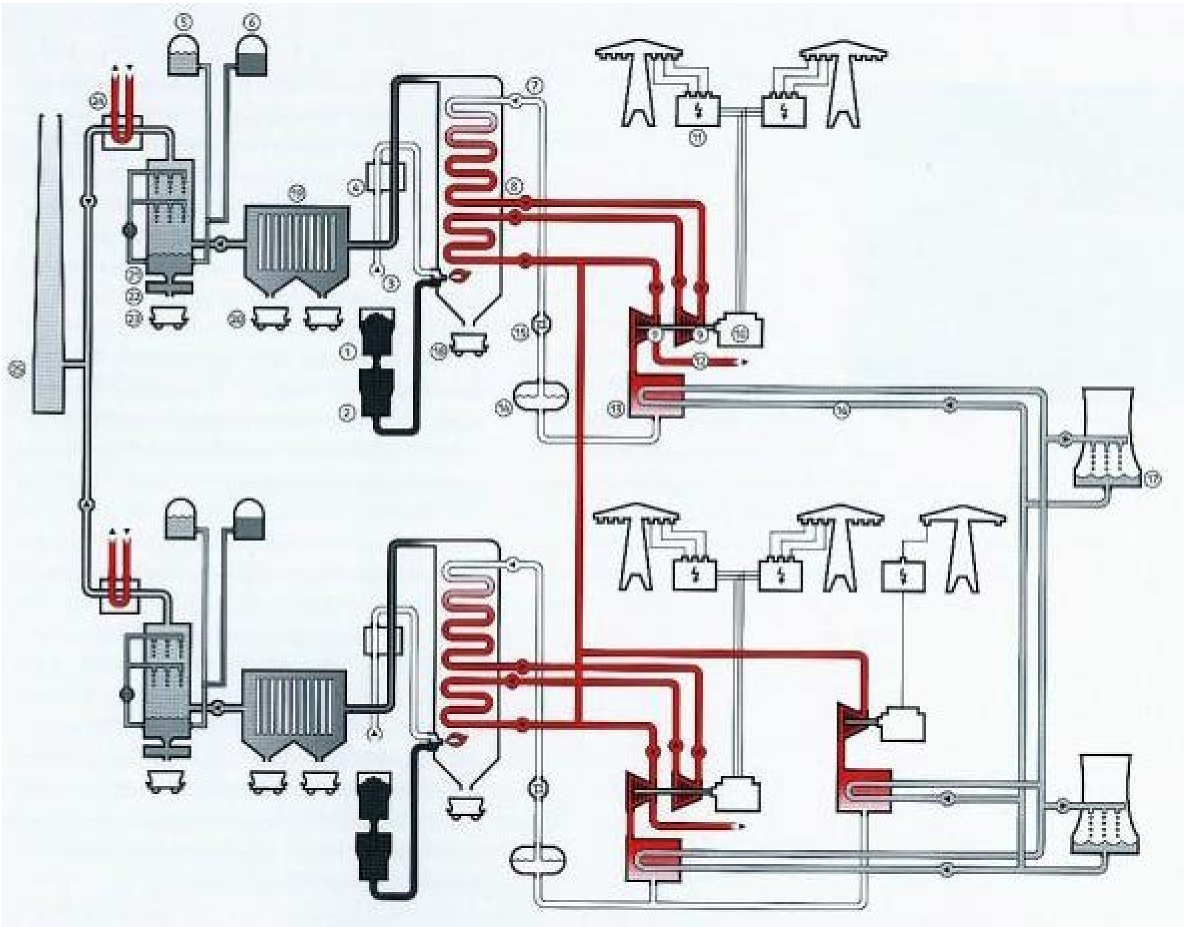

Figure 60: Sketch of the design of reference no. 133

The total rated thermal input of the plant (both boilers) is 2530 MW_{th}, the gross electric power output is 900 MW_{el}. Process steam for a nearby chemical facility can be extracted from the turbines at 18 bar (90 t/h) or at 4.3 bar (110 t/h). The maximal thermal power output is 157.7 MW_{th}.

Table 220 shows values for the fuel energy input and energy output in the reference year 2010. Five years have been taken into account for the rolling average value.

Table 220: General operating data for reference no. 133

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	1.33E+07	1.52E+07
Gross electric energy output	MWh_{el}	5.13E+06	5.96E+06
Net electric energy output	MWh_{el}	4.59E+06	5.34E+06
Gross heat output – steam	MWh_{th}	1.01E+06	1.01E+06
Net heat output – steam	MWh_{th}	1.01E+06	1.01E+06
Total operating time under normal operating conditions	h	6634	6700
Equivalent full load operating factor	%	80.0	90.5

The plant was operated for about 6700 h/a with an equivalent full load operating factor of 80 to 90 %. The net electrical utilisation ratio is 34.4 % (reference year) and 35.1 % (rolling average value). The thermal utilisation ratio is 7.6 % and 6.6 %, respectively. Therefore, the fuel utilisation factor is above 40 %.

Environmental aspects

The plant produces air and water emissions typical for lignite-fired power plants as well as corresponding solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO_x, CO and Hg are continuously measured in the flue gas. There are primary and secondary measures taken for emission abatement. Primary measures are air staging as well as low-NO_x-burners. Further NO_x reduction is not necessary. Figure 61 shows the schematic diagram of the FGT.

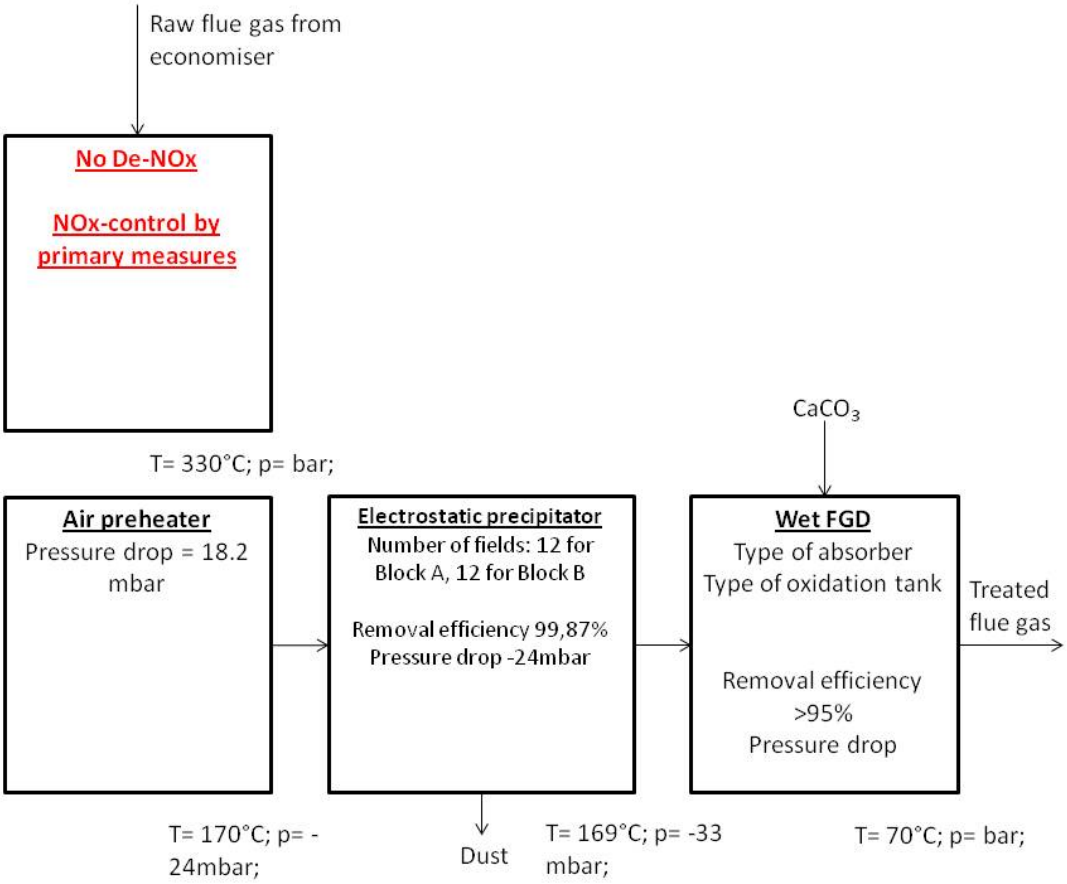

Figure 61: Schematic diagram of the FGT process for reference no. 133

The flue gas is cooled (air heater), before dust is removed in the ESP. SO_x is removed in the wet FGD, where it reacts with $CaCO_3$ to form gypsum. The treated flue gas is emitted via a stack.Table 221 shows the concentration and the annual load for the measured air-pollutants in the flue gas for one of the two boilers. The emission values of the second boiler are similar. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do include OTNOCs. The reference oxygen content is 6 %.

Table 221: Air emissions for reference no. 133

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority 1/2 h	Emission limit values prescribed by competent authority d
Dust	mg/Nm³	0	1.25	4.63	6.49	6.95	15.45	HHV	Cont.	Yes	40	20
	kg/year	3.9E+04										
SO_x	mg/Nm³	0	22.34	215.1	344.3	357.6	478.8	HHV	Cont.	Yes	800	400
	kg/year	2E+06										
SO_x removal	(%)	94.92	96.21	97.62	99.73	99.79	100	HHV	Cont.	Yes	-	95
NO_x	mg/Nm³	86.58	140.6	168.4	193.7	197.8	503	HHV	Cont.	Yes	400	200
	kg/year	1.6E+06										
CO	mg/Nm³	0	0	19.36	76.82	94.33	294.4	HHV	Cont.	Yes	400	200
	kg/year	2.1E+05										
	kg/year	-										
Hg	mg/Nm³	0	0.008	0.014	0.024	0.025	0.04	HHV	Cont.	Yes	0.05	0.03
	kg/year	136.82										

Waste water is pre-treated on site, before it is discharged into a nearby river. Figure 62 shows a schematic diagram of the WWT.

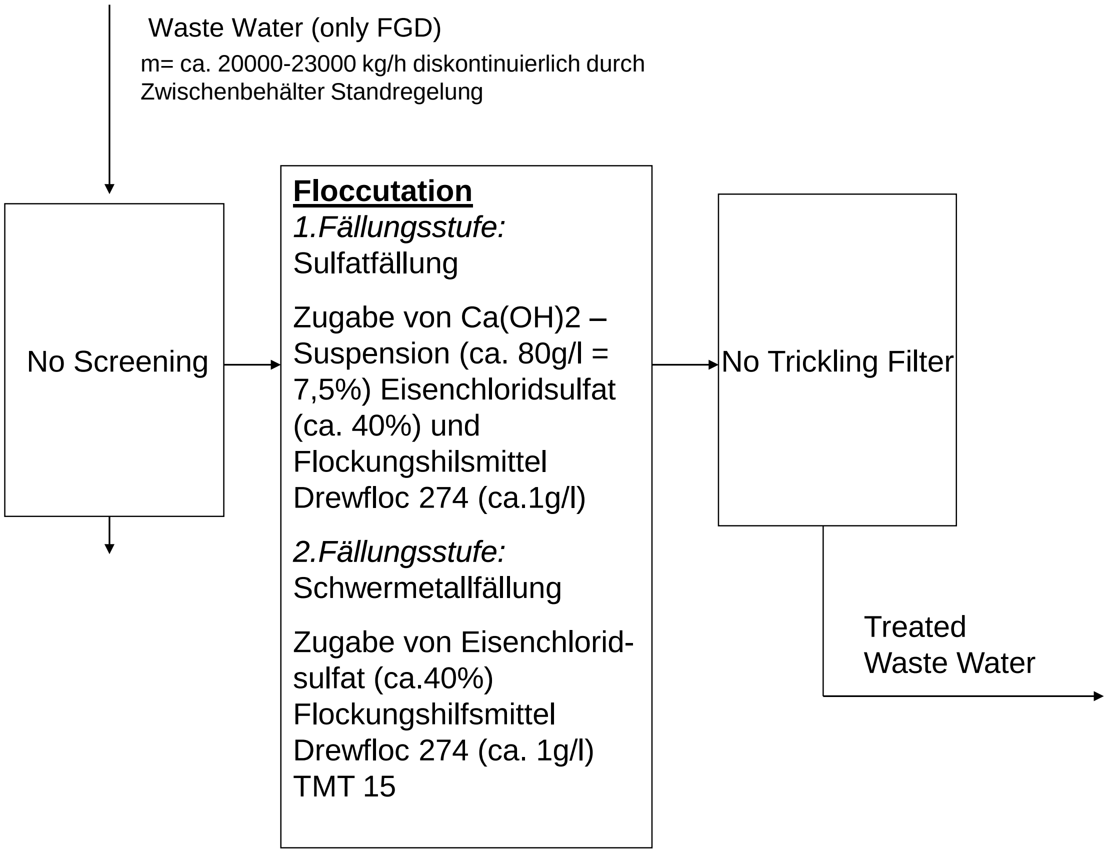

Figure 62: Schematic diagram of WWT process for reference no. 133

The waste water is produced mainly from the cooling system. Other waste water streams originate from the FGD and the steam system. The total mass flow of waste water was 3536204 m^3 in the reference year. The water emissions are presented in Table 222. In the effluent of the FGD-WWT of plant no. 133, pollutants, defined in appendix 47 D of the waste water regulations (Fluoride, Cu, Cd, Hg and Pb), are measured. However, not all these values are given by the operator for the sake of clarity. The values given in the here presented table refer to the common discharge point at which all occurring waste water streams are discharged. The concentrations of pollutants originating from the FGD are therefore rather small, as the FGD waste water has been diluted by other waste waters, and are therefore not comparable to the stated emission values for hard coal-fired boilers.

Table 222: Water emissions for reference no. 133 - after WWT

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	-	-	-	-	-	-	-
Temp.	(°C)	-	25	-	-	-	-	-	30
pH		-	8.1	-	-	-	-	-	6.5 to 9.5
TDS	(mg/l)	-	8	-	-	-	-	12	30
	(kg/year)			-					
COD	(mg/l)	-	45	-	-	Grab sample	-	-	15
	(kg/year)			-					
TOC	(mg/l)	-	10	-	-	Grab sample	-	12	-
	(kg/year)			-					
Cl^-	(mg/l)	-	3968	-	-	Grab sample	-	12	-
	(kg/year)			-					
F^-	(mg/l)	-	5	-	-	Grab sample	-	12	30
	(kg/year)			-					
S^{2-}	(mg/l)	-	0.1	-	-	Grab sample	-	12	0.2
	(kg/year)			-					
SO_3^{2-}	(mg/l)	-	0.7	-	-	Grab sample	-	12	20
	(kg/year)			-					
SO_4^{2-}	(mg/l)	-	1290	-	-	Grab sample	-	12	2000
	(kg/year)			-					
Cd	(mg/l)	-	0.005	-	-	Grab sample	-	12	0.02
	(kg/year)			-					
Hg	(mg/l)	-	0,0002	-	-	Grab sample	-	12	-
	(kg/year)								
Pb	(kg/year)	-	0.1	-	-	Grab	-	12	-

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
	(kg/year)			-		sample			
Cr	(mg/l)	-	0.02	-	-	Grab sample	-	12	-
	(kg/year)			-					
Cu	(mg/l)	-	0.02	-	-	Grab sample	-	12	-
	(kg/year)			-					
Zn	(mg/l)	-	0.1	-	-	Grab sample	-	12	1
	(kg/year)			-					

Table 223 shows the solid by-products. The by-products can be utilised in the construction material industry and for refilling of open cast mining areas.

Table 223: Solid residues for reference no. 133

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Flyash	Flue-gas treatment facilities	-	2.62E+05	Utilisation - others	refilling open cast mining
Bottom ash	Combustion process	-	6.68E+04	Utilisation - others	refilling open cast mining
Gypsum	Flue-gas treatment facilities	-	4.43E+05	Utilisation - Construction industry	refilling open cast mining and construction industry

Special characteristics

The plant configuration - two boilers with two steam turbines and one common turbine for railway-electricity - allows for a very flexible operation (for a lignite-fired LCP). Railway-electricity, electricity for the public network and process steam can be produced. These specifications are suggested as BAT by the operator.

3.4.3 Biomass-fired Boilers

3.4.3.1 General Discussion and Explanation of the Technology and the Emission Abatement Measures

For a detailed description of the technology of biomass combustion and emissions abatement, please see the predecessor report from 2002[8] as well as the biomass chapter in the annex of this report.

3.4.3.2 Presentation of the Results (evaluation levels III and IV)

For biomass-fired LCP five combustion installations were evaluated. Combustion installation no. 108 consists of two boilers (two questionnaires) with a total rated thermal input of more than 50 MW_{th} each, so that the total rated thermal input of the combustion installation is more than 100 MW_{th}. As can be seen in Table 224, the biomass-fired boilers are operated in base load and were all commissioned in the last ten years. All plants fall under the incentive scheme of the EEG, which is why they are traded separately from the regular electricity market. All plants display a high equivalent full load operating factor of more than 90 %. The total rated thermal inputs of the plants are rather small (< 100 MW_{th}). All plants can be used for CHP, only plant no. 125 is not used for it. It should be noted, that plant no. 107 is authorised and approved in terms of the 13. BImSchV. Hence, only natural wood and forestry wood is allowed for combustion. All other plants combust waste wood (classes A I to A IV) and are therefore authorised in terms of the 17. BImSchV. Plants no. 108 and 655 are equipped with grate firing, while the boilers of plants no. 107 and 125 are CFB boilers.

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[8] Rentz, O. ; Gütlin, K. ; Karl, U.: Erarbeitung der Grundlagen für das BVT-Merkblatt Großfeuerungsanlagen im Rahmen des Informationsaustausches nach Art. 16(2) IVU-Richtlinie, Forschungsbericht 200 46 317 / Deutsch-Französisches Institut Für Umweltforschung Universität Karlsruhe (TH). 2002. – Forschungsbericht

Table 224: Evaluation level III: Group "Biomass-fired Boilers"

TRTI in MW_{th}	Plant no.	TRTI in MW_{th}	Year of commis-sioning (last retrofit)	Operating mode (according to EIPPCB)	Total operating time under normal conditions	Equivalent full load operating factor	CHP	Other
< 100	108-1	53 each	2004 ()	Base load	7228	94.3	Yes	17. BImSchV (waste wood), 2 identical boilers, 1 ST, Grate Firing
	108-2				6750	93.3		
	125	65	2003 (2006)	Base load	7857	99.0	No	17. BImSchV (waste wood), CFB
	107	67	2009 ()	Base load	6603	93.1	Yes	13. BImSchV (natural wood), CFB
	655	86	2004	Base load	8433	73.9	Yes	17. BImSchV (waste wood), Grate Firing

Table 225 shows the efficiencies and utilisation ratios for the plants. It can be seen that plants no. 108-1, 108-2 and 107 achieve higher fuel utilisation factors than plants no. 125 and 655. This is caused by the predominate CHP operation. Plant no. 125 displays the highest nominal gross electrical efficiency.

Table 225: Evaluation level IV, Table a: Efficiencies and Utilisation ratios for the Group "Biomass-fired Boilers"

TRTI in MW_{th}	Plant no.	Efficiency	Utilisation ratio			Fuel utilisation factor
		(el., gross, nom.) in %	(el., gross) in %	(el., net) in %	(th.) in %	(net) in %
< 100	108-1	18.9	19.5	16.5	42.8	59.3
	108-2	18.9	19.5	16.5	42.8	59.3
	125	34.3	34.3	30.9	-	30.9
	107	29.9	29.6	26.2	12.4	38.6
	655	23.3	26.9	24.0	6.6	30.6

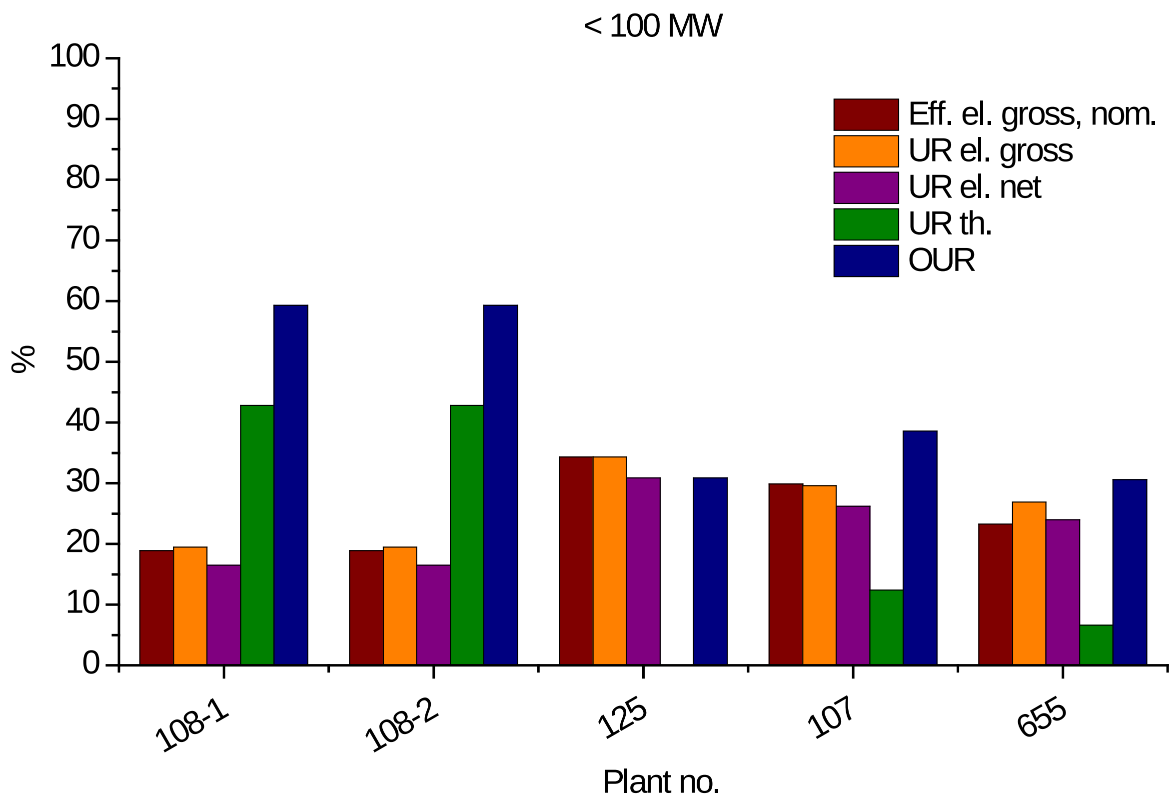


Figure 63: Evaluation level IV, Table a: Efficiencies and utilisation ratios for the Group "Biomass-fired Boilers"

In Table 226 and the subsequent diagrams, the air emissions for biomass-fired plants are shown.

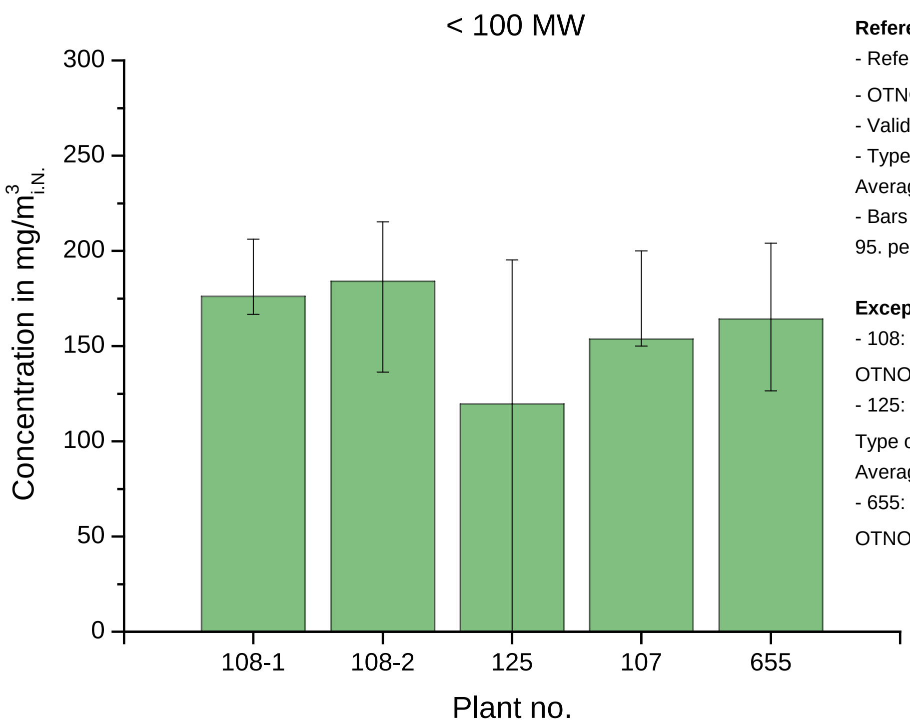
The NO_x emissions of plants no. 108-1, 108-2 and 655 are the highest, although these plants are equipped with a SNCR-technology. Plants no. 107 and 125 show lower values, which is due to the CFB combustion technology.

All plants use fabric filters for dust abatement and thus achieve very low emissions.

The SO_x emissions of plant no. 107, which is fired with natural wood, is below 1 mg/Nm^3. Plant no. 125 uses a dry adsorption with Ca(OH)2 and shows emissions values of 1.6 mg/Nm^3. Plants no. 108-1, 108-2 and 655 are not equipped with secondary measures and display emissions of 30 to 40 mg/Nm^3.

Table 226: Evaluation level IV, Table b: Air emissions for the Group "Biomass-fired Boilers"

TRTI in MW_{th}	Plant no.	NO_x		CO	Dust		SO_x		Hg	
		Ø in mg/Nm³	Secondary measures	Ø in mg/Nm³	Ø in mg/Nm³	Secondary measures	Ø in mg/Nm³	Secondary measures	Ø in mg/Nm³	Secondary measures
< 100	108-1	176.2	SNCR	15.7	0.42	Cyclone, fabric filter	42.1	Dry adsorption	0.0030	
	108-2	184.0	SNCR	21.6	0.34	Cyclone, fabric filter	42.6	Dry adsorption	0.0020	-
	125	119.7	-	27.5	3.31	Cyclone, fabric filter	1.6	Dry adsorption	0.0007	-
	107	153.6	-	11.8	0.42	Fabric filter	0.7	-	-	-
	655	164.2	SNCR	17.7	3.31	Cyclone, fabric filter	30.92	Dry adsorption	0.0005	-



Reference conditions:
- Reference O_2= 6 %
- OTNOCs = No
- Validated = Yes
- Type of Average = Average HHV
- Bars = 5. / 95. percentil

Exceptions:
- 108: Reference-O_2 = 11 %, OTNOCs = Yes
- 125: Reference-O_2 = 11 %, Type of Average = Average DV
- 655: Reference-O_2 = 11 %, OTNOCs = Yes

Figure 64: Evaluation level IV, Table b: NO_x emissions for the Group "Biomass-fired Boilers"

All plants show NO_x emissions in the range of 125 to 175 mg/Nm^3. It can be seen, that the CFB boilers achieve even lower NO_x emissions than the grate Firings with SNCR (plants no. 108 and 655).

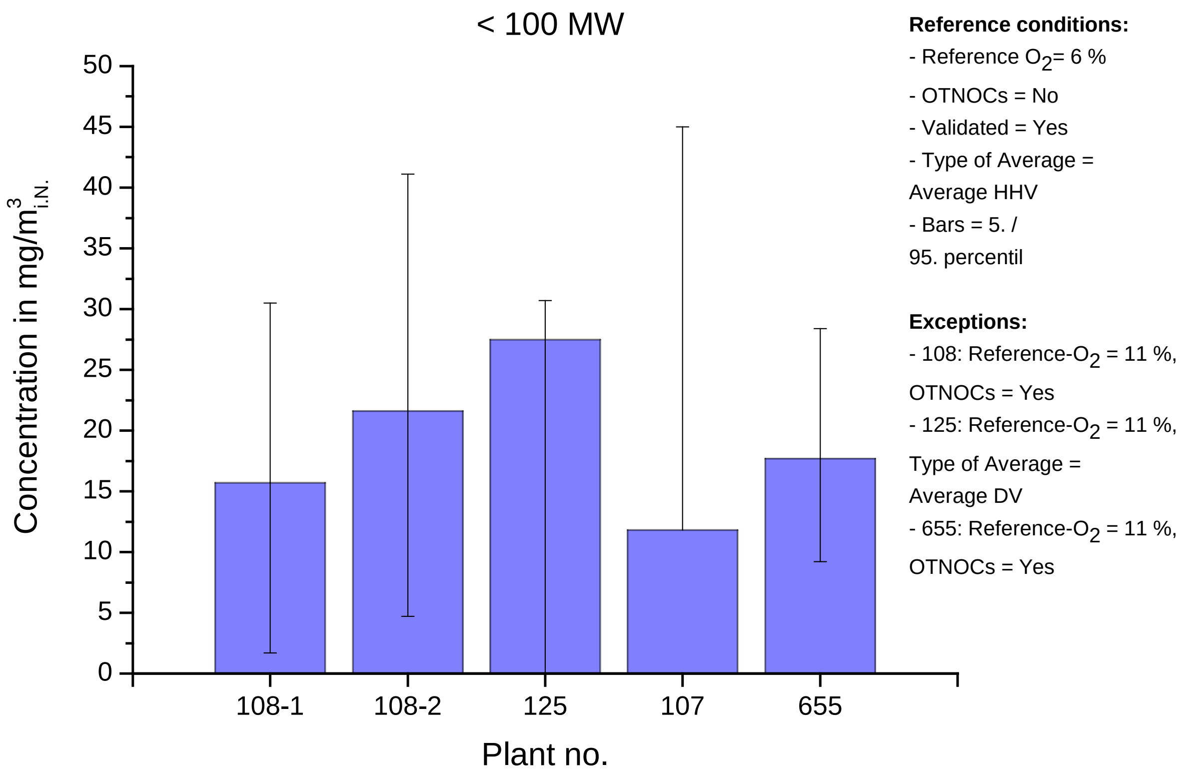


Figure 65: Evaluation level IV, Table b: CO emissions for the Group "Biomass-fired Boilers"

The CO emissions are in the range of 10 to 30 mg/Nm^3. The firing-technology is not of any significant influence.

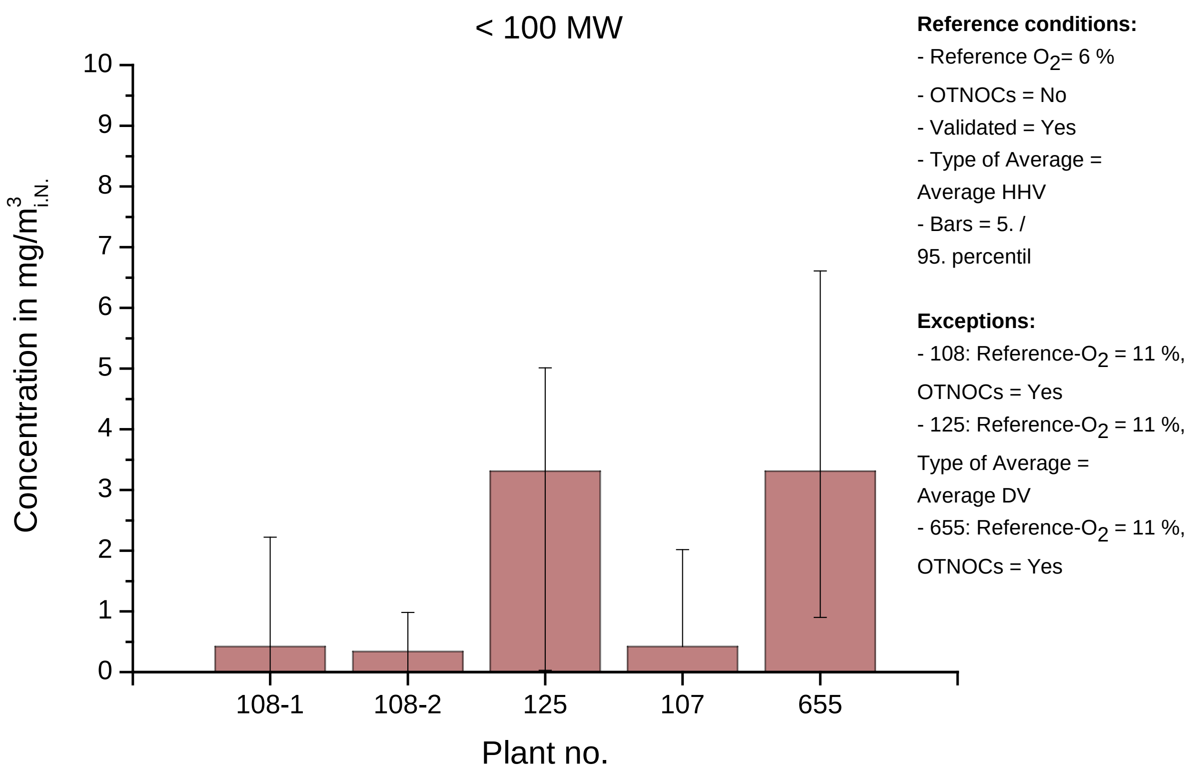


Figure 66: Evaluation level IV, Table b: Dust emissions for the Group "Biomass-fired Boilers"

The level of dust emissions of all plants is very low due to the application of fabric filters. The dust emissions of plants no. 108-1, 108-2 and 107 are well below 1 mg/Nm³. Plants no. 125 and 655 show slightly higher values of about 3 mg/Nm³. It has to be mentioned that the maintenance intervals of the fabric filters and the fuel used are of significant influence on the emissions, which is why multiple years of operation should be taken into consideration.

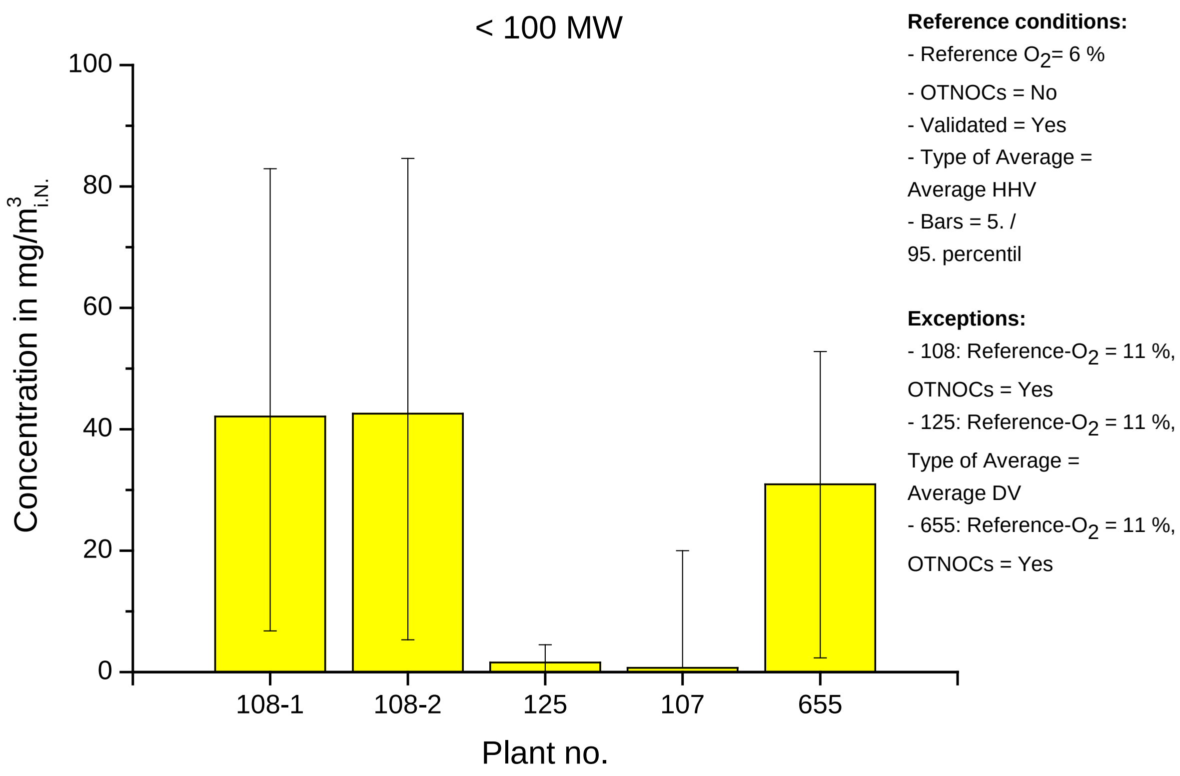


Figure 67: Evaluation level IV, Table b: SO_x emissions for the Group "Biomass-fired Boilers"

The influence of the combusted fuel on the SO_x emissions is very distinct. Plant no. 107, the only plant combusting natural wood, shows almost no emissions at all. Plant no. 125, which is equipped with a dry adsorption FGD, shows also very low values. Plants no. 108 and 655 are fuelled with waste wood and are also equipped with dry adsorption FGDs. They achieve emission values of about 40 mg/Nm^3.

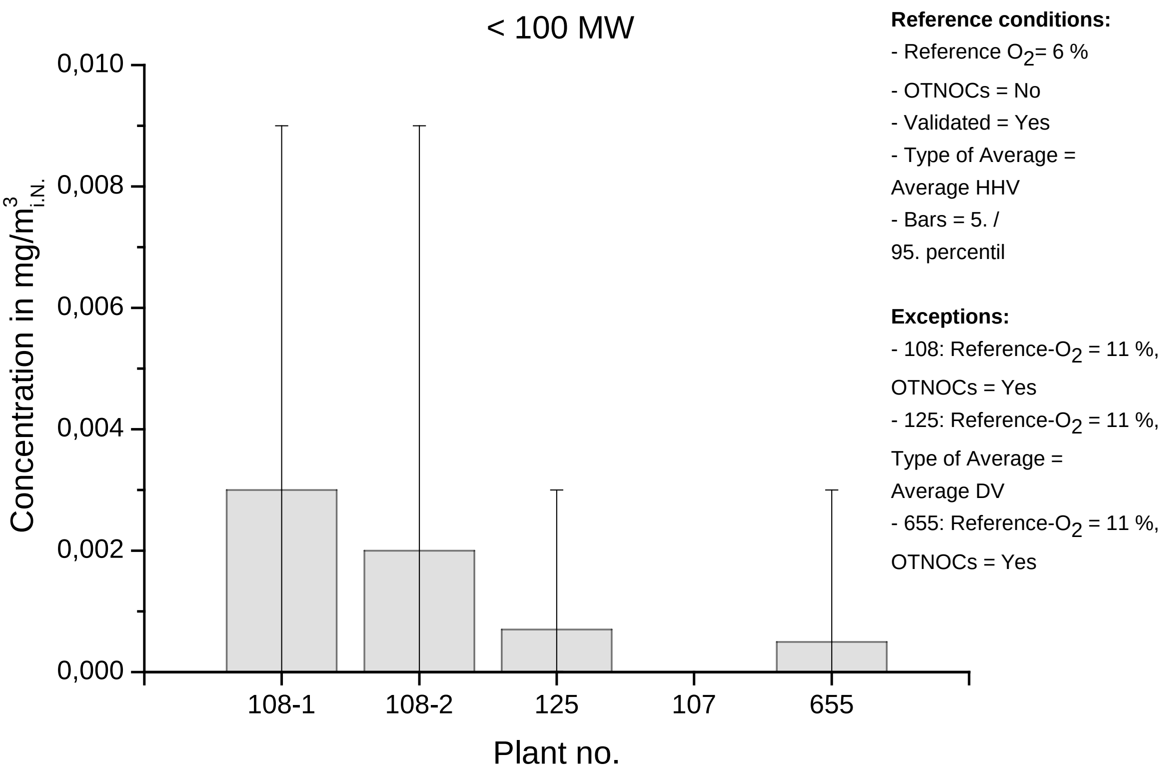


Figure 68: Evaluation level IV, Table b: Hg emissions for the Group "Biomass-fired Boilers"

The Hg emissions are in the range of 10 to 30 µg/Nm³. Plant no. 108 shows the highest values, while plant no. 107, which is fueld with natural wood, shows no Hg emissions at all.

The reference conditions and the exceptions for the biomass-fired plants are shown in Table 227.

Table 227: Reference conditions and exceptions for the Group "Biomass-fired Boilers"

Plant no.	Ref. O_2 in %	Includes OTNOCs	Validated	Type of average	Fuel	Other
Reference	6	No	Yes	HHV	Wood	-
107	-	-	-	-	-	CFB
108	11	Yes	-	-	Waste wood	2 boilers, 1 ST
125	11	-	-	DA	Waste wood	CFB, dry adsorption
655	11	Yes	-	-	Waste wood	Grate Firing, dry adsorption

For the water emissions, almost no information was given. At plants no. 108-1 and 108-2 4.4 mg/l of TOC and 0.01 mg/l of AOC were measured. Other pollutants were not recorded. Plant no. 107 emits 88 mg/l of sulphate (average basis) and traces of other metals, which are given in the more detailed plant description. For plant no. 125 and plant no. 655 no information of water emissions was submitted.

Table 228 shows the templates for biomass-fired plants. From plants no. 108-1, 108-2, 125 and 655 a total of twelve templates was submitted. Only for plant no. 107, no BAT suggestions were made. The templates mainly deal with air emission reduction and reduced water consumption. For more details, please see the individual plant descriptions.

Table 228: Evaluation level IV, Table d: BAT submissions for the Group "Biomass-fired Boilers"

TRTI in MW_{th}	Plant no.	No. of templates	Short summary	Technical domain	Level of detail
< 100	108-1, 108-2	9	Removal of disturbing substances	Fuel pre-treatment	Low
			Dust removal in delivery hall	Fuel pre-treatment	Low
			Cyclone	Air emissions	Low
			Sorbent dosing system	Air emissions	Low
			Fabric filter	Air emissions	Low
			Closed ash water circuit	Water	Low
			Air condenser	Water	Low
			Fuel and air staging	Combustion	Low
			SNCR	Combustion	Low
	125	3	Air condenser	Water	Low
			CFB boiler	Combustion	Medium
			Dry adsorption FGT	Air emissions	Low
	107	0	-		-
	655	1	Plant configuration	Whole plant	High

3.4.3.3 Descriptions of Evaluated Plants or Installations

Grate Firing, Reference no. 108

Reference no. 108 is a moving grate firing for electricity generation, which was commissioned in 2004. The plant consists of two natural circulation boilers, which feed one condensation steam turbine. The main fuel is waste wood (classes A I to A IV), which is why the plant had to be authorised and approved in terms of the 17. BImSchV. The start-up is aided with NG, which is also used as back-up fuel. The live steam parameters are 450 °C and 65 bar. Hot water for district heating can be produced with 3.3 bar/105 °C. The cooling system is an air cooling system. As the water consumption is reduced with this, this technology is suggested as BAT by the operator. The ash cooling is done with a circulating water cycle. The grate is air-cooled.

The total rated thermal input of the plant is 106°MW_{th}, 54 MW_{th} for each boiler. The nominal gross electric power output is 20°MW_{el} and the nominal gross heat power output is 66 MW_{th}.

Table 229 and Table 230 show values for the fuel energy input and energy output in the reference year 2010. Five years have been taken into account for the rolling average value.

Table 229: General operating data for reference no. 108 – Boiler 1

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	3.61E+05	3.45E+05
Gross electric energy output	MWh_{el}	7.05E+04	6.66E+04
Net electric energy output	MWh_{el}	5.95E+04	5.71E+04
Gross heat output – hot water	MWh_{th}	1.55E+05	1.37E+05
Total operating time under normal operating conditions	h	7228	6960
Equivalent full load operating factor	%	94	93

Table 230: General operating data for reference no. 108 – Boiler 2

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	3.34E+05	3.45E+05
Gross electric energy output	MWh_{el}	6.51E+04	6.66E+04
Net electric energy output	MWh_{el}	5.49E+04	5.71E+04
Gross heat output – hot water	MWh_{th}	1.42E+05	1.37E+05
Total operating time under normal operating conditions	h	6750	6844
Equivalent full load operating factor	%	93	95

In the reference year, the boilers were operated for 7200 h (boiler 1) and 6700 h (boiler 2) with equivalent full load operating factors of above 90 % (in both cases). The net electrical utilisation ratio is 16.5 % for boiler 1 and 16.4 % for boiler 2. With a thermal utilisation ratio of 42.9 % (boiler 1) and 42.8 % (boiler 2), the fuel utilisation factors are 59.3 % (boiler 1) and 59.2 % (boiler 2), respectively.

The total operating time for the rolling average value is about 7000 h with an equivalent full load operating factor of 90 %. The net electrical utilisation ratio is 16.6 % for both boilers, a thermal utilisation ratio is 39.7 % for each boiler. With this, a fuel utilisation factor of 56.3 % can be calculated.

Environmental aspects

The plant produces typical air emissions for waste wood-fired power plants. In accordance to the official authorisation (17. BImSchV), the air pollutants dust, SO_x, NO_x, CO, HCl, TOC and Hg are continuously measured in the flue gas. In addition to this, other pollutant emissions (e.g. NH_3 three measurements in the reference year) are periodically measured. There are primary and secondary measures taken for emission abatement. Primary measures are air grading as well as flue gas recirculation. Figure 69 shows a schematic diagram of the FGT process (secondary measures).

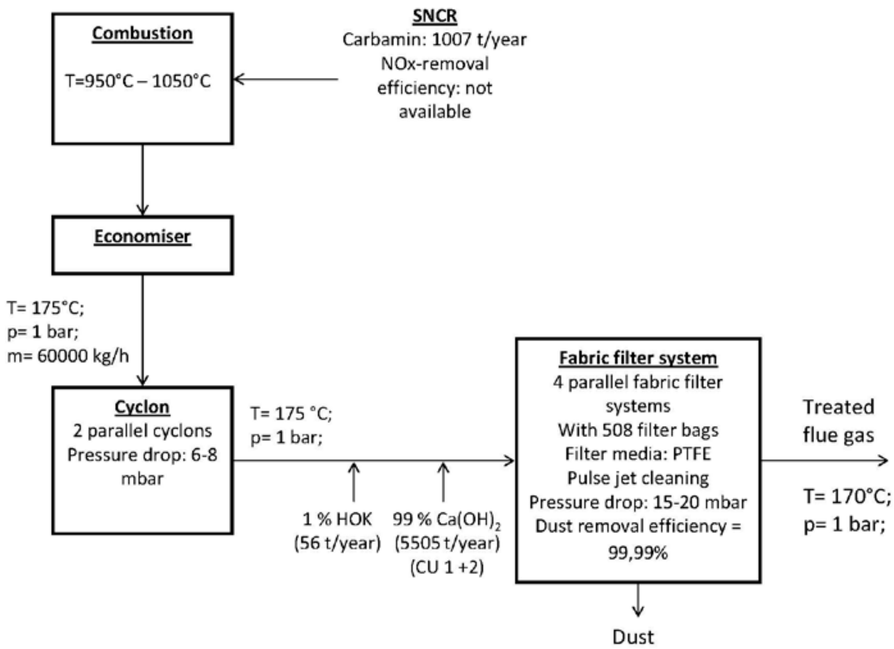


Figure 69: Schematic diagram of the FGT process for reference no. 108

The first stage of the FGT process (secondary measures) is the dust-removal, which is comprised of 2 cyclone separators. Furnace coke and $Ca(OH)_2$ are then added to the flue gas, so that acidic compounds and heavy metals are chemically bound. The subsequent fabric filter separates fine dust and the bonded pollutants from the gas. This FGT accounts for a high separation efficiency and is therefore suggested as BAT by the operator. NO_x emissions are reduced directly in the furnace by the addition of carbamin (SNCR).

Table 231 and Table 232 show the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do include OTNOCs. The reference oxygen content is 11 %.

Table 231: Air emissions for reference no. 108 –Boiler 1

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	0	0	0.42	2.2	2.43	53.36	HHV	Cont.	Yes	30	10
	kg/year	684										
SO_x	mg/Nm^3	0	6.81	42.14	82.98	91.67	319.4	HHV	Cont.	Yes	200	50
	kg/year	2.5E+04										
NO_x	mg/Nm^3	0	166.7	176.2	206.2	213.1	363.6	HHV	Cont.	Yes	400	200
	kg/year	1E+05										
CO	mg/Nm^3	0	1.77	15.72	30.51	33.35	160.8	HHV	Cont.	Yes	100	50
	kg/year	1.2E+04										
HCl	mg/Nm^3	0	0	2.17	5.94	6.97	60.09	HHV	Cont.	Yes	60	10
	kg/year	1550										
Hg	mg/Nm^3	0	0	0.003	0.009	0.01	0.039	HHV	Cont.	Yes	0.05	0.03
	kg/year	1.7										
NH_3	mg/Nm^3	-	-	11.4	-	-	15	HHV	Perio.	No	30	-
	kg/year	-										
TOC	mg/Nm^3	0	0	0.23	0.86	1.05	17.95	HHV	Cont.	Yes	20	10
	kg/year	220										

Table 232: Air emissions for reference no. 108 –Boiler 2

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	0	0	0.34	0.98	1.24	52.25	HHV	Cont.	Yes	30	10
	kg/year	305										
SO_x	mg/Nm^3	0	5.28	42.56	84.52	93.96	234.5	HHV	Cont.	Yes	200	50
	kg/year	2.6E+04										
NO_x	mg/Nm^3	0	136.3	184	215.3	224.7	523.5	HHV	Cont.	Yes	400	200
	kg/year	1.1E+05										
CO	mg/Nm^3	0	4.78	21.63	41.15	44.44	267.6	HHV	Cont.	Yes	100	50
	kg/year	2.7E+04										
HCl	mg/Nm^3	0	1.19	3.03	6.75	8.01	59.5	HHV	Cont.	Yes	60	10
	kg/year	2055										
Hg	mg/Nm^3	0	0	0.002	0.009	0.01	0.026	HHV	Cont.	Yes	0.05	0.03
	kg/year	1.6										
NH_3	mg/Nm^3			14.4			17	HHV	Perio.	No	30	-
	kg/year	N.A.										
TOC	mg/Nm^3	0	0	0.83	1.97	2.39	27.57	HHV	Cont.	Yes	20	10
	kg/year	659										

The plant produces 46400 m^3 of waste water each year. The water is discharged into the public sewerage. Only TOC and AOX emissions are measured (see Table 233).

Table 233: Water emissions for reference no. 108

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
Flow	(m^3/year)	-	4.6E+04	-	-	-	-	-	-
Temp.	(°C)	-	19	-	-	-	-	-	-
pH		-	8.1	-	-	-	-	-	-
TOC	(mg/l)	4.1	4.4	4.8	-	Grab sample	No	4	5
	(kg/year)	-							
AOX	(mg/l)	0.01	0.01	0.01	-	Grab sample	-	4	10 ↔g/l
	(kg/year)	-							

Table 234 shows the solid residues (by-products). Grate ash makes up the largest part of by-products, but cannot be utilised. Other by-products can be utilised in the construction material industry or the underground mining industry.

Table 234: Solid residues for reference no. 108

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Bottom ash	Combustion process	190111*	4.1E+04	Temporary stockpile	dumped in landfills
Cyclon ash	Flue-gas treatment facilities	190115*	4864	Utilisation - Underground mining	underground reutilisation as backfilling material in the mining industry
Filter ash	Flue-gas treatment facilities	190113*	7520	Utilisation - Underground mining	

Special characteristics

To ensure continuous operation, large wood pieces and metal objects are removed from the fuel.

The dusty air from the fuel storage is filtered in a bag filter system.

The FGT (capturing of pollutants and subsequent separation in a fabric filter) is suggested as BAT by the operator.

The amount of waste water and indirectly the occurring waste water emissions are reduced by the application of an air cooling system and a closed loop ash cooling system.

Circulating Fluidised Bed Combustion, Reference no. 107

Reference no. 107 is a Circulating Fluidised Bed (CFB) combustion for the generation of electricity and process steam, which was commissioned in 2009. The main fuel is woody biomass (forest residues). No waste wood is used, which is why the plant was authorised and approved in terms of the 13. BImSchV. The live steam parameters are 535 °C and 130 bar. The steam parameters of the produced process steam are 3.5 bar and 175 °C. The cooling system is an air-cooled mechanical draught closed circuit system.

The total rated thermal input is 67 MW_{th}, the gross electric power output is 20 MW_{el}, the gross heat power output is 10 MW_{th}. Table 235 shows the energy input and output for the reference year as well as the total operating time under normal operating conditions. The reference year for the given values is 2010. Rolling average values are not available, as the plant is only in operation since 2009.

Table 235: General operating data for reference no. 107

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	4.12E+05	-
Gross electric energy output	MWh_{el}	1.22E+05	-
Net electric energy output	MWh_{el}	1.08E+05	-
Gross heat output – steam	MWh_{th}	5.10E+04	-
Net heat output – steam	MWh_{th}	5.10E+04	-
Total operating time under normal operating conditions	h	6603	-
Equivalent full load operating factor	%	93.1	-

In the reference year, the plant was operated for about 6600 h with an equivalent full load operating factor of 93.1 %. The net electrical utilisation ratio is 26.2 %. With a thermal utilisation ratio of 12.4 % the fuel utilisation factor is 38.6 %.

Environmental aspects

The plant produces typical air emissions for wood-fired power plants as well as corresponding amounts of waste water and solid residues. In accordance to the official authorisation, the air pollutants dust, SO_x, NO, CO and TOC are continuously measured in the flue gas. In addition to this, the PCDD- and PCDF-emissions are periodically measured. There are primary and secondary measures taken for emission abatement. Due to the CFB combustion (primary measure), good burnout can already be achieved at low temperatures, so that NO_x and CO emissions are low.

The only secondary measure is the removal of dust with a fabric filter. The limits for NO_x and SO_x are kept without any further FGT.

Table 236 shows the concentration and the annual load for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do include OTNOCs. The reference oxygen content is 6 %.

Table 236: Air emissions for reference no. 107

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by compe tent authority	
											1/2 h	d
Dust	mg/Nm³	-	-	0.42	2	4	34	HHV	Cont.	Yes	20	-
	kg/year	239										
SO_x	mg/Nm³	-	-	0.7	20	20	220	HHV	Cont.	Yes	200	-
	kg/year	370										
SO_x removal	(%)	-	-	-	-	-	-	-	-	-	-	-
		-										
NO_x	mg/Nm³	75	150	153.6	200	225	550	HHV	Cont.	Yes	250	-
	kg/year	8.8E+04										
CO	mg/Nm³	-	-	11.78	45	75	372	HHV	Cont.	Yes	150	-
	kg/year	7214										
HCl	mg/Nm³	-	-	-	-	-	-	-	-	-	-	-
	kg/year	-										
HF	mg/Nm³	-	-	-	-	-	-	-	-	-	-	-
	kg/year	-										
Hg	mg/Nm³	-	-	-	-	-	-	-	-	-	-	-
	kg/year	-										
TOC	mg/Nm³	-	-	0.13	1	1	25	HHV	Cont.	Yes	10	-
	kg/year	80										
PCDD/ PCDF	ng/Nm³	0.001	-	0.002	-	-	0.004	average about 3 x 6 hours	Perio.	-	0.1	
	kg/year	1.7E-06										

The waste water, which is produced in the plant and in the on-site waste water pre-treatment facilities, is discharged into the public sewerage. Measurements are done periodically and are presented in Table 237.

Table 237: Water emissions for reference no. 107

		Minimum	Average	Maximum	Type of average	Method to obtain data	Validated	Number of samples considered for the values reported in this table	Emission limit values prescribed by competent authority
SO_4^{2-}	(mg/l)	5	88	305	-	Grab sample	-	12	-
	(kg/year)	751							
Cr	(mg/l)	0.01	0.01	0.01	-	-	-	-	-
	(kg/year)	0.85							
Cu	(mg/l)	0.01	0.01	0.01	-	Grab sample	-	4	-
	(kg/year)	0.85							
Ni	(mg/l)	0.01	0.01	0.01	-	Grab sample	-	4	-
	(kg/year)	0.85							
V	(mg/l)	0.01	0.01	0.01	-	Grab sample	-	4	-
	(kg/year)	0.85							
Zn	(mg/l)	0.02	0.038	1.08	-	Grab sample	-	4	-
	(kg/year)	0.324							
AOX	(mg/l)	0.001	0.019	0.069	-	Grab sample	-	12	1
	(kg/year)	0.164							

Table 238 shows the solid residues (by-products). Bottom ash, slag and fly ash make up the largest part of the by-products and can be utilised in the construction material industry. Other residues cannot be reused.

Table 238: Solid residues for reference no. 107

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Bottom ash, slag and boiler dust	Combustion process	10 01 01	3735	Utilisation – Construction industry	Land filling
Sludge	WWT facilities	10 01 21	11	-	-
Sludge from oil/water separator	WWT facilities	13 05 02	0.6	-	-
Saturated or spent ion exchange resins	Raw water treatment facilities	19 09 05	1.4	-	-
Mineral-based non-chlorinated engine, gear and lubricating oils	-	13 02 05	1.6	-	-
Absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by dangerous substances	-	15 02 02	1.35	-	-
Packaging containing residues of or contaminated by dangerous substances	-	15 01 10	0.3	-	-
Wastes containing oil	-	16 07 08	0.25	-	-

Special characteristics

The main fuel for the CFB combustion is woody biomass (forest residues). No waste wood is used, which is why the plant was authorised and approved in terms of the 13. BImSchV.

Circulating Fluidised Bed Combustion, Reference no. 125

Reference no. 125 is a circulating fluidised bed (CFB) combustion for electricity generation. The main fuel is wood waste (classes A II and A III, small amounts of A IV), which is why the plant had to be authorised and approved in terms of the 17. BImSchV. The live steam parameters are 520 °C and 85 bar. The cooling system for the condenser is an air cooling system. The exhaust steam pressure is about 100 mbar. This technology is suggested as BAT by the operator, because it reduces the water consumption. In 2006, soot blowers were retrofitted as well as a screen in the ash recirculation.

The total rated thermal input of the plant is 65 MW_{th}. The nominal gross electric power output is 22.3 MW_{el}, which leads to a nominal gross electrical efficiency of 34.3 %.

Table 239 shows the energy input and output for the reference year as well as the total operating time under normal operating conditions. The reference year for the given values is 2010. Five years have been taken into account for the rolling average value.

Table 239: General operating data for reference no. 125

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	5.06E+05	5.00E+05
Gross electric energy output	MWh_{el}	1.73E+05	1.70E+05
Net electric energy output	MWh_{el}	1.56E+05	1.53E+05
Total operating time under normal operating conditions	h	7857	7653
Equivalent full load operating factor	%	99	100.5

The plant was operated almost continuously in the past with an equivalent full load operating factor of 100 %. The net electrical utilisation ratio is 30.9 % and 30.5 %, respectively.

Environmental aspects

The plant produces typical air emissions for waste wood-fired power plants. Additionally, solid residues are produced as well as small amounts of waste water. In accordance to the official authorisation (17. BImSchV), the air pollutants dust, SO_x, NO_x, CO, HCl, TOC and Hg are continuously measured in the flue gas.

There are primary and secondary measures taken for emission abatement. Due to the CFB combustion technology, good burnout can be achieved at relatively low temperatures of 920 °C. In this way, NO_x and CO emissions are very low (primary measures). For this reason, the CFB is suggested as BAT by the operator.

Further FGT (secondary measures) is done in three stages. The first stage is the coarse dust removal in four gas cyclone separators. In the second stage, the flue gas is treated with blast furnace coke and $Ca(OH)_2$, which adsorb acidic constituents like SO_x, HCl, HF and heavy metals. Finally, the fine dust is removed in a fabric filter. The benefits of this configuration are good precipitation efficiency with low investment and energy consumption costs. For this reason, the technology used is suggested as BAT by the operator.

Table 240 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do include OTNOCs. The reference oxygen content is 11 %.

Table 240: Air emissions for reference no. 125

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	-	0.03	3.31	5.01	-	30	DV	Cont.	Yes	-	10
	kg/year						4098.09					
SO_x	mg/Nm^3	-	0.01	1.57	4.5	-	200	DV	Cont.	Yes	-	50
	kg/year						2640.27					
SO_x removal	(%)	93	-	-	-	-	99	DV	Cont.	Yes	-	-
							-					
NO_x	mg/Nm^3	-	0.01	119.7	195.2	-	400	DV	Cont.	Yes	-	200
	kg/year						1.4E+05					
CO	mg/Nm^3	-	0.01	27.54	30.7	-	95.24	DV	Cont.	Yes	-	50
	kg/year						3.1E+04					
HCl	mg/Nm^3	0.1	0.5	1.9	8.1	-	40	DV	Cont.	Yes	-	10
	kg/year						3981.08					
HF	mg/Nm^3	-	-	0.11	-	-	-	-	Perio.	No	-	1
	kg/year						77.5					
Hg	mg/Nm^3	-	-	-	-	-	0.03	DV	Cont.	Yes	-	0.03
	kg/year						1.61871					
TOC	mg/Nm^3	-	-	0.87	0.92	-	10.5	DV	Cont.	Yes	-	10
	kg/year						1091.96					
Cd	mg/Nm^3	-	-	1E-05	-	-	-	-	-	No	-	-
	kg/year						0.0077					
Ti	mg/Nm^3	-	-	2E-05	-	-		-	-	No	-	-
	kg/year						0.0155					
Cd + Ti	mg/Nm^3	-	-	-	-	-	-	-	Perio.	No	-	0.05
	kg/year						0.0232					

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
Sb	mg/Nm³	-	-	2E-04	-	-	-	-	Perio.	No	-	-
	kg/year	0.1239										
As	mg/Nm³	-	-	6E-05	-	-	-	-	Perio.	No	-	-
	kg/year	0.0465										
Pb	mg/Nm³	-	-	0.001	-	-	-	-	Perio.	No	-	-
	kg/year	0.8519										
Cr	mg/Nm³	-	-	2E-04	-	-	-	-	Perio.	No	-	-
	kg/year	0.1549										
Co	mg/Nm³	-	-	4E-05	-	-	-	-	Perio.	No	-	-
	kg/year	0.0310										
Cu	mg/Nm³	-	-	2E-04	-	-	-	-	Perio.	No	-	-
	kg/year	0.1781										
Mn	mg/Nm³	-	-	0.004	-	-	-	-	Perio.	No	-	-
	kg/year	3.2682										
Ni	mg/Nm³	-	-	4E-05	-	-	-	-	Perio.	No	-	-
	kg/year	0.0310										
V	mg/Nm³	-	-	9E-05	-	-	-	-	Perio.	No	-	-
	kg/year	0.0697										
Other *	mg/Nm³	-	-	0.006	-	-	-	-	Perio.	No	-	0.05
	kg/year	0.3020										
PCDD / PCDF	ng/Nm³	-	-	0.003	-	-	-	-	Perio.	No	-	-
	kg/year	0.0031										

* Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V

The waste water of the plants originates from different sources. While water from the steam system, the raw water treatment, the cooling system and from office buildings is discharged directly into the municipal sewerage, the surface run offs and other surface waters are treated in an onsite coalescence abatement system. Water emissions are not measured.

Table 241 shows the solid residues (by-products). Fly ash (including additives) from the FGT makes up the largest part of by-products. In addition to this, sand and coarse ash from the CFB are accumulated. The by-products can be utilised in the construction material industry or for reclamation of open cast mines, quarries and pits. A part of the filter ashes has to be used for land filling below ground as hazardous waste.

Table 241: Solid residues for reference no. 125

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Fluidised bed sand	Combustion process	190112	3357	Utilisation - Construction industry	fine particles, DK1; R5, D1
Coarse ash	Combustion process	190112	3055	Reclamation / restoration of open cast mines, quarries and pits	coarse particles, metal residues, DK1; D1
Filter dust	Flue-gas treatment facilities	190113	5996	Reclamation / restoration of open cast mines, quarries and pits	contains heavy metals, DK3; D1

Special characteristics

The effective dry adsorption and the air-cooled condenser are suggested as BAT by the operator.

Grate Firing, Reference no. 655

Reference no. 655 is a push grate firing for the generation of electricity and process steam, which was commissioned in 2004. The grate is cooled with primary air. The plant consist of two natural circulation boilers. The produced steam is fed into a extraction/condensation turbine. The main fuel is wood waste (classes A I to A IV), which is why the plant had to be authorised and approved in terms of the 17. BImSchV. The start-up is aided with NG, which is also used as back-up fuel. The live steam parameters are 450 °C and 60 bar. Steam can be extracted from the turbine to be used as process steam in a paper mill. The cooling system is a circulating cooling system with a forced draught cooling tower.

The total rated thermal input of the plant is 86°MW_{th}. The nominal gross electric power output is 20°MW_{el} and the nominal gross heat power output is 18 MW_{th}.

Table 242 shows values for the fuel energy input and energy output in the reference year 2011. Five years have been taken into account for the rolling average value.

Table 242: General operating data for reference no. 655

		Value for the reference year	Rolling average value
Fuel energy input (as lower heating value)	MWh_{th}	5.36E+05	4.86E+05
Gross electric energy output	MWh_{el}	1.44E+05	1.33E+05
Net electric energy output	MWh_{el}	1.29E+05	1.19E+05
Gross heat output – steam	MWh_{th}	3.53E+04	2.98E+04
Net heat output – steam	MWh_{th}	3.53E+04	2.98E+04
Total operating time under normal operating conditions	h	8433	7900
Equivalent full load operating factor	%	73.9	71.5

In the reference year, the plant was operated almost continuously. The equivalent full load operating factor is 74 %. The net electrical utilisation ratio is 24 %. With a thermal utilisation ratio of 6.6 % the fuel utilisation factor is 30.6 %. For the rolling average value a net electrical utilisation ratio of 23.9 % can be calculated as well as a thermal utilisation ratio of 6.6 %, which lead to a fuel utilisation factor of 30.5 %. The total operating time for the rolling average value is about 7900 h with an equivalent full load operating factor of 71.5 %.

Environmental aspects

The plant produces typical air emissions for waste wood-fired power plants. In accordance to the official authorisation (17. BImSchV), the air pollutants dust, SO_x, NO_x, CO, HCl, TOC and Hg are continuously measured in the flue gas. In addition to this, other pollutant emissions are periodically measured. There are primary and secondary measures taken for emission abatement. Primary measures are air grading as well as flue gas recirculation.

The secondary FGT process (secondary measures) is comprised of a cyclone separator, a quench and a fabric filter. Dioxins, furans and heavy metal compounds are captured by bonding to calcium hydroxide and hearth furnace coke before the fabric filter. In this way, the filter cannot only reduce dust, but also other pollutant emissions. NO_x is reduced in a SNCR system directly in the steam generator.

Table 243 shows the concentrations and the annual loads for the measured air-pollutants in the flue gas. In addition to this, the method to obtain the data and the emission limit values prescribed by competent authority is given. It should be noted, that the presented values are validated and do include OTNOCs. The reference oxygen content is 11 %.

Table 243: Air emissions for reference no. 655

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
											1/2 h	d
Dust	mg/Nm^3	0	0.9	3.31	6.6	7.4	139	HHV	Cont.	Yes	30	10
	kg/year						4367					
SO_x	mg/Nm^3	0	2.3	30.92	52.8	58.8	260	HHV	Cont.	Yes	200	50
	kg/year						36585					
NO_x	mg/Nm^3	0	126.5	164.2	204.1	210.7	418	HHV	Cont.	Yes	400	200
	kg/year						182440					
CO	mg/Nm^3	0	9.2	17.74	28.4	31.4	442	HHV	Cont.	Yes	100	50
	kg/year						20055					
HCl	mg/Nm^3	0	0	2.86	6.9	7.8	22	HHV	Cont.	Yes	60	10
	kg/year						3534					
HF	mg/Nm^3	0	0	0.3	-	-	-	-	Perio.	Yes	1	-
	kg/year						158.5					
Hg	mg/Nm^3	0	0	5E-04	0.003	0.003	0.052	HHV	Cont.	Yes	0.05	0.03
	kg/year						0.98					
TOC	mg/Nm^3	0	0.1	0.62	1.2	1.9	102	HHV	Cont.	Yes	20	10
	kg/year						740.3					
Sb	mg/Nm^3	-	-	2E-04	-	-	-	-	Perio.	No	-	-
	kg/year						0.106					
As	mg/Nm^3	-	-	1E-04	-	-	-	-	Perio.	No	-	-
	kg/year						0.05					
Pb	mg/Nm^3	-	-	0.001	-	-	-	-	Perio.	No	-	-
	kg/year						0.76					
Cr	mg/Nm^3	-	-	0.001	-	-	-	-	Perio.	No	-	-
	kg/year						0.05					

		Minimum	5th percentile	Average	95th percentile	97th percentile	Maximum	Type of average	Method to obtain data	Validated	Emission limit values prescribed by competent authority	
Cu	mg/Nm³	-	-	2E-04	-	-	-	-	Perio.	No	-	-
	kg/year	0.088										
Mn	mg/Nm³	-	-	2E-04	-	-	-	-	Perio.	No	-	-
	kg/year	0.088										
Other *	mg/Nm³	-	-	0.003	-	-	-	-	Perio.	No	-	0.05
	kg/year											
PCDD / PCDF	ng/Nm³	-	-	-	-	-	-	-	Perio.	No	-	0.1
	kg/year	1.8E-07										

* other: Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V

Taking account of the legal and regulatory provisions, some of the waste water (surface runoff, water from the compressed air supply and leach off from the water/steam cycle) is discharged directly into a river. Sanitary water is discharged into the public sewerage. Water emissions are not measured.

Table 244 shows the solid residues (by-products). Grate ash makes up the largest part of by-products. The by-products can be utilised in the construction material industry or the underground mining industry.

Table 244: Solid residues for reference no. 655

Description	Source	Code	Generation in t during reference year	Final destination	For utilisation, specify the activity the material is used in
Grate ash	Combustion process	100114*	9.79E+03	Utilisation - Construction industry	Substitute construction material
Fly ash	Flue-gas treatment facilities	100116*	1.50E+03	Utilisation – Underground mining	underground mining packing material
Bag filter by-product	Flue-gas treatment facilities	100118*	2.32E+03	Utilisation – Underground mining	

Special characteristics

The plant configuration is specially designed for the highly volatile fuel characteristics. It is therefore suggested as BAT by the operator.

4 Load-Dependent Emissions

The reason for the research presented in this chapter can be seen in the increased feed-in of electricity from renewable energy sources into the public grid and the here from arising changes to the operation of conventional, fossil-fuelled power plants. As has been stated in chapter 2, the emission levels of LCPs change in part load operation and during start-up and shutdown procedures. As the conclusions, which are drawn from the presented BAT suggestions, refer to high average loads, there is the danger of disregarding more flexible operation. To illustrate a more flexible behaviour, an additional case study was performed, using the example of a natural gas-fired CCGT plant and a hard coal-fired plant. As the investigations on this topic pose an additional workload to the operators, only two plants could be chosen due to reluctance of the operators. Thus, the evaluated plants do not represent the entirety of the plant pool, but rather exemplary case studies. For a deduction of (binding) consequences, this is of course not sufficient. Rather, a broader number of plants and plant concepts should be taken into consideration. Especially for gas turbines (GT), a more detailed study of this subject matter seems useful, as the emission behaviour is influenced significantly in part load, which is not included in definition for "normal operating conditions" in Germany. For more information on this, please see "national particularities". The part load emissions depend furthermore on the type of turbine and the manufacturer specific firing system.

4.1 CCGT Plant with CHP

4.1.1 Description

Type: 150 MW_{th} CCGT plant with Siemens SGT 800 – 47 (125 MW_{th}) and heat recovery boiler (HRB) for steam generation with two additional MAXON series AIRFLOW® duct burners for auxiliary firing (25 MW_{th}) without additional fresh air in CHP operation[9].

Fuels: NG

Purpose: Electricity generation and district heating

Cooling: District heating and air-cooled condenser

4.1.2 Emission Reduction

FGT systems:

No FGT.

WWT systems:

Like in other combined-cycle power plants the waste water is led into the sewage system. Waste water of the cooling system is discharged into a river.

Combustion unit characteristics:

Dual-fuel Dry Low Emissions (DLE) technology (gas turbine). Low NO_x duct burners for auxiliary firing.

Efficiency enhancement

Highly efficient gas turbine. Combined-cycle power plant with combined heat and power generation.

Operation

The CCGT power plant uses a Siemens SST400 steam turbine in the steam process. The live steam parameters are 72 bar and 524 °C. The steam for the district heating is extracted between the HP and LP section of the turbine.

The plant was newly built and started its operation within the last two years. The measurement equipment was calibrated and validated by the technical supervisory association (TÜV) in the end of 2011.

The CCGT plant is operated primarily to produce electricity and is therefore often forced to operate in part load. In combination with a coal-fired CHP plant and other boilers the district heating is provided.

The electric efficiency of the gas turbine is 36.9 % for an air inlet temperature of 15 °C. The gross electrical efficiency of the combined-cycle is 52.5 %. The fuel efficiency can add up to 87.6 %.

Load-dependent Emissions

[9] This CCGT plant was not included in the evaluation.

The air emissions and the emission limit values are regulated and prescribed by the Federal Immission Control Ordinance (13. BImSchV). The DV values must not exceed 50 mg/Nm^3 for NO_x and 100 mg/Nm^3 for CO when operating only the gas turbine. The reference oxygen content for gas turbine operation is 15 vol-% (dry basis). The half-HA values must not exceed twice the DV values. When operating the auxiliary firing, the emission limit values and the reference oxygen content are calculated with the proportion of the thermal input of the auxiliary firing. The reference oxygen concentration is calculated with the following formula:

$$O_{\mathrm{ref}} = \frac{\dot{Q}_{\mathrm{TI,GT}} * O_{\mathrm{ref,GT}} + \dot{Q}_{\mathrm{TI,HRB}} * O_{\mathrm{ref,HRB}}}{\dot{Q}_{\mathrm{TI,GT}} + \dot{Q}_{\mathrm{TI,HRB}}}$$

with O_{ref} as the sliding reference oxygen concentration, $\dot{Q}_{\mathrm{TI,GT}}$ as the thermal input of the gas turbine, $\dot{Q}_{\mathrm{TI,HRB}}$ as the thermal input of the auxiliary firing, $O_{\mathrm{ref,GT}}$ as the reference oxygen concentration of the gas turbine and $O_{\mathrm{ref,HRB}}$ as the reference oxygen concentration of the gas-fired boiler (3 vol-% on dry basis).

The emission limit value during the operation of the auxiliary firing is calculated similar to the reference oxygen content. The emission limit values for the gas-fired boiler are 100 mg/Nm^3 for NO_x and 50 mg/Nm^3 for CO as DV.

The emission values in this report are based on the installed measuring device. The measuring device is tested for the suitability and is calibrated. The measuring is done extractively with a Sidor-analyser (Sick-Mahaik) and a NDIR dual beam photometer as infrared measuring instrument. The devices and the sampling point conform to the German specifications for emission monitoring and are reviewed regularly in accordance with § 14 of the 13. BImSchV. They have been calibrated by the technical supervisory association (TÜV-Nord-Umweltschutz) for all load stage and all operating conditions. The regression and the standard deviation are set by a reference measurement. The data stored and calculated in an electronic evaluation system. First, the raw value is normalised with the temperature, oxygen content and humidity, even if the oxygen content is lower than the reference oxygen content. The normalised values are validated and the uncertainty of the measurement equipment, which is tested in the calibration, is taken into consideration. All values shown in this report are validated in this way and include OTNOCs.

The measuring device is only capable of measuring NO and not NO_2. NO_2 is mathematically taken account for by the regression.

Table 245 shows the different values for the half-HA values. The calibration of the measurement equipment was completed in the end of 2011. All here presented values refer to five month.

Table 245: HHV values in mg/Nm³

	CO	NO_x
Average value	8.79	35.51
5 % percentile	0.00	26.97
95 % percentile	15.53	41.25
97 % percentile	16.11	41.99

The plant is in normal operation conditions if the gas turbine generator power output is more than 21 MW_{el}. The emission values are therefore logged starting from approx. 45 % load of the generator of the gas turbine. The auxiliary firing is only in operation if the gas turbine generator power output is more than 30 MW_{el}. The plant is not equipped with any FGT facilities for part load.

NOx Emissions of the Gas Turbine

The half-HA values are scattered in Figure 70. The plotted values are without operation of the auxiliary firing. At full load, the NO_x concentration is around 35 mg/Nm^3. The NO_x emissions increase to 40 mg/Nm^3 at 65 % load (80 MW_{th}). At lower loads, the NO_x emissions can be up to 90 mg/Nm^3. At a load of 40 % they decrease to 10 mg/Nm^3. The CO emissions are nearly non-existent for operation without auxiliary firing and therefore are not included in the figure.

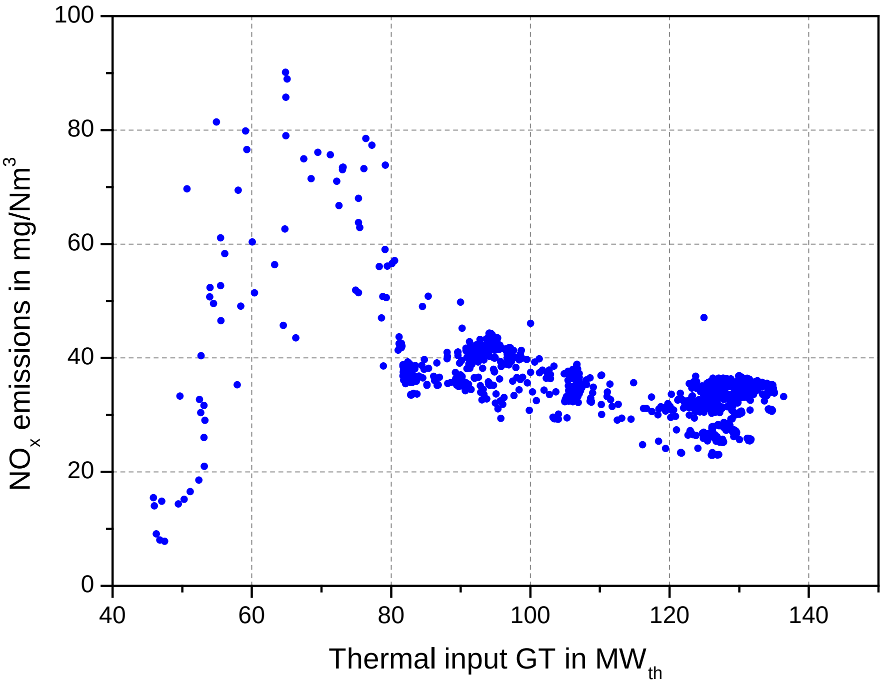


Figure 70: NO_x emissions as function of the thermal input of the gas turbine (reference oxygen concentration 15 vol- %)

Emissions due to Auxiliary Firing

In Figure 71, the half-HA values for operation with auxiliary firing are shown. The gas turbine is operated in full-load. The NO_x concentration is around 30 to 40 mg/Nm^3. The NO_x emissions are in the same range as the emissions without auxiliary firing. The CO emissions for full load operation of the auxiliary firing are between 10 to 20 mg/Nm^3 and decreases to nearly zero at a thermal input of 5 MW_{th} of the auxiliary firing. The reference oxygen content decreases to 13 vol-% at full load of the auxiliary firing.

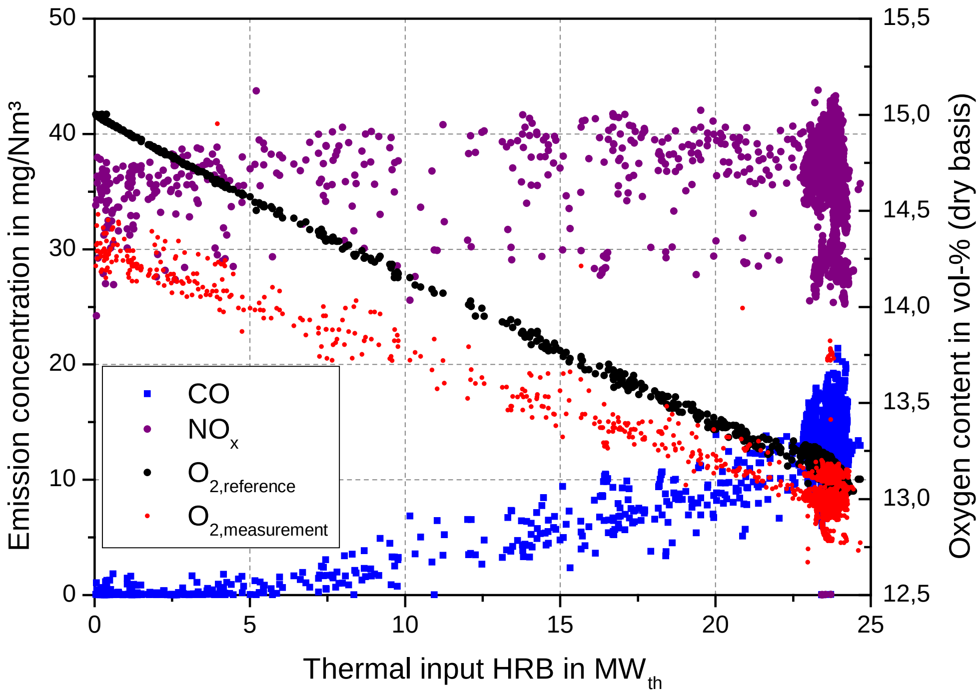


Figure 71: NO_x and CO emissions as well as reference and measured oxygen content as function of the thermal input of the auxiliary firing

Emissions During Operation

In Figure 72 NO_x and CO emissions are shown for transient operation. The lines consist of validated values measured every five seconds. The symbols represent half-hourly values. The reference oxygen content decreases during operation of the auxiliary firing to 13 vol-%.

For full-load operation of the gas turbine the NO_x concentration is between 30 and 35 mg/Nm^3. For part load (around 60 % of the thermal input) the concentration increases up to 40 mg/Nm^3. During the load change the concentration is fluctuating. When the load is reduced, the concentration decreases and the other way round. The operation of the auxiliary firing has no effect on the NO_x emissions. Only the start-up und shutdown of the auxiliary firing influences the NO_x concentration.

The CO concentration is mainly influenced by the operating of the auxiliary firing. The concentration increases to 15 mg/Nm^3 for full load of the auxiliary firing. In the transient operation the concentration is fluctuating.

The half-HA values describe the emissions very well. The strongly fluctuating areas and the peaks are not represented in the average values.

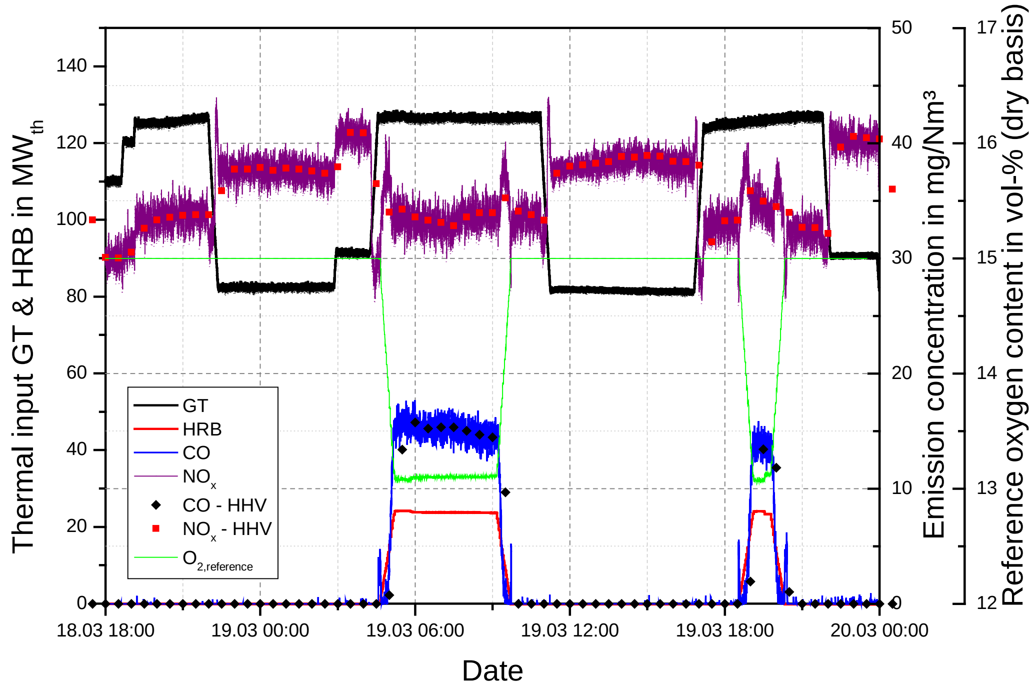


Figure 72: Thermal input, emissions and reference oxygen content during operation in a period of two days (18.03. – 19.03.12) including transient operation

Emissions During Start-up

The start-up of the gas turbine is shown in Figure 73. In start-up operation peaks of the CO concentration occur due to the start of the firing (switch from diffusion type of combustion to premixed combustion) and run up of the gas turbine. The NO_x concentration rises up to 100 mg/Nm^3 during the start-up. The emission values are logged for a generator power output of more than 21 MW$_{el}$ as the emission permit values are valid in this load stage. Above 80 MW$_{th}$ thermal input a stable operation can be assumed.

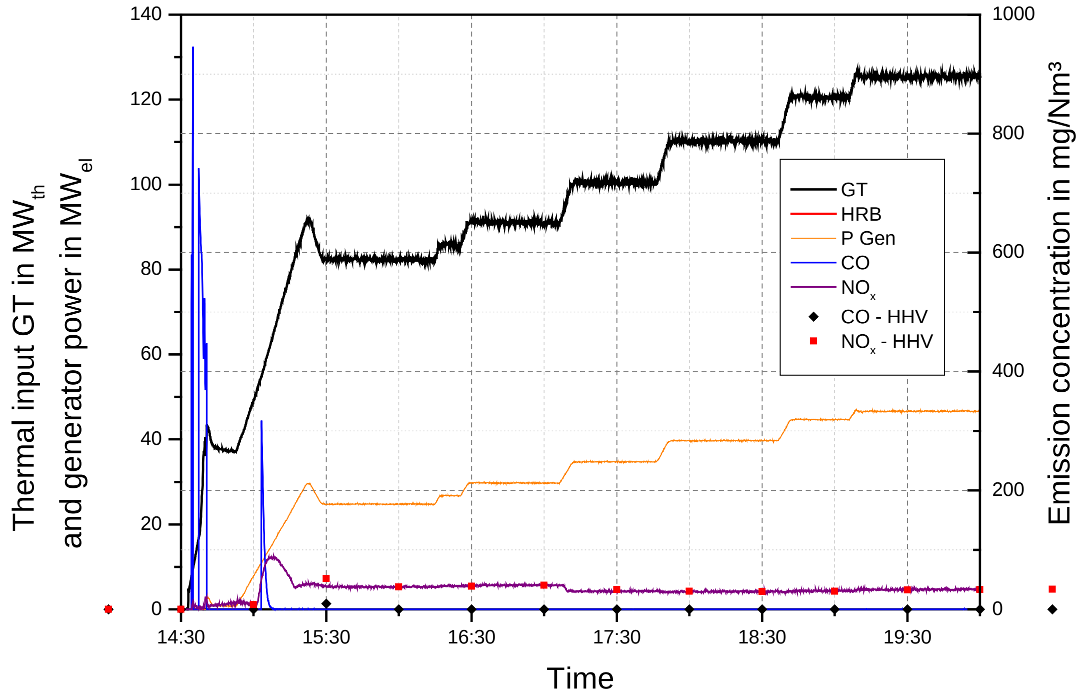


Figure 73: Emission during start-up of the CCGT (reference oxygen concentration 15 vol-%)

Emission Values for Longer Periods

In Figure 74 the emission values for one week are plotted. The lines are half-HA values and the symbols are DV values. The operation mode for a CCGT plant with CHP operation for this week can be seen. During the night, the power plant is operated in part-load. Auxiliary firing is often used during the day to generate the needed heat for the district heating. The half-HA values for the NO_x concentration can be up to 40 mg/Nm^3, but the DV is about 35 mg/Nm^3. The emission limit value for the DV is shown as star.

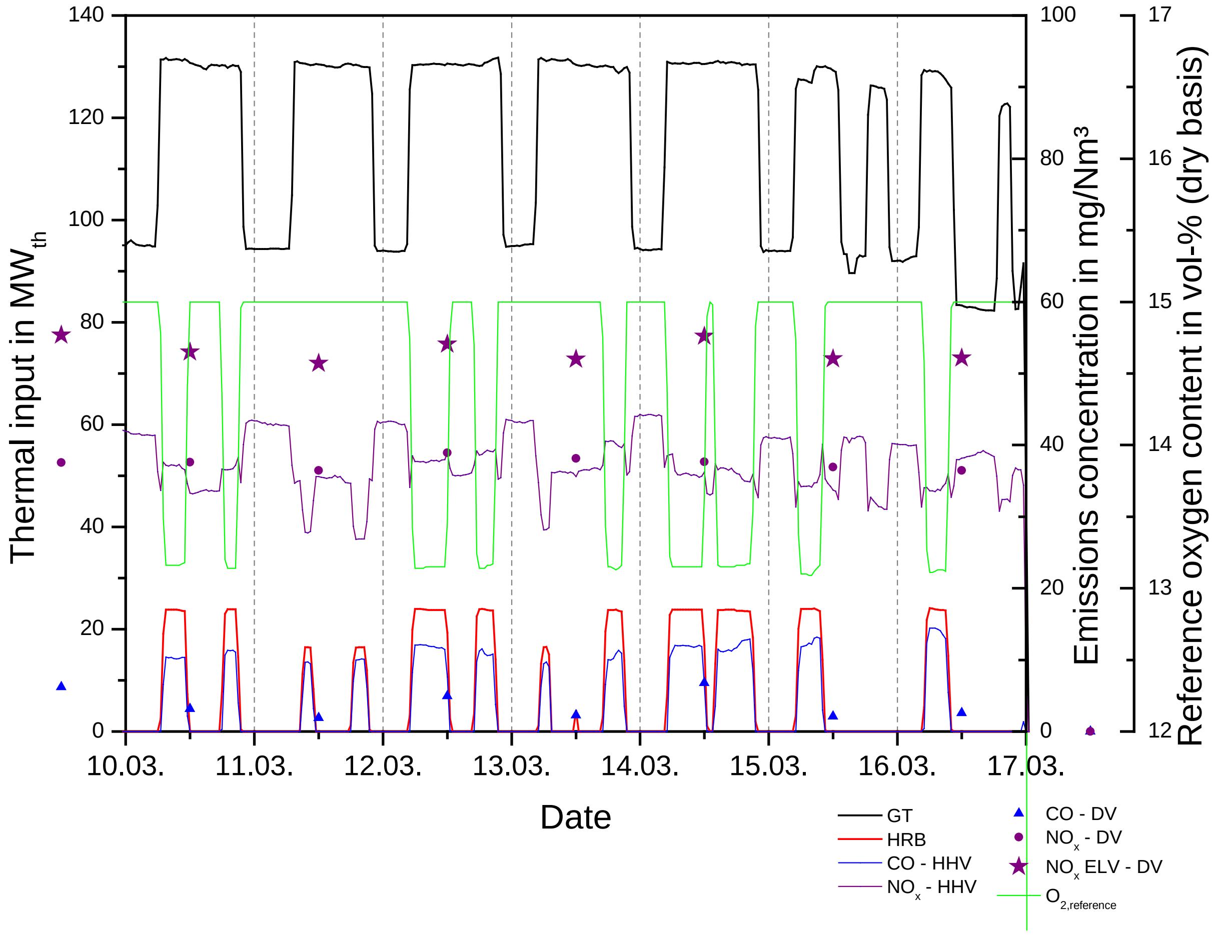


Figure 74: Emission values of half-hourly and DV values including thermal input and reference oxygen content (10.03 – 17.03.2012)

Example of Calculation of Emission Values

For the calculation of the different values half an hour of the measurement data will be used exemplarily. The thermal input is about 127.2 MW_{th} for the gas turbine and 23.89 MW_{th} for the auxiliary firing. The emission limit values are now 92.1 mg/Nm^3 for CO and 57.9 mg/Nm^3 for NO_x. The reference oxygen content is about 13.1 vol-% (dry basis). The measured raw value is about 15.6 mg/Nm^3 for CO and 35.5 mg/Nm^3 for NO_x. The oxygen content is 13.0 vol-% (dry basis). The normalised values are 15.3 mg/Nm^3 for CO and 35.0 mg/Nm^3 for NO_x. The validated values are 15.0 mg/Nm^3 for CO and 33.6 mg/Nm^3 for NO_x.

4.2 Hard Coal-fired Power Plant

4.2.1 Description

See the questionnaire no. 141 for more details.

4.2.2 Emission Reduction

See the questionnaire no. 141 for more details.

Operation

See the questionnaire no. 141 for more details.

4.2.3 Load-dependent Emissions

The emission values in this report are based on the installed measuring device. The measuring device is tested for its suitability and is calibrated. The devices and the sampling point conform to the German specifications for emission monitoring and are reviewed regularly in accordance with § 14 of the 13. BImSchV. They have been calibrated by the technical supervisory association for all load stage and all operating conditions. The devices, an Ultramat 23 (Siemens) multi component measuring device and a Durag DR-290-150 dust measuring device, are further described in the associated questionnaire. The data is stored and converted in an electronic evaluation system. First the raw values are normalised with the temperature, oxygen content and humidity. Afterwards, the normalised values are validated. Thereby, the uncertainty of the measuring equipment, which is tested in the calibration, is subtracted. The half-HA values and the values of the short time evaluation shown in this report are normalised and not validated.

Table 245 shows the half-HA values for the different emissions during the whole reference year including all operating conditions. All here presented values refer to the year 2010 and include other than normal operating conditions (OTNOCs). Values for the start-up and failure of the FGT facilities are not included.

Table 246: HHV values in mg/Nm^3

	CO	NO_x	SO_2	Dust
5 % percentile	16.55	86.89	4.12	0.39
Average value	27.55	95.35	71.46	0.58
95 % percentile	49.11	103.87	105.97	0.76
97 % percentile	55.66	104.93	116.72	0.84

In the following figures the air emissions are shown as half-HA values as a function of the thermal input excluding OTNOCs. Figure 75 shows the CO emissions. In full load the emissions increase up to about 100 mg/Nm^3 and the fluctuation is high. In part load the fluctuation decreases. In the majority of cases the CO emissions amount to about 25 mg/Nm^3.

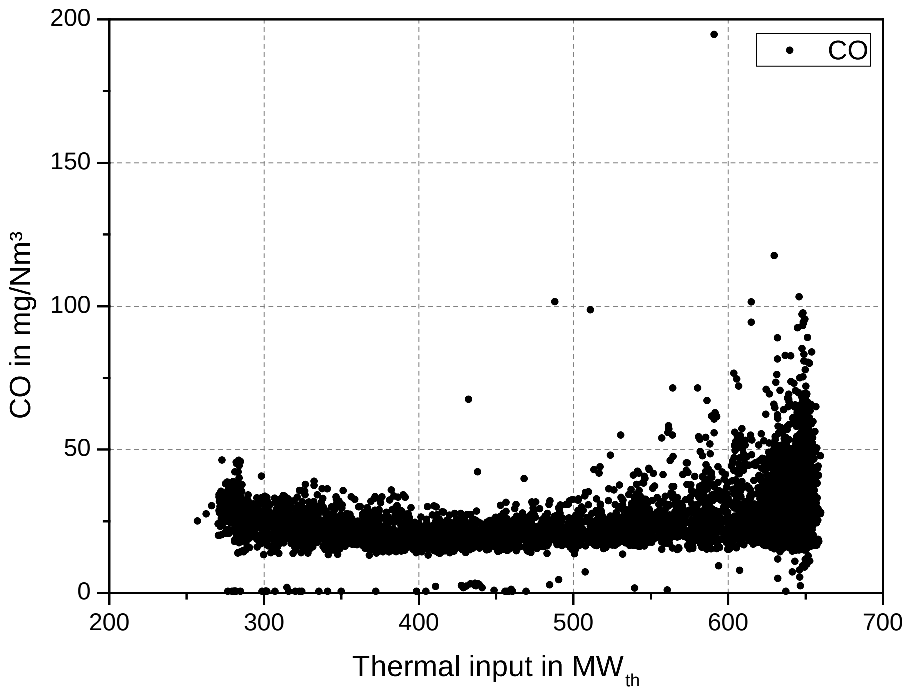


Figure 75: CO emissions as a function of the thermal input of the boiler

In Figure 76 the NO_x emissions are shown. The NO_x emissions show no load dependency because of controlling the emissions and adjustment of the $DeNO_x$ process. Usually, the NO_x emissions amount to about 100 mg/Nm^3.

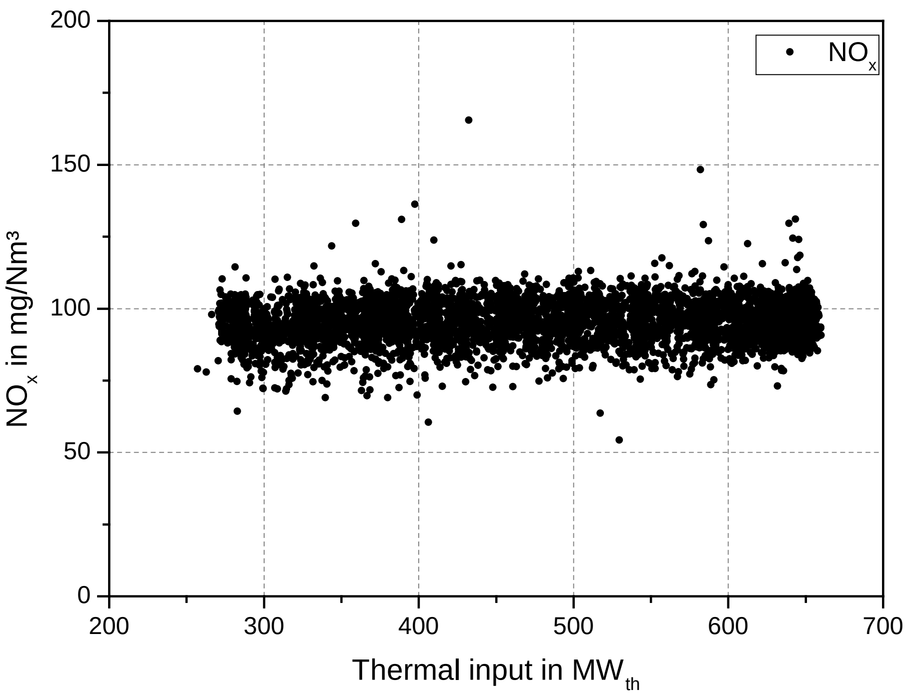


Figure 76: NO_x emissions as a function of the thermal input of the boiler

Figure 77 shows the SO_2 emissions as a function of the thermal input. In full load the SO_2 concentration in the flue gas increases to 150 mg/Nm^3. The fluctuation of the concentration is high. This has two main reasons: The variable sulphur content of different coals and the conditions of operation of the FGD plant. The fluctuation around the mean values can also be explained by the inertia of the control technique. In part load the concentration decreases because of the over dimensioning of the absorber.

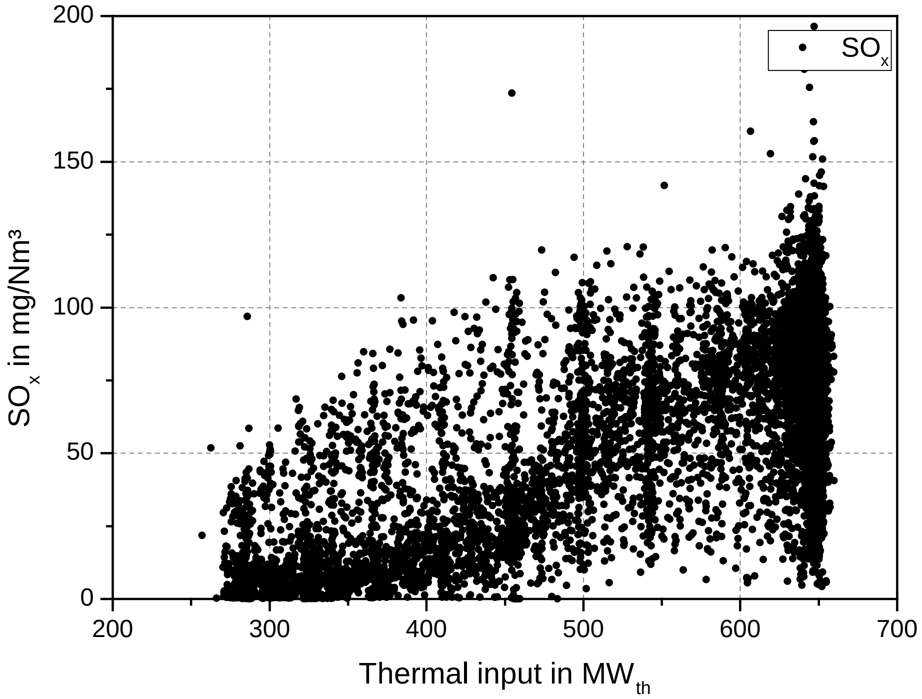


Figure 77: SO_2 emissions as a function of the thermal input of the boiler

Figure 78 shows the dust emissions of the power plant. The emissions are usually in the range of about 0.5 mg/Nm^3. The ESP of the plant is designed for highest separation efficiency. In the full load point the emissions are fluctuating and can rise up to 2.5 mg/Nm^3. A dependency of the load is not identifiable.

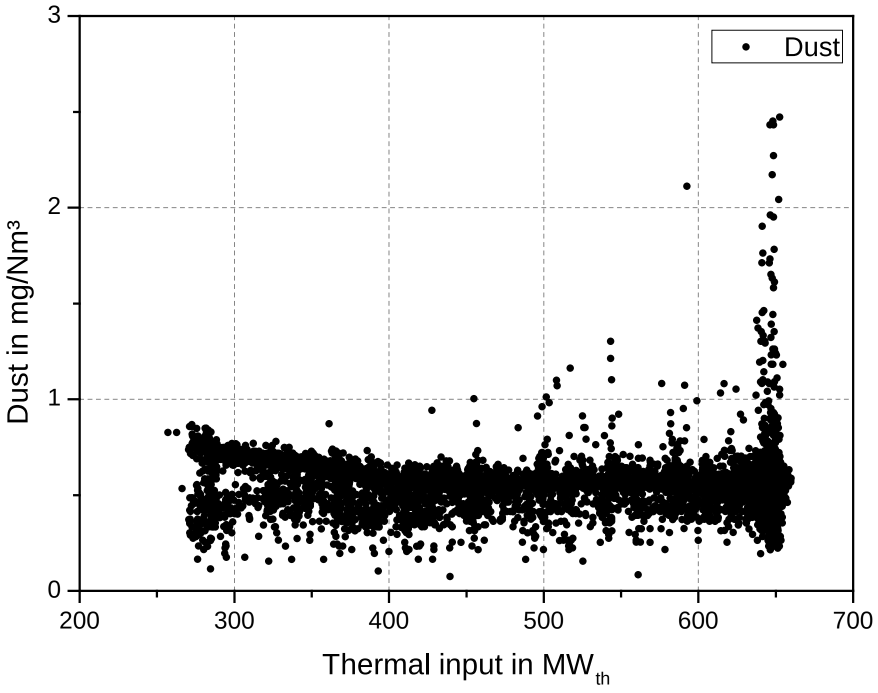


Figure 78: Dust emissions as a function of the thermal input of the boiler

Emissions During Operation

Figure 79 shows the emissions for one week. The short time values are measured every minute in the time period from 29.2.2012 to 5.3.2012. There are overnight shutdowns and load changes during this week. During shut-down und start-up the emissions increase. This will be shown in more detail in the following figure. In transient operation of the power plant, around 4th of March the emissions are fluctuating strongly.

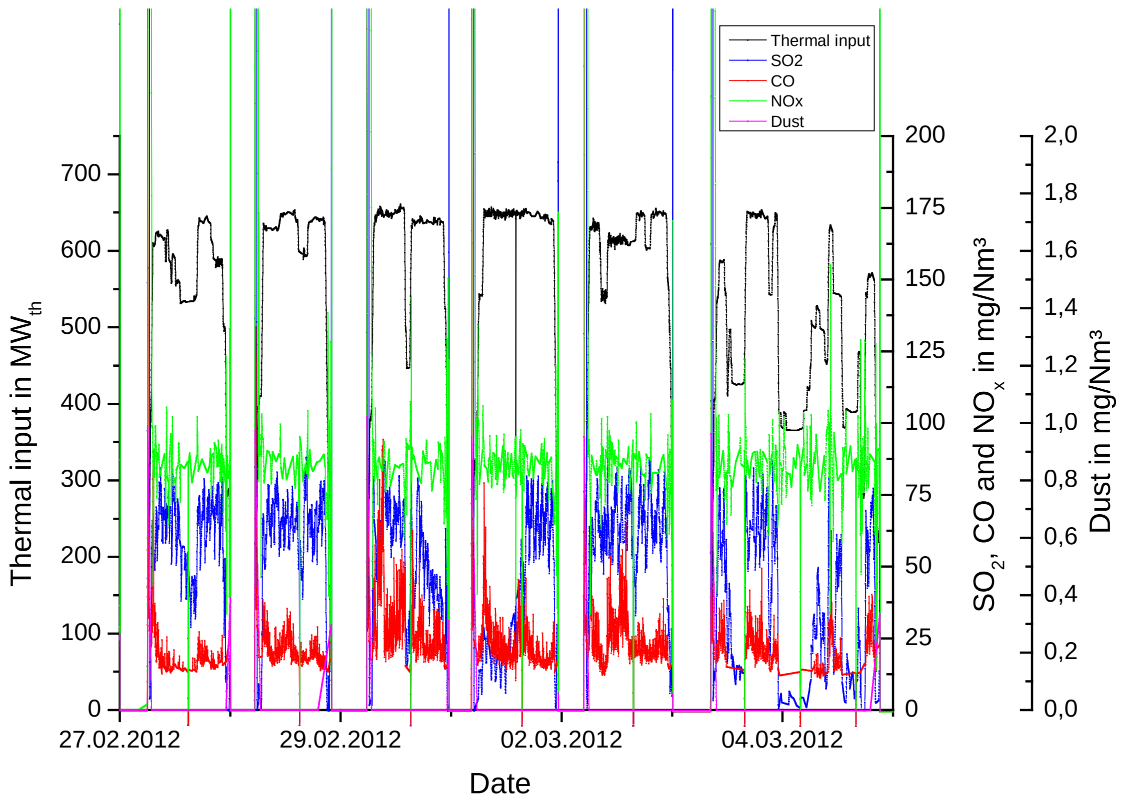


Figure 79: Thermal input, SO_2, CO, NO_x and dust emissions during operation in a period of one week (27.02. to 05.03.2012)

Emissions During Start-up and Shut-down

In Figure 80 the emissions during a start-up and shut-down are shown. In the start-up phase the SO_2 emissions can increase to the maximum of 1400 mg/Nm^3. Dust emissions increase during the start-up to 2 mg/Nm^3. The NO_x emissions increase to 900 mg/Nm^3. CO emissions raise up to about 500 mg/Nm^3 because of the ignition and fluctuating of the firing. This leads to a temporarily incomplete combustion. During the start-up of the power plant, the SCR plant operation is automatically controlled depending on the temperature of the catalyst. The electrostatic precipitator is in operation. The FGD is started together with the boiler, but due to process control interlocks and technical restrictions the SO_2 emissions can fluctuate. During the shut-down the SO_2 and dust emissions increase as they did during the start-up. NO_x and CO emissions are not increasing as much in the shut-down phase.

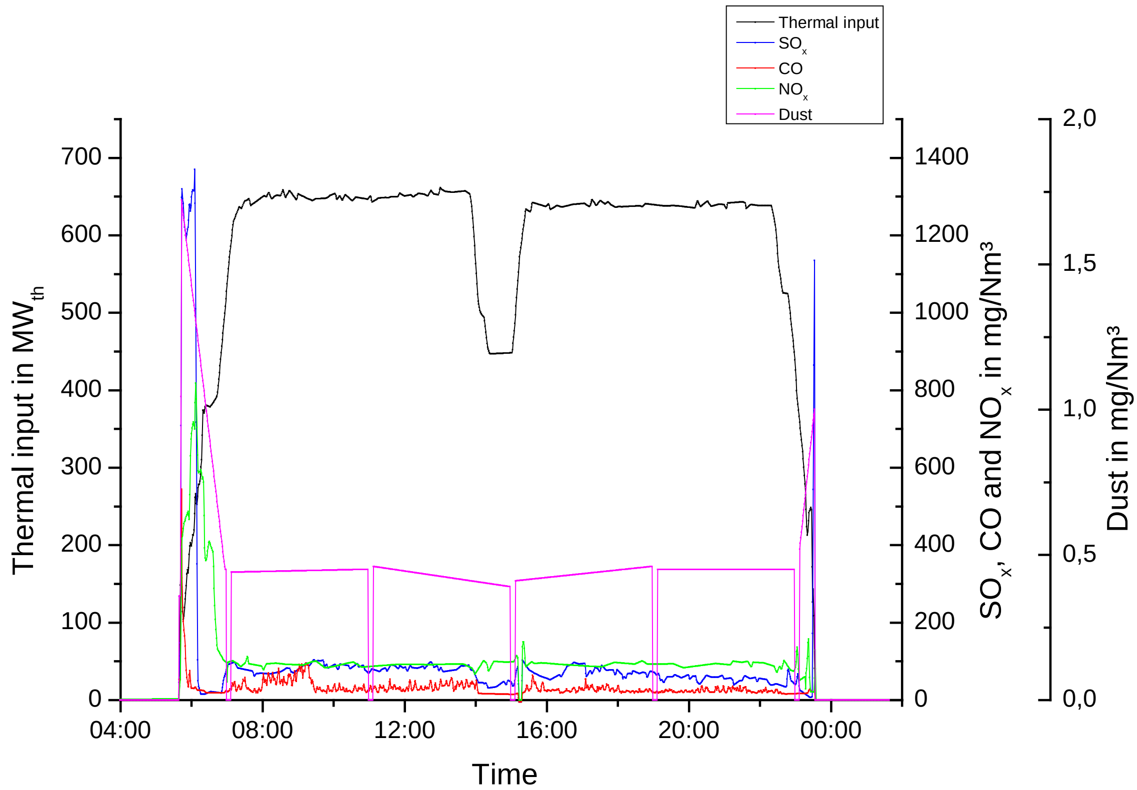


Figure 80: Thermal input, SO_2, CO, NO_x and dust emissions during start-up and shut-down

5 Lessons Learned

The focus of the research project was on the assistance for the data collection and analysis for the BAT reference document revision process. The results of the project, which are presented in this report, are limited to the data pool derived from the questionnaire.

The experience, which the TUHH-IET gathered during the different stages of the assisted revision, show that the national coordination, the data collection and data analysis are of extensive and time-consuming nature. The assistance given by an independent research institute was perceived very beneficial and useful by all parties involved.

The questionnaire, which was created by the EIPPCB with the aid of German institutions, is very detailed and covers all important aspects for LCP. A continuous, multi step iterative process among all parties (LCP operators, agencies and associations) was necessary to ensure a consistent and meaningful data quality. The effort made on the LCP operator site as well as on the side of the research institute, was high. Nonetheless, a throughout consistent data collection was not possible, because not all operators had sufficient capabilities for the filling-in and editing of the questionnaires.

The partial differences in the nomenclature between the IED and the national legislation led to additional complications during the data collection process. A comprehensive translation of the questionnaire could therefore be an interesting option for the next revision process. Some entries in the questionnaire were only filled in seldom, if at all (e.g. cost estimates for BAT). It is furthermore questionable, if Microsoft Excel is the best available format for the questionnaire.

As the plant specifics can be described only to limited extend in the questionnaire, it seems useful that for the next version of the revision process, several, more detailed and plant type specific questionnaires are created (for example: one for gas turbines, one for boilers). Furthermore, secondary emission abatement measures are only poorly covered and details on the flexibility topic cannot be given at all (only in separate documents). For this reason, additional comments were often added, which complicated the data collection and evaluation. The contextual consideration of these comments is of great importance for the comparability of the data. Also, other technical features, varying fuel compositions and operating modes should be included in the evaluation.

Although the questionnaire's amount of information is very extensive, the associated plant is only roughly described. Additional documents and information are necessary for the comprehension of the plant design and other characteristics. These were sometimes provided, but are of inconsistent quality. A more standardised plant description in textual format is desirable, but also time-consuming.

Regarding the topic of "energy efficiency", the questionnaire has also to be examined critically. Although the nominal electrical efficiency as well as multiple utilisation ratios for the reference year and the rolling average can be determined with the given data, the usefulness of these values for the approval process is of minor importance. This is due to the fact that the reference conditions for the submitted values (e.g. the total rated thermal input or the useful energy outputs) are not consistent for all questionnaires and therefore, especially for plants in CHP operation, hard to compare. The utilisation ratios are not relevant for the approval process, as they do indeed describe the actual operation of the plant, but cannot be used for acceptance testing. Here, defined nominal efficiencies are much more applicable. In addition to this, the very characteristic feature "boiler efficiency" is not included in the data collection. This variable and the associated topic should be incorporated in the next revision process for the BAT reference documents LCP.

Due to the aforementioned problems, which arose during the data collection, it is suggested to check if the acquired data is in accordance with the requirements of the implementing decision of the commission 2012/119/EU from February, 10th, 2012, published in the Official Journal of the European Union from march, 2nd, 2012, dealing with the guidelines for the data collection for and the creation of BAT reference documents (including quality control measures) in accordance with Directive 2010/75/EU of the European parliament and of the council (IED). The collected data is only reliable and comparable, if it is conform to these guidelines. It has therefore to be checked, if additional actions (e.g. further data collection) are to be taken, before conclusions can be drawn for the BAT reference document.

Further problems arise from the questionnaire's focus on normal operating conditions. According to footnotes (62) and (63) of the questionnaire, OTNOCs should not be included in the air emission values. This was done by most of the operators. By this practice, operating modes with partially much higher emission levels are lost, although they should be considered for conclusions drawn from the BAT reference document. It is therefore questionable, if the actual state of affairs draws a complete picture of the emission- and environmental relevant behaviour of LCPs.

Furthermore, it should be considered to include the increasing role of load flexibility of LCP in future data collections, which is not included in the present version of the questionnaire.

6 Conclusion

The report concludes a research project, by which the Institute of Energy Systems of the Hamburg University of Technology supported the German Federal Environmental Agency in the course of the revision of the BAT reference documents for Large Combustion Plants (LCP).

In chapter 2, the activities carried out in the research project are classified. As a part of the revision process of the BAT reference document LCP, a questionnaire was developed to collect comparable data from all European countries. This questionnaire has to be filled in by the LCP operators on a voluntary basis. In it, the LCP is characterised and described in detail, including information about plant design, environmental aspects and BAT-suggestions. Chapter 2 further comprises remarks on "national particularities", in which certain specifics of the German legislation are pointed out as well as the here from arising problems concerning the filling in of the questionnaires.

In chapter 3, the different types and applications of LCP, which were part of the data collection process, are presented. For this, the LCP are sorted by the type of fuel used, which results in the subchapters "gaseous fuels", "liquid fuels" and "solid fuels". A further differentiation by the actual fuel and other plant attributes is then done. At the beginning of each fuel-specific subchapter, the regarded plant technology is briefly described before a summary and evaluation of the most important data that has been gathered is presented. The emission levels and efficienciy parameters of the plants are compared and a summary of the suggested BAT entries is given. Subsequently, each plant that was included in the evaluation process is described in more detail, including information about the plant layout, efficiencies and utilisation ratios, solid residues as well as air and water emissions. For this purpose, tables were taken from the questionnaires. In addition to this, flue gas treatment and waste water treatment equipment is characterised and the BAT-suggestions are described comprehensively. If the presented description is not sufficient, the corresponding questionnaire can be examined to obtain further information.

In view of an increase of the share of electricity produced from renewable energy sources, such as solar power and wind power, it has to be assumed that LCP will have to be operated much more flexibly to account for the fluctuations in the power grid. To cover this topic of load flexibility and start-up/shutdown sequences, an additional chapter, chapter 4, is included in this report. In it, the load-dependent emissions of power plants are presented, using the example of a hard coal-fired plant and a natural gas-fired CCGT plant.

In chapter 5, "Lessons learned", potential improvements of the data collection and evaluation process are identified and suggestions on how to further process and evaluate the collected data are made for the EIPPCB. Furthermore, recommendations for future evaluation processes of the BAT reference document LCP are given. They deal, among others, with the creation of the questionnaire, a central analysis and evaluation of the collected data, a better comparability of the data and the consideration of load-flexibility and other than normal operating conditions. To draw comprehensive conclusions from the collected data, it might be useful to extend the current data pool by further investigations in the course of this evaluation process.

Furthermore, a draft for a biomass chapter is given, which could be implemented in the future BAT reference document.

Concluding, a number of remarks have to be made on the process of national gata collection, data analysis and discussion due to their high relevance:

- In addition to the annual average values of air emissions, the 95th and 97th percentile values of the measures half-hourly values are necessary to characterise the plant's emission behaviour and thus draw firm conclusions for achievable emission limits. This is also true for the maximal emission value. It is furthermore of high importance, in which way OTNOCs have been regarded and included in the submitted emission values.
- It can occur that not all possible operation modes and requirements of a plant have been present in the reference year (e.g. variations in the fuel quailty of process gas-fired boilers). It is furthermore likely that a broad number of plants will be operated differently in the near future due to the energy turnaround and the here from arising altered demands on operation mode. This attributes to a possible change in emission behaviour.
- A classification for plants with total rated thermal inputs of more than 300 MW_{th}, as it was done in the present report, seems useful, especially for hard coal- and lignite-fired plants.

Addendum

A Combustion of biomasses

At the beginning of this chapter the possible sources of biomass for large combustion plants are elucidated. Special attention is given to the dependency of chemical composition and physical properties of the biomass and their impact on the power plant infrastructure. Applied processes and techniques and primary and secondary measures for the control and prevention of gaseous, liquid and solid emissions are evaluated. Finally, achievable emission limits and efficiencies are discussed, backed by examples from state-of-the-art biomass-fired plants in operation in Germany. The utilisation of biomass in the pulp and paper industry is not included in this chapter.

A.1 General information

A.1.1 Sources of biomass

Biogenic fuels can be categorized with regard to various criteria. Generally, they are differentiated between arising (as waste or by-product) and cultivated biomass. Also, they can be distinguished between wooden and herbaceous biomass. Finally, the source of the biomass can be an appropriate property for its characterisation, where typical categories include forestry, agriculture and other as presented in Table BM 1.

The selection of an adequate biomass for heat and/or power production depends on mainly three aspects:

- Price
- Availability
- Properties

Price and availability of the utilised biomass determine the economics of a power plant in commercial operation and therefore are the main factors in deciding which fuel is used in a certain plant or where a biomass power plant is built. The question of choice of biomass (or choice of location) introduces regional aspects – thus no general conclusions can be drawn. Therefore, in the following only the chemical and mechanical properties of different biomass types are discussed with regard to their impact on gaseous, liquid and solid emissions and on the operability of the plant, the latter concerning issues with slagging, fouling and corrosion.

Table BM 1: Categories of biomass sources

Forestry	Agriculture	Other
Trunk wood	Short-rotation plantations	Waste wood
Waste wood	Energy crops	Sawmill residues
Bark	Fodder grass	Garden and park waste
	Straw	Algae
	Miscanthus[10]	

A.1.1.1 Forestry

Trunk wood is generally of high quality and used with a minimal diameter of approx. 7 cm. The (lower) calorific value of water free material is 18 MJ_{th}/kg in average. The density and therefore the volumetric calorific value of hardwood (deciduous trees) is generally higher than of softwood (coniferous trees), while the moistness of hardwood in green condition is generally lower than of softwood. Usually the moisture ranges between 40 and 45 % for winter felling and 60 % for summer felling [22]. Alkali and earth-alkali species in forestry biomass is generally low as no or only little external influence (fertiliser) during the growth period is applied.

A.1.1.2 Agriculture

The use of fertiliser has a large impact on the composition of the final biomass from agriculture. In contrast to biomass from forestry, the content of chloride, potassium, phosphor and nitrogen is much higher in agricultural biomass due to the use of fertiliser.

Energy crops

The moisture of the corn in energy crops ranges between 9 and 20 %. Energy crops commonly show high nitrogen concentrations.

Straw

Straw shows water contents between 10 and 40 % and a high fraction of potassium and chloride (leading to a low ash melting temperature). The straw can be stored outside after the harvest to be washed (“leached”) by the rain. Leaching reduces the K and Cl concentration (increasing the ash melting temperature) but can lead to an increased biologic decomposition [14].

Fodder grass

Fodder grass generally requires regular fertilisation and thus shows high concentrations of nitrogen, potassium and phosphor in the raw material. Moisture content varies between 15 and 80 % depending on the time of harvesting [25].

[10] aka elephant grass, porcupine grass, sword grass.

Miscanthus

Miscanthus shows lower sensitivity to the utilisation of fertiliser, as its underground rhizomes serve as a buffer. Moisture ranges between 16 and 45 %. Miscanthus has a relatively high ash fraction of 1.5 to 4 % [12].

Short-rotation plantations

Most common species of this category are willows and poplars. Sometimes locust trees (robinia) are also considered. Moisture content varies between 48 and 60 % depending on the time of harvesting. Depending on the age of the plant, the ash fraction ranges from 1 to 2.2 % and is generally lower than of fodder grass. Both moisture and nitrogen content are affected by the age of fast growing trees due to shifting ratios of trunks and bark [24]. The inventory increase depends mainly on the water supply. Therefore short-rotation plantations are generally less treated with fertilizer and thus show lower concentrations of chloride and alkali species.

A.1.1.3 Other

The largest fraction of biomass for heat and power generation in Germany is waste wood - such as railway sleepers and wood pallets - grouped into categories I to IV, where I signifies the lowest and IV the highest load of hazardous substances. Consequently, the composition of waste wood varies significantly, especially with respect to pollutants, but also concerning heating value and moisture. Due to the large required effort for flue gas cleaning, the use of waste wood is usually only considered in large scale combustion plants (> 10 MW_{th}) [5].

Besides waste wood, other biomass such as landscape conservation trimmings (both wooden and herbaceous biomass), sawmill waste, algae and garden and park waste can be considered as fuel for biomass power plants. However, most of these fuels are either used for biogas production, burned in waste incineration plants or are left on site for soil conditioning purposes. The ratio between energetic and substance utilisation varies depending on price and availability of both the biomass and the alternative (=fossil) fuels.

A.1.2 Chemical composition and physical properties of biomass

The quality of the biomass is checked for accordance with the supply contracts upon delivery. The chemical contents and the corresponding physical properties of biogenic fuels impact the entire process chain: fuel pre-treatment, combustion and flue gas cleaning.

Physical properties such as particle size distribution or bulk density can relatively easily be manipulated by adequate pre-treatment of the fuel, whereas the chemical composition is mainly determined by selection and treatment of the raw biomass during the growth period. One exception is the water content, which can be modified during storage and pre-treatment, however, requiring additional energy and compromising the efficiency of the overall process.

The main emissions from the combustion of biomass result from the oxidation of the chemical components carbon and hydrogen to carbon dioxide (CO_2) and water (H_2O). These emissions are inevitable, as the underlying reactions provide the majority of the desired heat release. Only an increase in plant efficiency (thermal & electrical) can reduce the specific emissions of CO_2 with regarded to the power and heat output of the plant. Nevertheless, the combustion of biomass is considered to be CO_2-neutral, as the biomass captures and metabolises just as much CO_2 during its growth phase via photosynthesis as is being released when combusted. The necessary transportation of biomass and the resulting emissions are not included in this balance and should be considered for each plant depending on the plant location and the origin of the biomass combusted.

With regard to emission prevention and control, the contents of nitrogen (N), sulphur (S), chlorine (Cl), alkali species such as sodium (Na) and potassium (K) and earth alkali species such as magnesium (Mg) and calcium (Ca) are in particular important, as they participate in the formation of pollutants such as nitrogen oxides (NOx), sulphur oxides (SOx), chloride compounds and particulates.

Furthermore, the contents of heavy metals in the biomass is critical as these species also contribute to the formation of gaseous pollutants and as they play an important role in the disposal and utilisation of the combustion ash [9].

The contents of particle forming elements, i.e. in particular K, Na, P, S and Cl depend on the plant species and variety and in particular on the natural and artificially provided supply of nutrients [2]. These nutrients are made available for the growth of the plant in form of minerals in the soil, atmospheric disposition and in particular systematic fertilisation. The essential nutrients nitrogen, phosphor and potassium are added in large quantities while secondary nutrients such as Mg, Ca and S as well as micronutrients (Mn, Fe, Cu, Zn) are included in small amounts. Although the direct influence on plant development of chlorine, sodium and silicum as nutrients has not been proved so far, these species are also part of common fertilisers [9].

In contrast to the sulphur content in the biomass, which is almost independent of the sulphur supply during the growth phase, the chlorine content can be significantly reduced by substituting a chloride-based fertiliser with a sulphate-based one. A chloride-based fertiliser causes approximately a two to four-fold release of alkalis during combustion compared to a sulphate-based one [9].

Furthermore, the mineral content in the biomass strongly depends on the time of harvest, due to two reasons [2, 9]:

- Due to the natural ageing process, the nutrients are shifted from the leafs to the roots.
- In mature herbaceous biomass rainfall leads to natural elution of nutrients (leaching).

A systematic elution or leaching of salts from the biomass is applicable after the harvest. With straw, the potassium content can be reduced by up to 70 % through rainfall and a prolonged field retention time. With subsequent (mechanical) drying of the biomass this technique can also be used in stationary pre-treatment facilities. In a test facility it was possible to reduce the alkali metal content of wooden biomass up to 35 %, for straw this value was as high as 95 % [9, 11, 10].

Since during the plant growths nutrients and alkali metals are needed primarily in leafs and other fast growing structures of the plant, the choice of the used part of the plant significantly determines the ash content, the elementary composition and thus the emission characteristics of the combustion unit.

In particular herbaceous but also wooden biomass can be pre-treated for transport and storage by pelletisation or briquetting, where the biomass is modified by thermal treatment or by the introduction of additives. In pelletisation units, the lignin is typically used as binder for the pellets, since it is partly liquefied by high temperatures which are generated through friction in the bale chambers [16, 19]. Sometimes additional starch, plant-derived paraffin or natural molasses is added as supplementary binder. Quick lime and kaolin are added to increase the ash melting temperature of the biomass fuel [26]. Lime is also used in combination with fabric filters to bind and separate gaseous pollutants such as mercury, dioxin, furan and hydrogen chloride [8]. Since the addition of kaolin leads to the integration of alkalis into the aluminum-silicate-molecules, the emission of fine particles ($PM_{2.5}$) can be reduced by up to 60 % [26, 1]. The alkali metals are then found with the aluminum silicates in the bottom ash [1]. The addition of quick lime can reduce the amount of fine particles by app. 30 % [26].

Measures to reduce particles emissions by modification of the biomass are therefore the dedicated leaching (requiring additional and energy intensive drying) or the addition of alkali-extracting solutions. One possible advantage of dedicated leaching can be the recovery and reuse of nutrients [4].

Table BM 2 shows the chemical composition of some selected biomasses. It is noticeable that herbaceous biomass and bark have significantly higher fractions of unwanted species than trunk wood. Especially the higher contents of sulphur and chlorine can cause problems with regard to emissions and corrosion. Additionally, higher contents of alkali species (such as potassium) decrease the ash melting temperature, increasing the risk of slagging and fouling issues [13].

In the following the connection between the chemical composition of biomass and the formation of pollutants is described to facilitate the discussion of emission prevention and control measures in later sections of this chapter.

Table BM 2: Elementary chemical composition and heating value of various biomass fuels (typical values) [12, 13]

	fuel composition							ash composition[b]									
	C[a]	H[a]	O[a]	N[a]	S[a]	Cl[a]	ash[b]	Ca[b]	Na[b]	K[b]	Cd[b]	Zn[b]	Pb[b]	Si[b]	LHV	$T_{ash,melt}$
Unit	wt%	wt%	wt%	wt%	mg/kg	mg/kg	wt%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	MJ/kg	°C
coniferous wood w/out bark	49.8	6.3	43.2	0.13	150	50	0.3	900	20	400	0.1	10	2	150	18.8	1.4
deciduous wood w/out bark	47.9	6.2	45.2	0.22	150	60	0.3	1200	50	800	0.1	10	2	150	18.4	
coniferous bark	51.4	5.7	38.7	0.48	850	190	4.0	5000	300	2000	0.5	100	4	2000	19.2	1.45
deciduous bark	55	6	40	0.3	850	190	5.0	15000	100	2000	0.5	50	5	10000	--	
willows	47.1	6.1	44.3	0.54	450	40	2.0	5	--	3	2	70	0.1	--	18.4	1.3
wheat straw	45.6	5.8	42.4	0.48	820	1900	5.0	4	500	10	0.1	10	0.5	10	17.3	950
wheat grain	43.6	6.5	44.9	2	1200	400	2.0	500	--	5	0.05	30	0.1	--	17.0	700
Waste wood [21]					300-2000	300-4000			200-3000	800-2500	0.3-3	200-1200	50-400	1500-15000		

	fuel composition							ash composition[b]								
Miscanthus	47.5	6.2	41.7	0.73	1500	2200	5.0	2	--	7	0.1	10	2	--	17.6	
recommend-ed limit	--	--	--	<0.6	<1000	<1000	<4	15000-35000	<500	<1.500	<0.1	<200	<100	<4.000	--	>1.000

a: water- and ash-free; b: water-free; c: short turnover plantations

A.1.2.1 Nitrogen

Of the three formation mechanisms of nitrogen oxides (fuel, thermal, prompt), in biomass combustion only fuel-NO_x plays a role due to the relatively low combustion temperatures of 800 – 1200 °C. The fuel nitrogen is converted almost entirely into molecular nitrogen (N_2) or nitrogen oxides (NOx); a negligible amount is retained in the ash. A high concentration of oxygen promotes the formation of NOx while a low local air ratio favours the formation of molecular N_2. This is considered in the primary measures (air staging/fuel staging) for NOx reduction.

An increase in nitrogen concentration in the biomass consequently leads to higher NO_x emissions. As a recommendation to avoid extensive primary and secondary emission reduction measures, the nitrogen content in the fuel should be < 0.6 Ma.-% (dry) [17]. This could especially occur for straw, cereals, grasses, grains and fruit residues.

On example of biomass with very high nitrogen contents is chipboards, where the cheapest and most common types, so called UF-chipboards, use resins based on urea ($(NH_2)_2CO$) and formaldehyde (CH_2O). Figure BM 1 shows the release of NO_x depending on the used fuel and the combustion temperature. As explained above, the prompt and thermal NO_x formation is negligible due to the low combustion temperature.

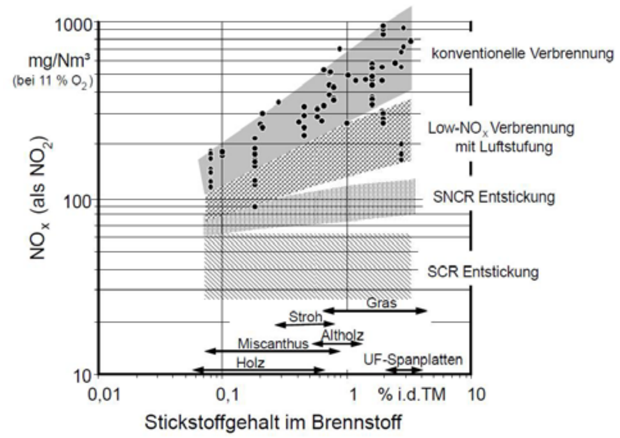


Figure BM 1: Nitrogen oxide emission levels depending on conventional combustion, primary and secondary measures for NO_x reduction firing for varying biomass nitrogen contents [15]

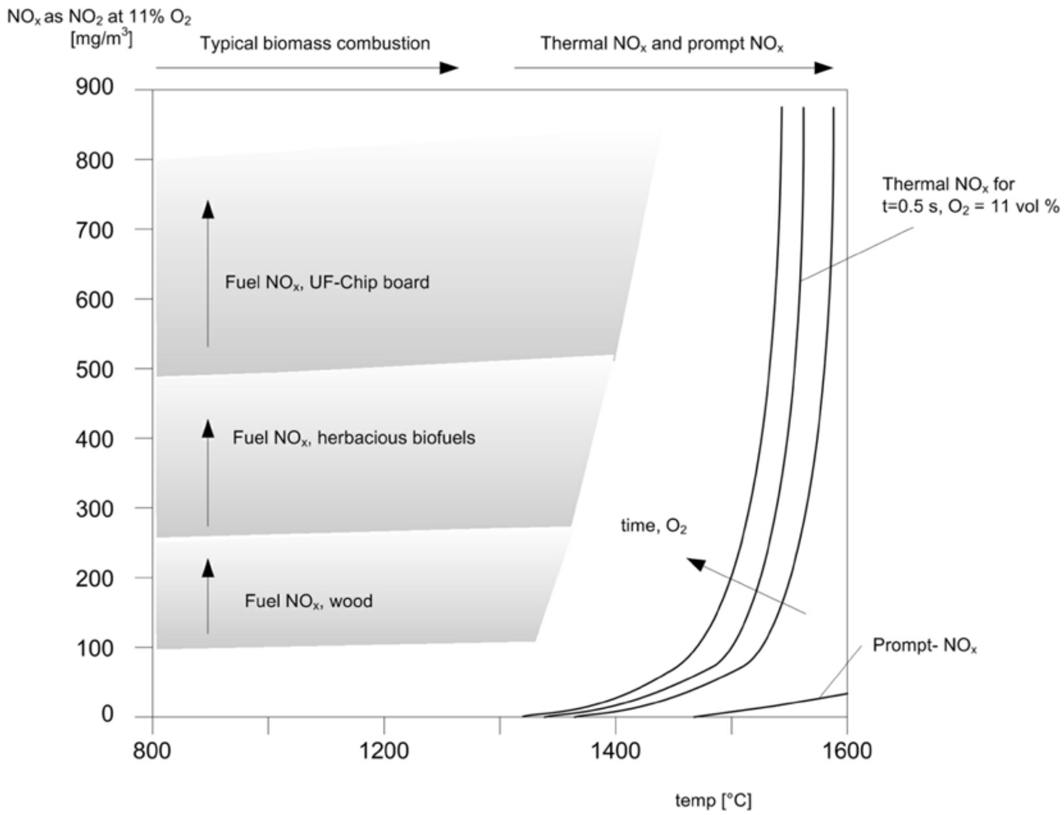


Figure BM 2: NO_x emission levels as a function of temperature and fuel type [14]

A.1.2.2 Sulphur

The majority of the fuel-sulphur is converted into sulphur dioxide (SO_2) and sulphur trioxide (SO_3) where the fraction of the latter is usually < 5 % of total SOx. There a range of values for the SO_2 to SO_3 conversion ratio in literature [3], [6]. A significant part of the sulphur is retained as solid compound in the ash. The rate of adsorption of sulphur into the ash depends on the temperature of the flue gas, the concentration of sulphur compounds in the flue gas and the fly ash properties, in particular its alkalinity, thus its contents of potassium (K), sodium (Na), calcium (Ca) and magnesium (Mg).

The sulphur content of the fuel is not only relevant with respect to gaseous emissions but also with regard to the corrosive nature of sulphurous acid (low temperature corrosion, i.e. condensation of SO_3 as H_2SO_4) and the tendency to amplify high temperature corrosion of chloride compounds: The sulphurous compounds in the flue gas condense with decreasing temperature on surfaces (heat exchangers, particles, ashes) to sulphates. The sulphation of alkali and earth-alkali chloride compounds releases parts of the chlorine which causes the formation of $FeCl_2$ and $ZnCl_2$ in the heat exchanger pipes and steam generator wall [9].

A.1.2.3 Chlorine

Hydrogen chloride (HCl) in the flue gas can – catalysed by alkali and earth-alkali species and SO_2 in deposits – form molecular chlorine (Cl_2) which can penetrate already existing passivating iron oxide layers. This mechanism leads to the formation of gaseous iron chlorides amplified with increasing temperature, causing so-called high temperature corrosion [20].

Chlorine can also from toxic, persistent and carcinogenic polychlorinated dibenzo-dioxins (PCDD) and polychlorinated dibenzo-furans (PCDF) and furthermore lowers the ash melting temperature leading to increased risk of slagging and fouling.

A.1.2.4 Heavy metals

The majority of heavy metals such as copper (Cu), lead (Pb), zinc (Zn), chromium (Cr), cadmium (Cd) and mercury (Hg) is partially retained in the ash and therefore has a critical impact on its re-usability. If necessary, the input of heavy metals has to be limited or a special FGT (dry adsorption) has to be installed. Of all heavy metals, Cd, Zn and Pb are the most volatile and re-condense preferably on fly ash particles. Some heavy metals also show a catalytic effect in the formation of PCCD and PCDF.

A.1.2.5 Ash and ash-forming elements

Alkali and earth-alkali species, potassium (K), sodium (Na), magnesium (Mg) and calcium (Ca), as well as chloride (Cl) and aluminum (Al) primarily determine the property of the ash which results from biomass combustion. In particular a lowered ash melting temperature[11] is responsible for severe operational problems caused by slagging and fouling. While Ca, Mg and Al increase the ash melting temperature, Cl, K and Na lower this value [9, 18]. This leads to a strong variation in ash melting temperatures of different biomass ranging from values as high as 1300 °C for wood down to app. 700 °C for wheat. The exact values also depend on storage and pre-treatment (e.g. “leaching” of Cl and K).

A positive effect of increased earth-alkali contents in the ash is an increased retention of sulphur and chloride, leading to a lower pollutant load for all downstream flue gas cleaning equipment.

Not only the properties but also the amount of ash of a certain biomass fuel is relevant for the operation of the plant and the prevention and control of emissions. From Table BM 2 it concludes that in this regards herbaceous biomass shows an unfavourable combination of high ash content with a large fraction of earth-alkalis. Especially the utilisation of straw, energy crops and miscanthus suffers from large amount of ash with low ash melting temperatures.

A.2 Applied processes and techniques

In the following, currently in Germany applied processes and techniques which are directly or indirectly connected to gaseous, liquid and solid emissions from biomass-fired power plants are described.

A.2.1 Feeding and handling of biomass

Biomass has certain characteristics which differentiate it from other solid fuel such as coal which put special demands on handling and transporting equipment. These include:

- relatively low calorific value
- low density
- tendency to freeze (due to the high moisture content)
- risk of spontaneous combustion

[11] sintering temperature < softening temperature < hemisphere temperature < melting temperature

- biologic degradation and degasification
- bridging
- dust-raising propensity
- often considerable contamination with wood and stones

Life cycle analyses have shown that the emissions from biomass production and transportation are of minor importance compared to the emissions from combustion.

Closed silos and storage areas with dedusting devices are necessary when storing fine dusty biomass. Chips and bark are stored for longer periods in open stockpiles, with covered storage reserved for the screened and crushed fuel that is to be used for daily use.

Belt conveyors can be used to transport the fuel from the stockpile (silos) to the boiler. An endless belt wound over two tail pulleys is used for carrying and hauling. Belt conveyors can be used for bulk material or unit loads. The construction is simple, inexpensive and offers the opportunity to install a conveyor belt weigher. However, belt conveyors are not suitable for inclined conveying and avoiding dust emissions is costly. Moreover, they are sensitive to external influences such as temperature or dirt accumulations on the pulleys. Tube-rubber belt conveyors enclose the material and therefore dust emissions are avoided. Chain conveyor systems such as chain trough conveyors or scraping conveyors can be used for sawdust, bark and woodchips. In order to avoid dust emissions, the conveyor can be entirely encased. Screw conveyors allow the conveying of bulk materials without dust emissions. In bucket elevators, problems due to dust emissions and dirt accumulation may occur if fine particles are elevated at high speeds [14].

A major hazard of biomass-fired power plants is the risk of fire and explosion, e.g. on the conveyors, or even in the articulated lorry. The raising of fugitive dust out of the fuel must be avoided, for example by applying water sprayers.

Transportation, unloading and storing of straw requires some special measures. The handling of straw is almost solely based on bales, each weighing approximately 400 – 700 kg. Trucks carrying 20 or 24 bales transport the bales from the fields or farmers' storage area to the plant. The trucks are unloaded by a specialized overhead crane, whilst simultaneously performing a quality check (weight and moisture) of the straw. The straw batches (10 or 12 bales per batch) are either transferred to a vacant position in the straw storage area or they are transferred directly to the processing equipment.

The straw bales are transported from the storage area by a crane and tier conveyors and are shredded before being fed into the boiler furnace.

A.2.2 Pre-treatment of biomass

Biomass can contain elements and compounds that, during combustion, cause the formation of both environmentally harmful emissions and deposits in furnaces and boilers. The pre-treatment of biomass should modify the composition in such a way that the combustion has the lowest impact on the power plant equipment, in particular on the boiler and on downstream flue gas cleaning components.

Large contaminant objects, such as iron pieces, can be removed by an overband magnet and magnetic roller. Subsequently, larger sizes of biomass are removed and, finally, non-ferrous metals are separated. As a result, fuel which is almost ferrous and non-ferrous metal free can be produced. In case of firing wood waste, it shows that the separation of undersized particles, as well as of metal and non-ferrous metal can significantly reduce the concentrations of impurities and crucial ash-forming elements [5].

A.2.3 Storage

The main risks during the time of storage of biomass between delivery and utilization involve: self ignition, fungus and odour formation, mass loss due to biologic degradation, remoistening, agglomeration by frost, demixing, formation of seepage water and dust emissions.

A low water content of the biomass (normally less than 20 %) avoids most of the problems stated above. A rain cover and ventilation reduces the moisture over time. If water contents remains to be a problem, drying of the biomass before storage is the only option. If possible, easily degradable material such as leafs should be removed before storage. To achieve a longer possible storage period it is advantageous to retain a rough structure and shred and mill the biomass only shortly before combustion.

A.2.4 Drying

The moisture content of biomass fuels varies widely, depending on the kind of material, the time of harvesting, the form of pre-treatment and the method and duration of storage. To optimise the combustion process (minimum emissions, maximum efficiency), the moisture content of the fuel should be as constant as possible. Fuel with varying moisture content requires a more complex combustion technology and process control system and therefore pushes up investment costs.

As mentioned above, storage and drying of biomass fuels is oftentimes interconnected. Active drying of the biomass using external heat is usually not applied in existing plants, unless there is an economically available (waste) heat source. Instead, the tendency is to exploit natural drying as much as possible.

Drying with passive ventilation can be divided into floor drying, drying by natural convection and drying by self-heating.

Floor drying is the spreading of moist biomass on the floor which is overflown by air. In case of good climatic conditions, the moisture content can be reduced rapidly down to 20 % within one day. Disadvantage of floor drying is the large required area, a possible re-moistening if no rain cover is applied and the contamination with pollutants if the material is placed on non-surfaced soil.

Natural convection occurs if the biomass is piled up as often done with wood directly after the harvest in the forest. Hereby the water content can be reduced from 50 to 20 – 30 % within one year.

Biomass has the tendency to self-heat if stored as loose bulk, which supports the drying by natural convection. If the floor is air-permeable and the biomass is coarsely piled, the self-heating leads to an efficient drying without large mass-loss.

Drying with active ventilation can be divided into variants with and without the use of external heat.

In particular smaller bulk biomass requires active ventilation to avoid the risk of self-ignition, to achieve a reasonable convective air flow and to guarantee an adequate drying effect. Active ventilation always improves the effect of self-heating by providing cold air which is then heated up transferring the moisture away from the biomass.

The pre-heating of drying air leads to lower water contents and a faster progression of the drying.

Drying without storage is seldom required. One example is the fabrication of pellets or briquettes. Available drying technologies include belt drier, feed-and-turn drier, rotary drier, tubular/drum drier, superheated steam drier, which can be driven either directly with flue gas or indirectly via hot water, steam or thermal oil.

The use of available waste heat or solar radiation is the most economical option. Additional costs for drying have to be compared to cost reductions due to higher efficiency (lower flue gas flow, lower fuel requirements).

A.2.5 Combustion

Either grate or fluidised bed combustion systems are used in all German biomass power plants. Pulverised fuel firing with biomass is not applied. In case of co firing biomass with coal, the pulverisation of biomass together with the coal is common.

Table BM 3: Properties of different biomass combustion techniques

	Reciprocating grate	Travelling grate	Fluidised bed
Range of fuel input (MW_{th})	5 - 100	10 - 110	50 - 400
Possible calorific value of fuel (MJ_{th}/kg)	7- 11 w/ pre-heated combustion air 11 - 16 w/ flue gas recirculation	10 - 13 w/ pre-heated combustion air 13 - 17 w/ flue gas recirculation	6 - 30
Thermal grate load (MW_{th}/m^2)	< 1.0	1.3 -2.0	1.5 - 7
Acceptable dust fraction < 1 mm (in fuel)	< 10 wt.-%	< 10 wt.-%	< 20 wt.-%
Air ratio	1.5	1.35	1.25-1.30

Regarding gaseous and solid emissions, fluidised bed combustion furnaces normally show low CO and NOx emissions due to a homogeneous and therefore well controllable combustion conditions. Grate firing and fixed bed furnaces, in turn, usually emit fewer dust particles and show a better burnout of the fly ash [14]. In a German study from 2008, 24 out of 30 biomass-fired power plants were equipped with grate firing (16 reciprocating grate & 8 travelling grate) the remaining 6 used fluidised bed firing (3 stationary & 3 circulating) [18]. In 2012, 28 biomass-fired power plants (with a thermal input of 50 MW_{th} or more) are in operation, of which 17 are grate firings and 11 CFB Firings.

A.2.5.1 Grate firing

Grate firing furnaces are one of the oldest combustion technologies and originally have been used only for coal. Due to their low sensitivity to problematic fuels, it is the most common technology for biomass combustion. For large combustion plants only reciprocating grates and travelling grates are relevant.

The combustion process in grate firing is not as well controllable as it is in pulverised fuel burners or in fluidised beds. However, grate firing systems are fairly tolerant towards volatile moisture content and calorific value which can vary between app. 5 - 60 % and 7-17 MJ_{th}/kg, respectively.

The advantage of grate firing in fuel variability becomes a disadvantage if the fuel properties vary during operation. Due to local variations in fuel properties even within the same fuel charge, combustion chemistry and temperature and with it emission formation as well as burnout characteristics can vary depending on the location on the grate, making the control of the combustion process a complex matter.

On a grate, all fuels are first dried then pyrolysed and, finally, the char is burned on the grate. The pyrolysed share of fuel energy can be about 80 % with biofuels [12].

Reciprocating grates

Reciprocating grates consist of alternately fixed and variable rods. A juddering movement of the rods guarantees the agitation and mixing of the fuel. Sloped (10-25°) grates are typically used for biofuels.

Since complete combustion in the first combustion zone directly on or above the grate is difficult to achieve as turbulent air flow has to be avoided, air-staging is used in all operational biomass-fired power plants in Germany. This guarantees low NOx emissions as well as a complete combustion with low CO emissions. The secondary air is blown into a secondary combustion zone achieving a profound mixing with the flue gas by large velocities and turbulent flow.

Reciprocating grate firing systems can be designed as counter-, mid- or co-current flow of the flue gas with the fuel (cf. Figure BM 3 and Figure BM 4).

Counter-current systems are designed for fuels with high water content of up to 60 % (and consequently low heating value) since the fresh biomass entering the combustion chamber is contacted with the hottest flue gas. This system requires a good mixing of flue gas and secondary air in the combustion chamber in order to avoid the formation of striated flows enriched with unburned gases entering the boiler and increasing emissions.

Co-current designs are used for dry fuels (such as waste wood) or for biomass with low ash melting temperature such as straw. This system increases the residence time of unburned gases released from the fuel bed and can improve NOx reduction by enhanced contact of the flue gas with the charcoal bed on the backward grate sections.

When considering biomass fuels with low ash melting temperatures such as straw, a water-cooled grate is used to avoid slagging and fouling on the rods. Additionally, the steam temperature have to be kept below approximately 500 °C to keep corrosion within acceptable limits and to avoid slagging, sintering an fouling.

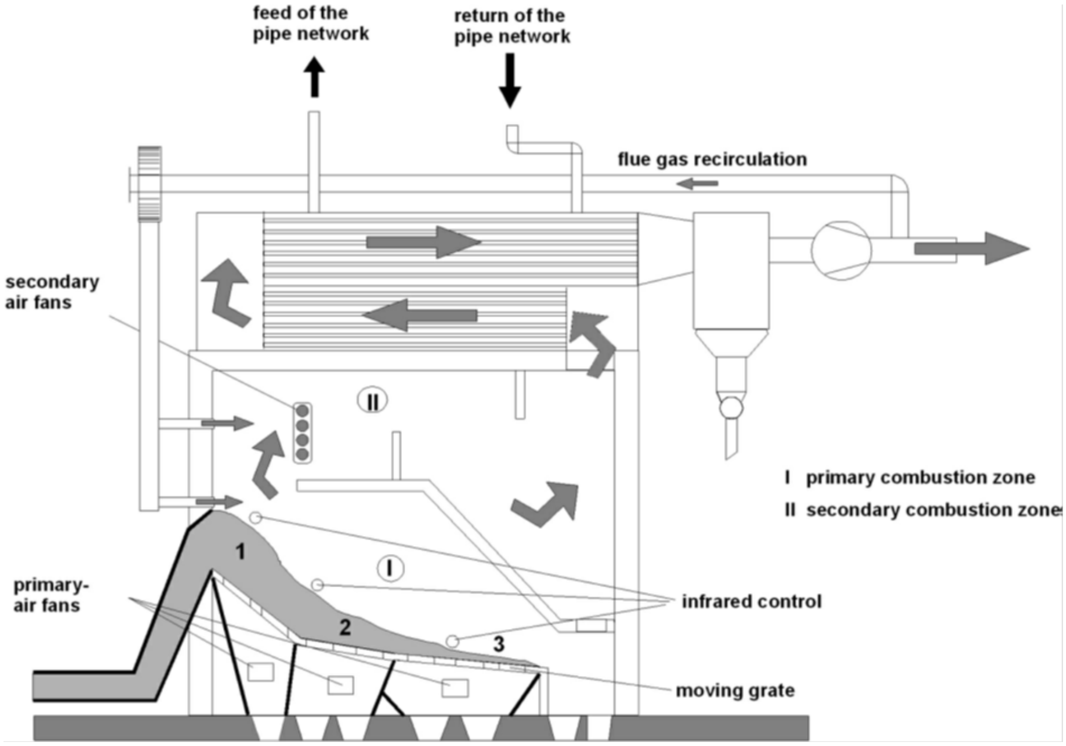


Figure BM 3: Reciprocating grate firing with countercurrent flow [14]

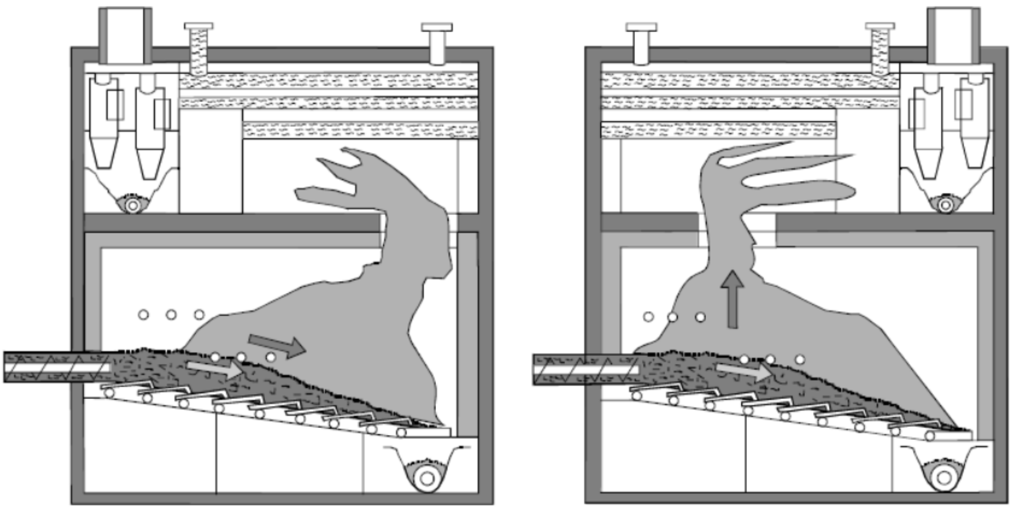


Figure BM 4: Reciprocating grate with co-current flow (left) and with mid-current flow (right) [12]

Travelling grates with spreader-stokers

A travelling grate is in fact an infinite belt consisting of individual segments which remain horizontally on the upper side and fold into a vertical position on the lower side for ash removal (cf. Figure BM 5). The spreader throws the fuel on the grate against the direction of the grate movement.

Uneven distribution of fuel over the grate surface requires a higher primary air input for complete combustion, implying a lower NOx reduction potential by primary measures. The use of spreader-stokers can partially avoid this problem, because the fuel-feeding mechanism causes an appropriate mixing [7].

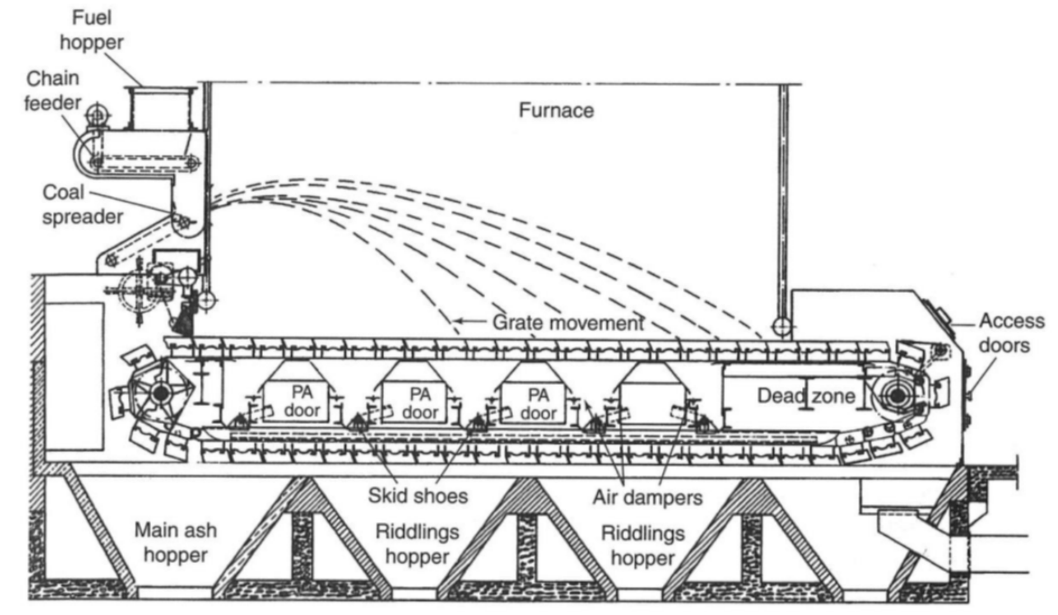


Figure BM 5: Spreader-stoker travelling grate firing [2]

A.2.5.2 Fluidised bed combustion

Fluidised bed combustion is mainly used for industrial applications where different solid fuels such as coal, lignite, peat and particularly biomass are burned. Two main types of fluidised bed combustion boilers exist – stationary (SFB) and circulating (CFB). SFB boilers are more popular for the combustion of biomass, especially in small sized boilers and in industrial applications while CFB boilers are more common in larger plants. For both systems, fuel is used in a coarse form and for this reason most ash is extracted as bottom ash. Table BM 4 shows the most important parameters of both systems.

Table BM 4: Typical characteristic parameters of stationary and fluidised bed combustion systems

	SFB	CFB
Temperature (°C)	800 - 950	800 - 950
Steam output (t/h)	< 150	100 – 2.000
Superficial gas velocity (m/s)	1.8 – 2.5	4.5 – 7.0
Loss of ignition	4 – 8 %	1 - 2 %
Particle size of inert material (mm)	0.5 - 1.5	0.1 - 0.3
Thermal load (MW_{th}/m^2)	1.5	5 - 7
Pressure loss (bar)	0.05 – 0.1	0.1 – 0.2
Primary/secondary air	90/10	60/40
Residence time (bed + freeboard) (sec.)	2.5 – 3.0	4.0 – 5.5

Stationary fluidised bed combustion

Stationary Fluidised Bed combustion (SFB) especially suited for burning inhomogeneous biofuels. SFB consists of a 0.5 – 1.5 m high bed on a fluidising air distribution plate. The fluidising velocity is about 2 m/s. The density of the bubbling bed is about 1000 kg/m^3. Typical bed materials used are sand, ash, fuel, dolomite and limestone. The particle size distribution in the fluidising bed material is typically within 0.5 – 1.5 mm, as smaller particles are carried out with the fluidising gas flow and larger particles sink onto the distribution plate.

Circulated fluidised bed combustion

Circulating Fluidised Bed combustion (CFB) differs from SFB in two ways: The bed material particle size is smaller, i.e. 0.1 – 0.3 mm and the fluidising velocity is faster, i.e. 5 – 7 m/s. These changes affect the fluidising conditions so that part of the bed material is carried out from the bed, transiting through the furnace to the second pass of the boiler. These particles exiting the furnace are separated from the flue-gas flow by a cyclone or by other separation methods, such as U beams and are recirculated back to the fluidised bed. The separation can be carried out in the middle of the second pass and, in part, also at the outlet of the boiler pass, where electrostatic precipitators and fabric filters can also be used.

Figure BM 6: Fuel and bed material flow in a biomass fired CFB boiler

New CFB boilers typically have a fuel input of less than 200 MW_{th} and they produce both electricity and heat to local industry or to the district heating system. Heavy oil is commonly used as an auxiliary start-up fuel. CFB is tolerant for fuel quality changes and there is no need for fuel drying and pulverising. With regard to emissions, low NOx emissions can be achieved owing to good air staging, good mixing and a low requirement of excess air. Moreover, the utilization of additives (e.g. limestone addition for SOx capture) works well due to the good mixing behaviour. The low excess air quantities necessary increase combustion efficiency and reduce the flue gas volume flow. This makes CFB plants especially interesting for large-scale applications (boiler capacity above 20 MW_{th}). For smaller combustion plants the investment and operation costs are usually too high in comparison to fixed-bed or grate firing systems.

One disadvantage of CFB plants is posed by the high dust loads entrained with the flue gas, which make efficient dust precipitators and boiler cleaning systems necessary. Bed material is also lost with the ash, making it necessary to periodically add new material to the plant. From the extracted bed material/ash mixture, coarse parts can be separated from the fine particles and sand in an air classifier and the fine material can be returned into the bed. Thus the bed material consumption of the boiler can be lowered [14].

A.2.5.3 Co Firing of biomass and fossil fuels

The main advantage co-firing biomass with coal, is the reduction of CO_2 emissions with existing infrastructure. The economics of using locally available fuels may improve considerably if they can be co-fired with a commercial fuel at an existing power plant. However, there are considerable technical and environmental restrictions.

In co-firing applications the challenges posed by the combustion of biomass remain the same but can be damped by a more favourable and more constant properties of the primary fuel. The higher the fraction of biomass co Firing, the more important the fuel blending in particular with regard to the chemical composition and its effect on slagging, fouling, sintering, corrosion and combustion product quality (ash, gypsum).

While co Firing of biomass leads to reduced CO_2 emissions, the negative effects on boiler capacity, efficiency, corrosion and fouling as well as possible (positive or negative) effects on NOx and SOx emissions must be considered. Furthermore, the residues from the gas cleaning as well as the ash composition can be negatively influenced due to alkali metals and chlorine in the biomass. Therefore, 5–10 per cent of the heat input is usually provided by biomass, which leads to acceptable effects on the ash and residues. The main application of co-firing is the co-combustion of dry pulverized biofuels in pulverized coal boilers, which usually makes fuel treatment necessary [14].

A.2.6 Steam generation

A.2.7 Sulphur oxides emission prevention and control

The majority of the fuel-sulphur is converted into sulphur dioxide (SO_2) and sulphur trioxide (SO_3) during combustion (cf. Section A.1.2.2). Depending on ash (and thus also biomass) composition, some of the fuel sulphur is incorporated into the ash.

SO_2 is removed from the flue gas by dry or wet sorption processes with calcium carbonate (limestone) and sometimes sodium carbonate. An advantage of dry processes, which are used in the majority of German biomass plants, is that no additional flue gas cooling is necessary. Through the addition of adsorption material such as hearth furnace coke, dioxins, furans and heavy metals can also be partially separated from the flue gas.

The prevention and control of SOx emissions is discussed in the following sections.

A.2.7.1 Grate combustion

Integrated sulphur removal in grate combustion systems is not possible because of the minimal contact time between sulphur oxides and the reactive alkali fed onto the grate. Limestone injection into the furnace is possible but usually not efficient.

If low sulphur fuels are used (cf. Table BM 2) sometime no desulphurisation is needed. With higher sulphur content, dry injection processes are usually applied to the flue gas stream. The injection of calcium hydroxide in a dry form before dust removal can achieve a reasonable SOx reduction. These measures also remove other harmful emissions, such as HCl.

A.2.7.2 Fluidised bed combustion

In a circulating fluidised bed, sulphur oxides can be captured *in-situ* by using dolomite or limestone as bed material at an optimal temperature of 840 – 850 °C. Dolomite or limestone is calcined in the bed and then reacts with sulphur oxides to form calcium sulphate (gypsum). The bed temperature in CFB (850 ºC) is optimal for calcium-based sulphur recovery.

SFB systems require a Ca to S ratio of 2.5 – 3 and achieve an SOx reduction by 85 %. Due to the longer residence times in CFB systems, lower Ca/S ratios of 1.8 – 2.5 are necessary to achieve an SOx reduction of up to 95 %.

In a bubbling bed, the combustion mainly occurs in the freeboard zone and the dense suspension only exists in the bubbling bed. Therefore, the efficiency of sulphur recovery is much lower in the SFB than in the CFB. The reduction efficiency in the SFB is typically 30 - 40 %. A higher efficiency requires high Ca/S mole ratios of up to 10, which, however, might jeopardise the re-use of precipitated fly ash, meaning that lower reduction rates (and sorbent amounts) are recommended.

Sorbent use increases the amount of ash produced by the power plant. There is a possibility of reduced efficiency in electrostatic precipitation, due to the sorbent properties. This causes more particulate emissions, especially when using larger amounts of sorbent to reduce the sulphur oxide emissions.

A.2.8 Nitrogen oxide emission prevention and control

Due to the relatively low combustion temperatures of 800 – 1200 °C in biomass combustion, only fuel-NOx plays a role. The fuel nitrogen is converted almost entirely into molecular nitrogen (N_2) or nitrogen oxides (NOx); a negligible amount is retained in the ash. The theoretical maximal formation of NOx is app. 380 mg/Nm^3 per 0.1 % of fuel N_2[12]. This value is reached if a fuel contains 0.1 % N_2 and the fuel-N_2 is oxidized completely to NO_2. Typical ranges of fuel-N_2 are presented in Table BM 2. It should be considered that only a part of the fuel-N_2 is oxidised to NO_2 (see Figure BM 2).

The prevention and control of NOx emissions is discussed in the following sections. First, primary and secondary measures that are commonly used in both grate combustion as well as fluidised bed combustion plants are explained. Afterwards, special aspects of NOx prevention and control with regard to the individual combustion systems are discussed.

A.2.8.1 Common primary measures

Due to the relatively low combustion temperature, NO_X emissions primarily stem from the fuel nitrogen. In this case the largest potential for NOx emission reduction lies in the combustion under substoichiometric conditions in the primary combustion zone.

[12] For an air excess of app. 20 % (λ=1.20)

Complete combustion is then achieved by (overstoichimetric/excess of stoichiometry) secondary air addition in the secondary combustion zone.

Air staging is the most common primary measure for reduction of NOx emissions (as well as of CO emissions, cf. Section A.2.10) in biomass power plants and is applied in most plants in Germany currently under operation. Air staging aims at complete combustion by assuring an adequate travelling time of the flue gas (> 2 seconds at 800 °C) and a good mixture of combustion air and flue gas. The potential of NOx emission reduction by air staging lies in the range of 50 to 75 %, depending on the nitrogen content in the fuel.

Since thermal NOx plays a minor role in the formation of nitrogen oxides, the potential of NOx reduction by decreasing the combustion temperature through the recirculation of flue gas is limited and can contribute only around 10 % in NOx emission reduction [14].

A.2.8.2 Common secondary measures

If primary measure for NOx reduction do not suffice, the reduction of NOx to molecular N_2 downstream of the combustion chamber is required. Biomass fuels with high nitrogen content, such as e.g. UF-chipboards (cf. Table BM 2), require secondary measures to achieve stringent NOx emission limits. In Germany only the selective non-catalytic reduction (SNCR) technology is applied, due to the observed problems with catalyst deactivation in SCR systems which is connected to the high alkali (mainly potassium) content in the flue gases. In SNCR system a reducing agent and a temperature between 850 and 950 °C is required[13]. The reduction agent, typically ammonia (NH_3), is sprayed into the combustion. To avoid an ammonia or urea slip to the environment, exact control of the dosage of ammonia and a sufficient residence time of flue gas and reduction agent is essential. The latter is sometimes achieved by installing baffles in the flue gas path.

A.2.8.3 Grate combustion

The low combustion temperatures of grate systems are advantageous for the suppression of NOx emissions. Efficient low NOx combustion requires a sophisticated secondary air system and a special furnace design enabling two combustion zones. Air-staging with overfire air is often used to reduce the generation of NOx emissions. However, as grate combustion requires a larger amount of primary air than fluidised bed systems, the applicability of this primary measure for NOx reduction is limited.

Air staging in grate combustion systems also needs to consider the cooling of the grate by the primary air. Therefore, the variation of primary air flow and the ratio of primary to secondary air underlie certain limits which consider the material temperature of individual grate rods. If water cooled rods are installed, primary air flow can be reduced and the degree of freedom for air staging is increased. Flue gas recirculation is another option to cool the grate.

A.2.8.4 Fluidised bed combustion

The formation of thermal NOx is avoided in fluidised bed combustion because of the low combustion temperature. Low NOx combustion is also enhanced in fluidised bed boilers by staging the combustion air. The staging in the CFB is always quite strong because of the poor horizontal mixing of gases over a dense suspension area. The dense suspension

[13] In Selective Catalytic Reduction (SCR) processes, the reduction of NOx to molecular N_2 is already achieved at temperature between 200 and 450 °C.

suppresses the turbulence and the combustion zone of volatile fuel components spreads upwards from the feeding point.

The production of nitrous oxide (N_2O) appears to be greater in FBC (especially in circulating fluidised beds) than in conventional pulverised fuel combustion, due to the slower degradation of the compound at the lower combustion temperatures.. The share of fuel nitrogen that forms nitrous oxide decreases to an insignificant value if the bed temperature is increased to over 950 ºC. On the other hand, a high combustion temperature can cause an increase in the emissions of nitrogen oxides (NO and NO_2). In SFB combustion systems, the risk of nitrous oxide emissions can be more easily avoided, as the temperature in the freeboard can be kept much higher than 950° C.

A.2.9 Dust emissions

In the combustion of biomass, secondary measures for emission reduction are in particular necessary for the abatement of dust emissions, which consist of anorganic particles (salts), elementary carbon (soot) and condensable organic compounds (tar). Particles can be removed from the gas stream by cyclones, electrostatic precipitators, baghouse filters or wet scrubbers. Figure BM 7 shows the precipitation efficiency of different particle removal technologies, Table BM 5 contains typical operational parameters. Filters and ESPs achieve the highest separation efficiencies but require the largest investment and operational costs. Their application poses limitations on the bearable temperature and velocity range of the flue gas but are the only options to separate fine particles. Measures to control the flue gas temperature include flue gas recycle and water cooled combustion chambers, both options reduce the combustion temperature and thus also reduce NOx formation and lower the risk of slagging and fouling. The quality of fly ash might suffer from condensed heavy metals; in particular Cd, Zn and Pb as the most volatile heavy metals.

In all German biomass-fired power plants, only multi cyclones and bag filters applied. With the former dust loads of 100 – 150 mg/Nm^3 are achievable, with the latter levels of in average 10 –20 sometimes as low as 1 mg/Nm^3.

Bag filters show high separation efficiencies (> 99.5 %) even with smallest particles (2 – 5 µm); they are sensitive towards moisture, thus start-ups and shut-downs, where the flue gas temperature falls below the dew point, are negative with regard to their lifetime.

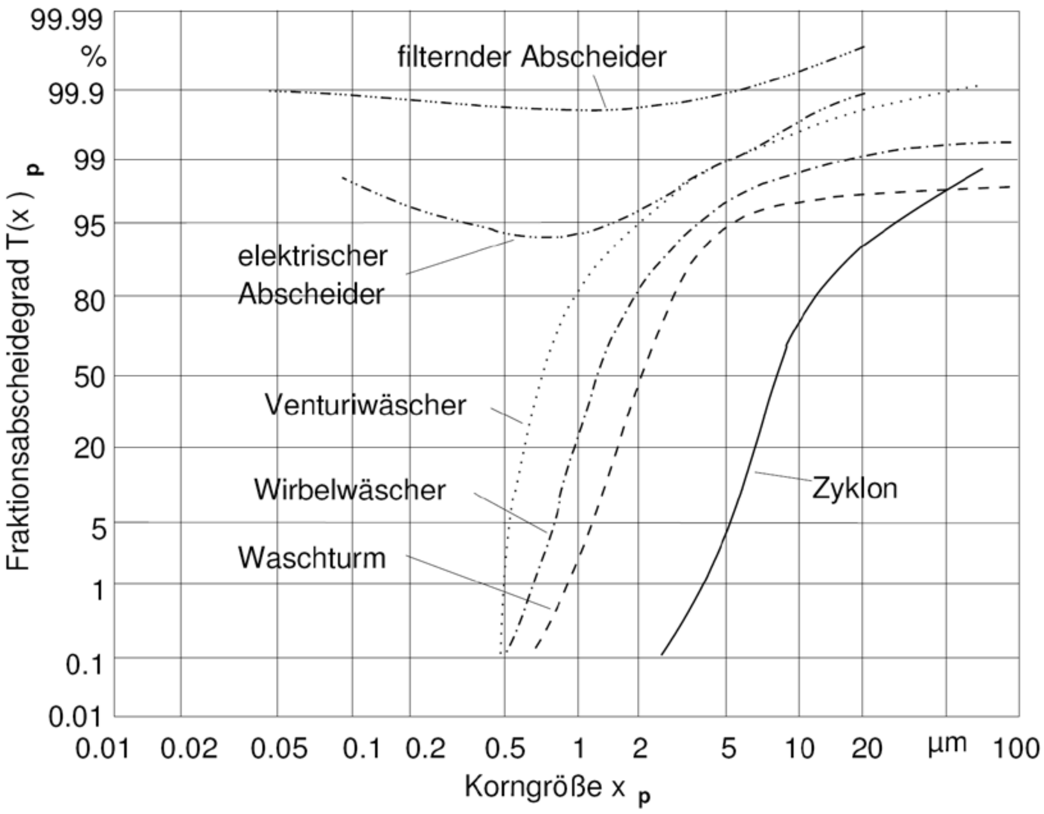


Figure BM 7: Efficiency of different particle removal devices [20]

Table BM 5: Typical operational parameters of particle removal devices [27]

	Cyclone	Baghouse filter	ESP (dry)	ESP (wet)
Removal efficiency (%)	85 – 95*	99 - 99.99	95 – 99.99	95 – 99.99
Gas velocity	15 – 25	0.5 - 5	0.5 – 2.0	0.5 – 2.0
pressure loss (mbar)	6 - 15	5 - 20	1.5 - 3.0	1.5 - 3.0
spec. energy consumption (kWh/1000 m^3, wet)	0.3 – 0.65	0.75 – 1.9	0.26 – 1.96	0.17 – 2.3

* for small particles < 1micrometer nearly 0

A.2.9.1 Grate firing

In grate combustion systems most of the ash is left on the grate and collected as bottom ash. Only a small quantity and fine particles of ash leaves the furnace as fly ash and must be collected in the dust removal devices. The high alkali and chlorine compound content in biomass causes the formation of salt with aerodynamic diameters partially smaller than 1 µm.

For dust abatement from grate-fired combustion plants, small plants can use ESPs, but for larger plants, fabric filters are applied.

A.2.9.2 Fluidised bed combustion

For dust abatement in biomass FBC boilers the fraction of fly ash arriving in the dust removal devices are larger than in grate combustion systems. Both ESPs and fabric filters are currently applied in FBC systems, where the fabric filter is often the preferred technology.

A.2.10 Emissions from incomplete combustion

Incomplete combustion is characterised by the emission of carbon monoxide (CO), unburned carbohydrates (tar) and unburned carbon (soot).

A.2.10.1 Carbon monoxide

Due to air staging in modern large-scale biomass combustion plants and burn out optimisation, CO emission levels are usually low. As a function of the excess air ration there is usually a minimal CO emission to be achieves: higher air ratios lead to lower temperatures while decreased excess air might results in inadequate mixing conditions. Sufficient residence time is also important to achieve low CO emission levels.

A.2.10.2 Hydrocarbons

Methane is a direct greenhouse gas and occurs as intermediate in fuel-C to CO_2 and H to H_2O conversion. Too low combustion temperatures, too short residence times and lack of available oxygen can promote the concentration of methane in the flue gas. Proper air staging and combustor design can usually decrease CH_4 emissions to a negligible amount.

Non-Methane Volatile Organic Components (NMVOC) as well as carciogenica Polycyclic Aromatic Hydrocarbons (PAH) are also intermediates in fuel-C to CO_2 and H to H_2O conversion. They condense and form particle emissions and can also be avoided by proper combustion air management and injection.

A.2.10.3 Polychlorinated dioxins and furans (PCDD/PCDF = PCDD/F)

Polychlorinated dioxins and furans are a group of highly toxic components. They are found to be a consequence of the de novo synthesis in the temperature window between 180°C and 500°C. Carbon, chlorine, catalysts (Cu) and oxygen are necessary for the formation of PCDD/F. PCDD/F can be formed in very small amounts from all biomass fuels containing chlorine. The emissions of PCDD/F are highly dependent on the conditions under which combustion and flue gas cooling take place; therefore, wide variations are found in practice. Although herbaceous biomass fuels have high chlorine contents, their PCDD/F emissions are usually very low. This may be explained by their high alkali content, which leads to the formation of salts (KCl, NaCl) and thus to a lower level of gaseous chlorine for the de novo synthesis. Because of the many factors influencing PCDD/F formation, wide variations may appear even within the same biomass combustion installation. In general, the PCDD/F emission level from biomass combustion applications using virgin wood as fuel is well below the health risk limit. PCDD/F emissions can be reduced by primary and secondary emission reduction measures [14], S.301].

The formation of PCDD or PCDF in biomass combustion can be reduced by avoiding the critical temperature range between 250 °C and 450 °C in which the De-novo-synthesis of dioxins and furans occur. This is achieved by applying a water quench of the hot flue gas, crossing quickly through the critical temperature window and by operating the dust removal below 220 °C. A lower content of chlorine and chlorine compounds in the fuel also reduces the PCDD and PCDF formation.

Some heavy metals also show a catalytic effect in the formation of PCCD and PCDF.

A.2.10.4 Ammonia

At very low temperatures incomplete conversion of NH3 formed during pyrolysis and gasification of the fuel might occur. Secondary measure for the prevention and control of NOx utilise NH_3 for NOx reduction. Improper dosage or removal device design might lead to ammonia slip.

A.2.11 Water and waste water treatment

Biomass-fired power plants generate waste waters from different sources. They are mainly related to the combustion process and its auxiliary systems, such as the FGT, the demineralisation faciliy, cooling water, etc. This waste water is treated with conventional waste water treatment technologies like in other power plants. In addition to this, the surface runoff can be polluted (high COD values and others) due to open air storage of biomass. If necessary, the surface runoff has to be collected and treated.

A.2.12 Handling of combustion residues and by-products

The ash residues from fluidized bed combustors are generally of two basic types:

- The fly-ash materials carried over from the combustor and captured by the particulate emission abatement equipment. These materials generally comprise the smaller fuel ash particles and particles of quartz sand or lime/limestone elutriated from the bed. The great majority of the ash discards from the system are of this type.
- The larger ash particles retained in the furnace, which can be removed periodically through the bed drains. These generally comprise agglomerated fuel ash and bed materials and slag deposit material detached from the furnace surfaces. When firing biomass materials, the quantities of bed ash discard materials tend to be relatively small.

The ash discarded from biomass combustion can be utilised depending on its composition. Due to the German fertilizer ordinance the ash can be used for fertilisation if it meets the required concentrations of nutrients and pollutants. Especially the maximum cadmium concentration of 1.5 mg/kg is critical for fertilisation.

A.2.13 Emission reduction by process control

A combined CO/λ control provides best results with regard to combustion control and CO emission reduction. CO/λ characteristic depends not only on the moisture content of the fuel but also on the actual load conditions of the furnace. Higher fuel moisture contents and decreasing load of the furnace usually increase the optimum excess air ratio and vice versa [14].

A.3 Techniques to consider in the determination of BAT

A.4 Best available techniques (BAT) for the combustion of biomass

A.5 Current consumption and emission levels

Please refer to chapter 3.4.3.

A.6 Emerging techniques for the combustion of biomass

A.6.1 Pre-treatment of biomass

In general pre-treatment is used to adapt the biomass characteristic to the needs for the following combustion process. Pre-treatment of biomass can be divided into thermal and physical pre-treatment. While physical pre-treatment like drying and milling is state of the art, some thermal pre-treatments techniques can be considered as emerging technology. Examples for reasons to pre-treat biomass are increasing the energy density or varying the chemical composition.

A.6.1.1 Pyrolysis

Pyrolysis is the thermal degradation of biomass under anaerobic atmosphere at around 500 °C. There are different processes available for pyrolysis. They deviate in the residence time of the biomass and the heating rate. There are three different qualities of products: oil, gas and char. The quantitative proportions of the products are for the most part an outcome of the applied process. . One advantage of the pyrolysis is that the alkali compounds are not evaporated and therefore can be separated in solid form with the ash and the char, which leaves behind a relatively clean product gas. Most of the existing pyrolysis plants are pilot plants and almost no commercially application has yet been achieved. Pyrolysis is an allothermal processes, meaning that it relies on external heat input. For this reason and because of the different emerging products, it can be beneficial to situate pyrolysis facilities near to existing power plants.

A.6.1.2 Torrefaction

Torrefaction is a thermo-chemical conversion for the upgrading of biomasses. It is performed in batch mode under anaerobic conditions at temperatures of up to 300 °C. . During the torrefaction, a part of the volatile matter leaves the fuel and is incinerated to create an autothermal process. The main product of the torrefaction is a solid fuel similar to lignite. Depending on the residence time and temperature realised in the torrefaction process up to 70 % of the original mass is maintained while the energy content is lowered by only 10 %. Most of the unwanted substances as alkali metals or chlorine are still contained within the fuel.

A.6.1.3 Hydrothermal carbonisation

Hydrothermal carbonisation (HTC) imitates the process of coalification. It hereto converts the biomass in aqueous phase and under the exclusion of oxygen into a lignite like substance. The process takes place at initial temperatures of 180 to 200 °C and pressures of 10 to 25 bar while being catalysed by acid. The occurring reactions are exothermal, thus making the concluding drying and the initial heat input more independent from external heat sources. The product is a stable solid that includes almost all carbon from the inserted biomass. Other energy contributing substances from the original fuel are used for the production of heat, which is why the product contains only about 2/3 of the original energy content. Through the contact to the water under the given conditions, inorganic substances like alkalis, chlorine or inert material are stripped from the fuel. This leads to the necessity of an excessive waste water treatment. Due to the liquid environment, the application of very wet biomasses, such as sewage sludge or animal litter is advantageous for HTC. Commercial plants are not available today.

A.6.2 Gasification of biomass

Atmospheric CFB gasification (ACFBG) is a process where solid fuel is converted to combustible gas by partial oxidation. Air is used to fluidise the bed in the CFB reactor and simultaneously, to oxidise part of the fuel to gas at an elevated temperature.

The atmospheric CFB gasifier (Figure BM 8) consists of a reactor where the gasification process takes place, a cyclone to separate the circulating bed material from the gas and a return pipe for returning the circulating material to the bottom part of the reactor. After the cyclone, hot product gas flows into the air preheater which is located below the cyclone. The gasification air, blown with the high pressure air fan, is fed to the bottom of the reactor via an air distribution grid. The fuel is fed into the lower part of the gasifier at a certain height above the air distribution grid.

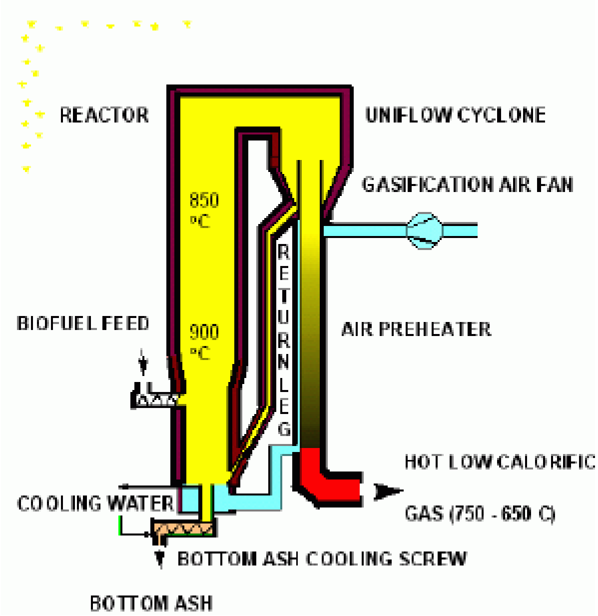


Figure BM 8: Example of a gasifier [28]

The operating temperature in the reactor is typically 800 – 1000 °C depending on the fuel and the application. When entering the reactor, the fuel particles dry rapidly and the first primary stage of the reaction, pyrolysis, occurs. During these reactions, fuel converts to gases, charcoal and tars. Part of the charcoal flows to the bottom of the bed and is oxidised to CO and CO_2, generating heat. After this, as these aforementioned products flow upwards in the reactor, a secondary stage of reactions take place. From these reactions, a combustible gas is produced, which then enters the cyclone and escapes the system together with some fine dust. Most of the solids in the system are separated in the cyclone and returned to the lower part of the gasifier reactor. These solids contain char, which is combusted with the fluidising air that is introduced through the grid nozzles to fluidise the bed. This combustion process generates the heat required for the pyrolysis process and subsequently, mostly endothermic reactions. The circulating bed material serves as a heat carrier and stabilises the temperatures in the process. The coarse ash accumulates in the gasifier and is removed from the bottom of the gasifier.

Fluidised beds are, however, quite sensitive to the low softening temperature of biofuel ash. The reducing atmosphere inside the gasifier further decreases the softening temperature of ash. This limits the gasification temperature from above. From below, the gasification temperature is limited because of incomplete gasification, i.e. the increase in tar compounds in the product gas. Tar is harmful to scrubbers when it condenses there. Tar can generate coke in the filters if high temperature dust removal is adopted. Therefore, the technical operating temperature window of biofuel gasification is quite limited and it can be a big economic drawback in new power plant investments, compared to the conventional power plant technology.

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