SNAP CODES: (See below)

SOURCE ACTIVITY TITLE: COMBUSTION IN ENERGY & TRANSFORMATION INDUSTRIES
Combustion Plants as Point Sources

The following activities are taken into account, when treating combustion plants individually as point sources.

Combustion plants with a thermal capacity < 300 MW, gas turbines and stationary engines, which may also be considered collectively as area sources, are covered by chapter B112 "Combustion Plants as Area Sources" as well.

SNAP97 Codes	NOSE CODE	NFR CODE	**Combustion plants as point sources** Boilers/Furnaces								
			Thermal capacity [MW]	Public power and cogeneration plants	District heating	Industrial combustion and specific sector	Commercial and institutional combustion	Residential combustion	Agriculture forestry and fishing	Gas turbines	Stationary engines
01 01 01	101.01	1 A 1 a	≥ 300	x							
01 02 01	101.01	1 A 1 a			x						
01 03 01	101.01	1 A 1 b				x					
01 04 01	101.01	1 A 1 c				x					
01 05 01	101.01	1 A 1 c				x					
02 01 01	101.01	1 A 4 a					x				
03 01 01	101.01	1 A 2 a-f				x					
01 01 02	101.02	1 A 1 a	≥ 50 and < 300	x							
01 02 02	101.02	1 A 1 a			x						
01 03 02	101.02	1 A 1 b				x					
01 04 02	101.02	1 A 1 c				x					
01 05 02	101.02	1 A 1 c				x					
02 01 02	101.02	1 A 4 a					x				
02 02 01	101.02	1 A 4 b i						x			
02 03 01	101.02	1 A 4 c i							x		
03 01 02	101.02	1 A 2 a-f				x					
01 01 03	101.03	1 A 1 a	< 50	x							
01 02 03	101.03	1 A 1 a			x						
01 03 03	101.03	1 A 1 b				x					
01 04 03	101.03	1 A 1 c				x					
01 05 03	101.03	1 A 1 c				x					
02 01 03	101.03	1 A 4 a					x				
02 02 02	101.03	1 A 4 b i						x			
02 03 02	101.03	1 A 4 c i							x		
03 01 03	101.03	1 A 2 a-f				x					
01 01 04	101.04	1 A 1 a	not relevant							x	
01 02 04	101.04	1 A 1 a								x	
01 03 04	101.04	1 A 1 b								x	
01 04 04	101.04	1 A 1 c								x	
01 05 04	101.04	1 A 1 c								x	
02 01 04	101.04	1 A 4 a								x	
02 02 03	101.04	1 A 4 b i								x	
02 03 03	101.04	1 A 4 c i								x	
03 01 04	101.04	1 A 2 a-f								x	
01 01 05	101.05	1 A 1 a	not relevant								x
01 02 05	101.05	1 A 1 a									x
01 03 05	101.05	1 A 1 b									x
01 04 05	101.05	1 A 1 c									x
01 05 05	101.05	1 A 1 c									x

SNAP97 Codes	NOSE CODE	NFR CODE	**Combustion plants as point sources** Boilers/Furnaces								
			Thermal capacity [MW]	Public power and cogeneration plants	District heating	Industrial combustion and specific sector	Commercial and institutional combustion	Residential combustion	Agriculture forestry and fishing	Gas turbines	Stationary engines
02 01 05	101.05	1 A 4 a									x
02 02 04	101.05	1 A 4 b i									x
02 03 04	101.05	1 A 4 c i									x
03 01 05	101.05	1 A 2 a-f									x

x = indicates relevant combination

1 ACTIVITIES INCLUDED

This chapter covers emissions from boilers, gas turbines and stationary engines as point sources. According to CORINAIR90, combustion plants with

– a thermal capacity ≥ 300 MW
or
– emissions of SO_2 or NO_x or NMVOC > 1,000 Mg/a[1]

should be considered as point sources /41/. Within CORINAIR other combustion plants may also be considered as point sources on a voluntary basis. Different criteria are applied for the classification of combustion plants according to the Large Combustion Plant Directive (88/609/EEC)[2] /9, 42/.

Boilers, gas turbines and stationary engines need to be treated separately (see table at start of this chapter). With regard to boilers, a combustion plant may consist of one single boiler or may comprise a series of boilers of different sizes (joint plant). Therefore, whenever there is more than one boiler on a site, a decision on the aggregation of these facilities to plants has to be taken. Through this decision, an allocation to the respective SNAP categories is achieved. For aggregation criteria see Section 3.2 and Annex 1.

The subdivision of SNAP activities according to CORINAIR90 concerning combustion plants takes into account two criteria:

a) the economic sector concerning the use of energy
  - public power and co-generation,
  - district heating,
  - commercial and institutional combustion,
  - industrial combustion in boilers,
    (Note: Process furnaces are allocated separately.)

---

[1] For CO_2 a further optional criterion for point sources is the emission of > 300 Gg/a.

[2] The Large Combustion Plant Directive covers combustion plants with a thermal capacity ≥ 50 MW in the EU. Gas turbines and stationary engines are excluded. Existing plants with a thermal capacity > 300 MW have to be reported as point sources on an individual basis.

b) the technical characteristics
  - with respect to boilers, the installed thermal capacity,
    - ≥ 300 MW,
    - ≥ 50 to < 300 MW,
    - ≤ 50 MW,
  - other combustion technologies,
    - gas turbines,
    - stationary engines.

Emissions considered in this section are released by a controlled combustion process (boiler emissions, emissions from the combustion chamber of gas turbines or stationary engines), taking into account primary reduction measures, such as furnace optimisation inside the boiler or the combustion chamber, and secondary reduction measures downstream of the boiler or the combustion chamber. Solid, liquid or gaseous fuels are used, where solid fuels comprise coal, coke, biomass and waste (as far as waste is used to generate heat or power). In addition, a non-combustion process can be a source of ammonia emissions, namely ammonia slip in connection with several NO_x abatement techniques.

2 CONTRIBUTION TO TOTAL EMISSIONS

This section covers emissions of SO_x, NO_x, CO, CO_2, NMVOC, CH_4, N_2O, NH_3 and heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn, V). The contributions of point source emissions released by combustion plants to the total emissions in countries of the CORINAIR90 inventory are given as follows in Table 1:

Table 1: Contributions of emissions from combustion plants as point sources to total emissions of the CORINAIR90 inventory reported as point sources

		Contribution to total emissions [%]							
Source category	SNAP90 code	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
≥ 300 MW	01 01 01 01 02 01 03 01 01	85.6	81.4	10.2	5.5	16.8	79.0	35.7	2.4
50-300 MW	01 01 02 01 02 02 02 00 01 03 01 02	6.4	5.4	1.1	0.6	3.1	6.5	1.9	0.2
< 50 MW	01 01 03 01 02 03 02 00 02 03 01 03	0.2	0.3	0.1	0.05	0.1	0.2	0.1	0
Gas turbines[1)]	01 01 04 01 02 04 02 00 03	0	0.39	0.07	0.06	0.05	0.35	0.02	-

	03 01 04								
Stationary engines[1]	01 01 05 01 02 05 02 00 04 03 01 05	0.04	0.10	0.04	0	0.01	0.02	0	-

- : no emissions are reported

0 : emissions are reported, but the precise number is under the rounding limit

[1] Gas turbines and stationary engines may be reported either as point or as area sources.

In the literature concerning heavy metal emissions across Europe, point source emissions are not reported separately. Giving an order of magnitude of heavy metal emissions released from combustion plants emission data of coal-fired public power plants in Germany and Austria is presented here as an example, due to the availability of data:

Table 2: Contributions of heavy metal emissions from coal-fired public power plants to national total emissions of Germany[1] /36/

	Contribution in [wt.-%]	
Pollutant	1982	1990
As	38	27
Cd[2]	7	7
Cr	12	4
Cu	22	8
Hg[3]	11	14
Ni	5	4
Pb	8	1
Se	1	1
Zn	7	6

[1] Western part of Germany

[2] E.g. emissions of Cd in Austria in 1992 were 0,2 % /37/.

[3] E.g. emissions of Hg in Austria in 1992 were 6 % /37/.

By comparing the heavy metal emissions in 1982 (without flue gas desulphurisation (FGD) installed) to the emissions in 1990 (where most plants are equipped with FGD), it can be seen that the application of FGD technologies has lead to a significant decrease in heavy metal emissions within the last years.

For Particulate Matter:
Combustion Plants < 50 MW (boilers) are now covered in the new supplementary chapter Particulate emissions from smaller Combustion Plants (<50MWth) B111(S1).

Combustion Plants >= 50 and < 300 MW (boilers) are now covered in the new supplementary chapter Particulate emissions from large Combustion Plants (>50MWth) B111(S2).

Gas Turbines are now covered in the new supplementary chapter Particulate emissions from gas turbines and internal combustion engines B111(S3).

3 GENERAL

3.1 Description

The emissions considered in this chapter are generated either by boilers or by gas turbines and stationary engines regardless of the allocation of plants to SNAP activities. Emissions from process furnaces (combustion with contact) and from waste incineration are not included here (therefore see SNAP code 090200).

3.2 Definitions

ar	as received, a reference state of coal which determines the conditions, when coal arrives at the plant /73/.
Availability (of an abatement technology)	ratio of full load operating hours with operating emission control technology to total full load operating hours of the power plant; the availability β normally amounts to 99 %; but extreme low values of β can occur down to 95 %. By taking into account the start-up behaviour of emission reduction technologies, the availability β can decrease further down to 92 %. Default values are proposed in Tables 7 and 11.
Boiler	any technical apparatus, in which fuels are oxidised in order to generate heat for locally separate use.
Coking coal (NAPFUE 101)	subcategory of hard coal with a quality that allows the production of a coke suitable for supporting a blast furnace charge /114/.
Co-generation plant	steam production in boilers (one or more boilers) for both, power generation (in a steam turbine) and heat supply.
Combined Cycle Gas Turbine (CCGT)	gas turbine combined with a steam turbine. The boiler can also be fuelled separately.
daf	dry and ash free, a reference state of coal which is calculated with reference to a theoretical base of no moisture or ash associated with the sample (equivalent to maf - moisture and ash free) /73/.
Hard coal	refers to coal of a gross caloric value greater than 23,865 kJ/kg on an ash-free but moist basis and with a mean random

reflectance[3] of vitrinite of at least 0.6. Hard coal comprises the subcategories coking coal and steam coal[4] /114/.

---

[3] Mean random reflectance: characteristic value, which stands for a defined coal composition (modular component is e.g. vitrinite).

[4] The following coal classification codes cover those coals, which would fall into these subcategories /114/:

International classification codes (UN, Geneva, 19956)	323, 333, 334, 423, 433, 435, 523, 533, 534, 535, 623, 633, 634, 635, 723, 733, 823
USA classification	Class II Group 2 „Medium Volatile Bituminous“
British classification	Class 202, 203, 204, 301, 302, 400, 500, 600
Polish classification	Class 33, 34, 35.1, 35.2, 36, 37
Australian classification	Class 4A, 4B, 5.

Integrated Coal Gasification Combined Cycle Gas Turbine (IGCC)	gas turbine fuelled by gas, which is a product of a coal gasification process.
Lignite (NAPFUE 105)	non-agglomerating coals with a gross caloric value less than 17,435 kJ/kg and containing more than 31 % volatile matter on a dry mineral matter free basis /114/.
maf	moisture and ash free, a reference state of coal (equivalent to daf - dry and ash free) /73/.
Plant/Joint Plant	classification with respect to boilers (one or more boilers) according to the respective boiler configuration on a given site and the applied concept of aggregation. The stack-by-stack principle considers all boilers linked to the same stack as a common plant. On the other hand, according to the virtual stack principle, all boilers which, for technical and economic reasons, could be connected to a common stack, are treated as one unit. It is also possible to carry out a still broader combination following e.g. administrative aspects. Gas turbines and stationary engines are allocated separately. A typical example of different allocation possibilities of boilers to the SNAP codes is given in Annex 1.
Power plant	steam generation in boilers (one or more boilers) for power generation.
Reduction efficiency (of an abatement technology)	difference between the pollutant concentration in the raw gas (c_{raw}) and the pollutant concentration in the clean gas (c_{clean}) divided by the pollutant concentration in the raw gas (referred to full load operating hours); default values for the reduction efficiency $\eta = (c_{raw} - c_{clean})/c_{raw}$ of different emission control technologies are recommended in Tables 7 and 11 (extreme low values of η can be up to ten percent below the values given).
Start-up emission	here start-up emissions have been considered for boilers equipped with secondary measures: For SO_2 and NO_2 from the time when burners switch on up to the time when the secondary abatement facility operates under optimum conditions; for CO up to the time when the boiler operates at minimum load.
Stationary engines	spark-ignition or compression-ignition engines (2- and 4-stroke).
Steam coal (NAPFUE 102)	subcategory of hard coal used for steam raising and space heating purposes. Steam coal includes all anthracite and bituminous coals not included under coking coal /114/.

Sub-bituminous coal (NAPFUE 103)	non-agglomerating coals with a gross caloric value between 17,435 and 23,865 kJ/kg containing more than 31 % volatile matter on a dry mineral free matter basis /114/
Sulphur retention in ash	difference between the sulphur dioxide concentration calculated from the total sulphur content of fuel (c_{max}) and the sulphur dioxide concentration of the flue gas (c_{eff}) divided by the sulphur dioxide concentration calculated from the total sulphur content of the fuel. Default values for the sulphur retention in ash $\alpha_s = (c_{max} - c_{eff})/c_{max}$ are proposed in Table 8.

3.3 Techniques

3.3.1 Combustion of coal

3.3.1.1 Dry bottom boiler (DBB)

The DBB is characterised by the dry ash discharge from the combustion chamber due to combustion temperatures from 900 up to 1,200 °C. This type of boiler is mainly used for the combustion of hard coal and lignite and is applied all over Europe.

3.3.1.2 Wet bottom boiler (WBB)

Typical combustion temperatures exceeding 1,400 °C lead to a liquid slag discharge from the combustion chamber. This type of boiler is used for hard coal with a low content of volatiles and is mainly applied in Germany.

3.3.1.3 Fluidised bed combustion (FBC)

The combustion of coal takes place by injection of combustion air through the bottom of the boiler into a turbulent bed. The typical relatively low emissions are achieved by air staging, limestone addition and low combustion temperatures of about 750 - 950 °C. FBC is in particular adapted to coals rich in ash. Only few large combustion plants are equipped with the FBC technique; in the category of thermal capacities ≥ 300 MW mostly Circulating Fluidised Bed Combustion (CFBC) is installed.

3.3.1.4 Grate Firing (GF)

The lump fuel (coal, waste) is charged on a stationary or slowly moving grate. The combustion temperatures are mainly between 1,000 and 1,300 °C.

3.3.2 Combustion of biomass

The combustion of biomass (peat, straw, wood) is only relevant for some countries (e.g. Finland, Denmark). FBC (mostly CFBC) and DBB facilities are installed.

3.3.3 Combustion of waste

For the combustion of waste, mostly grate firing installations are in use.

3.3.4 Combustion of gas/oil

3.3.4.1 Combustion in boilers (general aspects of the combustion techniques)
For both, gas and oil combustion, the fuel and oxidising agents are gaseous under combustion conditions. The main distinctions between gas/oil combustion and pulverised coal combustion are the operation designs of the individual burners of the boiler. With respect to emissions, a principal distinction can be made between burners with and without a pre-mix of fuel and combustion air: pre-mixing burners are characterised by a homogeneous short flame and a high conversion rate of fuel bound nitrogen; non-pre-mixing burners are characterised by inhomogeneous flames with understoichiometric reaction zones and a lower conversion rate of fuel bound nitrogen.

The importance of oil and gas combustion considered as point sources (see Section 1) is low compared to coal combustion, due to the smaller total capacity of these installations. The main parameters determining emissions from oil and gas fired plants are given in Table 3.

Table 3: Main parameters determining emissions from oil and gas fired boilers /40/

Pollutant	Fuel dependent	Process dependent
	Oil-fired boiler	
SO_2	x	-
NO_x	x	x
CO	-	x
	Gas-fired boiler	
SO_2	x[1)]	-
NO_x	-	x
CO	-	x

[1)] trace amounts x : relevant - : not relevant

3.3.4.2 Gas turbines
Gas turbines are installed with a thermal capacity ranging from several hundred kW up to 500 MW. Gaseous fuels are mainly used, such as natural gas or the product of coal gasification (e.g. CCGT or IGCC installations) or other process gases. Also liquid fuels are used, such as light distillates (e.g. naphtha, kerosene or fuel oil) and in some cases other fuels (e.g. heavy fuel oil). Combustion temperatures of up to 1,300 °C in the combustion chambers may lead to considerable NO_X emissions.

Gas turbines are installed as a part of different types of combustion plants such as Combined Cycle Gas Turbine (CCGT) or Integrated Coal Gasification Combined Cycle Gas Turbine (IGCC) Plants (see also Section 3.2). For IGCC plants, the only emission relevant unit considered here is the gas turbine (combustion chamber). For CCGT, in addition to the gas turbine any installed fossil fuelled boiler should also be taken into account.

3.3.4.3 Stationary engines

Stationary engines are installed as spark-ignition engines and compression-ignition engines (2- and 4-stroke) with electrical outputs ranging from less than 100 kW to over 10 MW (e.g. in co-generation plants) /cf. 46/. Both types represent relevant emission sources.

3.4 Emissions

Relevant pollutants are sulphur oxides (SO_x), nitrogen oxides (NO_x), carbon dioxide (CO_2) and heavy metals (arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se), zinc (Zn) and in the case of heavy oil also vanadium (V)). Emissions of volatile organic compounds (non-methane VOC and methane (CH_4)), nitrous oxide (N_2O), carbon monoxide (CO) and ammonia (NH_3) are of less importance. For species profiles of selected pollutants see section 9.

The emissions are released through the stack. Fugitive emissions (from seals etc.) can be neglected for combustion plants.

The emissions of sulphur oxides (SO_x) are directly related to the sulphur content of the fuel, which for coal normally varies between 0.3 and 1.2 wt.-% (maf) (up to an extreme value of 4.5 wt.-%) and for fuel oil (including heavy fuel oil) from 0.3 up to 3.0 wt.-% /15, 16/; usually, the sulphur content of gas is negligible. Sulphur appears in coal as pyritic sulphur (FeS_2), organic sulphur, sulphur salts and elemental sulphur. A major part of the sulphur in coal comes from pyritic and organic sulphur; both types are responsible for SO_x formation. The total sulphur content of coal is usually determined by wet chemical methods; by comparison with results from the X-ray method, it has been found that standard analytical procedures may overestimate the organic sulphur content of coal /30/. The uncertainty introduced by the analytical procedures should be determined by further research.

For nitric oxide (NO, together with NO_2 normally expressed as nitrogen oxides NO_x) three different formation mechanisms have to be distinguished (see also Section 9):

-formation of "fuel-NO" from the conversion of chemically bound nitrogen in the fuel (NO_{fuel}),

-formation of "thermal-NO" from the fixation of atmospheric nitrogen coming from the combustion air ($NO_{thermal}$),

-formation of "prompt-NO".

In the temperature range considered (up to 1,700 °C) the formation of "prompt6-NO" can be neglected. The majority of NO_x emissions from coal combustion (80 to more than 90 %) is formed from fuel nitrogen. Depending on combustion temperatures, the portion of thermal-NO_x formed is lower than 20 %. The content of nitrogen in solid fuels varies: for hard coal between 0.2 and 3.5 wt.-% (maf), for lignite between 0.4 and 2.5 wt.-% (maf), for coke between 0.6 and 1.55 wt.-% (maf), for peat between 0.7 and 3.4 wt.-% (maf), for wood between 0.1 and 0.3 wt.-% (maf), and for waste between 0.3 and 1.4 wt.-% (maf) /17/. The content of nitrogen in liquid fuels varies for heavy fuel oil between 0.1 and 0.8 wt.-%, and for fuel oil between 0.005 and 0.07 wt.-% /17/. Natural gas contains no organically bound nitrogen. The content of molecular nitrogen in natural gas has no influence on the formation of fuel-NO; only thermal-NO is formed.

Emissions of non-methane volatile organic compounds (NMVOC), e.g. olefins, ketones, aldehydes, result from incomplete combustion. Furthermore, unreacted fuel compounds such as methane (CH_4) can be emitted. The relevance of NMVOC/CH_4 emissions from boilers, which are often reported together as VOC, is very low for large-sized combustion plants. VOC emissions tend to decrease as the plant size increases (cf. /24/).

Carbon monoxide (CO) appears always as an intermediate product of the combustion process and in particular under understoichiometric combustion conditions. However, the relevance of CO released from combustion plants is not very high compared to CO_2. The formation mechanisms of CO, thermal-NO and VOC are similarly influenced by combustion conditions.

Carbon dioxide (CO_2) is a main product from the combustion of all fossil fuels. The CO_2 emission is directly related to the carbon content of fuels. The content of carbon varies for hard and brown coal between 61 and 87 wt.-% (maf), for wood it is about 50 wt.-% and for gas oil and heavy fuel oil about 85 wt.-% .

The formation mechanism of nitrous oxide (N_2O) has not yet been completely clarified. There is a possible formation mechanism based on intermediate products (HCN, NH_3), which is comparable to the formation of NO /55/. It has been found, that lower combustion temperatures, particularly below 1,000 °C, cause higher N_2O emissions /13/. At lower temperatures the N_2O molecule is relatively stable; at higher temperatures the N_2O formed is reduced to N_2 /55/. Compared to emissions from conventional stationary combustion units, nitrous oxides from either bubbling, circulating or pressurised fluidised bed combustion are relatively high /13, 14/. In laboratory experiments, it has been found that nitrous oxide is formed by Selective Catalytic Reduction (SCR) processes, passing a maximum at, or close to, the optimum temperature "window" of the SCR process /13/.

Emissions of ammonia (NH_3) are not caused by a combustion process; the emissions result from incomplete reaction of NH_3 additive in the denitrification process (slip of ammonia in SCR and SNCR units).

Most of the heavy metals considered (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn, V) are normally released as compounds (e.g. oxides, chlorides) in association with particulates. Only Hg and Se are at least partly present in the vapour phase. Less volatile elements tend to condense onto the surface of smaller particles in the flue gas stream. Therefore, an enrichment in the finest particle fractions is observed. The content of heavy metals in coal is normally several orders of magnitude higher than in oil (except occasionally for Ni and V in heavy fuel oil) and in natural gas. For natural gas only emissions of mercury are relevant. The concentrations are reported to be in the range of 2 - 5 $\mu g/m^3$ for natural gas /35, 63/. During the combustion of coal, particles undergo complex changes which lead to vaporisation of volatile elements. The rate of volatilisation of heavy metal compounds depends on fuel characteristics (e.g.

concentrations in coal, fraction of inorganic components, such as calcium) and on technology characteristics (e.g. type of boiler, operation mode).

From DBB, all heavy metals of concern are emitted as particulate matter, except Hg and Se. Emissions from lignite fired DBB are potentially lower than from hard coal, as the trace element content in lignite and the combustion temperatures are lower. In WBB, the recirculation of fly ash is a common operation mode, which creates an important increase in heavy metal concentrations in the raw gas. Heavy metal emissions from FBC units are expected to be lower due to the lower operating temperatures and a smaller fraction of fine particles. The addition of limestone in FBC facilities might reduce the emission of some heavy metals, corresponding to an increased retention of heavy metals in the bottom ash. This effect can be partially compensated by the increase in the fraction of fine particulates in the flue gas leading to increased emissions from particulates highly enriched by heavy metals.

High concentrations of As poison denitrification catalysts. Therefore, Selected Catalytic Reduction plants (SCR) in a high-dust configuration may require special measures (e.g. reduction of fly ash recirculation). /10, 11, 12/

3.5 Controls

Relevant abatement technologies for SO_x, NO_x and heavy metals are outlined below. Abatement techniques for gas turbines and stationary engines are treated separately. Average reduction efficiencies and availabilities of abatement technologies for SO_x and NO_x are summarised in Tables 7, 10, and 11. Due to the fact, that most published studies do not clearly distinguish between SO_x and SO_2, for the following chapters, it can be assumed that SO_2 includes SO_3, if not stated otherwise.

3.5.1 Sulphur oxides: Flue Gas Desulphurisation Processes (FGD) (Secondary measures) /cf. 18/

FGD processes are designed to remove SO_2 from the flue gas of combustion installations. Most processes, like the wet scrubbing process (WS), the spray dryer absorption (SDA), the dry sorbent injection (DSI) and the Walther process (WAP) are based on the reaction of the SO_2 with an alkaline agent added as solid or as suspension/solution of the agent in water to form the respective salts. In secondary reactions also SO_3, fluorides and chlorides are removed. In the case of the DESONOX process (see Section 3.5.4.2), the SO_2 is catalytically oxidised to SO_3 and reacts with water to form sulphuric acid. The Activated Carbon process (see Section 3.5.4.1) and the Wellman-Lord process remove the SO_2 to produce a SO_2 rich gas, which may be further processed to sulphur or sulphuric acid.

3.5.1.1 Lime/Limestone Wet Scrubbing (WS)

The pollutants are removed from the flue gas by chemical reactions with an alkaline liquid (suspension of calcium compounds in water). The main product is gypsum. The WS process represents about 90 % of the total FGD-equipped electrical capacity installed in European OECD countries. Facilities are in operation at combustion units using hard coal, lignite and oil with sulphur contents from about 0.8 to more than 3.0 wt.-%. Other fossil fuels (such as peat) are presently rarely used at combustion plants with a thermal capacity ≥ 300 MW. The SO_2 reduction efficiency is > 90 %.

3.5.1.2 Spray Dryer Absorption (SDA)

The SDA process removes the pollutant components from flue gas of fossil fired combustion units by injection of $Ca(OH)_2$. The process forms a dry by-product ($CaSO_3 \cdot 1/2\ H_2O$). This technology covers about 8 % of the total FGD-equipped electrical capacity installed in the European OECD countries. The SDA process is mostly in use at hard coal fired combustion units (sulphur content of fuel up to 3 wt.-%). Recent pilot studies have shown that this technique is also operational with other fossil fuels (oil, lignite, peat). The SO_2 reduction efficiency is > 90 %.

3.5.1.3 Dry Sorbent Injection (DSI, LIFAC Process)

The DSI process is based on a gas/solid reaction of the flue gas and a dry sorbent (e.g. lime/limestone, sodium hydrogen carbonate $NaHCO_3$) inside the boiler. There are three different process types according to the injection point of the additive into the boiler (e.g. primary or secondary air, flame front). The by-products are a dry mixture of the respective salts (mostly $CaSO_4$). Only few power plants (some 5 % of the total FGD-equipped electrical capacity installed in European OECD countries) are equipped with this technology due to its low SO_2 reduction efficiency of 40 - 50 %, which is not sufficient to meet the emission standards of some countries. DSI processes are presently in use for hard coal, lignite, oil and coal/oil fired boilers. The optimum reduction efficiency is obtained for the sulphur contents of fuel between 0.5 and 1.7 wt.-% (max. 2 wt.-%).

The LIFAC process is an advanced dry sorbent injection process using additional water injection in a separate reactor downstream of the boiler, in order to raise the reduction efficiency. Generally, the SO_2 reduction efficiency is > 50 %. At present, the LIFAC process is used in one plant in Finland with a SO_2 reduction efficiency of already 70 %.

3.5.1.4 Wellman-Lord (WL)

The WL process is a regenerable FGD process, which uses the sodium sulphite (Na_2SO_3)/ sodium bisulphite ($NaHSO_3$) equilibrium in order to remove SO_2 from the flue gas. An SO_2-rich gas is obtained, which is used for the production of sulphuric acid. At present only three installations with a total thermal capacity of 3,300 MW are in use (in Germany), due to the complexity of the process and the resulting high investments and operating costs (this technology represents about 3 % of the total thermal capacity installed in the European OECD countries). The WL process is operational with various types of fuel (e.g. hard coal, oil), especially with high sulphur contents (of about 3.5 wt.-%). The SO_2 reduction efficiency is > 97 %.

3.5.1.5 Walther Process (WAP)

The WAP process uses ammonia water in order to remove SO_2 from the flue gas. The by-product is a dry salt mixture of the respective ammonia salts (mainly ammonium sulphate ($(NH_4)_2SO_4$). One reference installation is currently operating in Germany. This process is operational with all types of fuel. However, the maximum sulphur content should be limited to 2 wt.-% (due to the increasing formation of ammonia sulphate aerosols). The SO_2 reduction efficiency is > 88 %.

3.5.2 Nitrogen oxides: Primary measures - Denitrification techniques /cf. 17, 18, 19/

3.5.2.1 Low NO_x burner (LNB)

A characteristic of LNB is the staged air to fuel ratio at the burner. Three different technical modifications are in use:

- Air-staged LNB: An understoichiometric zone is created by a fuel-air mixture and primary air. An internal recirculation zone occurs due to the swirl of primary air. A burn-out zone is created due to secondary air fed by air nozzles arranged around the primary air nozzles.
- Air-staged LNB with flue gas recirculation (FGR): The basic function is similar to air-staged LNB. The distances between the primary and secondary nozzles are greater, therefore, a flue gas layer is formed. As a result, the residence time in the reducing atmosphere increases and the oxygen concentration decreases.
- Air/Fuel staged LNB: An additional reduction zone around the primary zone is achieved by the extremely overstoichiometric addition of secondary fuel around the secondary flame.

LNB is operational with all fuels and all types of burners. The NO_x reduction efficiency for coal fired boilers varies between 10 and 30 % (see Table 10).

3.5.2.2 Staged Air Supply (SAS)

Staged air means the creation of two divided combustion zones - a primary zone with a lack of oxygen and a burn-out zone with excess air. SAS covers the low excess air (LEA), burners out of service (BOOS) and biased burner firing (BBF) techniques:

- Low excess air (LEA) means reduction of the oxygen content in the primary combustion zone of the burners. When firing hard coal, experience has shown that the general limitations are fouling and corrosion, caused by the reducing atmosphere and incomplete burn-out. When firing gas, the reduction efficiency is limited by the CO formed. LEA is more suitable for lignite and often used for retrofitting combustion plants. For oil fired boilers a reduction efficiency of 20 % has been achieved.
- Burners out of service (BOOS) means that the lower burner row(s) in the boiler operate under a lack of oxygen (fuel rich), the upper burners are not in use. This technology is in particular suitable for older installations, but the thermal capacity of the boiler decreases by about 15 - 20 %.
- Biased burner firing (BBF) means that the lower burner rows in the boiler operate under a lack of oxygen (fuel rich) and the upper burners with an excess of oxygen. The boiler efficiency is less compared to BOOS and the NO_x reduction is also lower.

The NO_x reduction efficiency for coal fired boilers varies between 10 and 40 % (see Table 10).

3.5.2.3 Overfire Air (OFA)

All burner rows in the boiler operate with a lack of oxygen. The combustion air is partly (5 - 20 %) injected through separate ports located above the top burner row in the boiler. OFA is operational with most fuels and most types of boilers. For gas fired boilers a reduction efficiency of 10 - 30 % and for oil fired boilers 10 - 40 % has been achieved. The NO_x reduction efficiency for coal fired boilers varies between 10 and 40 % (see Table 10).

3.5.2.4 Flue Gas Recirculation (FGR)

The recirculation of flue gas into the combustion air is an efficient NO_x abatement method for firing modes with high combustion temperatures, such as wet bottom boilers and especially for gas and oil fired boilers.

The recirculated flue gas can be added to the secondary or primary air. In the first case, the flame core is not affected and the only effect is a reduction of the flame temperature, which is favourable for thermal-NO_x abatement. The influence on dry bottom boilers is thus very limited, considering the fact that about 80 % of the NO_x formed originates from fuel bound nitrogen; FGR can be used as an additional measure. A more efficient method is the introduction of flue gas into the primary air of an unstaged burner. High reduction efficiencies of FGR in the primary flow (15 - 20 %) have been achieved in gas and oil fired boilers. The NO_x reduction efficiency for coal fired boilers varies between 5 and 25 % (see Table 10).

3.5.2.5 Split Primary Flow (SPF)

Split primary flow means fuel staging in the furnace. This technique involves injecting fuel into the furnace above the main combustion zone, thereby producing a second understoichiometric combustion zone. In the primary zone of the boiler the main fuel is burnt under fuel-lean conditions. This zone is followed by a secondary zone with a reducing atmosphere, into which the secondary fuel is injected. Finally, secondary air is injected into the burn-out zone of the boiler. This reburning technique can, in principle, be used for all types of fossil fuel fired boilers and in combination with low NO_x combustion techniques for the primary fuels. When nitrogen is present in the reburning fuel, a part of it will be converted into NO_x in the burn-out zone. Therefore, natural gas is the most appropriate reburning fuel. NO_x reduction efficiencies have not been yet reported.

3.5.3 Nitrogen oxides: Secondary measures - Denitrification Processes /cf. 18, 19/

3.5.3.1 Selective Non-Catalytic Reduction (SNCR)

The reduction of nitrogen oxides in the flue gas is based on the selective reaction of NO_x with injected ammonia, urea or caustic ammonia to form nitrogen and water. The SNCR process has been implemented at several installations (e.g. in Germany, in Austria and in Sweden) and has in principle proved to be operational with various types of fuels. The NO_x reduction efficiency is about 50 %, in some installations up to 80 %.

3.5.3.2 Selective Catalytic Reduction (SCR)

The reduction of nitrogen oxides is based on selective reactions with injected additives in the presence of a catalyst. The additives used are mostly gaseous ammonia, but also liquid caustic ammonia or urea. The SCR technology accounts for about 95 % of all denitrification processes. SCR is mostly used for hard coal. For brown coal, lower combustion temperatures lead to lower NO_x formation, so that primary measures fulfil the emission reduction requirements. Several heavy metals in the flue gas can cause rapid deactivation of the catalyst. The NO_x reduction efficiency varies between 70 and 90 %.

3.5.4 Nitrogen oxides and sulphur oxides: Simultaneous Processes /18, 19/

3.5.4.1 Activated Carbon Process (AC)

The AC process is a dry process for simultaneous SO_2 and NO_x removal based on the adsorption of the pollutants in a moving bed filter of activated carbon. The sulphur oxides undergo catalytic oxidation with the moisture in the flue gas to form sulphuric acid. NO_2 is completely reduced to N_2; NO reacts catalytically with the ammonia injected and forms N_2 and H_2O. The AC process has been installed at four power plants in Germany (in two cases downstream of an SDA process). The sulphur content in the fuel used should not exceed 2.3 wt.-%. The SO_2 reduction efficiency is > 95 %, the NO_x reduction efficiency is > 70 %.

3.5.4.2 DESONOX Process/SNOX Process (DESONOX)

The purification of the flue gas by the DESONOX process is based on the simultaneous catalytic reduction of nitrogen oxides (NO_x) to nitrogen (N_2) and water (H_2O) and on the catalytic oxidation of sulphur dioxide (SO_2) to sulphur trioxide (SO_3). The by-product is sulphuric acid. The process has been installed at one power plant in Germany, where hard coal is used with a sulphur content of about 1 wt.-%. The concentration of catalyst toxics (mainly arsenic, but also chromium, selenium etc.) has to be taken into account. The SO_2 reduction efficiency is up to 95 %, the NO_x reduction efficiency is also up to 95 %.

The SNOX process works on the same basic principle as the DESONOX process, with the main difference that reduction and oxidation take place in two separate reaction towers. The SNOX process has been applied at one Danish power plant. No reduction efficiency has been reported yet. The SNOX process is also known as a combination of the Topsøe WSA-2 process and the SCR process.

3.5.5 Heavy metals: Secondary measures /12, 20, 21, 22, 23/

Heavy metal emissions are mainly reduced by dust control equipment. Particulate control systems, which are used in coal-fired power plants, are cyclones, wet scrubbers, electrostatic precipitators (ESP), and fabric filters. In most power plants 99 % of the particulates are removed from the flue gases by using ESP or fabric filters. The latter are more efficient in controlling fine particulate matter; wet scrubbers and cyclones are less efficient.

The reduction efficiency of ESP for most elements in the solid state is > 99 %. Only for some higher volatile elements, such as Cd, Pb, Zn and Se, is the reduction efficiency less, but it remains above 90 %. The reduction efficiency of an ESP for Hg depends on the operating temperature of the ESP. A cold-side ESP operating at about 140 °C is estimated to have an average Hg reduction efficiency of about 35 %.

The influence of FGD- and $DeNO_x$-units on heavy metal emissions has been investigated mainly in the frame of mass balance studies. WS-FGD-units remove a further fraction of particulate matter in flue gas in addition to dust control. Particle bound elements are removed by FGD-units with an efficiency of about 90 %. In FGD-units, in particular WS-units, the gaseous compounds can additionally condense on particulate matter, which are mainly removed in the prescrubber. With regard to gaseous elements, various studies have shown reduction efficiencies of 30 - 50 % for Hg and 60 - 75 % for Se. Lime contributes over 90 % of the input of As, Cd, Pb and Zn to the FGD.

The abatement of Hg emissions is influenced indirectly by $DeNO_x$-units. A high dust SCR-unit improves Hg removal in a subsequent FGD-unit using a lime scrubbing system. The SCR-unit increases the share of ionic mercury ($HgCl_2$) to up to 95 %, which can be washed out in the prescrubber of the FGD-unit. A study in the Netherlands found no influence of LNB on heavy metal emissions.

3.5.6 Gas turbines /cf. 68, 69/

For gas turbines mainly NO_X emissions are of most relevance. Primary measures for NO_X reduction are the following: dry controls (e.g. overstoichiometric combustion in a dry low NO_X burner with $\eta = 0.6 - 0.8$, which is a relatively new development as a primary measure) and wet controls (injection of water and/or steam with $\eta \geq 0.6$ /114/) in order to regulate the combustion temperature. For large gas turbines secondary measures are also installed such as Selective Catalytic Reduction (SCR).

3.5.7 Stationary engines /cf. 70/

For spark-ignition engines the main pollutants emitted are NO_x, CO and unburned hydrocarbons (VOC). For diesel engines sulphur dioxide (SO_2) emissions have also to be considered. Emissions of soot also contribute to emissions of heavy metals and persistent organic pollutants, but at this stage insufficient information is available /35/.

Primary measures are installed to optimise combustion conditions (air ratio, reduced load, water injection, exhaust-gas recirculation, optimised combustion chamber etc.). Reduction efficiencies can be given e.g. for exhaust gas recirculation from 6.5 to 12 % and for internal exhaust gas recirculation from 4 to 37 %. External exhaust gas recirculation (turbo charged models) can have reductions of NO_x varying from 25 to 34 %. /cf. 114/

Secondary measures are installed, if the emission thresholds cannot be met by adjustments to the engine itself. The following methods are used depending on the air ratio λ:

$\lambda = 1$	Reduction of NO_X, CO and VOC by using a three-way catalytic converter (NSCR),
$\lambda > 1$	Reduction of NO_X by Selective Catalytic Reduction with NH_3 (SCR), Reduction of other emissions (CO, VOC) using oxidation catalytic converter (NSCR).

Typical conversion rates of NO_x range from 80 to 95 % with corresponding decreases in CO and VOC. Depending on the system design, NO_x removal of 80 up to 90 % is achievable. /114/

4 SIMPLER METHODOLOGY

4.1 General

4.1.1 General / specified emission factors

Here “simpler methodology“ refers to the calculation of emissions, based on emission factors and activities. The simpler methodology should only be used in cases where no measured data is available. The simpler methodology covers all relevant pollutants (SO_2, NO_x, NMVOC, CH_4, CO, CO_2, N_2O, NH_3, heavy metals). Special emphasis is put on the pollutants SO_x, NO_x and heavy metals, due to the significant contribution of combustion plants as point sources to the total emissions of these pollutants.

A combustion plant can be treated either as a whole (irrespective of kind/size of individual boilers) or on a boiler-by-boiler level. Differences in design and operation of boilers, in fuels used and/or controls installed require different emission factors. The same applies to gas turbines and stationary engines.

The annual emission E is derived from an activity A and a factor which determines their linear relation (see Equation (1)):

$$E_i = EF_i \cdot A \tag{1}$$

E_i annual emission of pollutant i
EF_i emission factor of pollutant i
A activity rate

The activity rate A and the emission factor EF_i have to be determined on the same level of aggregation by using available data (e.g. fuel consumption) (see Section 6). For the activity rate A, the energy input in [GJ] should be used, but in principle other relations are also applicable.

Two different approaches in order to obtain the emission factor EF_i are proposed:

- General emission factor EF_{G_i}

The general emission factor is a mean value for defined categories of boilers taking into account abatement measures (primary and secondary). A general emission factor is only related to the type of fuel used and is applicable for all pollutants considered, except of SO_2[5]. It should only be used where no technique specific data are available (only as a makeshift).

- Specified emission factor EF_{R_i}

The specified emission factor is an individually determined value for boilers taking into account abatement measures (primary and secondary). A specified emission factor is related to individual fuel characteristics (e.g. sulphur content of fuel) and to technology specific

---

[5] For the appropriate determination of SO_2 emissions the sulphur content of fuel is required. Therefore, the specified emission factor approach has to be applied.

parameters. The following sections provide determination procedures for suitable specified emission factors for the pollutants NO_x, SO_x and heavy metals.

In principle, plant specific data should be used, if available, for the determination of emission factors. The following Sections 4.1 to 4.8 give recommendations for the estimation and the use of general and specified emission factors as given in Table 4.

Table 4: Applicability of general emission factors EF_{G_i} and specified emission factors EF_{R_i}

Pollutant	General emission factor EF_{G_i}	Specified emission factor EF_{R_i}
SO_x	-	+
NO_x	+	++[1)]
Heavy metals	+	++[2)]
NMVOC, CH_4, CO, CO_2, N_2O, NH_3	+	*

+ : possible, but not recommended methodology; ++ : possible and recommended methodology;

- : not appropriate; * : not available

[1)] detailed calculation schemes are given for pulverised coal combustion

[2)] detailed calculation schemes are given for coal combustion

An accurate determination of full load emissions can only be obtained by using specified emission factors. For the calculation of specified SO_x and NO_x emission factors for pulverised coal combustion, a computer programme has been developed (see Annexes 2 - 6 and Annex 14).

If not stated otherwise, the general and specified emission factors presented refer to full load conditions. Start-up emissions have to be considered separately (see Section 4.1.2).

4.1.2 Start-up dependence

Start-up emissions depend on the load design of the plant and on the type of start-up (see Tables 5 and 6). A plant can be designed for:

- peak load:	to meet the short-term energy demand,
- middle load:	to meet the energy demand on working days,
- base load:	continuous operation.

Table 5: Load design and start-ups per year

Load design	Start-ups per year		Full load hours per year		Emission
	range	value	range	value	relevance[2)]
Peak load[1)]	150 - 500	200	1,000 - 2,500	2,000	x[1)]
Middle load	50 - 250	150	3,000 - 5,000	4,000	xxx
Base load	10 - 20	15	6,000 - 8,000	7,000	x

[1)] For peak load often high-quality fuels (e.g. gas, oil) and often gas turbines are used.

[2] x: low; xxx: high.

Table 6: Status of the boiler at starting time for a conventional power plant

Type of start-up	Time of stand-still [h] /65/	Status of the boiler	Frequency[2]	Emission relevance[2]
Hot-start	< 8	hot	xxx	x
Warm-start	8 - ca. 50	warm	xx	xx
Cold-start	> 50	cold	x[1]	xxx

[1] normally once a year, only for maintenance.

[2] x: low; xx: medium; xxx: high.

In order to take into consideration the relevance of start-up emissions, a detailed investigation has been carried out. There, start-up emissions and start-up emission factors have been determined for different types of boilers (DBB, WBB, gas-fired boiler, see Annex 15). Start-up emissions are only relevant if secondary measures are installed.

By taking into account boiler characteristics as given in Annex 15, the following general trends of start-up emissions of SO_x, NO_x and CO on the type of fuel and type of boiler are obtained (based on /116/).

- For the boilers considered in the detailed investigation it has been found that start-up emissions for the combustion of coal are significantly higher than for the combustion of gas.
- Start-up emissions are higher for dry bottom boilers than for wet bottom boilers and gas boilers.

In the following sections, start-up emissions and start-up emission factors derived from measured data are presented as ratios:

$$F^{EF} = EF^{A} / EF^{V} \tag{2}$$

F^{EF}	ratio of start-up and full load emission factors [ ]
EF^{A}	emission factor at start-up period [g/GJ]
EF^{v}	emission factor at full load conditions [g/GJ]

$$F^{E} = E^{A} / E^{V} \tag{3}$$

F^{E}	ratio of start-up and full load emissions [ ]
E^{A}	emission during start-up period (see Section 3.2) [Mg]
E^{v}	emission for full load conditions during start-up period [Mg]

Start-up emissions and full load emissions are related to comparable periods; the energy input (fuel consumption) during the start-up period is lower than during full load operation. The emission factor ratio F^{EF} is often higher than the emission ratio F^{E}. Increased specific emissions during the start-up period were found to be compensated to a high degree by the lower fuel consumption. Further pollutant specific results are given in the Sections 4.2 - 4.9.

If start-up emissions are taken into account the corresponding activity rates have to be determined as follows:

$$A = A_{\text{full load}} + A_{\text{cold}} + A_{\text{warm}} + A_{\text{hot}} \tag{4a}$$

A	activity rate within the period considered [GJ]
$A_{\text{full load}}$	activity rate for full load operation periods [GJ]
A_{cold}	activity rate for cold start periods [GJ]
A_{warm}	activity rate for warm start periods [GJ]
A_{hot}	activity rate for hot start periods [GJ]

Each sub-activity (e.g. A_{cold}) has to be determined separately by totalling the thermal energy input for the respective periods e.g. cold start periods.

Accordingly, Equation (1) becomes:

$$E = EF^{V} \cdot (A_{\text{full load}} + F^{EF}_{\text{cold}} \cdot A_{\text{cold}} + F^{EF}_{\text{warm}} \cdot A_{\text{warm}} + F^{EF}_{\text{hot}} \cdot A_{\text{hot}}) \cdot 10^{-6} \tag{4b}$$

E	emission within the period considered [Mg]
EF^{V}	emission factor at full load operation conditions [g/GJ]
$F^{EF}_{\text{cold/warm/hot}}$	ratio of start-up (cold/warm/hot start) to full load emission factor [ ]
$A_{\text{full load/cold/...}}$	activity rates at full load operation/cold start/... [GJ]

The emission factor at full load conditions EF^{V} can be approximated by using the emission factors given in Tables 24 and 25 (for NO_x) and Table 28 (for CO); SO_2 emission factors can be determined as given in Equation (5). A correction factor for the annual emission can be obtained by calculating the ratio of the annual emissions resulting from Equation (4b) to those determined without consideration of start-up emissions.

4.1.3 Load dependence

A load dependence of emissions has only been found for NO_x emissions released from older types of boiler (see Section 4.3).

4.2 SO_2 emission factors

For SO_2, only specified emission factors $EF_{R_{SO2}}$ are recommended here. For the determination of specified SO_2 emission factors the following general equation should be used (for emissions of SO_3 see Section 9):

$$EF_{R_{SO2}} = 2 \cdot C_{S_{fuel}} \cdot (1 - \alpha_S) \cdot \frac{1}{H_u} \cdot 10^{6} \cdot (1 - \eta_{sec} \cdot \beta) \tag{5}$$

$EF_{R_{SO2}}$	specified emission factor [g/GJ]
$C_{S_{fuel}}$	sulphur content in fuel [kg/kg]
α_s	sulphur retention in ash [ ]

H_u	lower heating value of fuel [MJ/kg]
η_{sec}	reduction efficiency of secondary measure [ ]
β	availability of secondary measure [ ]

Equation (5) can be used for all fuels, but not all parameters may be of relevance for certain fuels (e.g. α_S for gas). Default values for reduction efficiencies and availabilities of secondary measures installed are presented in Table 7. The technologies listed in Table 7 are mainly installed in the case of coal-fired boilers, but they can also be applied when burning other fuels.

Table 7: Default values for secondary measures for SO_2 reduction (all fuels) /18, 19/

No.	Type of secondary measure	Reduction efficiency η_{sec} [ ]	Availability β [ ]
1	WS	0.90	0.99
2	SDA	0.90	0.99
3	DSI	0.45	0.98
4	LIFAC	0.70	0.98
5	WL	0.97	0.99
6	WAP	0.88	0.99
7	AC	0.95	0.99
8	DESONOX	0.95	0.99

4.2.1 Combustion of coal

SO_2 emission factors for coal fired boilers can be calculated by using Equation (5). If some input data are not available, provided default values based on literature data can be used:

- $C_{S,fuel}$	see Annexes 7 and 8, Table 23,
- α_S	see Table 8,
- η_{sec} and β	see Table 7,
- H_u	see Annexes 7 and 8.

For further details concerning the calculation of SO_2 emission factors, see Annexes 2 (flowsheet of the computer programme) and 3 (description of the computer programme). Default values for sulphur retention in ash for coal fired boilers are presented in Table 8.

Table 8: Default values for the sulphur retention in ash (α_S) for pulverised coal fired boilers

Type of boiler	α_S [ ]	
	Hard coal	Brown coal
DBB	0.05	0.3[1)]
WBB	0.01	-

[1)] average value; in practice, a range of 0.05 - 0.60 can occur (e.g. in the Czech Republic 0.05 is used)

Emission factors obtained by using Equation (5) are related to full load conditions; start-up emissions are not taken into account. If a flue gas desulphurisation unit is installed, start-up emissions should be considered as given in Section 4.1.2. The relevance of start-up emissions of SO_2 depends strongly on the following parameters:

- the type of fuel (e.g. SO_x emissions are directly related to the fuel sulphur content),
- the status of the boiler at starting time (hot, warm or cold start, see also Table 6),
- start-up of the flue gas desulphurisation unit (FGD direct or in by-pass configuration),
- limit for SO_x emissions, which has to be met (boiler specific limits can be set up below the demands of the LCP Directive).

For the combustion of coal in dry bottom boilers, the following ranges and values of F^{EF}, F^{E} have been obtained within the investigation outlined in Annex 15:

Table 9: Ratios of start-up to full load emission factors F^{EF} and ratios of start-up to full load emissions F^{E} for SO_2 for dry bottom boilers

	Ratio of start-up to full load emission factors F^{EF} [ ]	Ratio of start-up to full load emissions F^{E} [ ]
Range	3 - max. 16	1 - max. 4
Values for direct start-up of the FGD	F^{EF}_{cold}: 5 F^{EF}_{warm}: 5 F^{EF}_{hot}: 4	F^{E}_{cold}: 1 F^{E}_{warm}: 1 F^{E}_{hot}: 1
Values for by-pass start-up of the FGD	F^{EF}_{cold}: 8.5 - 16 F^{EF}_{warm}: 5 - 14.5 F^{EF}_{hot}: 5 - 5.5	F^{E}_{cold}: 2 - 4.5 F^{E}_{warm}: 1 - 3.5 F^{E}_{hot}: 1.5

$F^{EF}_{cold,warm,hot}$ Ratio of start-up to full load emission factors for cold, warm or hot start-ups (see also Table 6)

$F^{E}_{cold,warm,hot}$ Ratio of start-up to full load emissions for cold, warm or hot start-ups (see also Table 6)

The values from the direct start-up of the FGD show, that start-up emissions of SO_2 are not relevant (ratio F^E of ca. 1). In the case of a by-pass start-up of the FGD, start-up emissions of SO_2 are significant for hot, warm and cold starts; start-up emissions can be up to 4 times higher than emissions in a comparable full load time span (based on /116/).

4.2.2 Combustion of other fuels (biomass, waste, liquid fuels, gaseous fuels)

SO_2 emissions are directly related to the sulphur content of biomass, waste, liquid and gaseous fuels (see Equation (5)). The sulphur retention in ash α_s is not relevant. The reduction efficiency η_{sec} and the availability β of installed secondary measures have to be taken into account (in particular for the combustion of waste). Default values for η and β are given in Table 7. Sulphur contents of different fuels are given in Table 23 and in Annexes 7 and 8.

4.3 NO_x emission factors

For the determination of NO_x emissions, general as well as specified NO_x emission factors can be used. Emission factors are listed in Tables 24 and 25 depending on installed capacity, type of boiler, primary measures and type of fuel used.

4.3.1 Combustion of pulverised coal

Specified NO_x emission factors can be calculated individually for pulverised coal fired boilers. Due to the complex reaction mechanism of NO_x formation (see also Section 3.4) an estimate of specified NO_x emission factors can only be made on the basis of empirical relations as given in Equation (6). The decisive step in Equation (6) is the undisturbed NO_x formation (without primary measures) inside the boiler ($C_{NO_{2.boiler}}$). $C_{NO_{2.boiler}}$ is determined by an empirical equation depending on fuel parameters only, as described in Annex 5.

$$EF_{R_{NO_2}} = C_{NO_2,boiler} \cdot (1-\eta_{prim}) \cdot \frac{1}{H_u} \cdot 10^6 \cdot (1-\eta_{sec}\,\beta) \qquad (6)$$

$EF_{R_{NO2}}$	specified emission factor [g/GJ]
$C_{NO_{2.boiler}}$	total content of nitrogen dioxide formed in the boiler without taking into account primary reduction measures (in mass NO_2/mass fuel [kg/kg])[6]
η_{prim}	reduction efficiency of primary measures [ ]
H_u	lower heating value of fuel [MJ/kg]
η_{sec}	reduction efficiency of secondary measure [ ]
β	availability of secondary measure

For further details concerning the calculation of specified NO_2 emission factors see Annexes 4 (flowsheet of the computer programme) and 5 (description of the computer programme).

If some input data are not available, default values based on literature data are provided for:

- $C_{N,\ fuel}$, content of fuel-nitrogen,	see Annexes 7 and 8,
- $C_{volatiles}$, content of volatiles in the fuel,	see Annexes 7 and 8,

---

[6] Note: The computer programme, which is described in Annex 5, provides $C_{NO2\ boiler}$ as (mass pollutant/mass flue gas [kg/kg]).

- η_{prim}	see Table 10,
- η_{sec} and β	see Table 11,
- H_u	see Annexes 7 and 8.

Default values for the reduction efficiency of primary measures are presented in the following Tables 10 and 11.

Table 10: Reduction efficiencies for selected primary measures for NO_X emissions in coal fired boilers /17, 18, 19, 28, 31, 32, 33, 34, 53/ (value means recommended value)

Type of primary measure[1]	Reduction efficiency DBB η [ ]				Reduction efficiency WBB η [ ]	
	Hard coal		Lignite		Hard coal	
	range	value[3]	range	value[3]	range	value[3]
no measure[4]	0	0	0	0	0	0
LNB	0.10 - 0.30	0.20	0.10 - 0.30	0.20	0.10 - 0.30	0.20
SAS	0.10 - 0.40	0.30	0.10 - 0.40	0.30	0.10 - 0.40	0.30
OFA	0.10 - 0.40	0.30	0.10 - 0.35	0.25	0.10 - 0.35	0.25
FGR	0.05 - 0.15	0.10	0.05 - 0.20	0.15	0.10 - 0.25	0.20
LNB/SAS	0.20 - 0.60	0.45	0.20 - 0.60	0.45	0.20 - 0.60	0.45
LNB/OFA	0.20 - 0.60	0.45	0.20 - 0.55	0.40	0.20 - 0.55	0.40
LNB/FGR	0.15 - 0.40	0.30	0.15 - 0.45	0.30	0.20 - 0.50	0.35
SAS/OFA	0.20 - 0.65	0.50	0.20 - 0.60	0.40	0.20 - 0.60	0.40
SAS/FGR	0.15 - 0.50	0.40	0.15 - 0.50	0.40	0.20 - 0.55	0.45
OFA/FGR	0.15 - 0.50	0.40	0.15 - 0.50	0.35	0.20 - 0.50	0.40
LNB/SAS/OFA	0.30 - 0.75	0.60	0.30 - 0.75	0.60	0.30 - 0.75	0.60
LNB/SAS/FGR	0.25 - 0.65	0.50	0.25 - 0.70	0.50	0.30 - 0.70	0.55
LNB/OFA/FGR	0.25 - 0.65	0.50	0.25 - 0.65	0.50	0.30 - 0.65	0.50
old installation/ optimised		0.15		0.15		0.15
old installation/ retrofitted[2]		0.50		0.50		0.50
new installation[2]		0.40		0.40		0.40

[1] Selection from the DECOF database developed by and available at the Institute for Industrial Production (IIP).

[2] Recommended values, when no information concerning the type of primary measure is available.

[3] Default values used in the computer programme.

[4] No primary measures are installed. This case is mainly relevant for old installations.

Table 11: Default values for reduction efficiency and availability of secondary measures for NO_X reduction /18, 19/ (all fuels)

No.	Type of secondary measure	Reduction efficiency η_{sec} [ ]	Availability β [ ]
1	SNCR	0.50	0.99
2	SCR	0.80	0.99
3	AC	0.70	0.99
4	DESONOX	0.95	0.99

Emission factors of NO_2 for different coal compositions have been calculated by using default values as given above and are listed in Table 25.

The load dependence of NO_X emissions can be split into two different phenomena (see Sections 4.1.2 and 4.1.3):

a) Load variations during normal operation:
Load variations are discussed very controversially in the literature. Often a strong correlation of NO_X emissions and load is reported. Load corrections, e.g. as given in /66/, may be appropriate for older types of boilers.

For boilers of modern design, with optimised combustion conditions e.g. by primary measures, only a negligible load dependence has been reported /64/. This is explained by the fact that for modern boilers (with primary measures) under reduced load conditions an overstoichiometric air ratio is applied in order to achieve an acceptable burning out of the fuel, which leads to NO_x emission factors similar to those obtained under full load conditions. Therefore, for boilers of modern design no load correction is proposed.

For older boilers (without primary measures) a load dependent emission factor can be calculated according to Equation (7), which has been derived for German dry bottom boilers (combustion of hard coal) /71/:

$$EF = 1{,}147 + 0.47 \cdot L \tag{7}$$

EF emission factor [g/MWh][7]
L actual load [MW]

At this stage, no general approach is available for estimating the load dependence of NO_x emissions. However, a load correction factor can be obtained by using a ratio between reduced load and full load emission factors:

---

[7] 1 MWh = 3.6 GJ

$$k^{load} = \frac{EF^{Reduced\ load}}{EF^{V}} = \frac{1,147 + 0.47 \cdot L}{1,147 + 0.47 \cdot L_{nominal}} \qquad (8)$$

k^{load}	ratio of reduced load to full load emission factor [ ]
$EF^{Reduced\ load}$	emission factor for reduced load conditions [g/MWh][6]
EF^{V}	emission factor for full load conditions [g/MWh][6]
L	actual load [MW]
$L_{nominal}$	nominal load [MW]

Figure 1.1 gives a graphic presentation of the results of Equation (8):

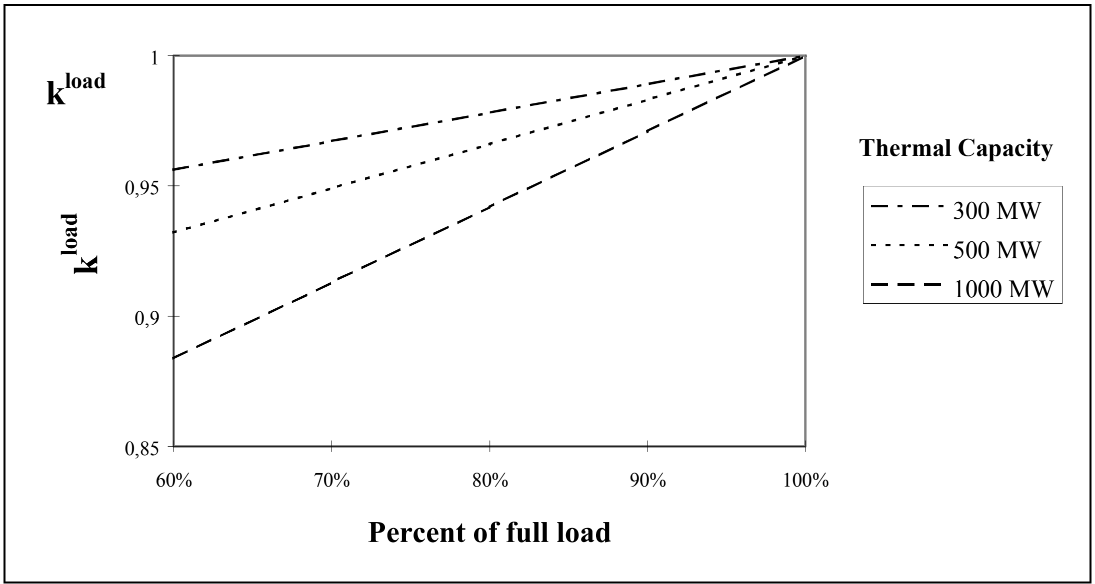


Figure 1.1: Variation of k^{load} with load

If reduced load operation is taken into account the corresponding activity rates have to be determined as follows:

$$A = A_{full\ load} + A_{load\ 1} + A_{load\ 2} + \ldots \qquad (9a)$$

A	activity rate within the period considered [GJ]
$A_{full\ load}$	activity rate for full load operation periods [GJ]
$A_{load\ i}$	activity rate for reduced load operation periods at level i [GJ]

Each sub-activity (e.g. $A_{load\ 1}$) has to be determined separately by totalling the thermal energy input for the respective periods of operation e.g. at load level 1.

Emissions are calculated according to Equation (9b):

$$E = EF^{V} \cdot (A_{\text{full load}} + k^{\text{load 1}} \cdot A_{\text{load 1}} + k^{\text{load 2}} \cdot A_{\text{load 2}} + ...) \cdot 10^{-6} \tag{9b}$$

E	emission within the period considered [Mg]
EF^{V}	emission factor at full load conditions [g/GJ]
$A_{\text{load i}}$	activity rates at load level i [GJ]
$k^{\text{load i}}$	ratio of reduced load to full load emission factor at load level i [ ]

If secondary measures are installed, no load correction for NO_X emissions has to be taken into account.

b) Load variations with respect to start-up behaviour:

Emission factors for NO_x, as given in Tables 24 and 25, are related to full load conditions; start-up emissions are not taken into account. If an SCR is installed, start-up emissions should be considered as given in Section 4.1.2. The relevance of start-up emissions of NO_x depends strongly on the following parameters:

- the type of boiler (e.g. NO_x emissions released by wet bottom boilers are always higher than those by dry bottom boilers, due to higher combustion temperatures),
- the type of fuel used (e.g. fuel nitrogen also contributes to the formation of NO_x),
- the status of the boiler at starting time (hot, warm or cold start),
- the specifications of any individual start-up, such as
  - -- the duration and the velocity of start-up,
  - -- the load level (reduced load or full load),
  - -- the configuration of secondary measures (e.g. the start-up time of the high-dust-configurations (SCR-precipitator-FGD) depends on the boiler load, due to the fact that the SCR catalyst is directly heated by the flue gas; tail-end-configurations (precipitator-FGD-SCR) can have shorter start-up times, due to the fact that the SCR catalyst can be preheated by an additional furnace),
  - -- emission standards, which have to be met (boiler-specific emission standards can be set up below the demands of the LCP Directive).

In the investigation mentioned in Annex 15 the measured data from different boilers have been analysed. For the combustion of coal the following ratios have been obtained (based on /116/):

- For the combustion of coal in dry bottom boilers the following ranges and values can be given:

Table 12: Ratios of start-up to full load emission factors F^{EF} and ratios of start-up to full load emissions F^{E} for NO_2 for dry bottom boilers

	Ratio of start-up to full load emissions factors F^{EF} [ ]	Ratio of start-up to full load emissions F^{E} [ ]
Range	2 - max. 6	1 - 2
Values for DBB	F^{EF}_{cold} : 3.5 – 6 F^{EF}_{warm} : 3 – 6.5 F^{EF}_{hot} : 2.5 – 3	F^{E}_{cold} : 1.5 – 2 F^{E}_{warm} : 1 – 2 F^{E}_{hot} : 1 – 1.5

$F^{EF}_{cold,warm,hot}$ Ratio of start-up to full load emission factors for cold, warm or hot start-ups (see also Table 6)

$F^{E}_{cold,warm,hot}$ Ratio of start-up to full load emissions for cold, warm or hot start-ups (see also Table 6)

The investigation revealed that start-up emissions of NO_2 were mostly higher than emissions under full load conditions. There is a dependence between start-up emissions (see Section 3.2) and the time of standstill of the boiler: cold starts showed emissions about 2 times higher, warm starts about 1 up to 2 times higher and hot starts about 1 up to 1.5 higher than at full load conditions. Start-up emission factors can be up to 6 times higher than full load emission factors. At the investigated boilers the SCR was installed in a high-dust configuration.

- For the combustion of coal in wet bottom boilers (SCR in tail-end configuration) it was found that start-up emissions were not higher than full load emissions (ratio of ≤ 1). However, this consideration is based on data of only two boilers. Measured data for hot starts was not available.

NO_x emissions, in particular for the combustion of coal in DBB, might be underestimated, if these effects are not taken into account.

4.3.2 Combustion of other fuels (biomass, waste, liquid fuels, gaseous fuels)

The emission calculation is based on Equation (1). During the combustion of solid and liquid fuels, fuel-NO and thermal-NO are formed. For gaseous fuels only thermal-NO_x is relevant, as gaseous fuels do not contain any fuel-nitrogen. For gaseous fuels the emission reduction is mainly achieved by primary measures. There are several biomass-fuelled plants with SNCR in Sweden.

The analysis of emission data from a gas fired boiler, equipped with an SCR, revealed that start-up emissions are not of relevance (ratios F^{E} were below 1) (based on /116/).

4.4 NMVOC/CH_4 emission factors

The emission calculation is based on Equation (1). Fuel and technique specific emission factors are given in Tables 26 and 27.

4.5 CO emission factors

The emission calculation is based on Equation (1). Fuel and technique specific emission factors are given in Table 28 (full load conditions); start-up emissions are not taken into account. CO emissions at starting time and under full load conditions are mainly influenced by the combustion conditions (oxygen availability, oil spraying etc.). In the detailed investigation start-up emissions for CO have only been found to be relevant for the combustion of coal. Start-up emissions for CO are determined for the time when burners switch-on up to the time when the boiler operates on minimum load.

For the combustion of coal and gas the following results have been obtained (based on /116/ see also Section 4.1.2):

- For the combustion of coal in dry bottom boilers the following ranges can be given:

Table 13: Ratios of start-up to full load emission factors F^{EF} and ratios of start-up to full load emissions F^{E} for CO for dry bottom boilers

	Ratios for start-up to full load emission factors F^{EF} [ ]	Ratios for start-up to full load emissions F^{E} [ ]
Range	0.5 - 3.5	0.1 - 0.7
Values for DBB	F^{EF}_{cold} : 1.5 – 3.5 F^{EF}_{warm} : 1 F^{EF}_{hot} : 0.5	F^{E}_{cold} : 0.4 – 0.7 F^{E}_{warm} : 0.2 – 0.7 F^{E}_{hot} : 0.1

$F^{EF}_{cold,warm,hot}$	Ratio of start-up to full load emission factors for cold, warm or hot start-ups (see also Table 6)
$F^{E}_{cold,warm,hot}$	Ratio of start-up to full load emissions for cold, warm or hot start-ups (see also Table 6)

The values in Table 13 show that start-up emissions for CO for DBB are lower than full load emissions for the boilers considered.

- Start-up emissions from wet bottom boilers can be up to 1.2 times higher than full load emissions for cold starts (F^{EF} = 4); they are lower for warm starts (F^{E} = 0.3; F^{EF} = 0.8).

- Start-up emissions of CO from gas boilers are also negligible.

4.6 CO_2 emission factors

The emission calculation is based on Equation (1). Fuel specific emission factors are given in Table 29. For the determination of specified CO_2 emission factors, the following general Equation (10) can be used:

$$EF_{R_{CO2}} = \frac{44}{12} \cdot C_{C_{fuel}} \cdot \varepsilon \cdot \frac{1}{H_u} \cdot 10^6 \qquad (10)$$

$EF_{R_{CO2}}$	specified emission factor [g/GJ]
$C_{C_{fuel}}$	carbon content of fuel (in mass C/mass fuel [kg/kg])
ε	fraction of carbon oxidised [ ]
H_u	lower heating value of fuel [MJ/kg]

Default values for carbon content and lower heating value of different coals, available on the world market, are given in Annexes 7 and 8. The fraction of carbon oxidised (ε) is defined as the main part of carbon which is oxidised to CO_2; small amounts of carbon may remain unoxidised. Default values for ε according to IPCC /61/ are for liquid fuels 0.99, for solid fuels 0.98 and for gaseous fuels 0.995. In this approach it is assumed that the only product of the oxidation is CO_2. Nevertheless, double counting of CO_2 has to be avoided: products of incomplete oxidation, like CO, must not be converted into CO_2.

The IPCC/OECD presented an overall model (the so-called reference approach) specially designed for the calculation of CO_2 emissions on a national level (not on a plant level) /61/. This methodology is based on national energy balances.

4.7 N_2O emission factors

The emission calculation is based on Equation (1). The fuel and technique specific emission factors are given in Table 30. At this stage, several pilot studies using measured data are described in the literature /13, 14, 25, 26, 27/. A complete list of influencing parameters has not yet been identified.

4.8 NH_3 emission factors

Emission factors referring to the energy input are not yet available. The available data for ammonia slip at SCR/SNCR installations are based on measurements and are related to the flue gas volume: SCR/SNCR installations are often designed for an ammonia slip of about 5 ppm (3.8 mg NH_3/m^3 flue gas) /45, 62/. The ammonia slip at SCR and SNCR installations increases with an increasing NH_3/NO_x ratio, but also with a decreasing catalyst activity.

4.9 Heavy metal emission factors

For heavy metals, general and specified emission factors can be used. Emission factors, depending on the fuel used and the technique installed, are given in Table 31.

The IPCC/OECD presented an overall model (the so-called reference approach) specially designed for the calculation of CO_2 emissions on a national level (not on a plant level) /61/. This methodology is based on national energy balances.

4.9.1 Combustion of coal

For an individual determination of specific heavy metal emission factors, three different methodologies can be applied, taking into account:

- fuel composition	(particle-bound and gaseous emissions),
- fly ash composition	(particle-bound emissions),
- fly ash concentration in clean gas	(particle-bound emissions).

The choice of the methodology depends on data availability.

4.9.1.1 Calculation of specified emission factors based on fuel composition /cf. 35/

Emissions of heavy metals associated with particulate matter and gaseous emissions are assessed subsequently as given in Equation (11). The enrichment behaviour of heavy metals with regard to fine particles is taken into account as an enrichment factor (see also Section 3.4). Gaseous emissions have to be taken into account additionally in the case of arsenic, mercury and selenium.

$$EF_{R_{HM}} = C_{HM_{coal}} \cdot f_a \cdot f_e \cdot 10^{-2} \cdot (1-\eta_p) + C_{HM_{coal}} \cdot f_g \cdot 10^{-2} \cdot (1-\eta_g) \qquad (11)$$

$EF_{R_{HM}}$	specified emission factor of heavy metal (in mass pollutant/mass coal [g/Mg])
$C_{HM_{coal}}$	concentration of heavy metal in coal [mg/kg]
f_a	fraction of ash leaving the combustion chamber as particulate matter [wt.-%]
f_e	enrichment factor [ ]
f_g	fraction of heavy metal emitted in gaseous form [wt.-%]
η_p	efficiency of the dust control equipment [ ]
η_g	efficiency of the emission control equipment with regard to gaseous heavy metals [ ]

The characteristics of fuel and technology are taken into account by f_a and f_e and the following default values are proposed:

Table 14: Default values for f_a for different combustion technologies (based on /35/)

Type of boiler	f_a [wt.-%]
DBB (Pulverised coal)	80
Grate firing	50
Fluidised bed	15

Table 15: Default values for f_e for different heavy metals released by the combustion of coal (based on /35/)

Heavy metal	f_e [ ]	
	range	value[1)]
Arsenic	4.5 - 7.5	5.5
Cadmium	6 - 9	7
Copper	1.5 - 3	2.3
Chromium	0.8 - 1.3	1.0
Nickel	1.5 - 5	3.3
Lead	4 - 10	6
Selenium	4 - 12	7.5
Zinc	5 - 9	7

[1)] Recommended value, if no other information is available.

Gaseous emissions (arsenic, mercury and selenium) are calculated from the heavy metal content in coal; the fraction emitted in gaseous form is given in Table 16. The efficiency of emission control devices with regard to these elements is outlined in Section 3.5.5.

Table 16: Fractions of heavy metals emitted in gaseous form (f_g) released by the combustion of coal /35/

Heavy metal	f_g [wt.-%]
Arsenic	0.5
Mercury	90
Selenium	15

4.9.1.2 Calculation of specified emission factors based on fly ash composition /cf. 39/

If the concentration of heavy metals in raw gas fly ash is known, emission factors of heavy metals can be assessed by Equation (12). Gaseous emissions have to be taken into account separately as outlined in Section 4.9.1.1.

$$EF_{R_{HM,P}} = EF_f \cdot C_{HM_{FA,raw}} \cdot 10^{-3} \cdot (1 - \eta_p) \tag{12}$$

$EF_{R_{HM,P}}$	specified emission factor of heavy metal in particulate matter (in mass pollutant/mass coal [g/Mg])
EF_f	fly ash emission factor of raw gas (in mass particulate matter/mass coal [kg/Mg])
$C_{HM_{FA,raw}}$	heavy metal concentration in raw gas fly ash (in mass pollutant/mass particulate matter [g/Mg])
η_p	efficiency of dust control equipment [ ]

Values of EF_f can be calculated in a technology specific way using default parameters, as given in Table 17 depending on the content of ash in coal (a) in [wt.-%].

Table 17: Fly ash emission factor for raw gas (EF_f) as function of the ash content in coal (a) [wt.-%] /cf. 39/

Technology	EF_f (in mass particulate matter / mass coal) [kg/Mg]
Cyclone	$1.4 \cdot a$
Stoker	$5.9 \cdot a$
Pulverised coal combustion	$7.3 \cdot a$

The emission factors calculated by taking into account the fuel or the fly ash composition mainly depend on the estimation of the efficiency of dust control equipment.

4.9.1.3 Calculation of specified emission factors based on fly ash concentration in clean flue gas /cf. 36/

If the concentration of heavy metals in fly ash in clean flue gas is known, emission factors of heavy metals can be assessed by Equation (13). Gaseous emissions have to be taken into account separately, as outlined in Section 4.9.1.1.

$$EF_{R_{HM,P}} = C_{HM_{FA,clean}} \cdot C_{FG} \cdot V_{FG} \cdot 10^{-9} \qquad (13)$$

$EF_{R_{HM,P}}$	specified emission factor of heavy metal in particulate matter (in mass pollutant/mass coal [g/Mg])
$C_{HM_{FA,clean}}$	concentration of heavy metal in fly ash in clean flue gas (in mass pollutant/mass fly ash [g/Mg])
C_{FG}	concentration of fly ash in clean flue gas (in mass fly ash/volume flue gas [mg/m^3])
V_{FG}	specific flue gas volume (in volume flue gas/ mass coal [m^3/Mg])

Fuel and technology specific heavy metal concentrations in fly ash in clean flue gas ($C_{HM_{FA.clean}}$) are given in Table 18 /36/:

Table 18: Concentration of heavy metals in fly ash in clean flue gas /36/

$C_{HM_{FA.clean}}$	DBB/hc [g/Mg]		WBB/hc [g/Mg]		DBB/hc [g/Mg]	
Heavy metal	range	value	range	value	range	value
As	61 - 528	300	171 - 1,378	690	70 - 120	100
Cd	0.5 - 18	10	18 - 117	80	7 - 12	10
Cr	73 - 291	210	84 - 651	310	10 - 250	70
Cu	25 - 791	290	223 - 971	480	13 - 76	50
Ni	58 - 691	410	438 - 866	650	n. a.	90
Pb	31 - 2,063	560	474 - 5,249	2,210	10 - 202	90
Se1)	18 - 58	45	7 - 8	7	n. a.	n. a.
Zn	61 - 2,405	970	855 - 7,071	3,350	50 - 765	240

1) does not include gaseous Se

n. a.: not available

Default values of particulate matter concentrations downstream of FGD (C_{FG}) are given in Table 19.

Table 19: Particulate matter concentrations downstream of FGD (C_{FG}) released by the combustion of coal based on /18/

Type of FGD	C_{FG} [mg/m^3]	
	range	value1)
WS	20 - 30	25
SDA	20 - 30	25
WL	5 - 10	8
WAP	5 - 10	8
AC	< 40	20
DESONOX	< 40	20

1) Recommended value, if no other information is available.

The concentration of fly ash in flue gas is often monitored continuously. In this case the total annual fly ash emissions can be derived from measured data (see Section 5.2).

4.9.2 Combustion of other fuels

General emission factors for oil and gas combustion can be found in Table 31. Among the other fuels, only waste is relevant for heavy metal emissions. Emission factors for the combustion of waste are currently not available (reported emission factors within the literature mainly refer to the incineration of waste).

5 DETAILED METHODOLOGY

The detailed methodology refers to the handling of measured data in order to determine annual emissions or in order to verify emission factors (for comparison purposes). Annual emissions from major contributors should only be obtained by using continuously measured data which are normally available if secondary abatement technologies are installed. Furthermore, the detailed methodology should be used whenever measured data are available; e.g. for medium and small sized combustion installations periodically measured data are often available.

Measurements are carried out downstream of the boiler or at the stack; measured values obtained by both variants are usable.

National monitoring programmes should include guidelines for quality assurance of measurements (measuring places, methods, reporting procedures, etc.).

The pollutants normally measured at power plants are SO_2, NO_x, CO, and particulate matter. Gaseous emissions of SO_2, NO_x, and CO are treated in Section 5.1. Continuously measured particulate matter emission data can be used to estimate heavy metal emissions (see Section 5.2).

5.1 Gaseous emissions

It is desirable to obtain annual emissions in [Mg]. The annual emission as a function of time is normally given by the following Equation (14):

$$E = \int_T e(t) \qquad dt \tag{14}$$

E	emission within the period T [Mg]
e (t)	emission per unit of time in the periods of operation [Mg/h]
t	time [h]
T	annual time period (see also Figure 1)

Usually, the emission e(t) cannot be or is not directly measured. Therefore, for practical reasons, the concentration of pollutants and the flue gas volume are used for the determination of e(t), as described by Equation (15):

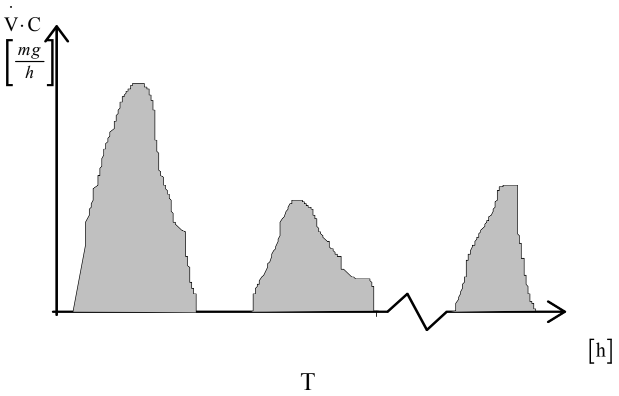
$$\mathrm{e(t)} = \dot{\mathrm{V}}(\mathrm{t}) \cdot \mathrm{C(t)} \tag{15}$$

e (t)	emission in the periods of operation [Mg/h]
$\dot{V}(t)$	flue gas volume flow rate [m^3/h]

C (t)	flue gas concentration of a pollutant [mg/m^3]

Usually, emission fluctuations occur within a year (see Figure 1) as:

- periodical fluctuations (e.g. daily, weekly, seasonally), due to load management depending on the demand of e.g. district heat or electricity,
- operational fluctuations (e.g. start-ups/shut downs, raw material properties, working conditions/reaction conditions).



$\dot{V}$	flue gas volume flow rate [m^3/h]
C	flue gas concentration of a pollutant (abatement techniques installed are included) [mg/m^3]
t	time [h]
t_{bn}	beginning of operation (e.g. start-up of boiler) [h]
t_{en}	ending of operation (e.g. shut down of boiler) [h]
T	annual time period

Figure 1: Periods of operation of a combustion installation

The following approaches can be used to determine annual emissions depending on the level of detail of measured data available.

– First approach:

The flue gas volume and the concentration of a pollutant are measured continuously (e.g. in Finland). Then, the annual emission is given exactly by the following Equation (16):

$$E = 10^{-9} \int_T V(t) \cdot C(t) dt \tag{16}$$

E	emission within the period T [Mg]
$\dot{V}(t)$	flue gas volume flow rate [m^3/h]
C (t)	flue gas concentration of a pollutant (abatement techniques installed are included) [mg/m^3]
t	time [h]
T	annual time period (see also Figure 1)

The precision of measurements of $\dot{V}(t)$ and C(t) depends on the performance of the analytical methods (e.g. state-of-the-art) used. In particular, the regular calibration of measuring instruments is very important. Analytical methods commonly used for NO_x detect only NO and those used for SO_x detect only SO_2. It is implicitly assumed that NO_2 in the flue gas is normally below 5 %, and that SO_3 in the flue gas is negligible. Nevertheless, for some combustion plants the amounts of NO_2 and/or SO_3 formed can be significant and have to be detected by appropriate analytical methods. The measured values have to be specified with regard to dry/wet flue gas conditions and standard oxygen concentrations[8].

For the annual time period T considered, a case distinction has to be made:

- calendar year T_1 (e.g. including time out of operation),
- real operating time T_2 of boiler/plant (e.g. start-ups are reported when „burner on/off“),
- official reporting time T_3 determined by legislation (e.g. start-ups are reported, as soon as the oxygen content in the flue gas goes below 16 %),

where $T_3 \subset T_2 \subset T_1$. If C(t) is only available for T_3, adequate corrections have to be provided.

– Second approach:

Due to the difficulty in measuring V(t) continuously in large diameter stacks, in most cases the flue gas volume flow rate V(t) is not measured. Then the annual emission can be determined by Equation (17):

$$E = 10^{-9} \overline{\dot{V}} \int_T C(t)dt \tag{17}$$

E	emission within the period T [Mg]
$\overline{\dot{V}}$	average flue gas volume flow rate [m^3/h]
C(t)	flue gas concentration of a pollutant (abatement techniques installed are included) [mg/m^3]
t	time [h]
T	annual time period (see also Figure 1)

The average flue gas volume flow rate $\overline{\dot{V}}$ (dry conditions) can be determined according to the following Equations (18) and (19):

$$\overline{\dot{V}} = V_{FG} \cdot \dot{m}_{fuel} \tag{18}$$

$\overline{\dot{V}}$	average flue gas volume flow rate [m^3/h]
V_{FG}	dry flue gas volume per mass fuel [m^3/kg]
$\dot{m}_{fuel}$	fuel consumption rate [kg/h]

$$V_{FG} \approx 1.852\left[\tfrac{m^3}{kg}\right] \cdot C_c + 0.682\left[\tfrac{m^3}{kg}\right] \cdot C_s + 0.800\left[\tfrac{m^3}{kg}\right] \cdot C_N + V_{N_{air}} \tag{19}$$

V_{FG}	dry flue gas volume per mass fuel [m^3/kg]
C_c	concentration of carbon in fuel [kg/kg]
C_s	concentration of sulphur in fuel [kg/kg]

---

[8] In some countries the measured values obtained are automatically converted into values under standard oxygen concentrations (e.g. in Germany).

C_N	concentration of nitrogen in fuel [kg/kg]
$V_{N_{air}}$	specific volume of air nitrogen (in volume/mass fuel [m^3/kg])

This calculation of V according to Equation (19) can be performed by the computer programme (see Annex 6) by using default values for C_C, C_S, C_N and $V_{N_{air}}$.

- Third approach:
  In some countries the term $\int_T C(t)dt$ is available as an annual density function P(C) (histogram). In this case Equation (17) can be simplified to:

$$E = \overline{\dot{V}} \cdot \overline{C} \cdot t_{op} \cdot 10^{-9} \tag{20}$$

$$\text{where} \quad \overline{C} = \int_0^\infty P(C) \cdot C \cdot dC \tag{21}$$

E	emission within the period T [Mg]
$\overline{\dot{V}}$	average flue gas volume flow rate [m^3/h]
$\overline{C}$	expected value (mean value) of the flue gas concentration for each pollutant (abatement techniques installed are included) [mg/m^3]
t_{op}	annual operating time [h]
P(C)	density function [ ]
C	flue gas concentration per pollutant as given in the histogram [mg/m^3]

The variable t_{op} has to be introduced consistently with $\overline{\dot{V}}$ and $\overline{C}$ according to periods T_1, T_2 or T_3 mentioned above. If e.g. start-ups are not included, they should be taken into account as given in Sections 4.1, 4.2 and 4.4.

- Fourth approach:
  If neither T_2 nor T_3 are available, the annual full load operating hours can also be used. Then Equation (20) becomes:

$$E = \overline{\dot{V}}_{normed} \cdot \overline{C} \cdot t_{op}^{full\,load} \cdot 10^{-9} \tag{22}$$

E	emission within the period considered [Mg]
$\overline{\dot{V}}_{normed}$	average flue gas volume flow rate related to full load operation [m^3/h]
$\overline{C}$	mean value of the flue gas concentration for each pollutant (abatement techniques installed are included) [mg/m^3]
$t_{op}^{full\,load}$	annual operating time expressed as full load operating hours [h]

From here, emission factors, based on measured values, can be derived e.g. for verification purposes:

$$EF = \frac{E}{A} \cdot 10^6 \tag{23}$$

EF	emission factor [g/GJ]

E	emission within the period considered [Mg]
A	activity rate within the time period considered [GJ]

5.2 Heavy metal emissions

Continuously measured values for the total heavy metal emissions (particle-bound and gaseous) are not available for the combustion of fossil fuels. National legislation can require periodical measurements, e.g. weekly measurements of heavy metal emissions [mg/m^3] in the case of waste incineration/combustion.

The emissions of particle-bound heavy metals depend on the emission of particulate matter which is normally periodically or continuously monitored. Therefore, the particle-bound heavy metal emissions can be derived from the element content in particulate matter. The heavy metal emission factor can be back-calculated as follows:

$$EF = \frac{\overline{\dot{m}}_{FA} \cdot \overline{C}_{HM_{FA.clean}}}{A} \qquad (24)$$

EF	emission factor [g/GJ]
$\overline{\dot{m}}_{FA}$	mass of fly ash within the period considered [Mg]
$\overline{C}_{HM_{FA.clean}}$	average concentration of heavy metal in fly ash (in mass pollutant/mass fly ash [g/Mg])
A	activity rate within the period considered [GJ]

Measured data should also be used to replace the default values of Equation (13) for $C_{HM_{FA.clean}}$ and C_{FG}.

6 RELEVANT ACTIVITY STATISTICS

In general, the published statistics do not include point sources individually. Information on this level should be obtained directly from each plant operator.

On a national level, statistics can be used for the determination of fuel consumption, installed capacity and/or types of boilers mainly used. The following statistical publications can be recommended:

- Office for Official Publication of the European Communities (ed.): Annual Statistics 1990; Luxembourg 1992
- Commission of the European Communities (ed.): Energy in Europe - Annual Energy Review; Brussels 1991
- Statistical Office of the European Communities (EUROSTAT) (ed.): CRONOS Databank, 1993
- OECD (ed.): Environmental Data, Données OCDE sur l'environnement; compendium 1993
- Commission of the European Communities (ed.): Energy in Europe; 1993 - Annual Energy Review; Special Issue; Brussels 1994

- EUROSTAT (ed.): Panorama of EU Industry'94; Office for official publications of the European Communities; Luxembourg 1994

7 POINT SOURCE CRITERIA

Point source criteria for a combustion plant according to CORINAIR are given in chapter AINT and in /41/.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Tables 23 - 31 list emission factors for all pollutants considered, except for SO_2. For SO_2 emission factors have to be calculated individually (see Equation (5)). Sulphur contents of different fuels are given. The emission factors have been derived from the literature, from the calculations presented here (see also Section 4) and from recommendations from expert panel members. All emission factor tables have been designed in a homogenous structure: Table 20 contains the allocation of SNAP activities used related to combustion installations, where three classes are distinguished according to the thermal capacity installed. Table 21 includes the main types of fuel used within the CORINAIR90 inventory. Table 22 provides a split of combustion techniques (types of boilers, etc.); this standard table has been used for all pollutants. The sequence of the emission factor tables is:

Table 20:	SNAP code and SNAP activity related to the thermal capacities installed in combustion plants
Table 21:	Selection of relevant fuels from NAPFUE and lower heating values for boilers, gas turbines and stationary engines
Table 22:	Standard table for emission factors for the relevant pollutants
Table 23:	S-contents of selected fuels
Table 24:	NO_x emission factors [g/GJ] for combustion plants
Table 25:	NO_x emission factors [g/GJ] for coal combustion according to the model description (see Annexes 4 and 5)
Table 26:	NMVOC emission factors [g/GJ] for combustion plants (coal combustion)
Table 27:	CH_4 emission factors [g/GJ] for combustion plants
Table 28:	CO emission factors [g/GJ] for combustion plants
Table 29:	CO_2 emission factors [kg/GJ] for combustion plants
Table 30:	N_2O emission factors [g/GJ] for combustion plants
Table 31:	Heavy metal emission factors [g/Mg] for combustion plants

References of the emission factors listed are given in footnotes of the following tables. Quality codes are not available in the literature.

Table 20: SNAP code and SNAP activity related to the thermal capacities installed in combustion plants

Thermal capacity [MW]	SNAP code	SNAP activity
>= 300	010101	Public power and co-generation combustion plants
	010201	District heating combustion plants
	010301	Petroleum and/or gas refining plants
	010401	Solid fuel transformation plants
	010501	Coal mining, oil, gas extraction/distribution plants
	020101	Commercial and institutional plants
	030101	Industrial combustion plants
>=50 up to < 300	010102	Public power and co-generation combustion plants
	010202	District heating combustion plants
	020102	Commercial and institutional plants
	020201	Residential combustion plants
	020301	Plants in agriculture, forestry and fishing
	030102	Industrial combustion plants
< 50	010103	Public power and co-generation combustion plants
	010203	District heating combustion plants
	020103	Commercial and institutional plants
	020202	Residential combustion plants
	020302	Plants in agriculture, forestry and fishing
	030103	Industrial combustion plants

Table 21: Selection of relevant fuels from NAPFUE and lower heating values for boilers, gas turbines and stationary engines

Type of fuel according to NAPFUE					NAPFUE code	H_u [MJ/kg][2]
s	coal	hc	coking [1]	GHV[11] > 23,865 kJ/kg	101	29.3[4]
s	coal	hc	steam [1]	GHV[11] > 23,865 kJ/kg	102	29.3[4]
s	coal	hc	sub-bituminous	17,435 kJ/kg < GHV[11] < 23,865 kJ/kg	103	20.6
s	coal	hc/bc	patent fuels	from hard/sub-bituminous coal	104	
s	coal	bc	brown coal/lignite	GHV[11] < 17,435 kJ/kg	105	12.1
s	coal	bc	briquettes		106	19.5[4]; 18.6[5]
s	coke	hc	coke oven		107	26.3[10]
s	coke	bc	coke oven		108	29.9[7]
s	coke		petroleum		110	30[10]
s	biomass		wood		111	12.4[4], 16[10]
s	biomass		charcoal		112	
s	biomass		peat		113	9.5[10]
s	waste		municipal		114	7.5[4]
s	waste		industrial		115	8.4[8]
s	waste		wood	except wastes similar to wood	116	
s	waste		agricultural	corncobs, straw etc.	117	
l	oil		residual		203	41.0[4]
l	oil		gas		204	42.7[4], 42.5[10]
l	oil		diesel	for road transport	205	
l	kerosene				206	
l	gasoline		motor		208	43.5[4]
l	naphtha				210	
l	black liquor				215	
g	gas		natural	except liquified natural gas	301	heavy 39.7 MJ/m^3 [3], light 32.5 MJ/m^3 [3]
g	gas		liquified petroleum gas		303	45.4[10]
g	gas		coke oven		304	19.8[10]
g	gas		blast furnace		305	3.0[10]
g	gas		coke oven and blast furnace gas		306	
g	gas		waste		307	
g	gas		refinery	not condensable	308	48.4[6], 87 MJ/m^3 [10]
g	gas		biogas		309	34.7[9]
g	gas		from gas works		311	

[1] A principal differentiation between coking coal and steam coal is given in section 3.2. Further differentiation between coking coal and steam coal can be made by using the content of volatiles: coking coal contains 20 - 30 wt.-% volatiles (maf), steam coal contains 9.5 - 20 wt.-% volatiles (maf) (based on official UK subdivision). This is necessary if no information concerning the mean random reflectance of vitrinite (see Section 3.2) is available.

[2] H_u = lower heating value; lower heating values for coals from different countries are given in Annexes 7 and 8 and for solid, liquid and gaseous fuels in (/88/, Table 1-2).

[3] given under standard conditions

[4] Kolar 1990 /17/

[5] /98/

[6] MWV 1992 /97/

[7] Boelitz 1993 /78/

[8] Schenkel 1990 /105/

[9] Steinmüller 1984 /107/

[10] NL-handbook 1988 /99/

[11] GHV = Gross heating value

Table 22: Standard table of emission factors for the relevant pollutants

						Thermal boiler capacity [MW][4]																				no specification
						>= 300			>= 50 and < 300						< 50											
						Type of boiler			Type of boiler						Type of boiler							GT[10]		Stat. E.[11]		CORINAIR90[12]
						DBB[5]	WBB[6]	FBC[7]	DBB	WBB	FBC[7]		GF[8]		DBB	WBB	FBC[7]			GF						
Type of fuel[1]			NAPFUE code[1]	H_u[2] [MJ/kg]	P1[3]	Primary measures[9]	Primary measures[9]	CFBC			CFBC	PFBC	ST1	ST2			AFBC	CFBC	PFBC	ST1	ST2	SC	CC	CI	SI	
s	coal	hc																								
s	coal	hc																								
s	coal	hc																								
s	coal	bc	...	...	...																					
s	coke																									
s	biomass																									
s	waste																									
l	oil																									
g	gas																									

[1] the type of fuel is based on the NAPFUE code, see table 21

[2] H_u = lower heating value, when different from table 21

[3] relevant parameter of fuel composition for SO_2: P1 = sulphur content of fuel;

[4] the corresponding SNAP-codes are listed in table 20

[5] DBB - Dry bottom boiler

[6] WBB - Wet bottom boiler

[7] FBC - Fluidised bed combustion; CFBC = Circulating FBC; PFBC = Pressurised FBC (Dense FBC); AFBC = Atmospheric FBC

[8] GF - Grate firing; ST1 and ST2 are different types of stoker (e.g. travelling stoker, spreader stoker)

[9] Primary measures are described by reduction efficiency

[10] GT = Gas turbine; SC = Simple cycle; CC = Combined cycle

[11] Stat. E. = Stationary engine; CI = Compression ignition; SI = Spark ignition

[12] CORINAIR90 data on combustion plants as point sources

Table 23: S-contents of selected fuels 1)

Type of fuel				NAPFUE code	Sulphur content of fuel		
					value 2)	range	unit
s	coal 3)	hc	coking	101		0.4 - 6.2	wt.-% (maf)
s	coal 3)	hc	steam	102		0.4 - 6.2	wt.-% (maf)
s	coal 3)	hc	sub-bituminous	103		0.4 - 6.2	wt.-% (maf)
s	coal 3)	bc	brown coal/lignite	105		0.4 - 6.2	wt.-% (maf)
s	coal	bc	briquettes	106		0.25 - 0.45 13)	wt.-% (maf)
s	coke	hc	coke oven	107		< 1 5)	wt.-% (maf)
s	coke	bc	coke oven	108		0.5 - 1 5) 6)	wt.-% (maf)
s	coke		petroleum	110			
s	biomass		wood	111		< 0.03 5)	wt.-% (maf)
s	biomass		charcoal	112		< 0.03 5)	wt.-% (maf)
s	biomass		peat	113			
s	waste		municipal	114			
s	waste		industrial	115			
s	waste		wood	116			
s	waste		agricultural	117			
l	oil		residual	203		0.3 8) - 3.5 9)	wt.-%
l	oil		gas	204	0.3 11)	0.08 - 1.0	wt.-%
l	oil		diesel	205	0.3 11)		wt.-%
l	kerosene			206			
l	gasoline		motor	208		< 0.05 12)	wt.-%
l	naphtha			210			
l	black liquor			215			
g	gas 4)		natural	301	(0.0075) 10)		$g \cdot m^{-3}$
g	gas		liquified petroleum gas	303	-		
g	gas		coke oven	304	8		$g \cdot m^{-3}$
g	gas		blast furnace	305	$45 \cdot 10^{-3}$ 10)		$g \cdot m^{-3}$
g	gas		coke oven and blast furnace gas	306			
g	gas		waste	307			
g	gas		refinery	308		<= 8 10)	$g \cdot m^{-3}$
g	gas		biogas	309			
g	gas		from gas works	311			

[1] for emission factor calculation see Section 4.1, and Annexes 2 and 3

[2] recommended value

[3] for complete coal composition see Annexes 7 and 8

[4] only trace amounts

[5] Marutzky 1989 /94/

[6] Boelitz 1993 /78/

[8] Mr. Hietamäki (Finland): Personal communication

[9] Referring to NL-handbook 1988 /99/ the range is 2.0 - 3.5

[10] NL-handbook 1988 /99/

[11] 87/219 CEE 1987 /113/

[12] $\alpha_s \sim 0$

[13] Davids 1986 /46/

Table 24: NO_x emission factors [g/GJ] for combustion plants

Type of fuel				NAPFUE code	Thermal boiler capacity [MW]				
					>= $300^{32)}$			>= 50 and < $300^{32)}$	
					Type of boiler$^{43)}$			Type of boiler	
					DBB/boiler$^{27)}$	WBB	FBC CFBC	DBB/boiler$^{27)}$	WBB
s	coal	hc	coking	101	see table 25	see table 25	$70^{1)}$	see table 25	see table 25
s	coal	hc	steam	102	see table 25	see table 25	$70^{1)}$	see table 25	see table 25
s	coal	hc	sub-bitumious	103	see table 25	see table 25	$70^{1)}$	see table 25	see table 25
s	coal	bc	brown coal/lignite	105	see table 25		$70^{1)}$	see table 25	
s	coal	bc	briquettes	106					
s	coke	hc	coke oven	107					
s	coke	bc	coke oven	108					
s	coke		petroleum	110				$300^{1)}$	
s	biomass		wood	111				$200^{1),15)}$	
s	biomass		charcoal	112					
s	biomass		peat	113	$300^{1),28)}$			$300^{1)}$	
s	waste		municipal	114					
s	waste		industrial	115					
s	waste		wood	116					
s	waste		agricultural	117					
l	oil		residual	203	$210^{1),29)}$, $260^{1),28)}$, 155 - $296^{19),20)}$			$150^{1),29)}$, $170^{1),29)}$, $190^{1),30)}$, $210^{1),30)}$	
l	oil		gas	204	64 - $68^{21)}$			$100^{1)}$	
l	oil		diesel	205					
l	kerosene			206					
l	gasoline		motor	208					
l	naphtha			210					
l	black liquor			215					
g	gas		natural	301	$170^{1)}$, 48 - $333^{22) 23)}$			$125^{1),25)}$, $150^{1),26)}$, 48 - $333^{22),23),24)}$	
g	gas		liquified petroleum gas	303	88 - $333^{23),24)}$			88 - $333^{23),24)}$	
g	gas		coke oven	304	$150^{1)}$, 88 - $333^{23) 24)}$			$110^{1),25)}$, $130^{1),26)}$, 88 - $333^{23),24)}$	
g	gas		blast furnace	305	$95^{1)}$, 88 - $333^{23) 24)}$			$65^{1)25)}$, $80^{1),26)}$, 88 - $333^{23),24)}$	
g	gas		coke oven and blast furnace gas	306	88 - $333^{23),24)}$			88 - $333^{23),24)}$	
g	gas		waste	307	88 - $333^{23),24)}$			88 - $333^{23),24)}$	
g	gas		refinery	308	88 - $333^{23),24)}$			$140^{1)}$, 88 - $333^{23),24)}$	
g	gas		biogas	309	88 - $333^{23),24)}$			88 - $333^{23),24)}$	
g	gas		from gas works	311					

to be continued

Table 24: continued

Thermal boiler capacity [MW]													no specification
> 50 and < 300 [32]			< 50[32]										
Type of boiler			Type of boiler						Gas turbine		Stationary engine		CORINAIR 90[44]
FBC		GF	DBB/boiler[27]	WBB	FBC			GF					
PFBC	CFBC				PFBC	CFBC	AFBC		SC	CC	CI	SI	
150[1]	70[1]	150[1]	180[1,31], 230[1,29]			70[1]		150[1]					545[44]
150[1]	70[1]	150[1]	180[1,31], 230[1,29]			70[1]		150[1]					36.5 - 761[44]
150[1]	70[1]	150[1]	180[1,31], 230[1,29]			70[1]		150[1]					20.5 - 1,683[44]
150[1]	70[1]	150[1]	180[1,31], 230[1,29]			70[1]		150[1]					180 - 380[44]
													33.3 - 175[44]
			300[1]		300[1]	300[1]							
		200[1], 33 - 115[15]	200[1], 33 - 115[15]					200[1,15]					50 - 200[44]
160[1]	100[1]	230[1]	280[1]		160[1]	100[1]							150 - 240[44]
		90 - 463[16,17]						90 - 463[16,17]					220[44]
		139 - 140[18]						139 - 140[18]					
													80 - 200[44]
		88[6]											160[44]
			140[1,29], 180[1,30]						250[45]		1,090-1,200[45]		24 - 370[44]
			80[1], 100[1]						120 [1,35], 350[1,33], 380[1,34], 780[1,36]		100 - 1,200[45]		50 - 269[44]
									100 - 700[45], 300[46]		600[1,37,42], 1,200[1,38]	1,000[1,40,42], 1,800[1,39,42]	
													180[44]
													20 - 440[44]
			100[1], 48 - 333[22,23,24]						150 - 360[45]		600[1,37,42], 1,200[1,38,42]	1,000[1,40,42], 1,800[1,39,42]	22 - 350[44]
									188[4,41]	187[4,41]			
			88 - 333[23,24]										35 - 100[44]
			90[1,23,24]										70 - 571[44]
			88 - 333[23,24]										6.7 - 330[44]
			88 - 333[23,24]										
			88 - 333[23,24]										35 - 327[44]
			140[1,23,24]						150-151[45]				35 - 140[44]
			88 - 333[23,24]										60[44]

[1] CORINAIR 1992 /80/, without primary measures

[2] Ratajczak 1987 /103/, Kolar 1990 /17/

[3] Lim 1982 /91/, Kolar 1990 /17/

[4] Mobley 1985 /96/, Kolar 1990 /17/

[5] LIS 1977 /92/

[6] Radian 1990 /102/, IPCC 1994 /88/, without primary measues

[7] UBA 1985 /111/, Kolar 1990 /17/

[8] Kolar 1990 /17/

[9] Bartok 1970 /75/, Kolar 1990 /17/

[10] Kremer 1979 /90/, Kolar 1990 /17/

[11] UBA 1981 /110/, Kolar 1990 /17/

[12] LIS 1987 /93/

[13] Davids 1984 /81/, Kolar 1990 /17/

[14] Ministry 1980 /95/, Kolar 1990 /17/

[15] utility boiler: 112[6], commercial boiler: 33[6], industrial boiler: 115[6]

[16] utility boiler (GF): 140[6], commercial boiler: 463[6], commercial open burning: 3[6] kg/Mg waste

[17] GF: 90 - 180[8]

[18] industrial combustion (mass burn.): 140[6], industrial combustion (small burner): 139[6]

[19] DBB (power plants): 240[11], 245[10], 296[9], 270[10]

[20] utility boiler: 201[6], commercial boiler: 155[6], industrial boiler: 161[6]

[21] utility boiler: 68[6], commercial boiler: 64[6]

[22] utility boiler: 267[6], commercial boiler: 48[6], industrial boiler: 67[6]

[23] power plant: 160[9], 170[10], 185[10], 190[11], 215[10], 333[13]

[24] industry: 88[9], 100[11]

[25] 50 - 100 MW thermal

[26] 100 - 300 MW thermal

[27] DBB for coal combustion; boiler for other fuel combustion

[28] wall firing

[29] tangential firing

[30] wall/bottom firing

[31] wall/tangential firing

[32] The emission factors [g/GJ] are given at full load operating modus.

[33] no specification

[34] with diffusion burner

[35] modern with pre-mixer

[36] derived from aero engines

[37] prechamber injection

[38] direct injection

[39] 4 stroke engines

[40] 2 stroke engines

[41] 80[1,35], 250[1,33], 160 - 480[1,34], 650[1,36]

[42] 1000[1,33]

[43] The formation of thermal-NO is much more influenced by the combustion temperature than by the burner arrangement within the boiler /64/. Therefore, no emission factors are given for different burner arrangements (e.g. tangential firing).

[44] CORINAIR90 data of combustion plants as point sources with thermal capacity of > 300, 50 - 300, <50 MW

[45] CORINAIR90 data of combustion plants as point sources

[46] AP42 /115/

Table 25: NO_x emission factors [g/GJ] for coal combustion according to the model (see Annexes 4 and 5)

Type of fuel			coal mining country	NAPFUE code	H_u [MJ/kg] (maf)	Thermal boiler capacity [MW] >= 50 [1]									
						Type of boiler									
						DBB					WBB				
						PM0[2]	PM1	PM2	PM3	PM4	PM0	PM1	PM2	PM3	PM4
						η= 0	η= 0.20	η=0.45	η=0.45	η=0.60	η= 0	η= 0.20	η=0.45	η=0.40	η=0.60
s	coal	hc	Australia	(101)	34	568	454	312	312	227	703	562	387	422	281
			Canada	(101)	33	500	405	278	278	202	627	501	345	376	251
			China	(101)	32	413	331	227	227	165	512	409	281	307	205
			Columbia	(101)	32	535	428	394	394	214	662	529	364	397	265
			Czech Republic	(101)	34	483	387	266	266	193	598	479	329	359	239
			France	101	35	374	299	205	205	149	463	370	254	278	185
			Germany RAG	102	35	384	307	211	211	154	476	381	262	285	190
			Germany others	101	30	495	396	272	272	198	613	490	337	368	245
			CIS	(101)	32	308	247	169	169	123	382	305	210	229	153
			Hungary	101	34	401	320	220	220	160	496	397	273	298	198
			India	103	30	551	441	303	303	220	682	545	375	409	273
			South Africa	(101)	32	569	456	313	313	228	705	504	388	423	282
			USA	(101)	34	563	450	310	310	225	697	558	383	418	279
			Venezuela	(101)	34	588	471	324	324	235	728	583	401	437	291
						η= 0	η= 0.20	η=0.45	η=0.40	η=0.60					
s	coal	bc	Czech Republic	105	28	506	405	278	304	202					
			Germany												
			- Rheinisch Coal	105	27	325	260	179	195	130					
			- Middle Germany	105	25	504	403	277	302	202					
			- East Germany	105	26	539	431	296	323	215					
			Hungary-1	105	36	379	303	208	227	151					
			Hungary-2	103	28	379	304	209	228	152					
			Poland	105	25	531	425	292	319	213					
			Portugal	105	25	461	369	254	277	185					
			Turkey-2	103	27	725	580	399	435	290					

[1] The emission factors [g/GJ] are given at full load operating modus.

[2] PM0 ... PM4 = most used combinations of primary measures; η = reduction efficiencies [ ]

PM0 - no primary measures
PM1 - one primary measure: LNB
PM2 - two primary measures: LNB/SAS
PM3 - two primary measures: LNB/OFA
PM4 - three primary measures: LNB/SAS/OFA

Table 26: NMVOC emission factors [g/GJ] for combustion plants

Type of fuel				NAPFUE code	Thermal boiler capacity [MW]					no specification
					>= 50		< 50			
					boiler	GF	boiler	Gas turbine	Stationary engine	CORINAIR90[6]
s	coal	hc	coking	101	3[5], 30[2]	50[2]	600[1]			3[6]
s	coal	hc	steam	102	3[5], 30[2]	50[2]	600[1]			1 - 15[6]
s	coal	hc	sub-bituminous	103	3[5], 30[2]	50[2]	600[1]			1.5 - 15[6]
s	coal	bc	brown coal/lignite	105	30[2],[3]	50[2]				1.5 - 15[6]
s	coal	bc	briquettes	106			150[1]			
s	coke	hc	coke oven	107			12[1]			5 - 15[6]
s	coke	bc	coke oven	108						
s	coke		petroleum	110						1.5[6]
s	biomass		wood	111	80[2]		100[5], 150[1], 400[4]			10 - 48[6]
s	biomass		charcoal	112						
s	biomass		peat	113	30[2],[3]	30[2]				3 - 48[6]
s	waste		municipal	114						10[6]
s	waste		industrial	115						
s	waste		wood	116						40 - 48[6]
s	waste		agricultural	117						50[6]
l	oil		residual	203	10[2],[3]			3[7]	50[7]	1.5 - 47.6[6]
l	oil		gas	204	5[2]		15[1]	5[2], 1.5 - 2[7]	1.5 - 100[7], 100[2]	1.5 - 9.3[6]
l	oil		diesel	205						
l	kerosene			206						3[6]
l	gasoline		motor	208						
l	naphtha			210						3[6]
l	black liquor			215						3[6]
g	gas		natural	301	5[2]			5[2], 2.5 - 4[7]	200[2]	2 - 4[6]
g	gas		liquified petroleum gas	303						2 - 2.6[6]
g	gas		coke oven	304						2.5 - 167[6]
g	gas		blast furnace	305						1 - 2.5[6]
g	gas		coke oven and blast furnace gas	306						
g	gas		waste	307						2.5[6]
g	gas		refinery	308	25[2]			2.5[7]		2.1 - 10[6]
g	gas		biogas	309						2.5[6]
g	gas		from gas works	311						

[1] LIS 1977 /92/ [2] CORINAIR 1992 /80/ [3] DBB only [4] small consumers cf. /24/ [5] power plants cf. /24/

[6] CORINAIR90 data of combustion plants as point sources with a thermal capacity of > 300, 50 - 300, < 50 MW

[7] CORINAIR90 data, point sources

Table 27: CH_4 emission factors [g/GJ] for combustion plants

Tpe of fuel				NAPFUE code	Type of combustion										stat. E.	no specification CORINAIR90[5]
					Utility combustion			Commercial comb.		Industrial combustion						
					DBB/WBB FBC/ boiler[3]	GF stoker		boiler	GF	boiler	GF stoker		GT			
						spreader	travell.				spreader	travell.	SC	CC		
s	coal	hc	coking	101	0.6[1]	0.7[1]		10[1]		2.4[1]						0.3 - 15[5]
s	coal	hc	steam	102	0.6[1]	0.7[1]		10[1]		2.4[1]						1.5 - 15[5]
s	coal	hc	sub-bituminous	103	0.6[1]	0.7[1]		10[1]		2.4[1]						0.3 - 15[5]
s	coal	bc	brown coal/lignite	105	0.6[1]	0.7[1]		10[1]		2.4[1]						
s	coal	bc	briquettes	106												
s	coke	hc	coke oven	107												0.2 - 15[5]
s	coke	bc	coke oven	108												
s	coke		petroleum	110												1.5[5]
s	biomass		wood	111	18[1]			15[1]		15[1]						1 - 40[5]
s	biomass		charcoal	112												
s	biomass		peat	113												1 - 39[5]
s	waste		municipal	114				6.5[1),4)]								1[5]
s	waste		industrial	115												10[5]
s	waste		wood	116												4 - 40[5]
s	waste		agricultural	117				9[1),4)]								32[5]
l	oil		residual	203	0.7[1]			1.6[1]		2.9[1]			3[5]		3[6]	0.1 - 10[5]
l	oil		gas	204	0.03[1]			0.6[1]					1 - 8[5]		1.5[6]	0.1 - 8[5]
l	oil		diesel	205												
l	kerosene			206												7[5]
l	gasoline		motor	208												
l	naphtha			210												3[5]
l	black liquor			215												1 - 17.7[5]
g	gas		natural	301	0.1[1]			1.2[1] [2]		1.4[1]			2.5 - 4[6]			0.3 - 4[5]
													5.9[1]	6.1[1]		
g	gas		liquified petroleum gas	303												1 - 2.5[5]
g	gas		coke oven	304												0.3 - 4[5]
g	gas		blast furnace	305												0.3 - 2.5[5]
g	gas		coke oven and blast furnace gas	306												
g	gas		waste	307												2.5[5]
g	gas		refinery	308												0.1 - 2.5[5]
g	gas		biogas	309									2.5[6]			0.5 - 2.5[5]
g	gas		from gas works	311												

[1] Radian 1990 /102/, IPCC 1994 /88/ [2] for all types of gas [3] DBB/WBB/FBC for coal combustion; boiler for fuel combustion [4] open burning

[5] CORINAIR90 data of combustion plants as point sources with thermal capacity of >300, 50 - 300 and <50 MW

[6] CORINAIR90 data, point sources

Table 28: CO emission factors [g/GJ] for combustion plants

					Type of combustion										no specification
					Utility combustion			Commercial comb.		Industrial combustion					
Type of fuel				NAPFUE code	DBB/WBB/ boilers$^{1)}$	GF stoker		boiler	GF	DBB/WBB/ boiler$^{1)}$	GF stoker		GT	stat. E.	CORINAIR90$^{9)}$
						spreader	travell.				spreader	travelling			
s	coal	hc	coking	101	14$^{3)}$	121$^{3)}$		195$^{3)}$		9.7$^{2)}$, 13$^{4)}$	81$^{2)}$, 115$^{4)}$	97.2$^{2)}$			15$^{9)}$
s	coal	hc	steam	102	14$^{3)}$	121$^{3)}$		195$^{3)}$		9.7$^{2)}$, 13$^{4)}$	115$^{4)}$	9.7$^{2)}$			10 - 175.2$^{9)}$
s	coal	hc	sub-bituminous	103	14$^{3)}$	121$^{3)}$		195$^{3)}$		9.7$^{2)}$, 13$^{4)}$	81$^{2)}$, 115$^{4)}$	97.2$^{2)}$			12 - 246.9$^{9)}$
s	coal	bc	brown coal/lignite	105	14$^{3)}$	121$^{3)}$		195$^{3)}$		16$^{2)}$, 13$^{4)}$	133$^{2)}$, 115$^{4)}$	160$^{2)}$			9.6 - 64.4$^{9)}$
s	coal	bc	briquettes	106											
s	coke	hc	coke oven	107											102 - 121$^{9)}$
s	coke	bc	coke oven	108											
s	coke		petroleum	110											15$^{9)}$
s	biomass		wood	111	1,473$^{3)}$			199$^{3)}$		1,504$^{3)}$					30 - 300$^{9)}$
s	biomass		charcoal	112											
s	biomass		peat	113											30 - 160$^{9)}$
s	waste		municipal	114		98$^{3),6)}$		19$^{3)}$			19$^{3)7)}$, 96$^{3)7)}$, 42 kg/Mg$^{3),8)}$				30$^{9)}$
s	waste		industrial	115											
s	waste		wood	116											12 - 300$^{9)}$
s	waste		agricultural	117				58 kg/Mg$^{3),8)}$							20$^{9)}$
l	oil		residual	203	15$^{3)}$			17$^{3)}$		15$^{3)}$			10 - 15$^{10)}$	100$^{10)}$	3 - 32.6$^{9)}$
l	oil		gas	204	15$^{3)}$			16$^{3)}$		12$^{3)}$			10 - 20$^{10)}$ 20.6$^{11)}$	12 - 1,130$^{10)}$	10 - 46.4$^{9)}$
l	oil		diesel	205											
l	kerosene			206											12$^{9)}$
l	gasoline		motor	208											
l	naphtha			210											15$^{9)}$
l	black liquor			215											11.1 - 314$^{9)}$
g	gas		natural	301	19$^{3)}$			9.6$^{3)}$		17$^{3)}$, 13$^{5)}$				10 - 20$^{10)}$, 32$^{3)}$	0.05 - 60$^{9)}$
g	gas		liquified petroleum gas	303											10 - 13$^{9)}$
g	gas		coke oven	304											0.03 - 130$^{9)}$
g	gas		blast furnace	305											0.3 - 64.4$^{9)}$
g	gas		coke oven and blast furnace gas	306											
g	gas		waste	307											0.1 - 25.5$^{9)}$
g	gas		refinery	308										10$^{10)}$	2 - 15$^{9)}$
g	gas		biogas	309											13$^{9)}$
g	gas		from gas works	311											

[1] DBB/WBB for coal combustion; boiler for other fuel combustion

[2] EPA 1987 /85/, CORINAIR 1992 /80/

[3] Radian 1990 /102/, IPCC 1994 /88/, without primary measure

[4] OECD 1989 /100/, CORINAIR 1992 /80/

[5] CORINAIR 1992 /80/, part 8

[6] grate firing without specification

[7] small combustion 19 g/GJ, mass burning 96 g/GJ

[8] open burning

[9] CORINAIR90 data of combustion plants as point sources with a thermal capacity of > 300, 50 - 300, < 50 MW

[10] CORINAIR90 data, point sources

[11] AP42 /115/

Table 29: CO_2 emission factors [kg/GJ] for combustion plants

				NAPFUE	Emission factors		
Type of fuel				code	value	range	remarks
s	coal	hc	coking	101		92 - 93 5), 89.6 - 94 2)	
s	coal	hc	steam	102	93.7 3), 92 5)	92 - 93 5), 10 - 98 2)	
s	coal	hc	sub-bituminous	103	94.7 3)	91 - 115.2 2)	
s	coal	bc	brown coal/lignite	105	100.2 3)	94 - 107.9 2), 110 - 113 5)	
s	coal	bc	briquettes	106	98	97 - 99 5)	
s	coke	hc	coke oven	107	95.9 4), 108 1)	100 - 105 5), 105 - 108 2)	
s	coke	bc	coke oven	108		96 - 111 5)	
s	coke		petroleum	110	101 5), 121.2 4), 100.8 2)		
s	biomass		wood	111	100 1), 124.9 4)	92 - 100 2)	
s	biomass		charcoal	112			
s	biomass		peat	113	98 5)	102 - 115 2)	
s	waste		municipal	114	15 5), 28 2)	109 - 141 1)	
s	waste		industrial	115		13.5 - 20 5)	
s	waste		wood	116		83 - 100 2)	
s	waste		agricultural	117			
l	oil		residual	203	75.8 4), 76.6 3), 78 5)	15 - 93 2)	petroleum oil 72.6 3)
l	oil		gas	204	72.7 4), 74 5), 75 1)	73 - 74 5), 57 - 75 2)	
l	oil		diesel	205	72.7 4), 73 5)		
l	kerosene			206	73.3 2)	72 - 74 5)	
l	gasoline		motor	208	70.8 3), 71.7 4), 72.2 1)	72 - 74 5)	
l	naphtha			210	72.6 3), 74 2)		
l	black liquor			215		100 - 110 2)	
g	gas		natural	301	55.5 3), 60.8 4)	55 - 56 5), 44 - 57 2)	
g	gas		liquified petroleum gas	303		64 - 65 5), 57 - 65 2)	
g	gas		coke oven	304	44 5)	44 - 49 5), 41.6 - 90 2)	
g	gas		blast furnace	305	105 5)	100 - 105 5), 92 - 280 2)	
g	gas		coke oven and blast furnace gas	306			
g	gas		waste	307		44.4 - 57 2)	
g	gas		refinery	308	60 5)		
g	gas		biogas	309	75 2)	10.5 - 73.3 2)	
g	gas		from gas works	311	52 2)		

1) Schenkel 1990 /105/

2) CORINAIR90 data on combustion plants as point sources with thermal capacity of > 300, 50 - 300, < 50 MW

3) IPCC 1993 /87/

4) Kamm 1993 /89/

5) BMU 1994 /77/

Table 30: N_2O emission factors [g/GJ] for combustion plants

Type of fuel				NAPFUE code	Type of boiler								GT	stat. E.	no speci-fication CORINAIR90$^{4)}$
					DBB		WBB		FBC		GF				
					value	remarks	value	remarks	value	remarks	value	remarks			
s	coal	hc	coking	101	0.8 $^{1)}$	utility, no PM$^{3)}$	0.8 $^{1)}$	utility, no PM$^{3)}$			0.8 $^{1)}$	utility, no PM$^{3)}$			14$^{4)}$
s	coal	hc	steam	102	0.8 $^{1)}$	utility, no PM$^{3)}$	0.8 $^{1)}$	utility, no PM$^{3)}$			0.8 $^{1)}$	utility, no PM$^{3)}$			2.5 - 100$^{4)}$
s	coal	hc	sub-bituminous	103	0.8 $^{1)}$	utility, no PM$^{3)}$	0.8 $^{1)}$	utility, no PM$^{3)}$			0.8 $^{1)}$	utility, no PM$^{3)}$			2.5 - 30$^{4)}$
s	coal	bc	brown coal/lignite	105	0.8 $^{1)}$	utility, no PM$^{3)}$					0.8 $^{1)}$	utility, no PM$^{3)}$			1.4 - 30$^{4)}$
s	coal	bc	briquettes	106											
s	coke	hc	coke oven	107											1.4 - 25$^{4)}$
s	coke	bc	coke oven	108											
s	coke		petroleum	110											14$^{4)}$
s	biomass		wood	111	4.3 $^{1)}$	commercial, no PM$^{3)}$			4.3 $^{1)}$	commercial, no PM$^{3)}$	4.3 $^{1)}$	commercial, no PM$^{3)}$			1.4 - 75$^{4)}$
s	biomass		charcoal	112											
s	biomass		peat	113											2 - 75$^{4)}$
s	waste		municipal	114					14 - 165 $^{2)}$	g/t waste	11 - 270 $^{2)}$	g/t waste			4$^{4)}$
s	waste		industrial	115											1.4$^{4)}$
s	waste		wood	116											2 - 6$^{4)}$
s	waste		agricultural	117											5$^{4)}$
l	oil		residual	203	46.5 $^{1)}$	commercial, no PM$^{3)}$							2.5 - 14$^{5)}$	2.5$^{5)}$	1.4 - 14.8$^{4)}$
l	oil		gas	204	15.7 $^{1)}$	commercial, no PM$^{3)}$							2 - 3$^{5)}$	2.5$^{5)}$	0.6 - 14$^{4)}$
l	oil		diesel	205											
l	kerosene			206											14$^{4)}$
l	gasoline		motor	208											
l	naphtha			210											14$^{4)}$
l	black liquor			215											1 - 21.4$^{4)}$
g	gas		natural	301	2.4 $^{1)}$	commercial, no PM$^{3)}$								1 - 3$^{5)}$	0.1 - 3$^{4)}$
g	gas		liquified petroleum gas	303											2 - 4.3$^{4)}$
g	gas		coke oven	304											1.1 - 3$^{4)}$
g	gas		blast furnace	305											1.1 - 3$^{4)}$
g	gas		coke oven and blast furnace	306											
g	gas		waste	307											1.1 - 2.5$^{4)}$
g	gas		refinery	308										2.5$^{5)}$	2.5 - 14$^{4)}$
g	gas		biogas	309											1.4 - 2.5$^{4)}$
g	gas		from gas works	311											

[1] Radian 1990 /102/, IPCC 1994 /88/ [2] DeSoete 1993 /83/, IPCC 1994 /88/ [3] PM: Primary measure [5] CORINAIR90 data, point sources

[4] CORINAIR90 data on combustion plants as point sources with thermal capacity of > 300, 50 - 300, < 50 MW

Table 31: Heavy metal emission factors (g/Mg fuel) for combustion plants

					Thermal boiler capacity [MW]								
					>= 300				>= 50 and < 300				< 50
					Type of boiler				Type of boiler				
Type of fuel			NAPFUE code	Heavy metal element	DBB		WBB		DBB	WBB	FBC	GF	GF
					Dust control [1]	Dust control and FGD [2]	Dust control [1]	Dust control and FGD [2]					
s	coal	hc	101/102	Mercury	0.05 - 0.2	0.02 - 0.08	0.05 - 0.2	0.02 - 0.08					
				Cadmium	0.003 - 0.01	0.0001 - 0.004	0.01 - 0.07	0.004 - 0.03					
				Lead	0.02 - 1.1	0.007 - 0.5	0.3 - 3	0.1 - 1.2					
				Copper	0.01 - 0.4	0.006 - 0.2	0.05 - 0.4	0.05 - 0.2					
				Zinc	0.03 - 1.3	0.01 - 0.5	0.5 - 4	0.2 - 1.6					
				Arsenic	0.03 - 0.3	0.01 - 0.1	0.1 - 0.8	0.04 - 0.3					
				Chromium	0.04 - 0.2	0.02 - 0.06	0.05 - 0.4	0.02 - 0.2					
				Selen	0.01 - 0.03	0.004 - 0.01	-	-					
				Nickel	0.03 - 0.4	0.01 - 0.5	0.2 - 0.5	0.1 - 0.2					
s	coal	bc	105	Mercury	0.05 - 0.2	0.02 - 0.08							
				Cadmium	0.002 - 0.004	0.0008 - 0.001							
				Lead	0.003 - 0.06	0.001 - 0.02							
				Copper	0.004 - 0.02	0.002 - 0.01							
				Zinc	0.01 - 0.2	0.006 - 0.1							
				Arsenic	0.03 - 0.04	0.008 - 0.01							
				Chromium	0.003 - 0.07	0.001 - 0.03							
				Selen	-	-							
				Nickel	0.02 - 0.04	0.01							
l	oil, heavy fuel		203	Mercury	$1.0^{4)}$								
				Cadmium	$1.0^{4)}$								
				Lead	$1.3^{4)}$								
				Copper	$1.0^{4)}$								
				Zinc	$1.0^{4)}$								
				Arsenic	$0.5^{4)}$								
				Chromium	$2.5^{4)}$								
				Selen									
				Vanadium	$4.4^{5)}$								
				Nickel	$35^{4)}$								
g	gas, natural		301	Mercury	0.05 - 0.15 g/TJ$^{3)}$								

[1] clean gas particle concentration 50 mg/m [3] 2 mg/m^3 gas UBA 1980 /63/; 5 mg/m^3 PARCOM 1992 /101/ [5] Jockel 1991 /36/

[2] FGD = Flue gas desulphurisation, clean gas particle concentration 20 mg/m^3 [4] general emission factor according to Stobbelaar 1992 /37/

9 SPECIFIC PROFILES

9.1 SO_x emissions

Sulphur dioxide SO_2 and sulphur trioxide SO_3 are formed in the flame. Emissions of SO_2 and SO_3 are often considered together as SO_x. Due to the equilibrium conditions at furnace temperature, sulphur trioxide SO_3 normally decomposes to sulphur dioxide SO_2. Then the amount of SO_2 in the flue gas is approximately 99 %. Therefore, SO_x is given in this chapter as SO_2.

9.2 NO_x emissions

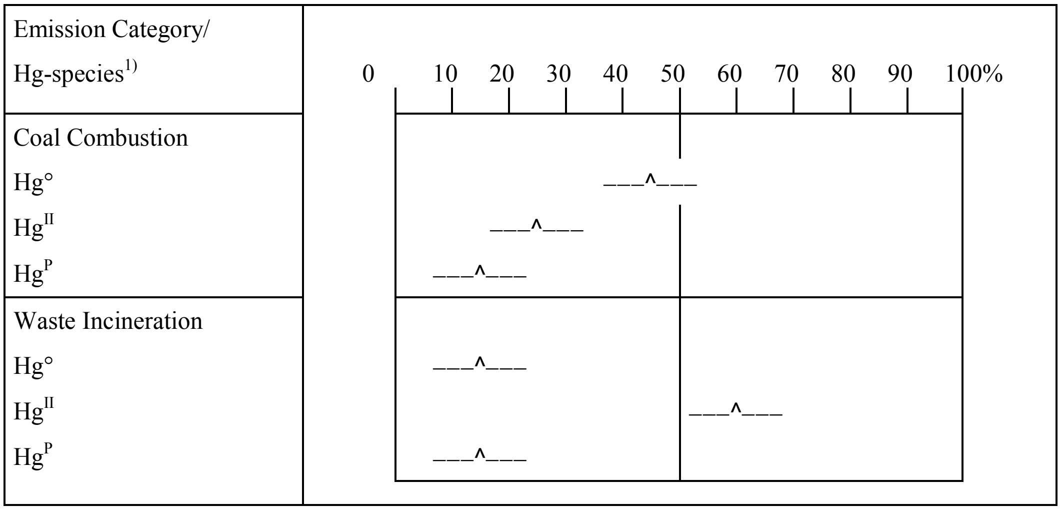
The most important oxides of nitrogen formed with respect to pollution are nitric oxide (NO) and nitrogen dioxide (NO_2), jointly referred to as NO_x. The main compound is NO, which contributes over 90 % to the total NO_x. Other oxides of nitrogen, such as dinitrogen-trioxide (N_2O_3), dinitrogen-tetroxide (N_2O_4), and dinitrogen-pentoxide (N_2O_5), are formed in negligible amounts. Nitrous oxide (N_2O) is considered separrately.

9.3 NMVOC emissions

Due to the minor relevance of NMVOC emissions for power plants no split of species is given.

9.4 Heavy metal emissions

The heavy metals, which are of most environmental concern, are: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn). This selection has been laid down by the UN-ECE Task Force on Heavy Metals, the PARCOM/ATMOS programme (cf. /35/) and the HELCOM programme. In the case of heavy oil combustion, vanadium emissions (V) are also of importance. In fly ash particles most of these elements occur as oxides or chlorides. The contribution of various forms of mercury to the emissions from combustion source categories in Europe is given in the following Figure 2:



[1] Hg° elemental form
Hg^{II} oxidised form
Hg^{P} particle-bound

Figure 2: Contribution of various forms of mercury to the emissions from combustion source categories in Europe in 1987 (in % of total) /29/

10 UNCERTAINTY ESTIMATES

Uncertainties of emission data result from the use of inappropriate or inaccurate emission factors, and from missing or inappropriate statistical information concerning activity data. Uncertainty estimates discussed here are related to the use of emission factors with different background information. At this stage a quantification of the uncertainty related to the use of emission factors is not feasible, due to the limited availability of data. However, the precision of emission estimates can be improved by applying individually determined emission factors.

The aim of the following procedure is to show the Guidebook-user how a lack of information concerning the fuel and technical characteristics of a combustion facility gives rise to a high uncertainty in the allocation of the appropriate emission factor. The whole span of possible emission factors is defined by the specification of the type of fuel used, the type of boiler, and the type of primary and secondary measures. The more information about these topics can be gathered, the smaller the span of possible emission factors becomes.

The following diagram (Figure 3) gives as an example the range of NO_x emission factors [g/GJ] for pulverised coal combustion depending on the level of specification.

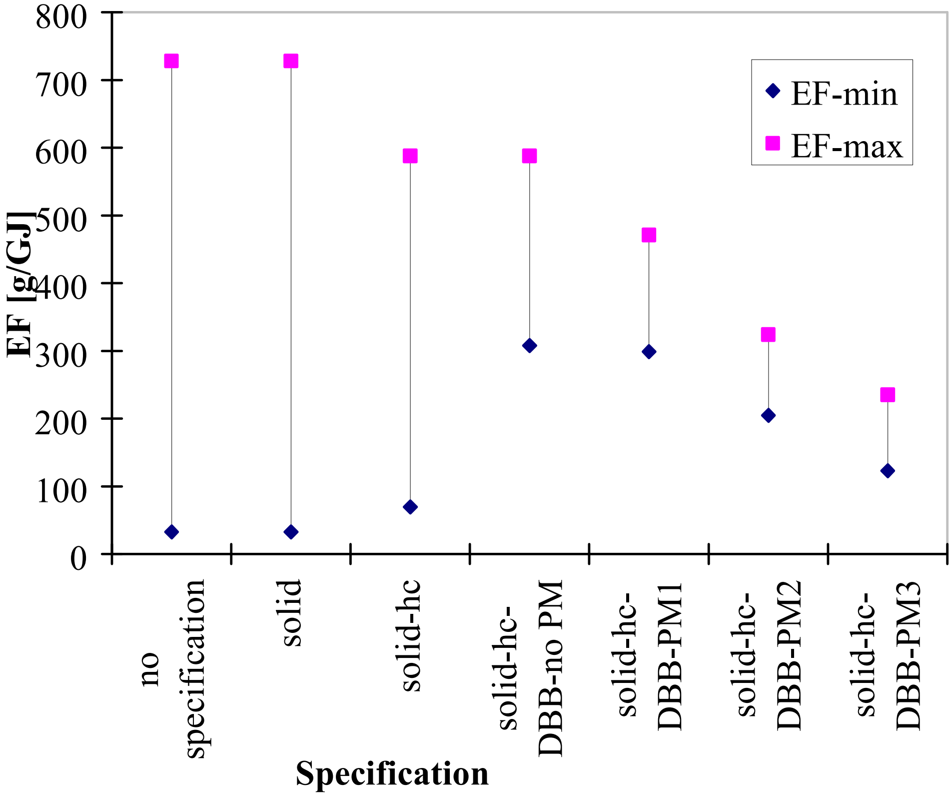


Figure 3: Ranges of NO_x emission factors for the combustion of pulverised coal

The level of specification is defined as follows:

- „no information“	- the whole range of combustion sources is taken into account,
- „solid“	- only solid fuels are taken into account,
- „solid-hc“	- only hard coal is considered,
- „solid-hc-DBB-no PM“	- hard coal and combustion technique are taken into account (here dry bottom boiler (DBB), without primary measures),
- „solid-hc-DBB-PM1“	- hard coal, DBB and primary measures are taken into account with a reduction efficiency of 0.2 ,
- „solid-hc-DBB-PM2“	- hard coal, DBB and primary measures are taken into account with a reduction efficiency of 0.45 ,
- „solid-hc-DBB-PM3“	- hard coal, DBB and primary measures are taken into account with a reduction efficiency of 0.6 .

In Figure 3 a large difference between minimum and maximum emission factors indicates high uncertainties in the allocation of appropriate emission factors. A specification of emission factors only concerning the type of fuel used (e.g. hard coal) is not sufficient. The range of NO_x emission factors for the combustion of pulverised coal is significantly reduced if technique related specifications are considered.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The weakest aspects discussed here are related to the determination of emission factors. Methodological shortcomings are discussed in this section for the main pollutants SO_2, NO_X and heavy metals.

11.1 SO_2 emissions

The approach for the determination of SO_2 emission factors is based on a simple mass balance calculation as the formation mechanisms of sulphur dioxide within the boiler depend almost entirely on the sulphur input. Therefore, for the formation of sulphur dioxide, fuel characteristics are of main influence. The accuracy of this approach is determined by the following fuel parameters: lower heating value, fuel sulphur content and sulphur retention in ash (see Equation (5)). The sulphur content and the lower heating value can be highly variable between different fuel categories and can furthermore vary to a large extent within one fuel category. Therefore, default values for sulphur content and lower heating value should be avoided. However, if emission factors for SO_2 have to be calculated, representative values for the sulphur content and the lower heating value should be based on measured data from individual fuel analysis.

The sulphur retention in ash α_S depends mainly on the content of alkaline components of the fuel. This is only relevant for coal (e.g. CaO, MgO, Na_2O, K_2O) and for the case of additive injection. For a more precise determination of α_S, the Ca/S ratio (amount of calcium/sulphur content of fuel)[8], the particulate diameter, the surface character of CaO, the temperature (optimum ca. 800 °C), the pressure, the residence time, etc. should be taken into account. Therefore, the assessment of α_S should be based on an extended set of parameters.

Besides the fuel characteristics, the reduction efficiency and availability of secondary measures are of relevance for the determination of the SO_2 emission factors. Default values are proposed in Table 7, but measured data from individual combustion plants should preferably be used.

11.2 NO_X EMISSIONS

The approach for the calculation of NO_X emission factors is based on empirical relations. For fuel-NO only fuel characteristics are taken into account. The formation of thermal-NO increases exponentially with combustion temperatures above 1,300 °C (see /56/). At this

---

[8] Alternatively the Ca/S ratio is defined as the amount of additives related to the sulphur content of the flue gas, and is given for a brown coal fired dry bottom boiler as 2.5 - 5 as an example, for a stationary FBC as 2 - 4, for a circulating FBC < 2 etc. /55/.

stage, no satisfactory result has been achieved to determine the thermal-NO formation by using kinetic equations. For inventory purposes, an empirical parameter γ has been introduced (see Annex 5), which represents the fraction of thermal-NO formed. At this stage default values of γ depending on the type of boiler are given. Further work should focus on a more precise determination of this factor.

Load dependence of the pollutant NO_x has been taken into account. For old installations a quantitative relation has been given as an example for German power plants. The validity of this relation should be verified for other countries.

Furthermore, the reduction efficiency of primary or secondary measures are of relevance for the determination of NO_x emission factors. Default values for reduction efficiencies and availabilities are proposed in Tables 10 and 11, but measured data from individual combustion plants should preferably be used.

11.3 Heavy metals

Heavy metals undergo complex transformations during the combustion process and downstream of the boiler, referring to e.g. fly ash formation mechanisms. The approaches for the determination of heavy metal emission factors are based on empirical relations, where fuel and technical characteristics are of main influence. The heavy metal contents can be highly variable between different fuel categories (e.g. coal and heavy fuel oil) and can furthermore vary to a large extent within one fuel category (up to 2 orders of magnitude). Therefore, default values for heavy metal contents in fuel should be avoided and measured values should be used as far as possible.

For inventory purposes, parameters, such as enrichment factors, fractions of fly ash leaving the combustion chamber, fraction of heavy metals emitted in gaseous form, have been introduced. Further work should be invested into a more precise determination of these parameters. In addition, it should be taken into account, that the reduction efficiency of (dust) abatement measures depends on the heavy metal. Heavy metal specific reduction efficiencies should be determined.

11.4 Other aspects

Emission factors for SO_2, NO_2 and CO, whether calculated or given in the tables, are related to full load conditions. In order to assess the relevance of start-up emissions, a detailed investigation has been accomplished by using measured values from different types of boiler (see also Annex 15). The qualitative and quantitative statements obtained in this approach should be verified.

The emission factors have been determined by considering the pollutants separately. Possible mutual interactions between the formation mechanisms of different pollutants (e.g. NO and N_2O) have been neglected and should be assessed in further work.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

This section is not relevant for combustion plants considered as point sources.

13 TEMPORAL DISAGGREGATION CRITERIA

The temporal disaggregation of annual emission data (top-down approach) provides a split into monthly, weekly, daily and hourly emission data. Temporal disaggregation of annual emissions released from combustion plants as point sources can be obtained from the temporal change of the production of electrical power or the temporal change of the consumption, taking into account a split into:

- summer and winter time,
- working days and holidays,
- standstill times,
- times of partial load behaviour and
- number of start-ups / type of load design.

This split should be carried out for defined categories of power plants which take into account the main relevant combinations of types of fuel used and types of boiler installed (similar split as used for the emission factor Tables in Section 8).

The disaggregation of annual emissions into monthly, daily or hourly emissions can be based on a step-by-step approach /76/ according to the following equations:

- Monthly emission:

$$E_{M_n} = \frac{E_A}{12} \cdot f_n \tag{25}$$

E_{M_n}	Emission in month n; n = 1, ..., 12 [Mg]
E_A	Annual emission [Mg]
f_n	Factor for month n; n = 1, ..., 12 [ ]

- Daily emission:

$$E_{D_{n,k}} = \frac{E_{M_n}}{D_k} \cdot f_k \cdot \frac{1}{CF_n} \tag{26}$$

$E_{D_{n,k}}$	Emission of day k in month n; k = 1, ..., D_k ; n = 1, ..., 12 [Mg]
E_{M_n}	Emission in month n; n = 1, ..., 12 [Mg]
D_k	Number of days in month n [ ]
f_k	Factor for day k; k = 1, ..., D_k [ ]
CF_n	Correction factor for month n [ ]

- Hourly emission:

$$E_{H_{n,k,l}} = \frac{E_{D_{n,k}}}{24} \cdot f_{n,l} \tag{27}$$

$E_{H_{n,k,l}}$ Emission in hour l in day k and month n; l = 1, ..., 24; k = 1, ..., D_k ; n = 1, ..., 12 [Mg]

$E_{D_{n,k}}$ Emission of day k in month n; k = 1, ..., D_k ; n = 1, ..., 12 [Mg]

$f_{n,l}$ Factor for hour l in month n; l = 1, ..., 24; n = 1, ..., 12 [ ]

D_k Number of days in month n [ ]

The factors (relative activities) for month f_n, day f_k and hour $f_{n,l}$ can be related e.g. to the total fuel consumption or the net electricity production in public power plants. Figure 4 gives an example of a split for monthly factors based on the fuel consumption e.g. for Public Power Plants:

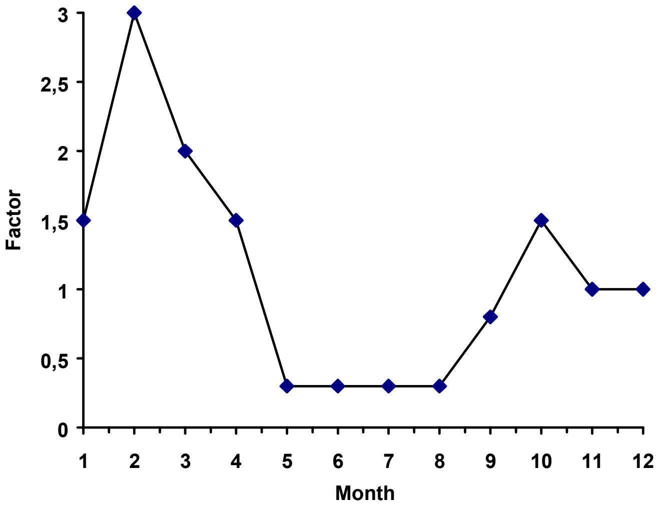
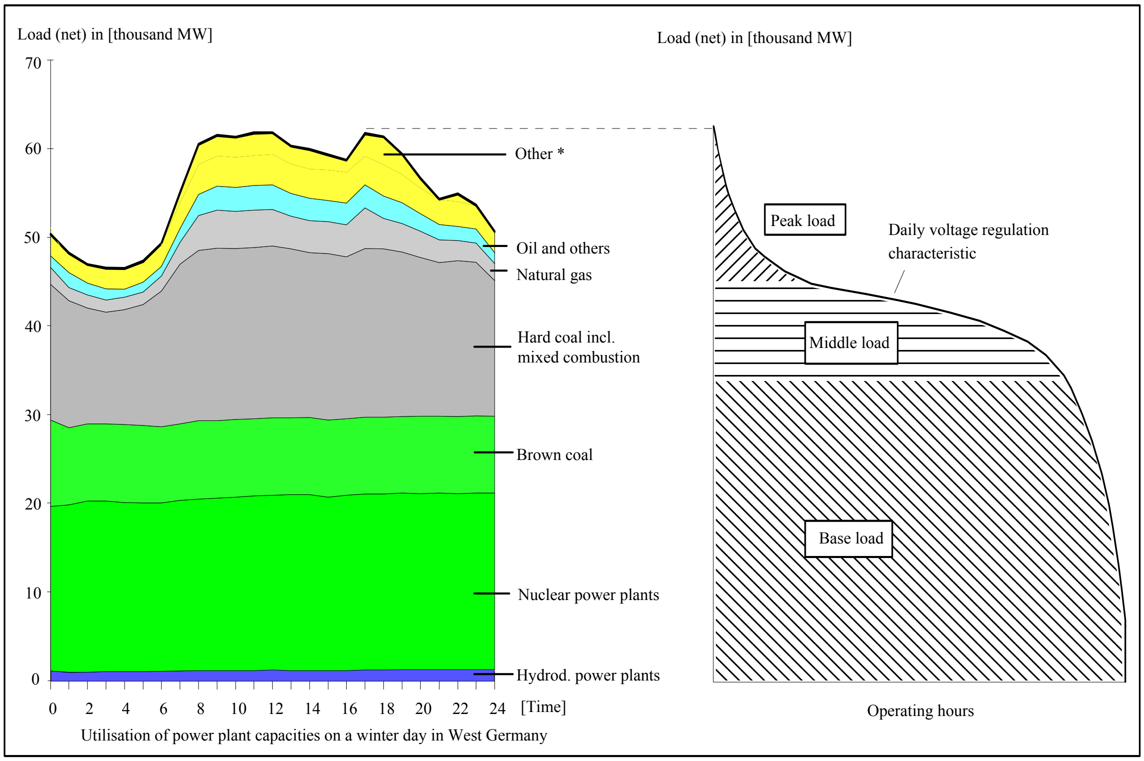


Figure 4: Example of monthly factors for total fuel consumption in Public Power Plants

A split concerning the load design, which determines the annual number of start-ups can be given as follows (see also Table 11):

- Base load: The boiler/plant is normally in continuous operation during the year; start-ups occur relatively seldom (ca. 15 times per year) depending on maintenance periods which occur mostly in summer. The fuel mostly used in base load boilers is brown coal.
- Middle load: The boiler/plant is in operation in order to meet the energy demand on working days (Monday until Friday); start-ups can occur up to 150 times per year. The fuel mostly used in middle load boilers is hard coal.
- Peak load: The boiler/plant is in operation in order to meet the short term energy demand; start-ups can occur up to 200 times per year. The fuels mostly used in peak load boilers are gas or oil.

The allocation of power plants to the different load designs is given as an example in Figure 5.



*Other includes: Storage pump power plants, power supply from industry etc.

Figure 5: Load variation and arrangement of power plants according to the voltage regulation characteristic (cf. /117/, /118/).

It can be assumed that all power plants of a country with the same allocation of fuel, boiler and load have the same temporal behaviour.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

15.1 Computer programme

A computer programme for the calculation of SO_2 and NO_2 emission factors for pulverised coal combustion has been designed, and is available on floppy disc. It has been designed under MICROSOFT EXCEL 4.0 (English version). Default values for the required input data are proposed to the user; a detailed users manual is given in Annex 14. For example, NO_X concentrations in [mg/m³] were calculated with the computer programme and presented together with the emission factors in [g/GJ] as listed in Annexes 10 and 11. An integral part of the computer programme is the calculation of the flue gas volume as given in Annex 6.

15.2 LIST OF ANNEXES

Annex 1: Example of different possible considerations of boilers as a common plant

Annex 2: Determination of SO_2 emission factors (flow sheet)

Annex 3: Determination of SO_2 emission factors (description)

Annex 4: Determination of NO_X emission factors (flow sheet)

Annex 5: Determination of NO_X emission factors (description)

Annex 6: Determination of the specific flue gas volume (flow sheet and description)

Annex 7: Composition and lower heating value (H_u) of hard coal in coal mining countries

Annex 8: Composition and lower heating value (H_u) of brown coal in coal mining countries

Annex 9: Conditions for exemplary calculation of NO_X emission factors

Annex 10: Emission factors and flue gas concentrations for NO_X obtained by model calculations (see Annexes 4 and 5) for hard coal (see Annex 7)

Annex 11: Emission factors and flue gas concentrations for NO_X obtained by model calculations (see Annexes 4 and 5) for brown coal (see Annex 8)

Annex 12: Comparison between measured and calculated SO_2 and NO_X emission data

Annex 13. Sensitivity analysis of the computer programme results

Annex 14: Users' manual for the emission factor calculation programme (for version September, 1995)

Annex 15: Determination of start-up emissions and start-up emission factors.

Annex 16: List of abbreviations

16 VERIFICATION PROCEDURES

As outlined in the chapter "Concepts for Emission Inventory Verification", different general verification procedures can be recommended. The aim of this section is to develop specific verification procedures for emission data from combustion plants as point sources. The verification procedures considered here are principally based on verification on a national and on a plant level. Moreover, it can be distinguished between the verification of activity data, of emission factors and of emission data.

16.1 Verification on a national level

For combustion plants as point sources, emissions and activities have to be verified. The total emissions from point sources are added together to obtain national total emissions (bottom-up approach). These national total emissions should be compared to emission data derived independently (top-down approach). Independent emission estimates can be obtained by using average emission factors and corresponding statistical data like the total fuel input for all sources, total thermal capacity, total heat or power produced, or by using emission estimates from other sources (e.g. organisations like energy agencies).

The total fuel consumption should be reconciled with energy balances, which often have break-downs for large point sources (e.g. electricity, heat generation and industrial boilers). Furthermore, the total number of plants installed as well as their equipment should be checked with national statistics.

Emission density comparisons can be achieved through comparison of e.g. emissions per capita or emissions per GDP with those of countries with a comparable economic structure.

16.2 Verification on a plant level

It should firstly be verified that separate inventories have been compiled for boilers, stationary engines, and gas turbines (according to SNAP code). The verification at plant level relies on comparisons between calculated emission factors and those derived from emission measurements. An example for such a comparison is given in Annex 12.

17 REFERENCES

/1/ Bretschneider, B.: Paper presented at the second panel meeting, Karlsruhe; Oct. 21/22, 1993

/2/ Hietamäki, M.: Personal communication, October 21, 1993

/3/ Fontelle, J.-P.: Paper presented at the first panel meeting, Karlsruhe; Feb. 18/19, 1993

/4/ Umweltbundesamt (ed.): Daten zur Umwelt 1990/91; Berlin; 1992

/5/ Civin, V.: Personal communication, October 21, 1993

/6/ Pulles, M.P.J.: Emission Inventory in the Netherlands, Industrial Emissions for 1988; Ministry of Housing, Physical Planning and Environment (ed.); s´-Gravenhage; Dec. 1992

/7/ Berdowski, J.J.M.: Combustion Emissions from Large Combustion Plants in the Netherlands in 1990 and 1991; Ministry of Housing, Physical Planning and Environment (ed.); s´-Gravenhage; March 1993

/8/ Paper presented by Mr. Debski at the first panel meeting: „Electricity generation and emission statistics"; Karlsruhe; Feb. 18/19, 1993

/9/ Council Directive of 24 November 1988 on the limitation of emissions of certain pollutants into the air from large combustion plants (88/699/EEC)

/10/ Proceedings of the second meeting of the UN-ECE Task Force on Heavy Metal Emissions, Prague, October 15 - 17, 1991

/11/ Neckarwerke Elektrizitätsversorgungs-AG, Kraftwerk Walheim, Block 2: Demonstrationsanlage zur Reduzierung von NO_X-Emissionen aus Schmelzkammerkessel mit Ascherückführung, Abschlußbericht, Gesch.-Z: II 1.1-50441-1/43

/12/ Clarke, L.B.; Sloss, L.L.:Trace Element - Emissions from Coal Combustion and Gasification, IEA Coal Research, Rep.-Nr. IEACR, 1992

/13/ DeSoete, G.; Sharp, B.: Nitrous oxide emissions: Modifications as a consequence of current trends in industrial fossil fuel combustion and in land use; Commission of the European Communities (ed.), Brussels, Luxemburg, 1991

/14/ Andersson, Curt; Brännström-Norberg, Britt-Marie; Hanell, Bengt: Nitrous oxide emissions from different combustion sources; Swedish State Power Broad, Vaellingby (Schweden), 1989

/15/ DIN 51603: Flüssige Brennstoffe; Teil 1: Heizöl EL, Mindestanforderungen (1995); Teil 2: Heizöle L, T und M, Anforderungen an die Prüfung (1992)

/16/ VDI Richtlinie 2297: Emissionsminderung; Ölbefeuerte Dampf- und Heißwassererzeuger; 1982

/17/ Kolar, Jürgen; Stickstoffoxide und Luftreinhaltung, Springer Verlag Berlin, Heidelberg, New York, 1990

/18/ Rentz, O; Dorn, R.; Holschumacher, R.; Padberg, C.: Application of advanced SO_2 and NO_X emission control technologies at stationary combustion installations in OECD countries; Institute for Industrial Production, University of Karlsruhe; June 1992

/19/ Rentz, O.; Ribeiro, J.: NO_X Task Force - Operating Experience with NO_X Abatement at Stationary Sources; Report for the ECE; Dec. 1992

/20/ Gutberlet, H: Measurement of heavy metal removal by a flue gas desulfurization plant working by the lime scrubbing method, Research report No. ENV-492-D(B), Luxembourg, Commission of the European Communities, 1988

/21/ Maier, H.; Dahl, P.; Gutberlet, H.; Dieckmann, A.: Schwermetalle in kohlebefeuerten Kraftwerken, VGB Kraftwerkstechnik, 72(1992)5, S. 439

/22/ Fahlke, J.: Untersuchungen zum Verhalten von Spurenelementen an kohlebefeuerten Dampferzeugern unter Berücksichtigung der Rauchgaseinigungsanlagen, VGB Kraftwerkstechnik, 73(1993)3, S. 254

/23/ Gutberlet, H.; Spiesberger, A.; Kastner, F.; Tembrink, J.: Zum Verhalten des Spurenelements Quecksilber in Steinkohlenfeuerungen mit Rauchgasreinigungsanlagen, VGB Kraftwerkstechnik, 72(1992)7, S. 636 - 641

/24/ Rentz, O.; Holtmann, T.; Oertel, D.; Röll, C. et al: Konzeption zur Minderung der VOC-Emissionen in Baden-Württemberg; Umweltministerium Baden-Württemberg (ed.); Heft 21; Karlsruhe (Germany), 1993

/25/ Hulgaard, Tore: Nitrous Emissions from Danish Power Plants; Danmarks Tekuiske Hoejkole, Lyngby (Denmark); Institute for Kemiteknik, 1990

/26/ Clayton, Russ; Sykes, Alston; Machilek, Rudi; Krebs, Ken; Ryan, Jeff: NO Field study; prepared for the US-EPA; Research Triangle Park (NC), 1989

/27/ Bonn, B.: NO_x-Emissionen bei Wirbelschichtfeuerungen; VDI-Berichte Nr. 1081; Düsseldorf (Germany), 1993

/28/ Economic Commission for Europe: NO_X Task Force - Technologies for Controlling NO_X Emissions from Stationary Sources, April 1986

/29/ UN-ECE Task Force on Heavy Metal Emissions: State-of-the-Art Report; 1994

/30/ IEA-coal research (ed.): The problems on sulphur; London 1989

/31/ EVT Energie- und Verfahrenstechnik GmbH (ed.): Taschenbuch; Stuttgart, 1990

/32/ Reidick, H.: Primärmaßnahmen zur NO_X-Minderung bei Neu- und Altanlagen als Voraussetzung für optimale Sekundärmaßnahmen; in: Sammelband VGB-Konferenz "Kraftwerk und Umwelt 1985", p. 129-135

/33/ Reidick, H.: Erfahrungen mit primärer und sekundärer NO_X-Minderung der Abgase von Dampferzeuger-Feuerungen; in: EV-Register 45/86, S. 39 - 50

/34/ Rüsenberg, D.; Hein, K.; Hoppe, K.: Feuerungsseitige Maßnahmen zur Minderung der NO_X-Emission; in: VGB-Kraftwerkstechnik 67 (1987) 3, S. 275-279

/35/ van der Most, P.F.J.; Veldt, C.: Emission Factors Manual PARCOM-ATMOS, Emission factors for air pollutants 1992, Final version; TNO and Ministry of Housing, Physical Planning and the Environment, Air and Energy Directorate Ministry of Transport and Water Management; The Netherlands; Reference number 92 - 235; 1992

/36/ Jockel, W.; Hartje, J.: Die Entwicklung der Schwermetallemissionen in der Bundesrepublik Deutschland von 1985 bis 1995; Forschungsbericht 94-104 03 524; TÜV Rheinland e. V. Köln; 1995

/37/ Stobbelaar, G.: Reduction of Atmospheric Emissions under the terms of the North Sea Action Programme, Report Lucht 102, Ministry of Housing, Physical Planning and Environment, The Netherlands, 1992

/38/ Bouchereau, J.M.: Estimation des Emissions Atmosphériques de Métaux Lourds en France pour le Chrome, le Cuivre, le Nickel, le Plomb et le Zinc, CITEPA, France (1992)

/39/ Axenfeld, F.; Münch. J.; Pacyna, J.M.; Duiser, J.; Veldt, C.: Test-Emissionsdatenbasis der Spurenelemente As, Cd, Hg, Pb, Zn und der speziellen organischen Verbindungen Lindan, HCB, PCB und PAK für Modellrechnungen in Europa, Forschungsbericht 104 02 588, Dornier GmbH, NILU, TNO, 1992

/40/ Marx, E.: Reduzierung von Emissionen und Beseitigung von Rückständen unter Berücksichtigung ernergetischer Nutzung; in: Die Industriefeuerung; 49 (1989); S. 75 - 87

/41/ CORINAIR 90 Emission Inventory (Proposals) - working paper for the 19 - 20 September 1991 meeting - Annex 4: Definition of Large Point Sources

/42/ Hernández, R.; Martínez, J.; Ortiz, A.: CORINAIR Relational schema and data dictionary 1st version; AED; March 1992

/43/ Fontelle, J-P.: The Implementation of the Directive 88/609 on Large Combustion Plants - Proposal for the achievement of air emission inventories, CORINAIR (ed.); Nov. 1991

/44/ Fontelle, J-P.: The Implementation of the Directive 88/609 on Large Combustion Plants - LCP Directive inventory reporting; CITEPA (ed.); June 1992

/45/ Necker, Peter; Lehmann, Bernhard: Kraftwerk Walheim, Block 2 - Demonstrationsanlage zur Reduzierung von NO_X-Emissionen aus Schmelzkammerkesseln mit Ascherückführung; Neckarwerke Elektrizitäts-versorgung AG; i. Zusammenarbeit mit Umweltbundesamt Berlin; Esslingen, 1992

/46/ VDI (ed.): Efficient Energy Supply with Combustion - Engine Plants; Part II; Aachen; 1993

/47/ Brandt, F: Brennstoffe und Verbrennungsrechnung, FDBR - Fachbuchreihe; Vol. 1; Essen; 1981

/48/ N.N.: Ruhrkohlenhandbuch; Verlag Glückauf GmbH, Essen, 1984, 6th Edition, p. 118

/49/ Wagner, W.: Thermische Apparate und Dampferzeuger - Planung und Berechnung; Vogel - Fachbuch Technik, Würzburg 1985

/50/ Schnell, U.: Berechnung der Stickoxidemissionen von Kohlenstaubfeuerungen; VDI Reihe 6: Energieerzeugung Nr. 250, Düsseldorf 1991

/51/ Pohl, J.H.; Chen, S.L.; Heap, M.P.; Pershing, D.W.: Correlation of NO_X Emissions with Basic Physical and Chemical Characteristics of Coal; in: Joint Symposium on Stationary Combustion NO_X Control, Volume 2, Palo Alto 1982, S. (36-1) - (36-30).

/52/ Davis, W.T.; Fiedler, M.A.: The Retention of Sulfur in Fly Ash from Coal-Fired Boilers; in: Journal of the Air Pollution Control Association (JAPCA), 32 (1982), p. 395 - 397

/53/ Heer, W.: Zur Konfiguration von Emissionsminderungsmaßnahmen an Kohlekraftwerken, Dissertation Universität Karlsruhe 1987

/54/ Zelkowski, J: Kohleverbrennung; Fachbuchreihe "Kraftwerkstechnik", Vol. 8, Essen 1986

/55/ Görner, K.: Technische Verbrennungssysteme - Grundlagen, Modellbildung, Simulation; Springer Verlag Berlin, Heidelberg, New York, 1991

/56/ Leuckel, W.; Römer, R.: Schadstoffe aus Verbrennungsprozessen; in: VDI Berichte Nr. 346, 1979, S. 323 - 347

/57/ Hansen, U.: Update and Temporal Resolution of Emissions from Power Plants; in: GENEMIS, Paper presented at the 3rd GENEMIS Workshop, Vienna 1993

/58/ CITEPA (ed.): CORINAIR Inventory - Default Emission Factor Handbook, Commission of the European Community (ed.), second edition, January 1992

/59/ US-EPA (ed.): Compilation of Air Pollutant Emission Factor, Vol. 1; Stationary Point and Area Sources; 1985

/60/ Pacyna, Josef: Emission Inventorying for Heavy Metals in the ECE; Draft Paper for the Final Report of the Task Force on Heavy Metals Emission; 1994

/61/ IPCC/OECD (ed.): Greenhouse Gas Inventory Workbook, IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2; 1995

/62/ Ribeiro, Jacqueline: Techno-economic analysis of the SCR plant for NO_X abatement; University of Karlsruhe; Institute for Industrial Production; 1992

/63/ Umweltbundesamt, Germany (ed.): Umwelt- und Gesundheitskritierien für Quecksilber; UBA-Berichte 5/80; Berlin 1980

/64/ Personal communications with different power plant operators; answers to a questionnaire from March 8, 1994

/65/ Deutsche Verbundgesellschaft e. V. (ed.): Das versorgungsgerechte Verhalten der thermischen Kraftwerke; Heidelberg; 1991

/66/ TNO report 88 - 355/R 22/ CAP included in /58/

/67/ Winiwater, D.; Schneider, M.: Abschätzung der Schwermetallemissionen in Österreich; Umweltbundesamt Österreich, Wien; 1995

/68/ VDI (ed.): Gasturbineneinsatz in der Kraft-Wärme-Kopplung; Rationelle Energieversorgung mit Verbrennungs-Kraftmaschinen-Anlagen; Teil V; Aachen; 1993

/69/ Veaux, C.; Rentz, O.: Entwicklung von Gasturbinen und Gasturbinenprozessen; Institut für Industriebetriebslehre und Industrielle Produktion; Karlsruhe; 1994 (unpublished)

/70/ VDI (ed.): Co-generation Technology-Efficient Energy Supply with Combustion Engine Plants; Part II; Aachen; 1993

/71/ VGB (ed.): Hinweise zur Ausfertigung der Emissionserklärung für Anlagen aus dem Bereich der Kraft- und Energiewirtschaft gemäß 11. Verordnung zur Durchführung des Bundesimmissionsschutzgesetzes vom 12.12.1991 (Stand März 1993); Essen; 1993

/72/ Association of German Coal Importers / Verein Deutscher Kohleimporteure e.V.: Datenbank Kohleanalysen; Stand 27. Januar 1992; Hamburg (Germany)

/73/ ASTM-ISO 3180-74: Standard Method for Calculating Coal and Coke Analyses from as-determined to different Bases

/74/ N. N.: Update and Temporal Resolution of Emissions from Power Plants in GENEMIS; Paper published at the 3rd Genemis-Workshop in Vienna; 1983

/75/ Bartok, W. et. al.: Stationary sources und control of nitrogen oxide emissions; Proc. second International Clean Air Congress; Washington; 1970; p. 801 - 818.

/76/ N. N.: Update and Temporal Resolution of Emissions from Power Plants, in: GENEMIS; Paper from the 3rd Workshop; Vienna; 1993

/77/ Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (ed.): Umwelt-politik - Klimaschutz in Deutschland, Erster Bericht der Regierung der Bundesrepublik Deutschland nach dem Rahmen-übereinkommen der Vereinten Nationen über Klimaänderungen; 1994
The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (ed.): Environmental Policy - Climate Protection in Germany - First Report of the Federal Government of the Federal Republic of Germany according to the United Nations Framework Convention of Climate Change, 1994

/78/ Boelitz, J.; Esser-Schmittmann, W.; Kreusing, H.: Braunkohlenkoks zur Abgasreinigung; in: Entsorger-Praxis (1993)11; S. 819 - 821

/79/ Breton, D.; Eberhard, R.: Handbuch der Gasverwendungstechnik, Oldenburg 1987

/80/ CITEPA: CORINAIR Inventory-Default Emission Factors Handbook (second edition); CEC-DG XI (ed.); 1992

/81/ Davids, P.; Rouge M.: Die Großfeuerungsanlagenverordnung. Technischer Kommentar; VDI, Düsseldorf 1984

/82/ Davids, Peter; Rouge, Michael: Die TA Luft ´86, Technischer Kommentar; Düsseldorf; 1986

/83/ DeSoete, G.: Nitrous Oxide from Combustion and Industry: Chemistry, Emissions and Control; Working Group Report: Methane Emissions from Biomass Burning; in: van Amstel, A.R. (ed.): Proceedings of an International IPCC Workshop on Methane and Nitrous Oxide: Methods in National Emission Inventories and Options for Control. RIVM Report no. 481507003; Bilthoven (The Netherlands); p. 324 - 325

/84/ Environment Agency: Air polluters unveiled by Tokio Government, Japan; Environment Summary 1973-1982, Vol. 1, (1973); p. 18/19

/85/ US-EPA (ed.): Criteria Pollutant Emission Factors for the NAPAP Emission Inventory; EPA/600/7-87/015; 1987

/86/ Gerold, F. et. al.: Emissionsfaktoren für Luftverunreinigungen; Materialien 2/80; Berlin; 1980

/87/ IPCC/OECD (ed.): Joint Work Programme on National Inventories of Greenhouse Gas Emissions: National GHG-Inventories (ed.): Transparency in estimation and reporting; Parts I and II; Final report of the workshop held 1 October 1992 in Bracknell (U.K.); published in Paris; 1993

/88/ IPCC/OECD (ed.): Greenhouse Gas Inventory Reference Manual; IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3; 1995

/89/ Kamm, Klaus; Bauer, Frank; Matt, Andreas: CO-Emissionskataster 1990 für den Stadtkreis Karlsruhe; in: WLB - Wasser, Luft und Boden (1993)10; p. 58 ff.

/90/ Kremer, H.: NO_X-Emissionen aus Feuerungsanlagen und aus anderen Quellen; in: Kraftwerk und Umwelt 1979; Essen; 1979; p. 163 - 170

/91/ Lim, K.J. et. al.: A promising NO_X-control-technology; Environmental Progress, Vol. 1; Nr.3; 1982; p. 167 - 177

/92/ Landesanstalt für Immissionsschutz des Landes NRW (ed.): Emissionsfaktoren für Feuerungsanlagen für feste Brennstoffe; in: Gesundheits-Ingenieur 98(1987)3; S. 58 - 68

/93/ Landesanstalt für Immissionsschutz des Landes NRW (ed.): Erstellung eines Emissionskatasters und einer Emissionsprognose für Feuerungsanlagen im Sektor Haushalte und Kleinverbraucher des Belastungsgebietes Ruhrgebiet Ost; LIS Bericht Nr. 73; 1987

/94/ Marutzky, R: Emissionsminderung bei Feuerungsanlagen für Festbrennstoffe; in: Das Schornsteinfeger-handwerk (1989)3, S. 7 - 15

/95/ Ministerium für Arbeit, Gesundheit und Soziales des Landes NRW (ed.): Luftreinhalteplan Ruhrgebiet Ost 1979-1983; Luftreinhalteplan Ruhrgebiet Mitte 1980-1984; Düsseldorf; 1978 bzw. 1980

/96/ Mobley, J.D.; Jones G.D.: Review of U.S. NO_X abatement technology; Proceedings: NOx-Symposium Karlsruhe 1985 B1/B 74

/97/ MWV: Jahreszahlen 1992, Hamburg 1992

/98/ N.N.: Untersuchung zur Emissionsbegrenzung bei bestimmten Anlagenarten; in: Umweltschutz in Niedersachsen - Reinhaltung der Luft, Heft 8; S. 145 - 169

/99/ Ministry of Housing, Physical Planning and Environment (ed.): Handbook of Emission Factors, Stationary Combustion Sources, Part 3; The Netherlands, The Hague; 1988

/100/ OECD Environment Directorate (ed.): Greenhouse Gas Emissions and Emission Factors; 1989

/101/ van der Most, P. F J.; Veldt, L.: Emission Factors Manual Parcom-Atmos, Emission factors for air pollutants 1992; Final version; TNO; The Netherlands; Reference number 92 - 235, 1992

/102/ Radian Corporation (ed.): Emissions and Cost Estimates for Globally Significant Anthropogenic Combustion Sources of NO_X, N_2O, CH_4, CO and CO_2; Prepared for the Office of Research and Development; U.S. Environmental Protection Agency; Washington D.C.; 1990

/103/ Ratajczak, E.-A.; Akland, E.: Emissionen von Stickoxiden aus kohlegefeuerten Hausbrandfeuerstätten; in: Staub, Reinhaltung Luft; 47(1987)1/2, p. 7 - 13

/104/ Riediger, Bruno: Die Verarbeitung des Erdöls, Springer-Verlag 1971, p. 31

/105/ Schenkel, W.; Barniske, L.; Pautz, D.; Glotzel, W.-D.: Müll als CO-neutrale Energieresource; in: Kraftwerkstechnik 2000 - Resourcen-Schonung und CO-Minderung; VGB-Tagung 21./22.2.1990; p. 108

/106/ Skuschka, M; Straub, D.; Baumbach, C.: Schadstoffemissionen aus Kleinfeuerungen; Institut für Verfahrenstechnik und Dampfkesselwesen; Abt. für Reinhaltung der Luft; Stuttgart; 1988

/107/ Steinmüller-Taschenbuch -Dampferzeugertechnik, Essen 1984

/108/ Stromthemen, 6(1989)6, p. 7

/109/ Tornier, W.: Derzeit erreichbare Emissionswerte von Kesselanlagen und ihre Minderung durch Primärmaßnahmen; VDI-GET-VK-Tagung: Kessel- und Prozeßwärmeanlagen; Essen; 1985

/110/ Umweltbundesamt (ed.): Luftreinhaltung 1981; Berlin; 1981

/111/ Umweltbundesamt (ed.): Jahresbericht 1985; Berlin; 1986

/112/ VGB Technische Vereinigung der Großkraftwerksbetreiber e.V. (ed.): VGB- Handbücher VGB-B301: NO_X-Bildung und NO_X-Minderung bei Dampferzeugern für fossile Brennstoffe; Essen; 1986

/113/ CEE (ed.): Directive du Conseil du 30 mars 1987 modifiant la directive 75/716/CEE relative au rapprochement des législations des Ètats membres concernant la teneur en soufre de certains combustibles liquides, 87/219/CEE

/114/ Meijer, Jeroen: Personal communication, IEA (International Energy Agency), Fax of April 24, 1995.

/115/ US-EPA (ed.): AP 42 - CD rom, 1994

/116/ Personal communication with power plant operators in Germany, 1995

/117/ Verein Deutscher Elektrizitätswerke (VDEW) (ed.): Jahresstatistik 1991; Frankfurt; 1992

/118/ Kugeler, F.; Philippen, P.: Energietechnik; 1990

18 BIBLIOGRAPHY

Additional literature, which is related to combustion:

Strauß sen., K.: NO_X-Bildung und NO_X-Minderung bei Dampferzeugern für fossile Brennstoffe, VGB - B 301, Part B 5.1; Essen; 1986

Zelkowski, J.: NO_X-Bildung bei der Kohleverbrennung und NO_X-Emissionen aus Schmelzfeuerungen, in: VGB Kraftwerkstechnik 66 (1986) 8, S. 733 - 738

Rennert, K. D.: Mögliche Seiten der Stickstoffreduzierung in Feuerräumen; Sonderdruck aus Fachreport Rauchgasreinigung 2/86, S. FR 13 - 17

Schreiner, W.: Rennert, K. D.: Emissionsverhalten von Brennern mit Luftstufung in Groß- und Versuchsanlagen, in: BWK Bd. 40 (1988) 5, Mai 1988

Visser, B.M.; Bakelmann, F.C.: NO_x-Abatement in Gas Turbine Installations; in: Erdöl und Kohle-Erdgas-Petrochemie vereinigt mit Brennstoff-Chemie, 46 (1993) 9, S. 333 - 335

Alaghon, H.; Becker, B.: Schadstoffarme Verbrennung von Kohlegas in GuD-Anlagen; in: VGB Kraftwerkstechnik, 64 (1984) 11, S. 999 - 1064

Arbeitsgruppe Luftreinhaltung der Universität Stuttgart (ed.): Verbrennungsmotoren und Feuerungen-Emissionsminderung; in: Jahresbericht der Arbeitsgruppe Luftreinhaltung; Stuttgart 1988

Scherer, R.: Konzept zur Rauchgasreinigung bei schwerölbetriebenen Motorheizkraftwerken; in: BWK 45 (1993) 11, S. 473 - 476

N.N.: NO_X-Emissions by Stationary Internal Combustion Engines; in: Erdöl und Kohle-Erdgas-Petrochemie vereinigt mit Brennstoff-Chemie, 40 (1987) 9, p. 375 - 376

Kehlhofer, R.; Kunze, N.; Lehmann, J.; Schüller, K.-H.: Gasturbinenkraftwerke, Kombikraftwerke, Heizkraftwerke und Industriekraftwerke; Köln 1984, 1992

19 RELEASE VERSION, DATE AND SOURCE

Version: 3.1

Date: November 1995

Source: Otto Rentz; Dagmar Oertel
University of Karlsruhe (TH)
Germany

Updated with particulate matter details by:
Mike Woodfield
AEA Technology
UK
December 2006

20 POINT OF ENQUIRY

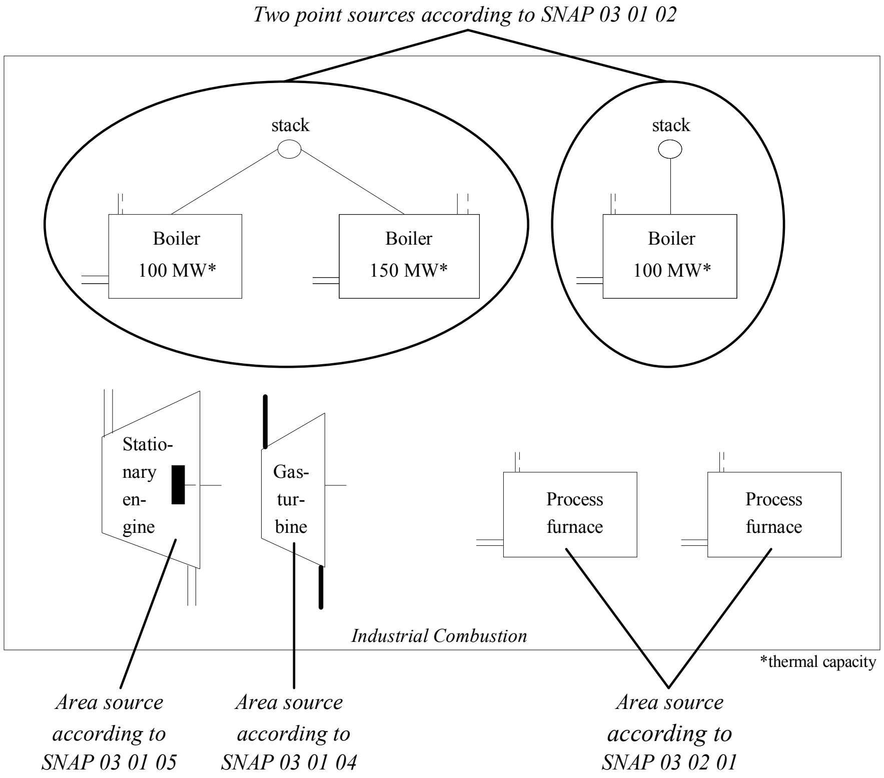
Any comments on this chapter or enquiries should be directed to:

Ute Karl

French-German Institute for Environmental Research
University of Karlsruhe
Hertzstr 16
D-76187 Karlsruhe
Germany

Tel: +49 721 608 4590
Fax: +49 721 75 89 09
Email: ute.karl@wiwi.uni-karlsruhe.de

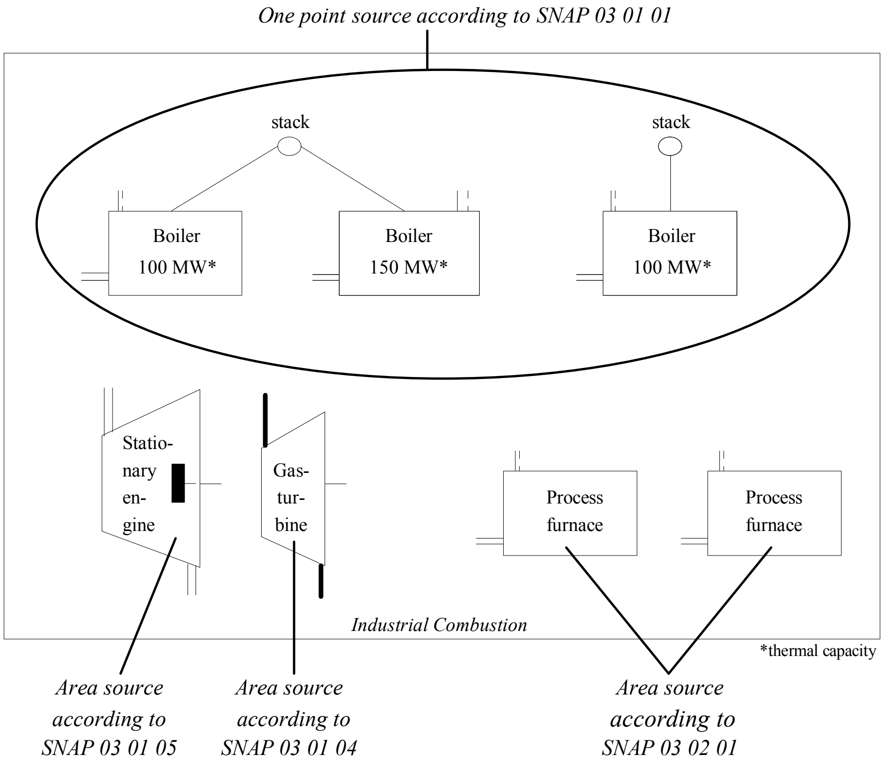
Annex 1: Example of different possible considerations for boilers as a common plant


Two point sources according to SNAP 03 01 02

Area source according to SNAP 03 01 05

Area source according to SNAP 03 01 04

Area source according to SNAP 03 02 01

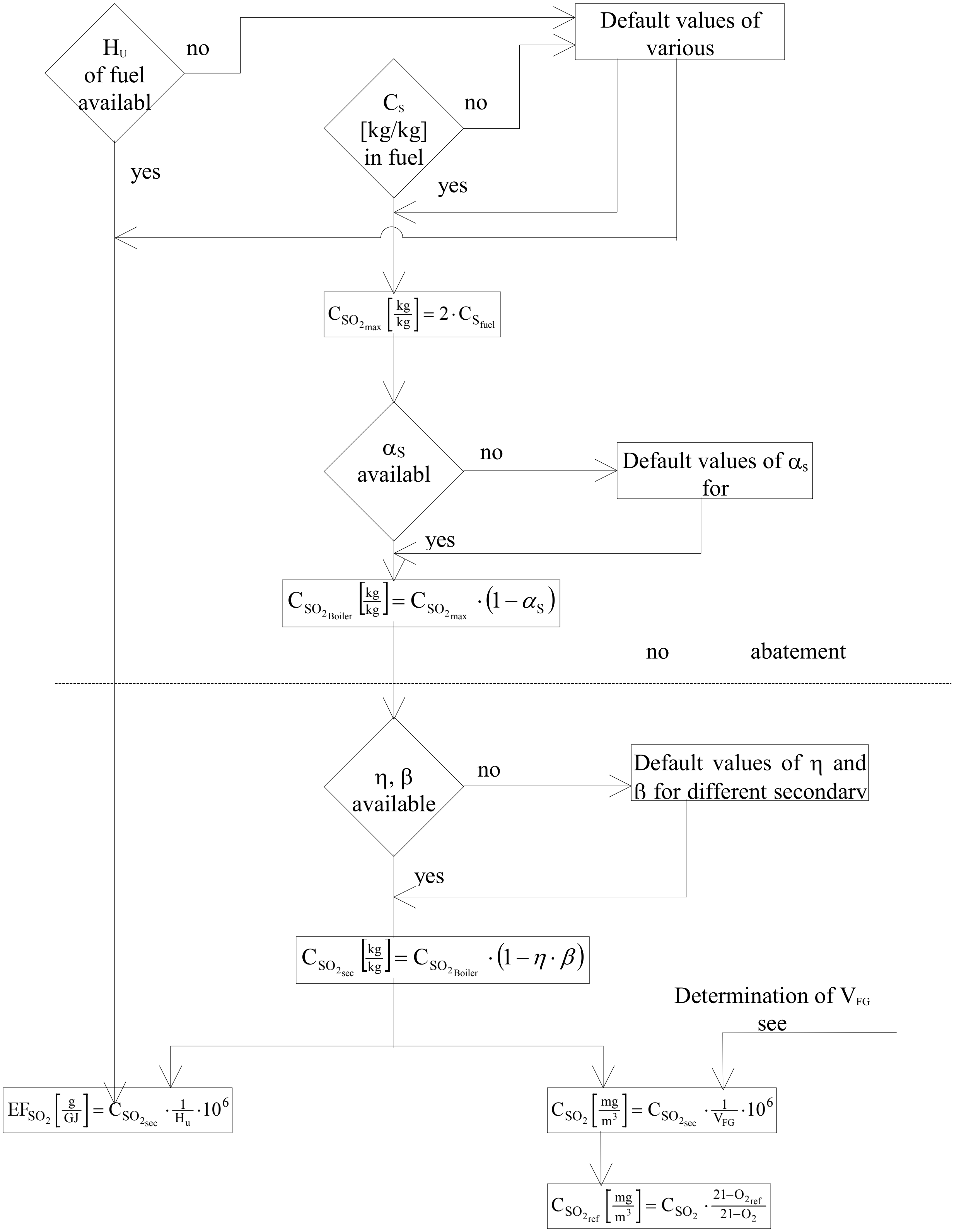

One point source according to SNAP 03 01 01

Area source according to SNAP 03 01 05

Area source according to SNAP 03 01 04

Area source according to SNAP 03 02 01

Annex 2: Determination of SO_2 emission factors (flow sheet, for description see Annex 3)



Annex 3: Determination of SO_2 emission factors (description)

The calculation procedure is performed in three steps:

I The fuel sulphur reacts stoichiometrically with oxygen O_2 to sulphur dioxide SO_2. Default values for the sulphur content $C_{S_{fuel}}$ in hard and brown coal are given in Annexes 7 and 8. The result is the maximum attainable amount of sulphur dioxide $C_{SO_{2.max}}$ given by:

$$C_{SO_{2max}} = 2 \cdot C_{S_{fuel}} \tag{3-1}$$

$C_{S_{fuel}}$	sulphur content of fuel (in mass element/mass fuel [kg/kg])
$C_{SO_{2.max}}$	maximum attainable amount of sulphur dioxide (in mass pollutant/mass fuel [kg/kg])

II The maximum attainable amount of sulphur dioxide $C_{SO_{2.max}}$ is corrected by the sulphur retention in ash α_s. As a result, the real boiler emission of sulphur dioxide $C_{SO_{2,boiler}}$ fuel is obtained:

$$C_{SO_{2boiler}} = C_{SO_{2max}} \cdot \left(1 - \alpha_s\right) \tag{3-2}$$

$C_{SO_{2.boiler}}$	real boiler emission of sulphur dioxide (in mass pollutant/mass fuel [kg/kg])
$C_{SO_{2.max}}$	maximum attainable amount of sulphur dioxide (in mass pollutant/mass fuel [kg/kg])
α_S	sulphur retention in ash [ ]

The sulphur retention in ash depends e.g. on fuel characteristics and temperature inside the boiler. If there is no data for α_S available, default values for various fuels are given in Table 8.

III The boiler emission of sulphur dioxide is corrected by the reduction efficiency η and availability β (for definition of β see Section 3.2) of the secondary measure installed, according to:

$$C_{SO_{2sec}} = C_{SO_{2boiler}} \cdot \left(1 - \eta \cdot \beta\right) \tag{3-3}$$

$C_{SO_{2.sec}}$	sulphur dioxide downstream secondary measure (in mass pollutant/mass fuel [kg/kg])
$C_{SO_{2.boiler}}$	real boiler emission of sulphur dioxide (in mass pollutant/mass fuel [kg/kg])
η	reduction efficiency of secondary measure [ ]
β	availability of secondary measure [ ]

The result is called secondary sulphur dioxide $C_{SO_{2.sec}}$. If there is no data for η and β available, default values for various flue gas desulphurisation techniques (FGD) are given in Table 7.

The obtained $C_{SO_{2.sec}}$ value is converted to C_{SO_2} in flue gas and to the emission factor EF_{SO_2} according to the following Equations:

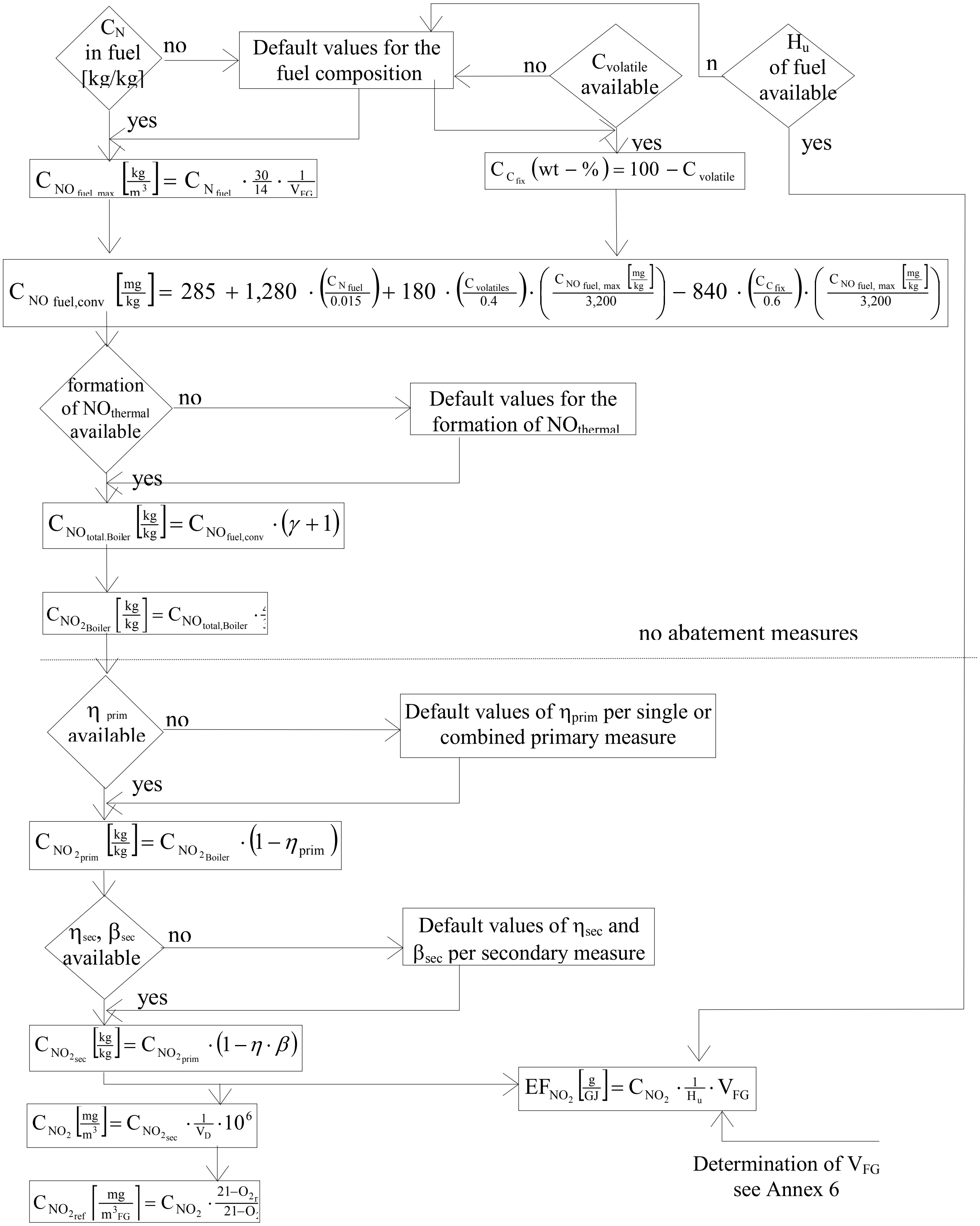
$$C_{SO_2} = C_{SO_{2.sec}} \cdot \frac{1}{V_{FG}} \cdot 10^6 \qquad (3\text{-}4)$$

$$EF_{SO_2} = C_{SO_{2.sec}} \cdot \frac{1}{H_u} \cdot 10^6 \qquad (3\text{-}5)$$

C_{SO_2}	sulphur dioxide in flue gas (in mass pollutant/volume flue gas [mg/m^3])
$C_{SO_{2.sec}}$	sulphur dioxide downstream of secondary measure (in mass pollutant/mass fuel [kg/kg])
V_{FG}	dry flue gas volume volume (in volume flue gas/mass fuel [m^3/kg])
EF_{SO_2}	emission factor for sulphur dioxide [g/GJ]
H_u	lower heating value [MJ/kg]

The dry flue gas volume V_{FG} can be determined according to Annex 6. Emission data in [mg/m^3] are useful to compare measured and calculated values. The same equations are used for the unit conversion of $C_{SO_{2.boiler}}$. Default values for the lower heating values of hard and brown coal are given in Annexes 7 and 8.

Annex 4: Determination of NO_x emission factors (flow sheet, for description see Annex 5)



Annex 5: Determination of NO_X emission factors (description)

The determination of NO_x emission factors takes into account the formation of fuel-NO and thermal-NO. The formation of fuel-NO is based on fuel parameters. But the total amount of fuel-nitrogen cannot be completely converted into fuel-NO (as obtained in Equation (5-1)). Therefore, the realistic formation of fuel-NO is described by an empirical relation (see Equation (5-2)). The formation of thermal-NO is expressed by an an additional fraction which depends on the type of boiler.

The calculation procedure of the NO_X emission factor is performed in three steps: In the first step the maximum NO emission resulting from stoichiometric conversion of fuel nitrogen is calculated. The NO emission obtained is further corrected by taking into account the formation of thermal-NO. NO is converted into NO_2 and primary and secondary measures are taken into account in steps two and three.

I The fuel-nitrogen reacts in a stoichiometric manner with oxygen O_2 to form nitrogen oxide. The default values for the nitrogen content $C_{N_{2fuel}}$ in hard and brown coal are given in Annexes 7 and 8. The maximum attainable amount of fuel nitrogen oxide $C_{NO_{fuel.max}}$ is obtained:

$$C_{NO_{fuel_{max}}} = C_{N_{fuel}} \cdot \frac{30}{14} \cdot \frac{1}{V_{FG}} \tag{5-1}$$

$C_{NO_{fuel.max}}$	maximum attainable amount of fuel nitrogen oxide (in mass pollutant/volume flue gas [kg/m^3])
$C_{N_{fuel}}$	nitrogen content in fuel (in mass nitrogen/mass fuel [kg/kg])
V_{FG}	specific flue gas volume (in volume flue gas/mass fuel [m^3/kg])[9]

The fuel-nitrogen content $C_{N_{fuel}}$ is not completely converted into $C_{NO_{fuel}}$. The converted part of fuel-nitrogen to fuel-NO $C_{NO_{fuel.conv}}$ can be determined by the following empirical formula /50, 51/ related to zero percent of oxygen in dry flue gas:

$$C_{NO_{fuel_{conv}}} = 285 + 1{,}280\left(\frac{C_{N_{fuel}}}{0.015}\right) + 180\left(\frac{C_{volatiles}}{0.4}\right)\left(\frac{C_{NO_{fuel_{max}}}}{3{,}200}\right) - 840\left(\frac{C_{C_{fix}}}{0.6}\right)\left(\frac{C_{NO_{fuel_{max}}}}{3{,}200}\right) \tag{5-2}$$

$C_{NO_{fuel.conv}}$	fuel-NO released (in mass pollutant/mass flue gas [mg/kg])[2]
$C_{N_{fuel}}$	nitrogen content in fuel (in mass nitrogen/mass fuel [kg/kg]), maf
$C_{volatiles}$	fuel content of volatiles (in mass volatiles/mass fuel [kg/kg]), maf
$C_{NO_{fuel.max}}$	maximum attainable amount of fuel nitrogen oxide (in mass pollutant/mass flue gas [mg/kg])[10]
$C_{C_{fix}}$	fixed carbon in fuel (in mass carbon/ mass fuel [kg/kg]), maf

---

[9] The programme calculates stoichiometrically the specific flue gas volume based on the complete fuel composition.

[10] Note: $C_{NO.fuel.max}$ and $C_{NO.fuel.conv}$ are given in the unit (mass pollutant/mass flue gas [mg/kg]). For the conversion between (mass pollutant/mass flue gas [mg/kg]) and (mass pollutant/volume flue gas [kg/m3]) the flue gas density (in mass flue gas/volume flue gas [kg/m³]) has to be taken into account, which is calculated stoichiometrically from the fuel composition within the computer programme.

The fixed carbon in the fuel is determined according to the equation $C_{C_{fix}} = 1 - C_{volatiles}$. Equation (5-2) is valid for nitrogen oxide emissions from premixed flames; the coefficient of correlation is $r^2 = 0.9$ for 20 coals and $r^2 = 0.75$ for 46 coals /51/. The data has been obtained by field and pilot-scale measurements. Basically tests are conducted in a 70,000 Btu/hr (20.5 kW) refractory lined furnace with variable heat extraction. Coal was injected through special configurations. A nozzle produces an uniform heterogeneous mixture of coal and air prior to combustion and represents the limit of intensely mixed flames produced with high swirl. Further tests have been established in large scale furnaces. The results from all measurements combined with additional information based on literature data have been used to establish a correlation which predicts the relative dependence of nitrogen oxide emissions on fuel properties. /51/ Further calculations with Equation (5-2) based on measured data have been provided in /50/. The comparison between measured and calculated values has shown that the results from Equation (5-2) are very good for high volatile coals and are satisfactory for medium volatile coals /50/.

Assuming that the formation of fuel-NO is much more important than the formation of thermal-NO (fuel-NO amounts to 70 - 90 %), the content of thermal-NO formed can be expressed as a fraction γ (where γ depends on the type of boiler) of NO_{fuel}. The total content of nitrogen oxide formed in the boiler $C_{NO_{total.boiler}}$ is given by:

$$C_{NO_{total_{boiler}}} = C_{NO_{fuel_{conv}}} + C_{NO_{thermal}} = C_{NO_{fuel_{conv}}} \cdot (1+\gamma) \tag{5-3}$$

$C_{NO_{total.boiler}}$	total content of nitrogen oxide formed in the boiler (in mass pollutant/mass flue gas [kg/kg])
$C_{NO_{fuel.conv}}$	fuel-NO released (in mass pollutant/mass flue gas [kg/kg])
$C_{NO_{thermal}}$	content of thermal-NO formed (in mass pollutant/mass flue gas [kg/kg])
γ	fraction for thermal-NO formed [ ]

The following default values for γ can be recommended: DBB γ = 0.05, WBB γ = 0.3. Furthermore, the amount of thermal-NO can be influenced by load (see also Section 11.2).

The total boiler emissions of nitrogen dioxide $C_{NO_{2.boiler}}$ can be calculated as follows:

$$C_{NO_{2_{boiler}}} = C_{NO_{total_{boiler}}} \cdot \frac{46}{30} \tag{5-4}$$

$C_{NO_{2_{boiler}}}$	total content of nitrogen dioxide formed in the boiler (in mass pollutant/mass flue gas [kg/kg])
$C_{NO_{total_{boiler}}}$	total content of nitrogen oxide formed in the boiler (in mass pollutant/mass flue gas [kg/kg])

II The total boiler content of nitrogen dioxide given by $C_{NO_{2.boiler}}$ is reduced by taking into account primary measures with the reduction efficiency η_{prim}. The result is the content of primary nitrogen dioxide $C_{NO_{2.prim}}$:

$$C_{NO_{2prim}} = C_{NO_{2boiler}} \cdot \left(1 - \eta_{prim}\right) \qquad (5\text{-}5)$$

$C_{NO_{2.prim}}$	content of primary nitrogen dioxide (in mass pollutant/mass flue gas [kg/kg])
$C_{NO_{2boiler}}$	total content of nitrogen dioxide formed in the boiler (in mass pollutant/mass flue gas [kg/kg])
η_{prim}	reduction efficiency of primary measure(s) [ ]

As there is only incomplete data available for reduction efficiencies, default values are given for the individual and relevant combinations of primary measures for different types of boilers and fuels (see Table 8). In the case of combined primary measures with known individual reduction efficiencies $\eta_{prim,1}$, $\eta_{prim,2}$, etc., the following equation can be used:

$$C_{NO_{2prim}} = C_{NO_{2boiler}} \cdot \left(1 - \eta_{prim1}\right) \cdot \left(1 - \eta_{prim2}\right) \cdot \left(1 - \eta_{prim3}\right) \qquad (5\text{-}6)$$

$C_{NO_{2.prim}}$	content of nitrogen dioxide taking into account primary measures (in mass pollutant/mass flue gas [kg/kg])
$C_{NO_{2boiler}}$	total content of nitrogen dioxide formed in the boiler (in mass pollutant/mass flue gas [kg/kg])
η_{prim_k}	individual reduction efficiency of primary measure k [ ]

It should be taken into account, that the reduction efficiencies of primary measures are not independent of each other.

III The emission of primary nitrogen dioxide $C_{NO_{2.prim}}$ is corrected by the reduction efficiency η_{sec} [ ] and the availability β_{sec} [ ] (for definition of β see Section 3.2) of the secondary measure installed, according to:

$$C_{NO_{2sec}} = C_{NO_{2.prim}} \cdot \left(1 - \eta_{sec} \cdot \beta_{sec}\right) \qquad (5\text{-}7)$$

$C_{NO_{2.sec}}$	nitrogen dioxide downstream of secondary measure (in mass pollutant/mass flue gas [kg/kg])
$C_{NO_{2.prim}}$	content of nitrogen dioxide taking into account primary measures (in mass pollutant/mass flue gas [kg/kg])
η_{sec}	reduction efficiency of secondary measure [ ]
β_{sec}	availability of secondary measure [ ]

If there is no data for η_{sec} and β_{sec} available, default values for various DeNOx techniques are given in Table 9.

The obtained value of $C_{NO_{2.sec}}$ is converted into C_{NO_2} and into the emission factor EF_{NO_2} according to the following equations:

$$C_{NO_2} = C_{NO_{2sec}} \cdot \frac{1}{V_D} \cdot 10^6 \qquad (5\text{-}8)$$

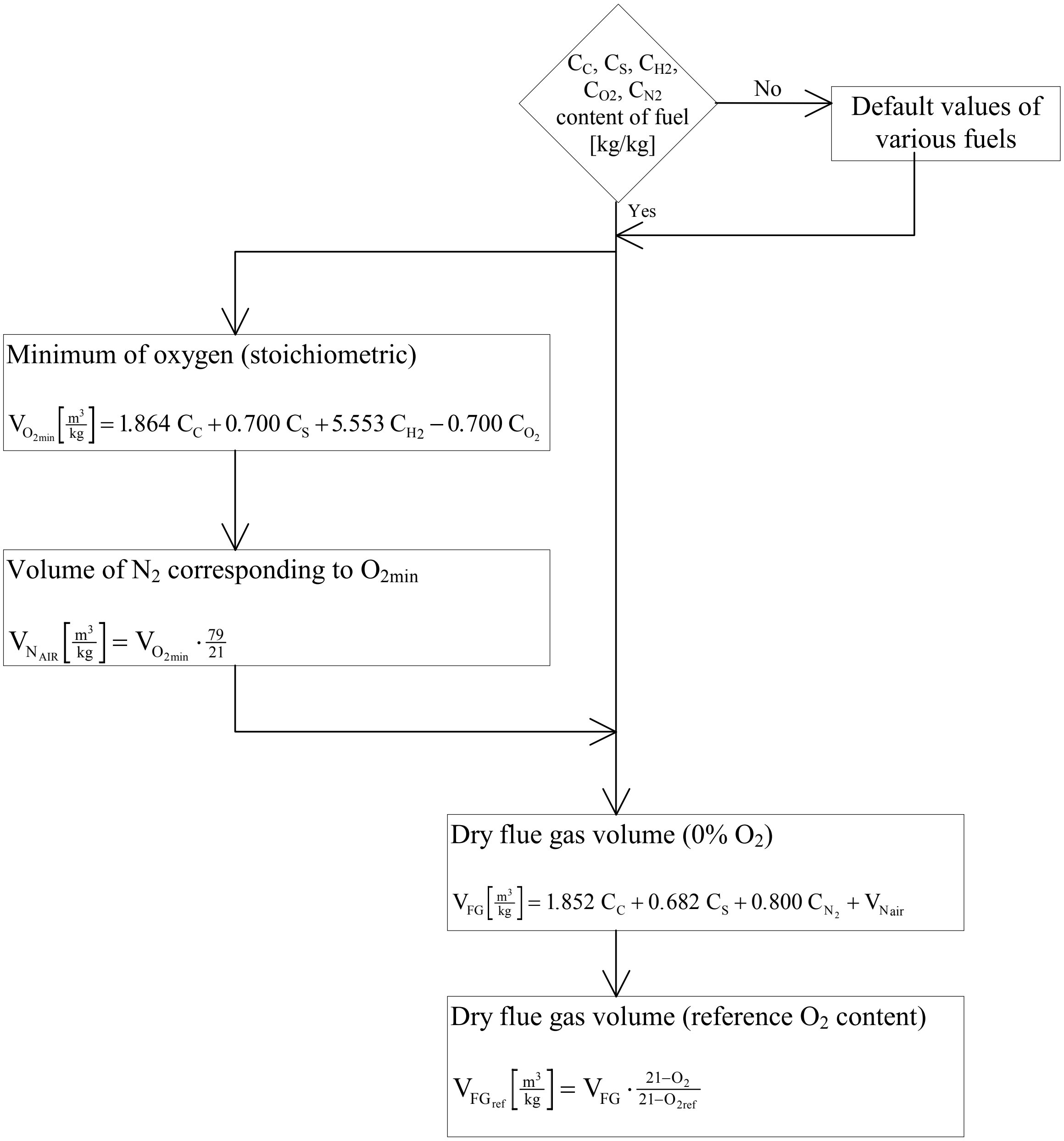
$$EF_{NO_2} = C_{NO_2} \cdot \frac{1}{H_u} \cdot V_{FG} \qquad (5\text{-}9)$$

C_{NO_2}	nitrogen dioxide in flue gas (in mass pollutant/volume flue gas [mg/m^3])
$C_{NO_{2sec}}$	nitrogen dioxide downstream of secondary measure (in mass pollutant/mass flue gas [kg/kg])
V_D	dry flue gas volume (in volume flue gas/mass flue gas [m^3/kg])
V_{FG}	specific dry flue gas volume (in volume flue gas/mass fuel [m^3/kg])
EF_{NO_2}	emission factor for nitrogen dioxide [g/GJ]
H_u	lower heating value [MJ/kg]

The specific dry flue gas volume V_{FG} can be determined according to Annex 6. Emission data expressed in [mg/m^3] are used for comparing measured and calculated values. Default values for lower heating values for hard and brown coal are given in Annexes 7 and 8.

Annex 6: Determination of the specific flue gas volume (flow sheet and description)

The specific flue gas volume has to be determined in order to convert the emission factors, which have been obtained in [g/GJ], into [mg/m^3], which allows a comparison to measured data. The approach is given in the following flow sheet:



For the determination of the flue gas volume, the elemental analysis of the fuel (content of carbon C_C, sulphur C_S, hydrogen C_H, oxygen C_{O_2} and nitrogen C_N (maf)) has to be known. If no data of the elemental analysis is available, default values of hard and brown coals are proposed in Annexes 7 and 8. The volume of oxygen required for a stoichiometric reaction $V_{O_{2min}}$ can be determined as follows:

$$V_{O_{2min}} = 1.864 \cdot C_C + 0.700 \cdot C_S + 5.553 \cdot C_H - 0.700 \cdot C_{O_2} \qquad (6\text{-}1)$$

$V_{O_{2min}}$	volume of oxygen required for stoichiometric reaction (in volume oxygen/mass fuel [m^3/kg])
C_C	content of carbon in fuel (in mass carbon/mass fuel [kg/kg])
C_S	content of sulphur in fuel (in mass sulphur/mass fuel [kg/kg])
C_H	content of hydrogen in fuel (in mass hydrogen/mass fuel [kg/kg])
C_{O_2}	content of oxygen in fuel (in mass oxygen/mass fuel [kg/kg])

The constants in Equation (6-1) represent stoichiometric factors for the volume of oxygen required for the combustion of 1 kg carbon, sulphur or hydrogen in [m^3/kg]. The corresponding volume of nitrogen in the air $V_{N_{air}}$ is given by Equation (6-2):

$$V_{N_{air}} = V_{O_{2min}} \cdot \tfrac{79}{21} \qquad (6\text{-}2)$$

$V_{N_{air}}$	volume of nitrogen in the air (in volume nitrogen/mass fuel [m^3/kg])
$V_{O_{2min}}$	volume of oxygen required for stoichiometric reaction (in volume oxygen/mass fuel [m^3/kg])

The specific dry flue gas volume at 0 % oxygen V_{FG} can be determined by using Equation (6-3):

$$V_{FG} = 1.852 \cdot C_C + 0.682 \cdot C_S + 0.800 \cdot C_N + V_{N_{air}} \qquad (6\text{-}3)$$

V_{FG}	specific dry flue gas volume (in volume flue gas/mass fuel [m^3/kg])
C_C	content of carbon in fuel (in mass carbon/mass fuel [kg/kg])
C_S	content of sulphur in fuel (in mass sulphur/mass fuel [kg/kg])
C_N	content of nitrogen in fuel (in mass nitrogen/mass fuel [kg/kg])
$V_{N_{air}}$	volume of nitrogen in the air (in volume nitrogen/mass fuel [m^3/kg])

The constants in Equation (6-3) represent stoichiometric factors for the volume of oxygen required for the combustion of 1 kg carbon, sulphur or nitrogen in [m^3/kg]. The obtained values of V_{FG} at 0 % oxygen are converted to the reference content of oxygen in flue gas according to Equation (6-4):

$$V_{FG_{ref}} = V_{FG} \cdot \tfrac{21 - O_2}{21 - O_{2_{ref}}} \qquad (6\text{-}4)$$

$V_{FG_{ref}}$	volume of specific flue gas under reference conditions (in volume flue gas/mass fuel [m^3/kg])
V_{FG}	volume of specific flue gas obtained (in volume flue gas/mass fuel [m^3/kg])
O_2	content of oxygen in the flue gas obtained [%]
$O_{2_{ref}}$	content of oxygen in the flue gas under reference conditions [%]

Annex 7: Composition and lower heating value (H_u) of hard coal in coal mining countries

country	elemental analysis (maf) [wt.-%]										volatiles (maf) [wt.-%]		H_u (maf) [MJ/kg]	
	C		N		O		H		S					
	value	standard deviation	value	standard deviation	value	standard deviation	value	standard deviation	value	standard deviation	value	standard deviation	value	standard deviation
Australia1)	84.6	2.26	1.8	0.15	7.8	2.08	5.2	0.29	0.6	0.21	34.0	5.94	33.70	1,03
Canada1)	86.6	1.8	1.4	0.15	6.1	1.5	5.1	0.56	0.9	0.43	33.9	6.34	33.04	2.32
China1)	81.9	1.95	1.1	0.32	11.4	2.4	4.9	0.21	1.05	0.35	36.3	2.32	32.06	0,80
Columbia1)	78.5	6.37	1.5	0.13	12.4	4.3	5.2	0.62	0.9	0.19	42.2	2.70	31.83	1.93
Czech Rep.2)	85.98	2.23	1.5	0.17	6.27	2.30	5.09	0.70	1.16	0.68	30.88	8.92	34.00	2.44
France2)	87.91	1.76	1.29	0.24	5.60	1.58	4.50	0.47	0.70	0.17	22.81	5.82	34.86	1.56
Germany RAG1)6)	90.2	1.77	1.6	0	3	1.41	4.4	0.56	0.9	-	15.8	9.60	35.23	0.29
Ger. others2)	87.00	2.44	1.49	0.27	5.75	1.94	4.76	0.68	1.02	0.32	25.52	6.58	30.10	1.75
CIS1)	77.5	0	0.7	0	16.1	0	5.4	0	0.3	0	39.0	3.20	31.85	1.66
Hungary2)	84.10	1.51	1.42	0.69	5.79	0.54	5.09	0.11	3.62	0.55	24.4	3.98	34.16	1.05
India1)	76.5	3.22	1.3	0.25	16.2	4	5.6	0.4	0.4	0.32	47.9	2.44	29.48	2.25
Poland4)	80.0		1.0		7.0		5.0		1.0		38.5		(21.00)5)	
Portugal3)	87.0		0.95		5.4		4.9		0.94		32.1		(27.58)5)	
South Africa1)	80.3	5.78	2.1	0.73	8.8	1.2	4.9	1.19	0.9	0.24	31.9	2.37	32.36	0.73
UK1)	84.5	0.6	1.8	0	n. a.		5.4	0.06	n. a.		38.2	1.84	33.80	0.58
USA1)	84.3	2	1.6	0.17	7.5	1.65	5.5	0.38	1.1	0.58	38.1	4.31	33.89	0.88
Venezuela1)	84.2	1.7	1.5	0.07	7.6	2.19	6	0.49	0.7	0	43.2	3.98	34.00	1.00

1) Association of German Coal Importers 1992 /72

2) Brandt 1981 /47/

n.a. - no data are available

3) Madeira: Personal communication, EDP-Electricielade Portugal, Lisboa, May 1994

4) Debsky: Personal communication, Energy Information Centre, Warsaw, May 1994

5) lower heating value as received (ar)

6) RAG= Ruhr coal

Annex 8: Composition and lower heating value (H_u) of brown coal in coal mining countries

	elemental analysis (maf) [wt.-%]										volatiles (maf)		H_u (maf)	
country	C		N		O		H		S		[wt.-%]		[MJ/kg]	
	value		value		value		value		value		value		value	
Czech Rep.2)	70.09	3.32 4)	1.07	0.22 4)	21.74	3.42 4)	5.64	0.64 4)	1.48	0.82 4)	56.67	4.62 4)	28.2	2.39 4)
Germany														
-Rheinisch coal1)	68	62-72 5)	1.0	0.7-1.3 5)	25.2	22-30 5)	5	4.5-5.5 5)	0.8	0.2-1.1 5)	38 6)	-	27.3	19.4-31.7 5)
-Middle Ger.1)	72		0.8		18.3		5.5		3.4		57.5		28.8	
-East Ger.1)	69.5		1.0		23.1		5.8		0.6		58.7		25.7	
Hungary1) - 1	63.8		(1.1)		26.8		4.8		3.5		61.8		35.7	28.8-42.6 5)
Hungary2) - 2	69.82	2.62 4)	1.06	0.45 4)	18.91	2.23 4)	5.54	0.12 4)	4.49	2.46 4)	39.30	1.04 4)	28.4	1.20 4)
Poland7)	69.5	66-73 5)	1.1	0.7-1.5 5)	19	13-25 5)	6	5-7 5)	1		50		25	23 - 26 5)
Portugal2)	67.44	1.01 4)	0.91	0.18 4)	22.61	2.89 4)	4.4	0.74 4)	4.62	2.43 4)	54.64	8.84 4)	24.8	2.6 4)
Turkey1) - 1	61.4		0.8		29.6		5.1		5.1		n. a.		21.2	19.8-22.7 5)
Turkey3) - 2	62.6	7.84 4)	2.0	0.67 4)	24.0	4.48 4)	4.9	0.56 4)	6.2	4.77 4)	56.0	3.93 4)	26.6	

1) IEA coal research - brown coal
2) Brandt
3) Kücükbayrak, S.; Kadioglu, E.: Desulphurisation of some Turkish lignites by pyrolysis, FUEL, Vol. 67, 6/1988
4) standard deviation
5) range
6) value recommended by RAG
7) Debsky: Personal communication, Energy Information Centre, Warsaw, May 1994
n. a. - no data available

Annex 9: Conditions for exemplary calculation of NO_x emission factors

Annex 9 presents the values which have been chosen for the calculation of NO_x emission factors (according to Section 4.2.1). The results of the calculations are given in the following Annexes 10 (for hard coal) and 11 (for brown coal). Both annexes contain emission factors in [g/GJ] as well as concentrations in [mg/m^3] which have been determined under the conditions given in Table 9-1:

Table 9-1: Selected input parameters for model calculations determining NO_X emission factors as given in Annexes 10 and 11

Type of coal$^{1)}$	Type of boiler	Fraction of thermal NO NO_{th} [ ]	Reduction efficiency of primary measures $\eta_{prim}$$^{2)}$ [ ]	Reduction efficiency of secondary measures η_{sec} [ ]	Availability β_{sec} [ ]
hc	DBB	0,05	LNB 0,20 LNB/SAS 0,45 LNB/OFA 0,45 LNB/SAS/OFA 0,60	SCR 0,8	0,99
	WBB	0,30	LNB 0,20 LNB/SAS 0,45 LNB/OFA 0,40 LNB/SAS/OFA 0,60	SCR 0,8	0,99
bc	DBB	0,05	LNB 0,20 LNB/SAS 0,45 LNB/OFA 0,40 LNB/SAS/OFA 0,60	-	-

1) Elementary analyses of hard and brown coal are given in Annexes 7 and 8.

2) The reduction efficiency is given as an example for selected primary measures (see Section 4.2).
Abbreviations: hc = hard coal, bc = brown coal

For individual calculations of NO_X emission factors, the computer programme (users' manual see Section 15 and Annex 14) can be used.

Annex 10: Emission factors and flue gas concentrations for NO_X obtained by model calculations (see Annexes 4 and 5) for hard coal (Annex 7)

Hard coal from	Type of boiler	Uncontrolled		Primary control[2)]			Secondary control[3)]	
		EF [g/GJ]	Flue gas concentration [mg/m^3]	PM[1)]	EF [g/GJ]	Flue gas concentration [mg/m^3]	EF [g/GJ]	Flue gas concentration [mg/m^3]
Australia	DBB	568	1620	LNB	454	1300	95	270
				LNB/SAS	312	893	65	186
				LNB/OFA	312	893	65	186
				LNB/SAS/OFA	227	649	47	135
	WBB	703	2140	LNB	562	1720	117	357
				LNB/SAS	387	1180	80	245
				LNB/OFA	422	1290	88	268
				LNB/SAS/OFA	281	858	59	178
Canada	DBB	506	1390	LNB	405	1110	84	230
				LNB/SAS	278	762	58	158
				LNB/OFA	278	762	58	158
				LNB/SAS/OFA	202	554	42	115
	WBB	627	1830	LNB	501	1460	10	304
				LNB/SAS	345	1010	72	209
				LNB/OFA	376	1100	78	228
				LNB/SAS/OFA	251	732	52	152
China	DBB	413	1180	LNB	331	943	69	196
				LNB/SAS	227	648	47	135
				LNB/OFA	227	648	47	135
				LNB/SAS/OFA	165	472	34	98
	WBB	512	1560	LNB	409	1250	85	259
				LNB/SAS	281	856	59	178
				LNB/OFA	307	934	64	194
				LNB/SAS/OFA	205	623	43	130
Columbia	DBB	535	1570	LNB	428	1250	89	261
				LNB/SAS	294	861	61	179
				LNB/OFA	294	861	61	179
				LNB/SAS/OFA	214	626	45	130

for footnotes see bottom of this table

Annex 10 continued, for footnotes see bottom of this table

		Uncontrolled		Primary control[2]			Secondary control[3]	
Hard coal from	Type of boiler	EF [g/GJ]	Flue gas concentration [mg/m^3]	PM[1]	EF [g/GJ]	Flue gas concentration [mg/m^3]	EF [g/GJ]	Flue gas concentration [mg/m^3]
Columbia	WBB	662	2070	LNB	529	1650	110	344
				LNB/SAS	364	1140	76	237
				LNB/OFA	397	1240	83	258
				LNB/SAS/OFA	265	827	51	172
Czech Republic	DBB	483	1370	LNB	387	1100	80	228
				LNB/SAS	266	753	55	157
				LNB/OFA	266	753	55	157
				LNB/SAS/OFA	193	548	40	114
	WBB	598	1810	LNB	479	1450	100	301
				LNB/SAS	329	995	68	207
				LNB/OFA	359	1080	75	226
				LNB/SAS/OFA	239	723	50	150
France	DBB	374	1080	LNB	299	863	62	180
				LNB/SAS	205	594	43	123
				LNB/OFA	205	594	43	123
				LNB/SAS/OFA	149	432	31	90
	WBB	463	1430	LNB	370	1140	77	237
				LNB/SAS	254	784	53	163
				LNB/OFA	278	855	58	178
				LNB/SAS/OFA	185	570	39	119
Germany RAG	DBB	384	1090	LNB	307	872	64	181
				LNB/SAS	211	600	44	125
				LNB/OFA	211	600	44	125
				LNB/SAS/OFA	154	436	32	90
	WBB	476	1440	LNB	381	1150	779	240
				LNB/SAS	262	792	54	165
				LNB/OFA	285	864	59	180
				LNB/SAS/OFA	190	576	40	120

Annex 10 continued, for footnotes see bottom of this table

Hard coal from	Type of boiler	Uncontrolled		Primary control[2)]			Secondary control[3)]	
		EF [g/GJ]	Flue gas concentration [mg/m^3]	PM[1)]	EF [g/GJ]	Flue gas concentration [mg/m^3]	EF [g/GJ]	Flue gas concentration [mg/m^3]
Germany others	DBB	495	1240	LNB	396	990	82	206
				LNB/SAS	272	681	57	142
				LNB/OFA	272	681	57	142
				LNB/SAS/OFA	198	495	41	103
	WBB	613	1630	LNB	490	1310	102	272
				LNB/SAS	337	899	70	187
				LNB/OFA	368	980	76	204
				LNB/SAS/OFA	245	654	51	136
Hungary	DBB	401	1150	LNB	320	920	67	191
				LNB/SAS	220	633	46	132
				LNB/OFA	220	633	46	132
				LNB/SAS/OFA	160	460	33	96
	WBB	496	1520	LNB	397	1220	82	253
				LNB/SAS	273	835	57	174
				LNB/OFA	298	911	62	190
				LNB/SAS/OFA	198	608	41	126
CIS	DBB	308	923	LNB	247	739	51	154
				LNB/SAS	169	508	35	106
				LNB/OFA	169	508	35	106
				LNB/SAS/OFA	123	369	26	77
	WBB	382	1220	LNB	305	975	64	203
				LNB/SAS	210	671	44	139
				LNB/OFA	229	732	48	152
				LNB/SAS/OFA	153	488	32	101
India	DBB	551	1540	LNB	441	1230	92	256
				LNB/SAS	303	845	63	176
				LNB/OFA	303	845	63	176
				LNB/SAS/OFA	220	615	46	128

Annex 10 continued, for footnotes see bottom of this table

Hard coal from	Type of boiler	Uncontrolled		Primary control[2)]			Secondary control[3)]	
		EF [g/GJ]	Flue gas concentration [mg/m^3]	PM[1)]	EF [g/GJ]	Flue gas concentration [mg/m^3]	EF [g/GJ]	Flue gas concentration [mg/m^3]
India	WBB	682	2030	LNB	545	1620	113	338
				LNB/SAS	375	1120	78	232
				LNB/OFA	409	1120	85	253
				LNB/SAS/OFA	273	812	57	169
South Africa	DBB	569	1650	LNB	456	1320	95	275
				LNB/SAS	313	910	65	189
				LNB/OFA	313	910	65	189
				LNB/SAS/OFA	228	662	47	138
	WBB	705	2180	LNB	564	1750	117	364
				LNB/SAS	388	1200	81	250
				LNB/OFA	423	1310	88	273
				LNB/SAS/OFA	282	874	59	182
USA	DBB	563	1610	LNB	450	1290	94	268
				LNB/SAS	310	885	64	184
				LNB/OFA	310	885	64	184
				LNB/SAS/OFA	225	644	47	134
	WBB	697	2120	LNB	558	1700	116	353
				LNB/SAS	383	1170	78	243
				LNB/OFA	418	1270	87	265
				LNB/SAS/OFA	279	850	58	177
Venezuela	DBB	588	1670	LNB	471	1340	98	278
				LNB/SAS	324	919	67	191
				LNB/OFA	324	919	67	191
				LNB/SAS/OFA	235	668	49	139

Annex 10 continued

Hard coal from	Type of boiler	Uncontrolled		Primary control[2)]			Secondary control[3)]	
		EF [g/GJ]	Flue gas concentration [mg/m^3]	PM[1)]	EF [g/GJ]	Flue gas concentration [mg/m^3]	EF [g/GJ]	Flue gas concentration [mg/m^3]
Venezuela	WBB	728	2210	LNB	583	1760	121	367
				LNB/SAS	401	1210	83	252
				LNB/OFA	437	1320	91	275
				LNB/SAS/OFA	291	882	61	184

[1)] PM = primary measures

[2)] primary measures as mostly used, see Table 8

[3)] taking into account secondary measures mostly used: SCR: reduction efficiency = 0.8, availability = 0.99

Annex 11: Emission factors and flue gas concentrations for NO_X obtained by model calculations (see Annexes 4 and 5) for brown coal (see Annex 8)

Brown coal from	Type of boiler	Uncontrolled		Primary control		
		EF $\left[\frac{g}{GJ}\right]$	Conc. $\left[\frac{mg}{m^3}\right]$	PM[1]	EF $\left[\frac{g}{GJ}\right]$	Conc. $\left[\frac{mg}{m^3}\right]$
Czech Republic	DBB	506	1.480	LNB	405	1190
				LNB/SAS	278	816
				LNB/OFA	304	890
				LNB/SAS/OFA	202	593
Germany						
- Rheinisch coal	DBB	325	985	LNB	260	788
				LNB/SAS	179	542
				LNB/OFA	195	591
				LNB/SAS/OFA	130	394
- Middle Germany	DBB	504	1.250	LNB	403	996
				LNB/SAS	277	685
				LNB/OFA	302	747
				LNB/SAS/OFA	202	498
- East Germany	DBB	539	1.460	LNB	431	1.160
				LNB/SAS	296	801
				LNB/OFA	323	873
				LNB/SAS/OFA	215	582
Hungary - 1	DBB	379	1.590	LNB	303	1.270
				LNB/SAS	208	874
				LNB/OFA	227	953
				LNB/SAS/OFA	151	635
Hungary - 2	DBB	379	1.100	LNB	304	879
				LNB/SAS	209	604
				LNB/OFA	228	659
				LNB/SAS/OFA	152	439
Portugal	DBB	461	1.260	LNB	369	1.010
				LNB/SAS	254	696
				LNB/OFA	277	759
				LNB/SAS/OFA	185	506
Turkey - 2	DBB	725	2.240	LNB	580	1.790
				LNB/SAS	399	1.230
				LNB/OFA	435	1.340
				LNB/SAS/OFA	290	895

[1] PM = primary measures as given in Table 8

Annex 12: Comparison between measured and calculated SO_2 and NO_x emission data

The proposed methodology for the determination of SO_2 and NO_x emission factors is described in the Sections 4.1 and 4.2. Calculated flue gas concentrations in [mg/m^3] have been used for the derivation of emission factors in [g/GJ]. A comparison of measured concentrations in combustion plants in [mg/m^3] with calculated concentrations in [mg/m^3] can be used for verification purposes.

A comparison of measured concentrations with calculated flue gas concentrations downstream of the boiler is given as an example for some power plants in Table 12-1.

Table 12-1: Comparison of measured and calculated flue gas concentrations in raw gas of the boiler (taking into account primary reduction measures)$^{13)}$

Type of boiler	Power plant	C_{SO_2} [mg/m^3]		C_{NO_2} [mg/m^3]	
		measured	calculated	measured	calculated
DBB	Altbach (FRG)$^{1)}$	ca. 1,700	1,380 - 1,610	ca. 600	599 - 681
	Münster (FRG)$^{2)}$	1,644 - 1,891	1,380 - 1,440	800 - 900	1,090
	Karlsruhe (FRG)$^{3)}$	1,600 - 2,000	1,310 - 1,650	900 - 1,000	923 - 1,140
	Hanover (FRG)$^{4)}$	1,600 - 1,800	1,610	ca. 800	681
	Mehrum (FRG)$^{5)}$	ca. 2,700	1,610	ca. 800	990
	Nuremberg (FRG)$^{6)}$	ca. 1,800	1,610	n. d.	1,240
	Heilbronn (FRG)$^{7)}$	ca. 1,800	1,900 - 2,200	≤ 800	1,050 - 1,070
	IMATRAN (SF)$^{8)}$	n. d.	1,480 - 1,700	ca. 225	516 - 747
	EPON (NL)$^{9)}$	1,429 - 1,577	1,580 - 2,190	363 - 609	999 - 1,010
WBB	Aschaffenburg (FRG) $^{10)}$	2,400	1,530	1,000	1,010
	Charlottenburg (FRG) $^{11)}$	1,800	1,530	1,300	1,080
	Karlsruhe (FRG) $^{12)}$	1,295 - 1,716	1,610	ca. 960	1,460

1) coal: Germany RAG, Germany others; reduction measures: WS; LNB/SAS, SCR; thermal capacity 1,090 MW

2) coal: Germany others, $\alpha_S = 0.15$; reduction measure: DESONOX ($\eta_{SO2} = 0.94$, $\eta_{NO2} = 0.82$); thermal capacity 100 MW

3) coal: individual data, $\alpha_S = 0.4$; reduction measures: WS ($\eta = 0.85$); LNB/opt. ($\eta = 0.3$); SCR; thermal capacity 1,125 MW

4) coal: Germany others; reduction measures: SDA; LNB/OFA, SCR; thermal capacity 359 MW

5) coal: Germany others; reduction measures: WS; LNB, SCR; thermal capacity 1,600 MW

6) coal: Germany others; reduction measures: SDA; SCR; thermal capacity 110 MW

7) coal: individual data; reduction measures: WS ($\eta = 0.95$); OFA, SCR; thermal capacity 1,860 MW

[8] coal: individual data; reduction measures: WS; LNB/OFA; electrical capacity 650 MW

[9] coal: individual data; reduction measures: FGD (η = 0.93); high temperature NO_x reduction (η = 0.4), electrical capacity 630 MW

[10] coal: Germany RAG; reduction measures: WS; SAS, SCR; thermal capacity 395 MW

[11] coal: Germany RAG; reduction measures: WS; OFA; thermal capacity 120 MW

[12] coal: individual data; reduction measures: WS (η = 0.88); SCR (η = 0.9; thermal capacity) 191 MW

[13] values refer to full load conditions

n. d. = no data available

Table 12-2: Comparison of measured and calculated flue gas concentrations downstream of secondary reduction measure (if installed)[13]

Type of boiler	Power plant	C_{SO_2} [mg/m^3]		C_{NO_2} [mg/m^3]	
		measured	calculated	measured	calculated
DBB	Altbach (FRG)[1]	ca. 250	150 - 176	ca. 200	125 - 142
	Münster (FRG)[2]	85 - 181	820 - 859	163 - 176	74
	Karlsruhe (FRG)[3]	240 - 300	208 - 261	190	192 - 238
	Hanover (FRG)[4]	200	176	150	142
	Mehrum (FRG)[5]	400	176	190	206
	Nuremberg (FRG)[6]	50 - 140	176	70 - 100	257
	Heilbronn (FRG)[7]	100 - 200	207 - 240	≤ 200	218 - 223
	IMATRAN (SF)[8]	n. d.	161 - 186	ca. 225	516 - 747
	EPON (NL)[9]	ca. 148	113 - 184	ca. 609	999 - 1,010
WBB	Aschaffenburg (FRG) [10]	70	167	200	209
	Charlottenburg (FRG) [11]	175	167	163	1,080
	Karlsruhe (FRG) [12]	47 - 165	207	ca. 150	159

[1] - [13] for footnotes see Table 12-1 above

n.d. = no data available

The quality and quantity of data obtained by the power plant operators vary greatly. For unknown compositions of coal and other missing parameters default values have been used (e.g. for coal compositions see Annexes 7 and 8).

The values in Table 12-1 are compared in the Figure 12-1 below:

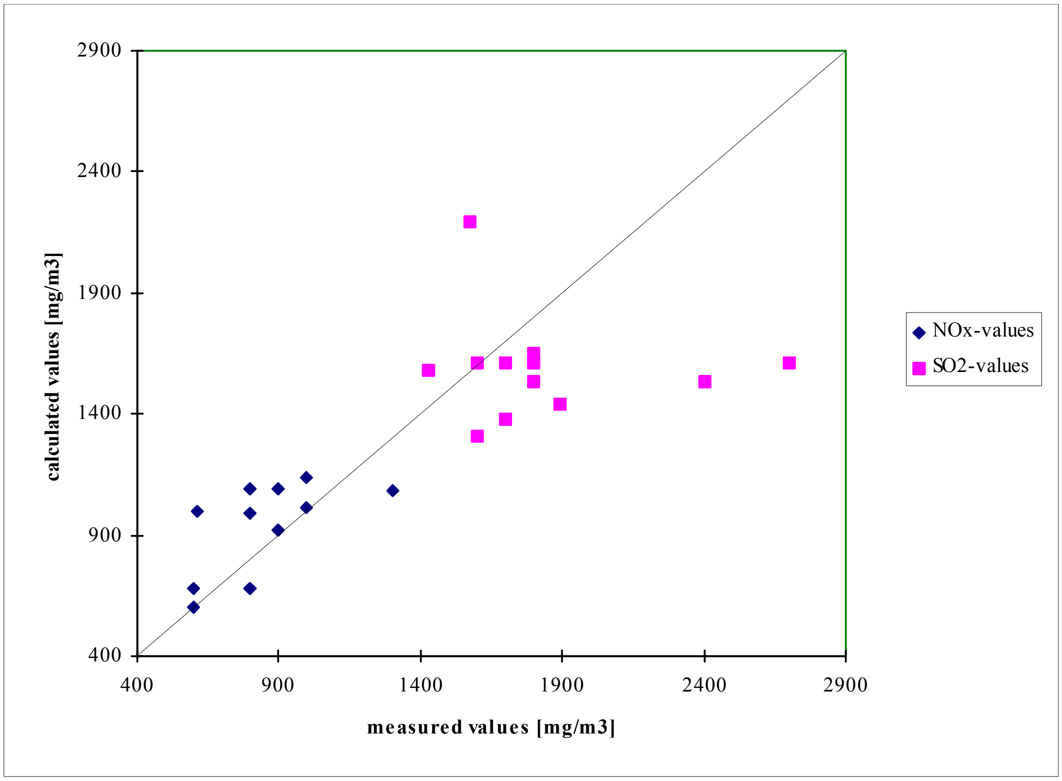


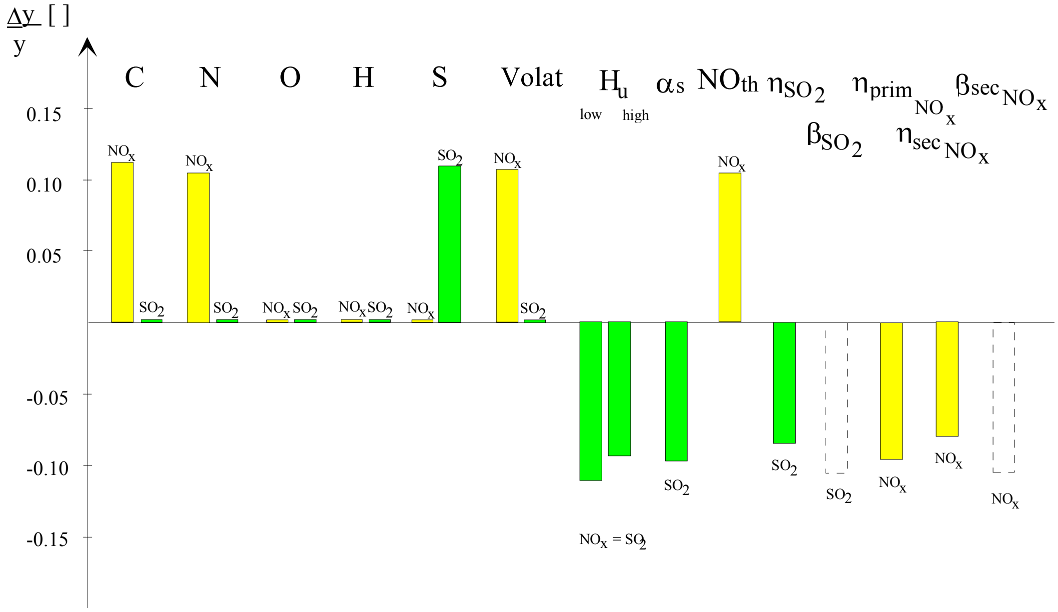
Figure 12-1: Comparison of measured flue gas concentrations [mg/m^3] and calculated flue gas concentrations [mg/m^3] downstream of the boiler

The comparison of measured flue gas concentrations and calculated flue gas concentrations shows that most values are scattered close to the middle axis.

Good correlations between measured and calculated values have been obtained for calculations which are only based on plant specific data provided by power plant operators. But for most calculations a mixture of plant specific data and default values for missing parameters has been used which leads to deviations from the middle axis. In particular strong differences occur for SO_2 emissions which show a tendency to be overestimated. The tendency can be explained by assumptions with regard to default values; e.g. the sulphur retention in ash varies greatly depending on the data availability.

Annex 13: Sensitivity analysis of the computer programme results

A sensitivity analysis was carried out with all model input parameters used. The 14 input parameters (fuel content of carbon C, nitrogen N, oxygen O, hydrogen H, sulphur S, volatiles Volat, lower heating value H_u, sulphur retention in ash α_S, fraction of thermal nitrogen oxide NO_{th}, reduction efficiency η and availability β of abatement measures) was arranged with respect to their influence on SO_2 and NO_x emissions. Each input parameter was varied by ±10 % except β_{SO2} and $\beta_{sec.NOx}$ which were varied only by - 4 % (dashed line); the variation of the calculated emission factors is presented in Figure 13-1.



Δy/y relative change of emission factors (pollutant as indicated)

Figure 13-1: Sensitivity analysis of the emission factor calculation programme results for pulverised coal combustion

For emission factors of SO_2 the sulphur content of fuel and the sulphur retention in ash are highly relevant. For emission factors of NO_x the fuel content of nitrogen, carbon and volatiles as well as the reduction efficiency of primary measures are highly relevant. The fuel contents of oxygen and hydrogen are not relevant. The relative change of emission factors concerning the lower heating value can be described for SO_2 and NO_x as an exponential curve: that means that uncertainties at lower levels of the heating values (e.g. for brown coal) influence the result stronger. The efficiency of secondary measures is of slightly less influence than the efficiency of primary measures. The availability of secondary measures is marked with a dashed line in Figure 13-1; a 4 % variation of this parameter has shown significant influence.

Annex 14: Users' manual for the emission factor calculation programme (for September 1995 version)

Determination of SO_2 and NO_x emission factors for large combustion plants

1 Computer specifications

This programme requires MICROSOFT WINDOWS 3.1, a 3½" floppy disc drive, and at least 200 Kbyte on the hard disc. The programme has been designed in MICROSOFT EXCEL 4.0 - English Version.

2 Installation

The floppy disc received contains 19 files. All these files have to be installed on the hard disc. The following users' guide is stored under README.DOC (written with MICROSOFT WORD FOR WINDOWS 2.1).

The software has to be installed on your hard disk "C" by using the following procedure:

- Create a new sub-directory with the name 'POWER_PL' by following the instructions:
  - in DOS go to C:\
  - type: MD POWER_PL
  - hit the <ENTER>-key
  - change into this sub-directory by typing: CD POWER_PL
  - hit the <ENTER>-key.
- To copy all the files from your floppy disc into the sub-directory 'POWER_PL' proceed as follows:
  - insert your disk into slot A (or B) of your PC
  - type COPY A: (or B:)*.*
  - hit the <ENTER>-key.

The installation of the programme is then complete.

3 How to work with the programme

3.1 Start the programme

- Start MICROSOFT WINDOWS 3.1 and MICROSOFT EXCEL 4.0 - English Version (or MICROSOFT EXCEL 5.0 - English Version).
- In 'FILE' - 'OPEN', go to hard disk 'C' and activate the sub-directory 'POWER_PL'. Then you will see all the necessary files in the programme in the left window.
- Choose the file 'POWER_PL.XLW' and hit the <ENTER>-key.
- Then the programme opens all the tables and macros needed.

3.2 Further proceedings with the programme

- When you see the first screen please type 'Ctrl'-'a' (or 'Strg'-'a') to start the programme. By hitting these two keys you start a macro, which takes you through all the levels of the programme. The input data for the programme are divided into background tables for the fuel used, for SO_2-specification and NO_x-specification.

Fuel data input

- First the programme asks for an identification of the model run. You are free to put in the name of the power plant, type of boiler, type of fuel (e. g. Heilbronn - dry bottom boiler - hard coal).
- The next window requests the type of coal (hard coal or lignite).
- The programme asks you to choose one of the fuel compositions listed. Select one of them by typing the corresponding number and hitting the 'OK'-key on the screen$^{1)}$. If the default values of the given fuel compositions do not correspond with your power plant, you have the possibility of putting in corrected values by choosing the last line of the table (line 17 or 10). Then the programme asks you to enter in the individual values. The values given by the 'question-window' can be kept by hitting the 'OK'-key on the screen.
- Then the programme asks for the water content of the fuel and the reference-content of oxygen in the flue gas. The value given by the 'question-window' can be retained by hitting the 'OK'-key on the screen.

SO_2 data specification

- The programme asks you to choose one of the listed numbers as a value for the sulphur retention in ash. Please select one of them by typing the corresponding number and hitting the 'OK'-key on the screen1). If the default values for the sulphur retention in ash do not correspond with your power plant, you have the possibility of putting in corrected values by choosing the last line of the table (line 3). Then the programme asks you to put in the value.
- The programme asks you to choose one of the listed secondary measures SO_2 . Please select one of them by typing the corresponding number and hitting the 'OK'-key on the screen$^{1)}$. If the default values of the efficiencies and availabilities of the secondary measures given do not correspond with those of your power plant, you have the possibility of putting put in corrected values by choosing the last line of the table (line 9). Then the programme asks you to put in the individual values.

  At this point the calculations for SO_2 are finished.

NO_x data specification

- The programme proceeds with the calculations of NO_2 by asking for a value for $NO_{thermal}$[1]. At this stage, the thermal NO (NOthermal) has to be put in as an exogenious value as given in the table. You have the possibility of putting in a new value by following the instructions on the screen.

- The next window requests the type of boiler (wet bottom boiler WBB- dry bottom boiler DBB).
- Then you have to choose a type of combination of primary measure installed. For some primary measures, reduction efficiencies are given as default values[11]. If you have better data available, you can put in new values choosing the last line of the table (line 17) and follow the instructions on the screen.
- Finally, you have to choose a type of combination of secondary measure installed[1]. As mentioned above, you can put in different values of efficiencies and availabilities by choosing one secondary measure from the table (typing the corresponding number). Or else you can put in your own values by selecting the last line of the table (line 6). Please follow the instructions on the screen.

At the end the following message appears on the screen: You can save the data-sheet named 'AINPUSO2.XLS' under a different name.

If you want to do further model runs, just type 'Ctrl'-'a' (or 'Strg'-'a') and the programme starts again.

In order to finish your calculation, just quit EXCEL without saving changes in any of the 19 basic files of this software.

---

[11] If the tables with the default values are overlapped by a 'question-window' you can move this window: point on the headline of this little window with your mouse-pointer, hold your left mouse-button and move it.

Annex 15: Frame conditions of the detailed investigation concerning start-up emissions and start-up emission factors /based on 116/

Approach

Start-ups have to be considered in a boiler-by-boiler approach. In order to determine the relevance of start-up emissions compared to full load emissions, measured emission data for SO_2, NO_2 and CO obtained from power plant operators have been analysed. Start-up emissions and start-up emission factors have been determined in principle by using the detailed methodology described in Section 5.

Technical specifications

The analysis of start-up emissions was accomplished by using measured values from dry bottom boilers, wet bottom boilers and a gas fired boiler. The interpretation of start-up emissions and start-up emission factors should take into account specifications in the design of the boilers and in the configuration of secondary measures installed. In the following, particularities of the boilers considered are given:

- *Dry bottom boiler (thermal capacity 1,050 MW and 1,147 MW, hard coal fuelled)*

  The smaller boiler is equipped with a primary measure for NO_x reduction (SAS). The SCR is arranged in a high dust configuration (SCR-precipitator-FGD). This boiler is often started slowly and directly connected to the FGD.

  The larger boiler is also equipped with a primary measure for NO_x reduction (SAS). The SCR is also arranged in a high dust configuration (SCR-precipitator-FGD). Due to special arrangements (individual construction of two heat exchangers without any slip between raw and clean flue gas) when this boiler is started up the FGD is by-passed. This boiler is also called „quick“ start-up boiler.

- *Wet bottom boiler (thermal capacity 499 MW each, hard coal fuelled)*

  One boiler is equipped with primary measures for NO_x (like OFA and improved coal mills). The other boiler is not equipped with primary measures. Both boilers are equipped with a common FGD. The SCR is arranged in a tail-end-configuration (precipitator-FGD-SCR) and equipped with a natural gas fired additional furnace. The type of FGD is wet scrubbing (WS). Both boilers are started up directly connected to the FGD.

- *Natural gas fired boiler (thermal capacity 1,023 MW)*

  This boiler is rarely used. It is designed for quick start-ups. As a primary measure, special NO_x burners are installed. As a secondary measure an SCR is installed. SO_x abatement is not necessary due to the fact that low sulphur fuels are used.

Boilers without secondary measures show start-up emissions which are below the emissions under full load conditions. During start-ups boilers with secondary measures often show significantly higher SO_2 emissions than during the same time under full load conditions. Start-up emissions are released until the secondary measures are working under optimal conditions (for

SO_2 and NO_2). CO emissions can be significant up to the time when the boiler operates at minimum load.

The relevance of start-up emissions depends on the following parameters which have to be considered when interpreting measured values (emissions or emission factors):

- the type of boiler (e.g. wet bottom boilers always release higher NO_x emissions than dry bottom boilers, due to higher combustion temperatures),
- the type of fuel used (e.g. SO_x emissions are directly related to the sulphur content of the fuel; fuel-nitrogen also contributes to the formation of NO_x),
- the status of the boiler at starting-time (hot, warm or cold start, see Table 11).
- the specifications of any individual start-up, like
  - the duration and the velocity of the start-up,
  - load level obtained (reduced load or full load),
  - the configuration of secondary measures (e.g. the start-up time of the high-dust-configurations (SCR-precipitator-FGD) depends on the boiler load, due to the fact that the SCR catalyst is directly heated by the flue gas; tail-end-configurations (precipitator-FGD-SCR) can have shorter start-up times, due to the fact that the SCR catalyst can be preheated by an additional burner),
  - start-up of the flue gas desulphurisation directly or in by-pass configuration,
  - emission standards which have to be met (boiler-specific emission standards can be set up below the demands of the LCP Directive).

Annex 16: List of abbreviations

a	Content of ash in coal (wt.-%)
AC	Activated Carbon Process
ar	As received
bc	Brown coal
BFCB	Bubbling Fluidised Bed Combustion
CF_n	Correction factor for month n [ ]
CFBC	Circulating Fluidised Bed Combustion
CC	Combined Cycle
CI	Compression Ignition
$CM_{HM_{FA.raw}}$	Heavy metal concentration in raw gas fly ash $[\frac{g}{Mg}]$
$CM_{HM_{FA.clean}}$	Heavy metal concentration in fly ash in clean flue gas $[\frac{g}{Mg}]$
$\overline{C}$	Expected value (mean value) of the flue gas concentration $[\frac{mg}{m^3}]$
C_i	Concentration $[\frac{kg}{kg}]$, $[\frac{g}{Mg}]$, $[\frac{mg}{m^3}]$, i = SO_2, S_{fuel} etc.
CODPOL	Code of pollutants according to CORINAIR
D_k	Number of days per month
DBB	Dry Bottom Boiler
DeNOx	Denitrification unit(s)
DESONOX	Type of simultaneous process for SO_2 and NO_x removal based on catalytic reaction
DSI	Dry Sorbent Injection
E	Emission within the period considered [Mg]
E^A	Emission during start-up period [Mg]
E^V	Emission for full load conditions during start-up period [Mg]
EF^A	Emission factor for start-up time [g/GJ]
$EF^{Reduced\ load}$	Emission factor for reduced load conditions [g/MWh]
EF^V	Emission factor under full load conditions [g/GJ]
EF_i	Emission factor, mostly in the unit $[\frac{g}{GJ}]$, i = SO_2, NO_x, CO_2 etc.
EF_f	Fly ash emission factor of raw gas [kg/Mg]
ESP	Electrostatic precipitator
f_a	Fraction of ash leaving combustion chamber as particulate matter (wt.-%)
f_e	Enrichment factor [ ]
f_g	Fraction of heavy metal emitted in gaseous form (wt.-%)
f_k	Factor of day k

f_n	Factor for month
$f_{n,l}$	Factor for hour
F^E	Ratio for start-up and full load emissions [ ]
F^{EF}	Ratio for start-up and full load emission factors [ ]
FBC	Fluidised Bed Combustion
FGD	Flue Gas Desulphurisation
FGR	Flue Gas Recirculation
g	Gaseous state of aggregation
GF	Grate Firing
GHV	Gross Heating Value
GT	Gas Turbine
hc	Hard coal
HM	Heavy metal, trace elements
H_u	Lower heating value $[\frac{MJ}{kg}]$
k^{load}	Ratio of reduced load to full load emission factor [ ]
K_c	Mean efficiency of dust control equipment (%)
K_t	Share of plant capacity connected to dust control equipment (%)
l	Liquid state of aggregation
L	Actual load
LCP	Large Combustion Plant
LIFAC	Special type of DSI, mostly used in Finland
LNB	Low NOx Burner
$\dot{m}^L$	Fuel consumption during periods at reduced load conditions [GJ]
$\dot{m}^V$	Fuel consumption during full load periods [GJ]
$\dot{m}_{fuel}$	Fuel consumption per time unit $[\frac{kg}{a}]$, $[\frac{kg}{h}]$
$\dot{m}_{FA}$	Average annually emitted fly ash $\left[\frac{Mg}{a}\right]$
$\dot{m}_q^A$	Fuel consumption during start-up period [GJ]; q= type of start-up (cold start, warm start, hot start)
maf	Moisture and ash free
NMVOC	Non-Methane Volatile Organic Compounds
$No_{f\ uel}$	Fuel based emission of nitrogen oxide
$NO_{thermal}$	Thermal nitric oxide
OFA	Overfire Air

P	Daily coal consumption $[\frac{Mg}{d}]$
PM	Primary Measure
RAG	Coal mined in Rhine area in Germany
s	Solid state of aggregation
SAS	Staged Air Supply
SC	Simple Cycle
SCR	Selective Catalytic Reduction
SI	Spark Ignition
SNAP	Selected Nomenclature of Air Pollutants
SNCR	Selective Non-Catalytic Reduction
SNOX	Technical specification of DESONOX-process
SPA	Spray Dryer Absorption
SPF	Split Primary Flow
ST	Stoker
Stat. E.	Stationary Engine
$\dot{V}$	Flue gas volume flow rate $[\frac{m^3}{h}]$
$\bar{\dot{V}}$	Average flow rate $[\frac{m^3}{h}]$
V_D	Dry flue gas volume per mass flue gas $[\frac{m^3}{kg}]$
V_{FG}	Dry flue gas volume per mass fuel $[\frac{m^3}{kg}]$
VOC	Volatile Organic Compounds
WAP	Walter Process
WBB	Wet Bottom Boiler
WL	Wellmann-Lord
WS	Wet Scrubbing
α_s	Sulphur retention in ash [ ]
β_{sec}	Availability of secondary abatement technique [ ]
γ	Fraction of thermal-NO formed [ ]
η_i	Reduction efficiency [ ], i = primary measure, secondary measure

SNAP CODE:	**010103** **010203** **020103** **020202** **020302** **030103**
SOURCE ACTIVITY TITLE:	**COMBUSTION IN ENERGY & TRANSFORMATION INDUSTRIES** ***Particulate emissions from smaller Combustion Plants (<50MWth)***
NOSE CODE:	**101.03**
NFR CODE:	**1 A 1 a-c** **1 A 2 a-f** **1 A 4 a, bi, ci**
ISIC	**3510**

1 ACTIVITIES INCLUDED

This chapter covers emissions of particulate matter released from smaller combustion installations within the energy and transformation industries in boilers and furnaces with a thermal capacity $\leq 50\ MW_{th}$. Emissions of other pollutants from these sources can be found in chapter B111. Note that Chapter B216 also includes some combustion technologies relevant to the energy and transformation industries.

2 CONTRIBUTION TO TOTAL EMISSION

The contributions of PM_{10} and $PM_{2.5}$ emissions released from combustion in small combustion installations to total emissions in countries of the CORINAIR90 inventory is presented in Table 2.1.

Table 2.1 Contribution to total particulate matter emissions from 2004 EMEP database (WEBDAB)

NFR Sector	**Data**	**PM_{10}**	**$PM_{2.5}$**	**TSP**
1 A 1 a - Public Electricity and Heat Production[a]	No. of countries reporting	26	26	27
	Lowest Value	0.2%	0.2%	0.2%
	Typical Contribution	11.7%	10.1%	12.8%
	Highest Value	48.8%	47.8%	48.4%
1 A 2 - Manufacturing Industries and Construction[b]	No. of countries reporting	26	26	26
	Lowest Value	0.7%	0.6%	0.6%
	Typical Contribution	9.0%	9.5%	7.9%
	Highest Value	20.7%	22.1%	25.7%
1 A 4 a - Commercial / Institutional[c]	No. of countries reporting	23	23	23
	Lowest Value	0.1%	0.1%	0.1%
	Typical Contribution	3.9%	3.4%	4.5%
	Highest Value	19.3%	22.2%	29.5%
1 A 4 b - Residential[d]	No. of countries reporting	3	2	3
	Lowest Value	2.0%	6.5%	3.7%
	Typical Contribution	14.9%	26.2%	10.8%
	Highest Value	36.6%	45.8%	15.4%
1 A 4 b i - Residential plants[e]	No. of countries reporting	23	23	23
	Lowest Value	2.7%	5.8%	0.8%
	Typical Contribution	28.3%	33.1%	22.0%
	Highest Value	67.1%	74.6%	53.2%
1 A 5 a - Other, Stationary (including Military)[f]	No. of countries reporting	7	7	7
	Lowest Value	0.0%	0.0%	0.0%
	Typical Contribution	0.1%	0.1%	0.1%
	Highest Value	0.5%	0.4%	0.6%

[a] Includes contribution from Chapter 112

[b] Includes contributions from Chapter 112 and 316 (SNAP 030106)

[c] Includes contribution from Chapter 112 and 216 (SNAP 020205)

[d] Includes contribution from Chapter 810

[e] Includes contribution from Chapter 112

[f] Includes contribution from Chapter 112 and 216 (SNAP 020106)

3 GENERAL

3.1 Description

This chapter considers emissions of PM generated by boilers smaller than 50 MWth, this chapter covers the energy and transformation industries use of combustion plant and the devices in use are generally larger than 1 MW_{th}. Information on smaller units can be found in Chapter B216. Other emissions from this source category are considered in B111.

3.2 Definitions

See B111.

3.3 Techniques

See B111 for information on boiler types and fuels. Combustion of coal and other solid fuels present the main source for primary PM emissions.

3.4 Emissions

Particulate emissions from small combustion installations burning solid fuels are often greater than emissions from larger plants (per unit of energy input); the physical and chemical characteristics of the PM also differ. This is because different combustion and abatement techniques are applied.

Combustion of fuels will generate solid residues which may be deposited in the combustion chamber (furnace bottom ash), within the furnace, boiler surfaces or ducting (fly ash). Coal and other fuels with a significant ash content have the highest potential to emit PM. Suspended ash material in exhaust gases will be retained by particulate abatement or other emission abatement equipment (abatement residues). Material which remains in the flue gases beyond the abatement equipment and passes to the atmosphere is primary PM. Secondary PM is formed by chemical and physical processes after discharge to atmosphere and is NOT considered here.

3.5 Controls

Particulate emission reduction for smaller boilers is usually obtained applying abatement equipment. It is unlikely that solid-fuel boilers or furnaces in the size range considered in this chapter would be unabated however; some may have comparatively low technology abatement measures. Settling Chambers use gravity separation to remove particles, but the collection efficiency is low. Cyclone separators can be used or, more commonly, units with multiple cyclones are applied to improve the collection efficiency. More efficient abatement measures are electrostatic precipitators and fabric filters, although use of these on the smallest boilers may be limited due to comparatively high capital and operating costs.

Other measures to prevent or reduce particle emissions can also be implemented, such as replacing coal with other fuels, or replacing old appliances with newer, more efficient equipment.

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

---

[1] The term “Tier” is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.
Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.
Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the Tier 1 simpler methodology, where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment. For a Tier 2 approach an approximation to the most appropriate technology factors can be adopted with potential, if more detailed activity data are available, for use of default sector or technology factors.

Consequently the simplest methodology (Tier 1) is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = \text{AR x EF}$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

The Tier 2 methodology is a modified version of this basic equation :

$$\text{Emission} = \sum((AR_1 \text{ x } EF_1) + (AR_2 \text{ x } EF_2) + \ldots.(AR_n \text{ x } EF_n))$$

Default emission factors for this purpose are provided in Sections 8.1 and 8.2.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tier 3) to estimate emissions of pollutants from combustion plant <50 MW_{th} is based on measurements or estimations using plant specific emission factors for the types of plant and technologies used within the country - guidance on determining plant specific emission factors is given in the Measurement Protocol Annex.

The recommended detailed methodology to estimate emissions of PM from combustion activities is based on measurements and/or estimations using technology-specific emission factors.

Information on the type of the process and activity data, for example combustion and abatement technologies, is required to assign appropriate emission factors.

Reference emission factors for comparison with users' own data are provided in Section 8.2.

6 ACTIVITY STATISTICS

Activity statistics for fuel consumption in industry sectors for estimating emissions using the simpler estimation methodology (Tiers 1 and 2) are usually derived from national statistics. However, data on fuel use by smaller combustion plant within industry sectors may not be readily available. However, fuel suppliers, regulators and individual operators may be able to provide some data and other information may be available through relevant surveys, energy modelling and other studies.

The detailed methodology (Tier 3) requires more detailed information such as the amount and types of fuel consumed and the type of installation it is used in. However, the large number of plant in most countries will be a constraint on a Tier 3 approach and these data are not always easily available.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 2 on energy, Chapter 1.

7 POINT SOURCE CRITERIA

The largest boilers may be considered point sources if plant specific data are available however; in general, this chapter covers area sources only.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Default Emission Factors For Use With Simpler Methodology (Tier 1)

Table 8.1 Default emission factors for the simple methodology for small combustion installations

Fuel	Emission factor, g GJ^{-1}			Notes[2]
	TSP	PM_{10}	$PM_{2.5}$	
Hard coal, brown coal, other solid fuels	80	60	60	From Chapter B216
Natural gas	0.9	0.9	0.9	US EPA
Derived gases	5	5	5	CEPMEIP worst case for derived gases
Heavy fuel oil	50	40	30	From chapter B216
Other liquid fuels	50	40	30	From Chapter B216
Biomass	50	40	40	From Chapter B216

8.2 Reference Emission Factors For Use With Tier 2 Methodology

Tables 8.2a-z contain reference particulate emission factors for fuel combustion in various technologies with different types of abatement. These are suitable for use with the Tier 2 methodology.

---

[2] Source: US EPA AP 42 (1996); CEPMEIP (2006)

Table 8.2a Emission factors for combustion processes burning hard coal.

Fuel	**NAPFUE**	**NFR Codes**	**Activity description**	**Activity detail**	**Emission factor**			**Notes**
Hard coal					**TSP**	**PM$_{10}$**	**PM$_{2.5}$**	
Bit. Coal	101	Various	Electricity, CHP, heat	FF <20 mg.Nm^{-3}	6	6	5	CEPMEIP 'BAT'
				ESP (or FF) <50 mg.Nm^{-3}	15	12	6	Scaled from CEPMEIP ESP factor. TSP scaled to a nominal 100 mg.Nm^{-3} limit
				ESP <100 mg.Nm^{-3}	30	25	12	From CEPMEIP sub-bit coal 'high efficiency ESP', TSP scaled to a nominal 100 mg.Nm^{-3} limit
				ESP Old/conventional <500 mg. Nm^{-3}	140	70	17	CEPMEIP
				Unit with multicyclone	100	60	35	CEPMEIP
				Unit, uncontrolled or cyclone	500	250	100	CEPMEIP (N.B. such a high emission concentration would apply to few if any plant)
Sub-bituminous coal	103	Various	Electricity, CHP, heat plant	FF <20 mg.Nm^{-3}	6	6	5	CEPMEIP 'BAT'
				ESP (or FF) <50 mg.Nm^{-3}	15	12	6	Scaled from CEPMEIP ESP factor (TSP scaled to a nominal 100 mg.Nm^{-3} limit)
				ESP <100 mg.Nm^{-3}	30	25	12	From CEPMEIP sub-bit coal 'high efficiency ESP', TSP scaled to a nominal 100 mg.Nm^{-3} limit
				ESP Old/conventional	140	70	17	CEPMEIP

Fuel	NAPFUE	NFR Codes	Activity description	Activity detail	Emission factor			Notes
				<500 mg. Nm^{-3}				
				Unit with multicyclone	100	60	35	CEPMEIP
				Unit, uncontrolled or cyclone	500	250	100	CEPMEIP (the lower of the two TSP factors, the 800 g GJ-1 for small uncontrolled plant is such a high emission concentration that would apply to few if any plant)
Coke	107	1 A 1 b	Oil refineries	Uncontrolled	500	250	100	Coke is unlikely to be burned as primary fuel, when co-fired use the factor for the principal fuel.

Table 8.2b Emission factors for combustion processes burning brown coal.

Fuel	NAPFUE	NFR Code	Activity description	Activity detail	Emission factor			Notes
					TSP	PM_{10}	$PM_{2.5}$	
Brown coal	105	Various	Electricity plant, CHP plant, heat plant	Modern FF <20 mg.Nm^{-3}	9	8	6	CEPMEIP 'BAT'
				High efficiency ESP (or FF)	40	30	14	CEPMEIP
				Conventional large unit with multicyclone	100	60	35	CEPMEIP
Peat	113	Various	Electricity plant, CHP plant, heat plant	Modern abatement (FF) <30 mg.Nm3	9	8	6	CEPMEIP
				Efficient abatement, <50 mg.Nm3	20	15	10	TSP Scaled from emission limit of 50 mg.Nm^{-3}
				Efficient abatement, <100mg.Nm3	40	30	20	TSP Scaled from emission limit of 100 mg.Nm^{-3}
				Conventional technology	120	40	20	CEPMEIP
				Conventional smaller, multicyclone	300	40	20	CEPMEIP

Table 8.2c Emission factors for combustion processes burning other solid fuels

Fuel	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Notes**
					TSP	**PM_{10}**	**$PM_{2.5}$**	
Municipal solid waste	114	Various	Electricity plant, CHP plant, heating plant	Effective emission control (BAT)	15	13	10	CEPMEIP, (N.B. care should be taken using this factor as waste burning is often controlled under national/international regulation to a more stringent specification)
				Conventional emission control	100	70	55	CEPMEIP (uncontrolled. optimised combustion), (N.B. care should be taken using this factor as waste burning is often controlled under national/international regulation to a more stringent specification)
Ind. waste	115	Various	Electricity, CHP, heating plant	Effective emission control (BAT)	15	13	10	CEPMEIP, (N.B. care should be taken using this factor as waste burning is often controlled under national/international regulation to a more stringent specification)
				Conventional emission control	100	70	55	CEPMEIP (uncontrolled, optimised combustion), (N.B. care should be taken using this factor as waste burning is often controlled under national/international regulation to a more stringent specification)

Fuel	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Notes**
				Older small uncontrolled	600	350	210	CEPMEIP (uncontrolled, optimised combustion), (N.B. care should be taken using this factor as waste burning is often controlled under national/international regulation to a more stringent specification)

Table 8.2d Emission factors for combustion processes burning natural gas.

Fuel	NAPFUE	NFR Code	Activity description	Activity detail	Emission factor			Notes
					TSP	**PM_{10}**	**$PM_{2.5}$**	
Natural gas	301	Various	Electricity, CHP and heating plant	Burner with optimised combustion	0.1	0.1	0.1	CEPMEIP
				Conventional installation	0.2	0.2	0.2	CEPMEIP
				Conventional installation	0.9	0.9	0.9	USEPA Filterable

Table 8.2e Emission factors for combustion of derived gases.

Fuel	NAPFUE	NFR Code	Activity description	Activity detail	Emission factor			Notes
					TSP	**PM_{10}**	**$PM_{2.5}$**	
Gas works gas	311	Various	Electricity, CHP and heating plant	Clean fuel, efficient combustion	0.1	0.1	0.1	CEPMEIP
				Clean fuel, Conventional installation	0.2	0.2	0.2	CEPMEIP (conventional installation)
				Conventional installation	5	5	5	CEPMEIP (High PM due to fuel quality)
Other gaseous fuel	314	Various	Electricity, CHP and heating plant	Clean fuel, efficient combustion	0.1	0.1	0.1	CEPMEIP
				Conventional installation	5	5	5	CEPMEIP

Fuel	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Notes**
Coke oven gas	304	Various	Electricity, CHP heating plant, coke ovens	Clean fuel, efficient combustion	0.1	0.1	0.1	CEPMEIP
				Clean fuel, conventional installation	0.2	0.2	0.2	CEPMEIP (conventional installation)
				Conventional installation	5	5	5	CEPMEIP
Blast furnace gas	305	Various	Electricity, CHP and heating plant, coke ovens	Clean fuel, efficient combustion	0.1	0.1	0.1	CEPMEIP
				Clean fuel, Conventional installation	0.2	0.2	0.2	CEPMEIP (conventional installation)
				Conventional installation	5	5	5	CEPMEIP

Table 8.2f Emission factors for combustion of heavy fuel oil.

Fuel	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Notes**
					TSP	PM_{10}	$PM_{2.5}$	
Residual fuel oil	203	Various	Electricity, CHP and heating plant	Low S fuel with optimised burner and abatement	3	3	2.5	CEPMEIP. (About 10 mg.Nm^{-3} or BAT)
				Low S fuel, efficient combustion	14	12	10	CEPMEIP (About 50 mg. Nm^{-3})
				Low-Medium S fuel, conventional installation	20	15	9	CEPMEIP (about 70 mg. Nm^{-3})
				Low-Medium S fuel, conventional installation	60	50	40	CEPMEIP (higher of two entries used. about 200 mg.N Nm^{-3})
				High S fuel	210	190	130	CEPMEIP (lower of two entries for high S used (higher entry 240 g GJ-1 for TSP). Very high emission concentration (about 750 mg. Nm^{-3})
Petroleum coke	110	1 A 1 b	Oil refineries	Conventional, multicyclone	100	60	35	CEPMEIP, *Bit. Coal factors more appropriate.*

Table 8.2g Emission factors for combustion of other liquid fuels.

Fuel	NAPFUE	NFR Code	Activity description	Activity detail	Emission factor			Notes
					TSP	PM_{10}	$PM_{2.5}$	
Gas/Diesel oil	205	Various	Electricity, CHP, heating plant	Optimised burner	2	2	2	CEPMEIP
				Conventional burner	5	5	5	CEPMEIP
Naphtha	210	1 A 1 b	Oil refineries	All units	5	5	5	CEPMEIP
Liquefied Petroleum gas	303	Various	Electricity, CHP, heating plant	Optimised burner	0.1	0.1	0.1	CEPMEIP
				Conventional burner	5	5	5	CEPMEIP
Refinery gas	308	Various	Electricity, CHP, heating plant	Optimised burner	0.1	0.1	0.1	CEPMEIP
				Conventional burner	5	5	5	CEPMEIP
Other oil	224	Various	Electricity, CHP, heating plant	Low S fuel, optimised burner	3	3	2.5	CEPMEIP
				Low S fuel, efficient combustion	14	12	10	CEPMEIP for residual oil. (About 50 mg. Nm^{-3} (LCPD limit for existing plant)
				Low-Medium S fuel, conventional installation	20	15	9	CEPMEIP. (about 70 mg. Nm^{-3})
				Low-Medium S fuel, conventional installation	60	50	40	CEPMEIP, (highest of similar entries with TSP of 35, 40, 50 and 60 used. About 200 mg.N Nm^{-3})
				High S fuel	210	190	130	CEPMEIP, lower of two entries for high S used.

Fuel	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Notes**
					TSP	**PM_{10}**	**$PM_{2.5}$**	
								(This is a very high emission concentration (about 750 mg.N Nm^{-3})

Table 8.2h Emission factors for combustion of biomass

Fuel	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Notes**
					TSP	**PM_{10}**	**$PM_{2.5}$**	
Wood	111	Various	Electricity, CHP, heating plant	Modern unit with FF, <20 mg.Nm3 TSP	7	7	6	TSP scaled from BAT benchmark, fractions applied based on Bit coal
				Older unit, <100 mg.Nm3 TSP	35	25	12	TSP scaled from emission concentration, fractions based on bit coal
				Uncontrolled conventional	100	70	55	CEPMEIP (Uncontrolled Multicyclone)
				Conventional minimal control	160	150	150	CEPMEIP for conventional installation
Charcoal	112	1 A 2 c	Chemicals	Conventional large unit with multicyclone	100	60	35	CEPMEIP, the use of charcoal is likely to be very rare.
					400	100	35	CEPMEIP, the use of charcoal is likely to be very rare. .
Black liquour	215	1 A 2 f	Textile & leather (Pulp and Paper)	Conventional installation	160	150	150	CEPMEIP (N.B. such a high emission concentration would apply to few if any

Fuel	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Notes**
					TSP	**PM_{10}**	**$PM_{2.5}$**	
								plant)
Biogas	309	Various	Electricity, CHP, heating plant	Modern optimised large installation	3	3	2.5	(CEPMEIP, clean fuel)
				Conventional burner	5	5	5	CEPMEIP
				Modern, optimised	20	15	10	CEPMEIP (gasification plant),

9 SPECIES PROFILES

The US EPA (2003) undertook a review of species profiles within $PM_{2.5}$ and reports particle size distribution data for a variety of fuels and combustion and abatement technologies. Some of these data are dated and have high uncertainty ratings. Profiles of other materials are not available.

Table 9-1 US EPA $PM_{2.5}$ species profile for combustion activities

Profile ref	Profile name	Component				
		POA	PEC	GSO4	PNO3	Other
22002	Residual Oil Combustion	0.1075	0.0869	0.5504	0.0005	0.2547
22003	Distillate Oil Combustion	0.0384	0.0770	0.3217	0.0024	0.5605
22004	Natural Gas Combustion	0.6000	0.0000	0.2000	0.0055	0.1945
22007	Liquid Waste Combustion	0.0540	0.1050	0.0680	0.0000	0.7730
22009	Solid Waste Combustion	0.0068	0.0350	0.0680	0.0000	0.8902
NCOAL	Coal Combustion	0.20	0.01	0.16	0.005	0.625
NWWAS	Wood Waste Boiler	0.39	0.14	0.08	0	0.39

Notes:
POA - Primary organic aerosol derived from organic carbon
PEC Elemental Carbon
GSO4 - Sulphate
PNO3 - Nitrate
Other – Remainder of $PM_{2.5}$ material emitted.

Note that the data for the coal combustion and some other profiles are derived from dilution tunnel measurements on large combustion plant and may not be directly comparable with primary $PM_{2.5}$ from sub-50 MW_{th} boilers.

10 UNCERTAINTY ESTIMATES

The overall 'Uncertainty' in national emission inventories may be significant – as illustrated in Table 9.1.

Table 9.1 Uncertainty estimate for selected pollutants in the UK air emission inventory (NAEI, 2005).

Pollutant	Estimated Uncertainty (%)
PM_{10}	-20 to +50
$PM_{2.5}$	-20 to +30
$PM_{1.0}$	-10 to +20
$PM_{0.1}$	+/- 10
Sulphur Dioxide	+/- 3
Oxides of Nitrogen	+/- 8
NMVOCs	+/- 10
Ammonia	+/- 20

There is uncertainty in both the aggregated emission factors and activity data used to estimate emissions i.e. the imprecision and error to be expected from the application of an 'average' emission factor or activity statistic to estimate emissions from a specific sector - an artificial grouping of 'similar' sources.

The uncertainty is partly the result of how emission factors are developed and applied. In the case of primary particulate matter, the expanded statistical uncertainty is made up of: between plant variance, within plant variance, and uncertainties associated with the measurement methodology used and the aggregation of data. The measurement data in Annex 1 illustrates the variability in emission factors that occurs from between plant variance.

Process measurements, from which emission factors are developed at individual facility level, are subject to both systematic and random errors in the determination of mass concentration, mass emission, size distribution, and analytical errors etc.

In addition bias may exist in emission factors arising from:

1. Assumptions made about the abatement used on 'typical' industrial installations. For example emission factors 'age', the factors widely used in the Guidebook and hence by many countries as default emission factors in their national inventories become out of date. Recent measurement work suggests that they may overestimate emissions from the industrial processes subject to more modern industrial emissions regulation. They may, however, still be fully representative for older plant, small plant, or for poorer fuels;
2. Assumptions about the relationship between TSP and PM10/$PM_{2.5}$. The technical literature is comprehensive for TSP and the data quality can be good if measurements

have been made using the international standard methods that are available (typically the 95% confidence limit ~10%). But a variety of methods are used for particle size fractionation and as yet there are no harmonised international standards to ensure comparability. Published measurement data for PM10 is sparse, that for $PM_{2.5}$ emissions more so. An added complication is that the methodology for the determination of TSP differs from that of PM10 and $PM_{2.5}$ and so the two need not correlate directly.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Knowledge of combustion and abatement techniques, dust removal efficiencies and operating techniques is limited.

Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges. Emission factors also need to be generated, which specifically relate to different levels of abatement on different types of plant.

The stack emission factors described in the Guidebook, and all the PM_{10} emission factors, are based whenever possible on measurements. Particle measurements have often been made on the mass of total particulate matter and then converted to PM_{10} based either on the size distribution of the sample collected or, more usually, on size distributions given in the literature. There may be secondary sources of particulate matter, that are diffuse or fugitive in nature e.g. emissions from coke ovens, stockpiles, ash handling etc. These emissions are difficult to measure and in some cases it is likely that no entirely satisfactory measurements have ever been made, in many cases estimates of emissions from such sources are missing.

There is very little published data suitable for emission inventory compilation. I.e. representative data of known quality relating a) quantities of (particulate) material released to b) the activity associated with the release of that pollutant. Suitable data and associated information would record the determination of mass emissions rates using standardized measurement methods or calculation-based methods. Ideally such methods would cover the planning and execution of the data collection programme including: the selection of sampling methodology, choice of equipment, suitable working procedures, the calculation of representative emissions rates, the selection of matching activity data, the determination of sampling/measurement uncertainty, and the reporting of information in a form that is suitable for calculating emissions factors.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Combustion plants should be considered as point sources if plant specific data are available. Otherwise national emissions should be disaggregated on the basis of plant capacity, employment, population or other relevant statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

Combustion processes in most industrial sectors can be considered as a continuous process however; district and agricultural heating plants will tend to have an operational profile determined by the season. Individual combustion plant may have daily and/or seasonal temporal profiles.

14 ADDITIONAL COMMENTS

See chapters B111 and B216.

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCESSES

17 REFERENCES

EMEP/CORINAIR Emission Inventory Guidebook – 2005, EEA (European Environment Agency) Chapter B216 and B111

IPPC Best Available Techniques Reference Document on Large Combustion Plants, December 2001, http://eippcb.jrc.es

NAEI (2005) UK National Atmospheric Emissions Inventory: UK Emissions of Air Pollutants 1970 to 2003, October 2005

US EPA (1996) Compilation of Air Pollutant Emission Factors Vol.1 Report AP-42 (5th ed.)

US EPA (2003) $PM_{2.5}$ Source Profiles
http://www.epa.gov/ttn/chief/emch/speciation/index.html

Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

For a detailed bibliography the primary literature mentioned in AP 42 can be used.

19 RELEASE VERSION, DATE AND SOURCE

Version: 1

Date: Aug 2006

Source: R. Stewart
AEA Technology
The Gemini Building
Didcot,
OXON
OX11 0QR

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Robert Stewart

AEA Technology Environment
The Gemini Building
Didcot
OXON
OX11 0QR

Tel: +44 870190 6575
Fax: +44 870190 6318
Email: robert.stewart@aeat.co.uk

Jozef Pacyna

NILU - Norwegian Institute of Air Research
PO Box 100
N-2027 Kjeller
Norway

Tel: +47 63 89 8155
Fax: +47 63 89 80 50
Email: JOZEF.PACYNA@NILU.NO

SNAP CODE:	**010101 & 010102** **010201 & 010202** **010301** **010401** **010501 & 010502** **020101 & 020102** **020201** **020301** **020302** **030101 & 030102**
SOURCE ACTIVITY TITLE:	**COMBUSTION IN ENERGY & TRANSFORMATION INDUSTRIES** ***Particulate emissions from large Combustion Plants (>50MWth)***
NOSE CODE:	**101.01** **101.02**
NFR CODE:	**1 A 1 a,b,c** **1 A 2 a-f** **1 A 4 b,c,i**
ISIC	**3510**

1 ACTIVITIES INCLUDED

This Supplement, to be read in conjunction with the existing Chapter B111, covers emissions of particulate matter (PM) released from combustion processes within the energy and transformation industries in boilers and furnaces larger than 50 MWth. This Supplement includes guidance on estimating total PM (TSP), PM_{10} and $PM_{2.5}$ emissions from these sources. Emissions of other pollutants from this sector are provided in chapter B111.

2 CONTRIBUTION TO TOTAL EMISSION

The contributions of PM_{10} and $PM_{2.5}$ emissions released from combustion in large combustion plant to total emissions in countries of the CORINAIR90 inventory is presented in Table 2.1.

Table 2.1 Contribution to total particulate matter emissions from 2004 EMEP database (WEBDAB)

NFR Sector	Data	PM_{10}	$PM_{2.5}$	TSP
1 A 1 a - Public Electricity and Heat Production[a]	No. of countries reporting	26	26	27
	Lowest Value	0.2%	0.2%	0.2%
	Typical Contribution	11.7%	10.1%	12.8%
	Highest Value	48.8%	47.8%	48.4%
1 A 2 - Manufacturing Industries and Construction[b]	No. of countries reporting	26	26	26
	Lowest Value	0.7%	0.6%	0.6%
	Typical Contribution	9.0%	9.5%	7.9%
	Highest Value	20.7%	22.1%	25.7%
1 A 4 a - Commercial / Institutional[c]	No. of countries reporting	23	23	23
	Lowest Value	0.1%	0.1%	0.1%
	Typical Contribution	3.9%	3.4%	4.5%
	Highest Value	19.3%	22.2%	29.5%
1 A 4 b - Residential[d]	No. of countries reporting	3	2	3
	Lowest Value	2.0%	6.5%	3.7%
	Typical Contribution	14.9%	26.2%	10.8%
	Highest Value	36.6%	45.8%	15.4%
1 A 4 b i - Residential plants[e]	No. of countries reporting	23	23	23
	Lowest Value	2.7%	5.8%	0.8%
	Typical Contribution	28.3%	33.1%	22.0%
	Highest Value	67.1%	74.6%	53.2%
1 A 5 a - Other, Stationary (including Military)[f]	No. of countries reporting	7	7	7
	Lowest Value	0.0%	0.0%	0.0%
	Typical Contribution	0.1%	0.1%	0.1%
	Highest Value	0.5%	0.4%	0.6%

[a] Includes contribution from Chapter 112

[b] Includes contributions from Chapter 112 and 316 (SNAP 030106)

[c] Includes contribution from Chapter 112 and 216 (SNAP 020205)

[d] Includes contribution from Chapter 810

[e] Includes contribution from Chapter 112

[f] Includes contribution from Chapter 112 and 216 (SNAP 020106)

3 GENERAL

3.1 Description

This chapter considers emissions of PM generated by boilers larger than 50 MWth. Other emissions from this source category are considered in B111.

3.2 Definitions

See B111.

3.3 Techniques

See B111 for information on boiler types and fuels. Combustion of coal and other solid fuels present the main source for primary PM emissions.

3.4 Emissions

Particulate emissions result from activities such as storage of fuels; on site transportation of solid fuel; combustion of fuels, transport, storage and disposal of combustion residues including furnace bottom ash, fly ash and, abatement residues.

Combustion of fuels will generate solid residues which may be deposited in the combustion chamber (furnace bottom ash), within the furnace, boiler surfaces or ducting (fly ash). Coal and other fuels with a significant ash content have the highest potential to emit PM. Suspended ash material in exhaust gases will be retained by particulate abatement or other emission abatement equipment (abatement residues). Material which remains in the flue gases beyond the abatement equipment and passes to the atmosphere is primary PM. Secondary PM is formed by chemical and physical processes after discharge to atmosphere and is NOT considered here.

3.5 Controls

Particulate emission reduction is usually achieved using abatement equipment. Electrostatic precipitators (ESPs) and fabric filters (FFs) are widely used on boilers. Cyclones (particularly multicyclones) can be found on smaller grate-fired boilers. Most pulverised coal fired power station boilers use ESPs although fabric filters are becoming more common. Flue gas desulphurisation (FGD) plant can also help reduce particulate emissions from pulverised coal-fired boilers. Wet limestone FGD systems retrofitted to existing plant are generally located downstream of existing ESPs and can provide a further stage of PM reduction. Dry lime injection FGD systems incorporate a FF for sorbent capture and PM removal.

Fabric filters are capable of achieving higher emission reductions than electrostatic precipitators but both are suitable[1] for the sector and can achieve PM emission concentrations of 5 - 30 mg/m^3.

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[2]:

---

[1] Either technology is considered part of Best Available Techniques (BAT) under EU Integrated Pollution Prevention and Control regulations.

[2] The term “Tier” is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.
Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.
Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

The Tier 1 simpler methodology, where limited information is available, uses a restricted set of default emission factors together with production capacity information specific to the country or region of interest; there is little or no specification of the type of industrial technologies or the type and efficiency of control equipment in place. The Tier 2 approach, in addition, requires an approximation of the mix of technologies in place, and more detailed activity data, but still allows the use of default sector or technology factors.

Consequently the simplest methodology (Tier 1) is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = \text{AR x EF}$$

In the energy sector, for example, fuel consumption would be the measure of activity and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

The Tier 2 methodology is a modified version of this basic equation:

$$\text{Emission} = \sum((AR_1 \text{ x } EF_1) + (AR_2 \text{ x } EF_2) + \ldots.(AR_n \text{ x } EF_n))$$

Default emission factors for this purpose are provided in Sections 8.1 and 8.2.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tier 3) to estimate emissions of pollutants from combustion plant >50 MW_{th} is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

In many countries, operators of combustion plant >50MWth will report emissions to comply with regulatory requirements and this data can be used to help compile the national inventory.

The recommended detailed methodology to estimate emissions of PM from combustion activities is based on measurements and/or estimations using technology-specific emission factors.

Information on the type of the process and activity data, for example combustion and abatement technologies, is required to assign appropriate emission factors.

Reference emission factors for comparison with users' own data are provided in Section 8.2.

6 ACTIVITY STATISTICS

Activity statistics for energy consumption or other relevant national activity data for estimating emissions using the simpler estimation methodology (Tiers 1 and 2) are available from national statistics.

The detailed methodology (Tier 3) requires more detailed information such as the amount and types of fuel consumed within individual combustion plant or industry sectors. These data are not always easily available although in many countries operators do report fuel use for emission trading or other legislative requirements.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 2 on energy, Chapter 1.

7 POINT SOURCE CRITERIA

Large combustion plants are regarded as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Default Emission Factors For Use With Simpler Methodology (Tier 1)

Fuel	**Technology**	**Emission factor, g GJ^{-1}**			**Notes**[3]
		TSP	**PM_{10}**	**$PM_{2.5}$**	
Hard coal, (assumes 20% ash) Brown coal, Other solid fuels	Pulverised coal, ESP	30	20	9	Based on AP 42 - assumes 20% ash content and PM emissions from solid mineral fuels generally similar to coal
	Pulverised coal, fluid bed, other FF	7.4	7.4	3.7	
	Cyclone furnace, ESP	6.1	4.2	2.3	
	Stoker with multicyclone	330	230	27	
	Pulverised coal ESP + wet limestone FGD	6	6	5	From CEPMEIP data (US EPA default factors for wet scrubbers are very high)
Natural gas		0.9	0.9	0.9	AP-42 filterable PM factor
Derived gases		5	5	5	CEPMEIP data, worst case for derived gases.
Heavy fuel oil (1% S)	No control	25	18	13	Assumes 1% sulphur as specified in the EU Sulphur content of liquid fuels Directive
	FGD	1.5	1.5	1.5	
Heavy fuel oil (3% S)	No control	64	45	33	Assumes 3% sulphur (maximum permitted in EU countries)
	FGD	3.8	3.8	3.7	
Other liquid fuels	LPG	2.0	2.0	2.0	
Biomass	FF	51	38	33	AP 42 Wood waste
	ESP	28	21	18	

The information provided in Section 8.2 provides further information for selection of more appropriate emission factors.

8.2 Reference Emission Factors For Use With Tier 2 Methodology

Tables 8.2a-z contain reference particulate emission factors for fuel combustion in various technologies with different types of abatement.

---

[3] Source: R. Stewart (2006); US EPA AP 42 (1996); CEPMEIP (2006)

Table 8.2a Emission factors for combustion processes burning hard coal.

Fuel	**NAPFUE**	**NFR Codes**	**Activity description**	**Activity detail**[4]	**Emission factor g.GJ^{-1}**			**Notes**[5]
Hard coal					**TSP**	**PM_{10}**	**$PM_{2.5}$**	
Bit. Coal	101	Various	Electricity plant, CHP plant	FGD, ESP or FF <20 mg.Nm^{-3} (BAT)	6	6	5	CEPMEIP
				ESP (or FF) <50 mg.Nm^{-3} (LCPD)	15	12	6	Scaled from CEPMEIP ESP factor
				ESP <100 mg.Nm^{-3} (LCPD)	30	25	12	From CEPMEIP sub-bit coal ‘high efficiency ESP’, TSP scaled to the EU LCP Directive existing plant sub 100MW$_{th}$ limit
				ESP Old/conventional <500 mg. Nm^{-3}	140	70	17	CEPMEIP
				Large unit with multicyclone	100	60	35	CEPMEIP
				Large unit, uncontrolled or cyclone	500	250	100	CEPMEIP (N.B. such a high emission concentration would apply to few if any plant)
Sub-bituminous coal	103	Various	Electricity plant, CHP plant, heat plant	FGD, ESP or FF <20 mg.Nm^{-3} (BAT)	6	6	5	CEPMEIP
				ESP (or FF) <50 mg.Nm^{-3} (LCPD)	15	12	6	Scaled from CEPMEIP ESP factor
				ESP <100 mg.Nm^{-3} (LCPD)	30	25	12	From CEPMEIP sub-bit coal ‘high efficiency ESP’, TSP scaled to LCPD existing plant sub 100MW$_{th}$ limit

---

[4] KEY: FGD: Flue gas desulphurisation, ESP: Electrostatic Precipitator, FF: Fabric Filter, BAT: Best Available Techniques, LCPD: Large Combustion Plant Data

[5] Sources: R. Stewart (2006); US EPA AP 42 (1996); CEPMEIP (2006)

Fuel	NAPFUE	NFR Codes	Activity description	Activity detail[4]	Emission factor g.GJ^{-1}			Notes[5]
				ESP Old/conventional <500 mg. Nm^{-3}	140	70	17	CEPMEIP
				Conventional large unit with multicyclone	100	60	35	CEPMEIP
				Conventional unit, uncontrolled or cyclone	500	250	100	CEPMEIP (N.B. such a high emission concentration would apply to few if any plant)
Coke	107							Coke is unlikely to be burned as primary fuel, when co-fired use the factor for the principal fuel.

Table 8.2b Emission factors for combustion processes burning brown coal.

Fuel	NAPFUE	NFR Code	Activity description	Activity detail	Emission factor			Reference/Comments
					TSP	PM$_{10}$	PM$_{2.5}$	
Brown coal	105	Various	Electricity plant, CHP plant, heat plant	FGD, ESP or FF <20 mg.Nm^{-3} (BAT)	9	8	6	CEPMEIP
				High efficiency ESP (or FF)	40	30	14	CEPMEIP (N.B. such a high emission concentration would apply to few if any plant)
				Conventional large unit with multicyclone	100	60	35	CEPMEIP (N.B. such a high emission concentration would apply to few if any plant)
				Older ESP	160	80	20	CEPMEIP (N.B. such a high emission concentration would apply to few if any plant)
				Older installation	500	250	100	CEPMEIP (N.B. such a high

Fuel	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Reference/Comments**
				uncontrolled or cyclone				emission concentration would apply to few if any plant)
Peat	113	Various	Electricity plant, CHP plant, heat plant	BAT/new LCPD, Modern end-of-pipe abatement FGD, ESP or FF. <30 mg.Nm3	9	8	6	CEPMEIP
				Efficient abatement LCP larger facility, <50 mg.Nm3	20	15	10	TSP Scaled from LCP emission limit of 50 $mg.Nm^{-3}$
				Efficient abatement LCP <100 MW_{th}, <100mg.Nm3	40	30	20	TSP Scaled from LCP emission limit of 50 $mg.Nm^{-3}$
				Conventional technology	120	40	20	CEPMEIP
				Conventional smaller, multicyclone	300	40	20	CEPMEIP

Table 8.2c Emission factors for combustion processes burning other solid fuels

Fuel	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Reference**
					TSP	**PM_{10}**	**$PM_{2.5}$**	
Municipal solid waste	114	Various	Electricity plant, CHP plant, heating plant	Effective emission control (BAT)	15	13	10	CEPMEIP, (N.B. care should be taken using this factor as waste burning is often controlled under national/international regulation to a more stringent specification)
(Solid)				Conventional emission control	100	70	55	CEPMEIP (uncontrolled. optimised combustion), (N.B. care should be taken using this factor as waste burning is often controlled under national/international regulation to a more stringent specification)
Ind. waste	115	Various	Electricity, CHP, heating plant	Effective emission control (BAT)	15	13	10	CEPMEIP, (N.B. care should be taken using this factor as waste burning is often controlled under national/international regulation to a more stringent specification)
				Conventional emission control	100	70	55	CEPMEIP (uncontrolled, optimised combustion), (N.B. care should be taken using this factor as waste burning is often controlled under national/international regulation to a more stringent specification)

Table 8.2d Emission factors for combustion processes burning natural gas.

Fuel (IPCC Cat)	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Reference**
					TSP	**PM_{10}**	**$PM_{2.5}$**	
Natural gas	301	Various	Electricity, CHP and heating plant	Burner with optimised combustion	0.1	0.1	0.1	CEPMEIP
				Conventional installation	0.2	0.2	0.2	CEPMEIP
				Conventional installation	0.9	0.9	0.9	USEPA AP-42 filterable PM (all PM stated to be PM_1)

Table 8.2e Emission factors for combustion of derived gases.

Fuel (IPCC Cat)	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Reference**
					TSP	**PM_{10}**	**$PM_{2.5}$**	
Gas works gas	311	Various	Electricity, CHP and heating plant	Clean fuel, efficient combustion	0.1	0.1	0.1	CEPMEIP
				Clean fuel, Conventional installation	0.2	0.2	0.2	CEPMEIP (conventional installation)
				Conventional installation	5	5	5	CEPMEIP. (N.B. High PM due to fuel quality)
Other gaseous	314	Various	Electricity, CHP and heating plant	Clean fuel, efficient combustion	0.1	0.1	0.1	CEPMEIP

Fuel (IPCC Cat)	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Reference**
fuel								
				Conventional installation	5	5	5	CEPMEIP
Coke oven gas	304	Various	Electricity, CHP heating plant, coke ovens	Clean fuel, efficient combustion	0.1	0.1	0.1	CEPMEIP
				Clean fuel, conventional installation	0.2	0.2	0.2	CEPMEIP (conventional installation)
				Conventional installation	5	5	5	CEPMEIP.
Blast furnace gas	305	Various	Electricity, CHP and heating plant, coke ovens	Clean fuel, efficient combustion	0.1	0.1	0.1	CEPMEIP
				Clean fuel, Conventional installation	0.2	0.2	0.2	CEPMEIP (conventional installation)
				Conventional installation	5	5	5	CEPMEIP.

Table 8.2f Emission factors for combustion of heavy fuel oil.

Fuel (IPCC Cat)	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Reference**
					TSP	**PM_{10}**	**$PM_{2.5}$**	
Residual fuel oil	203	Various	Electricity, CHP and heating plant	Low S fuel with optimised burner or abatement	3	3	2.5	CEPMEIP (equivalent to about 10 mg.Nm3 or BAT)
				Low S fuel, efficient combustion	14	12	10	CEPMEIP. About 50 mg.Nm3 (EU LCPD limit for existing plant)
				Low-Medium S fuel, conventional installation	20	15	9	CEPMEIP (equivalent. to about 70 mg.Nm3.
				Low-Medium S fuel, conventional installation	60	50	40	CEPMEIP, the higher of two entries used about 200 mg.Nm3
				High S fuel	210	190	130	CEPMEIP, the lower of two entries for high S used. (N.B. such a high emission concentration 750 mg.Nm3 would apply to few if any plant)
Petroleum coke	110	1 A 1 b	Oil refineries	Conventional, multicyclone	100	60	35	CEPMEIP, N.B the factor is very high compared to the EU LCP Directive ELVs and BAT for large furnaces. Bit Coal factors more appropriate.

Table 8.2g Emission factors for combustion of other liquid fuels.

Fuel (IPCC Cat)	NAPFUE	NFR Code	Activity description	Activity detail	Emission factor			Reference
					TSP	PM_{10}	$PM_{2.5}$	
Gas/Diesel oil	205	Various	Electricity, CHP, heating plant	Optimised burner	2	2	2	CEPMEIP
				Conventional burner	5	5	5	CEPMEIP
Naphtha	210	1 A 1 b	Oil refineries	All units	5	5	5	CEPMEIP
Liquefied Petroleum gas	303	Various	Electricity, CHP, heating plant	Optimised burner	0.1	0.1	0.1	CEPMEIP
				Conventional burner	5	5	5	CEPMEIP
Refinery gas	308	Various	Electricity, CHP, heating plant	Optimised burner	0.1	0.1	0.1	CEPMEIP
				Conventional burner	5	5	5	CEPMEIP
Other oil	224	Various	Electricity, CHP, heating plant	Low S fuel, optimised burner	3	3	2.5	CEPMEIP
				Low S fuel, efficient combustion	14	12	10	CEPMEIP for residual oil. About 50 mg.Nm3 (LCPD limit for existing plant)
				Low-Medium S fuel, conventional installation	20	15	9	CEPMEIP (equiv. to about 70 mg.Nm3.
				Low-Medium S fuel, conventional installation	60	50	40	CEPMEIP (highest of similar entries with TSP of 35, 40, 50 and 60 used. About 200 mg.Nm^{-3})

Fuel (IPCC Cat)	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Reference**
					TSP	**PM_{10}**	**$PM_{2.5}$**	
				High S fuel	210	190	130	CEPMEIP, lower of two entries for high S used. (N.B. this is a very high emission concentration ~750 mg.Nm3)

Table 8.2h Emission factors for combustion of biomass

Fuel (IPCC Cat)	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Reference**
					TSP	**PM_{10}**	**$PM_{2.5}$**	
Wood	111	Various	Electricity, CHP, heating plant	Modern, BAT unit <20 mg.Nm3 TSP	7	7	6	TSP scaled from BAT benchmark, fractions applied based on Bit coal
				Older unit, <100 mg.Nm3 TSP	35	25	12	TSP scaled from emission concentration, fractions based on bit coal
				Uncontrolled conventional	100	70	55	CEPMEIP (equiv. To an uncontrolled multicyclone)
Charcoal	112	1 A 2 c	Chemicals	Conventional large unit with multicyclone	100	60	35	CEPMEIP (N.B. the use of charcoal in LCP is likely to be rare.
Black liquour	215	1 A 2 f	Textile & leather (Pulp and Paper ?)	Conventional installation	160	150	150	CEPMEIP (N.B. such a high emission concentration would apply to few if any plant)

Fuel (IPCC Cat)	**NAPFUE**	**NFR Code**	**Activity description**	**Activity detail**	**Emission factor**			**Reference**
					TSP	**PM_{10}**	**$PM_{2.5}$**	
Biogas	309	Various	Electricity, CHP, heating plant	Modern optimised large installation	3	3	2.5	CEPMEIP (cleaned fuel)
				Conventional burner	5	5	5	CEPMEIP
				Modern, optimised	20	15	10	CEPMEIP (gasification plant), *seems high for gaseous fuel*
				Conventional installation	*160*	*150*	*150*	CEPMEIP (N.B. such a high emission concentration would apply to few if any plant)

8.3 Measured Emission Factors for consideration in Tier 3 Methodology

Annex 1 lists measurement derived PM emission factor data typical of that required for a tier 3 approach for large combustion plant – see also Section 15.

9 SPECIES PROFILES

The US EPA (2003) undertook a review of species profiles within $PM_{2.5}$ and reports particle size distribution data for a variety of fuels and combustion and abatement technologies. Some of these data are dated and have high uncertainty ratings. Profiles of other materials are not available.

Table 8.2j US EPA (2003) $PM_{2.5}$ species profiles

Profile ref	Profile name	Component				
		POA	PEC	GSO4	PNO3	Other
22002	Residual Oil Combustion	0.1075	0.0869	0.5504	0.0005	0.2547
22003	Distillate Oil Combustion	0.0384	0.0770	0.3217	0.0024	0.5605
22004	Natural Gas Combustion	0.6000	0.0000	0.2000	0.0055	0.1945
22007	Liquid Waste Combustion	0.0540	0.1050	0.0680	0.0000	0.7730
22009	Solid Waste Combustion	0.0068	0.0350	0.0680	0.0000	0.8902
NCOAL	Coal Combustion	0.20	0.01	0.16	0.005	0.625
NWWAS	Wood Waste Boiler	0.39	0.14	0.08	0	0.39

Notes:
POA - Primary organic aerosol derived from organic carbon
PEC - Elemental Carbon
GSO4 - Sulphate
PNO3 - Nitrate
Other – Remainder of $PM_{2.5}$ material emitted.

Note that the data for the coal combustion and other profiles are derived from dilution tunnel measurements and may not be directly comparable with primary $PM_{2.5}$.

10 UNCERTAINTY ESTIMATES

The overall ‘Uncertainty’ in national emission inventories may be significant – as illustrated in Table 9.1.

Table 9.1 Uncertainty estimate for selected pollutants in the UK air emission inventory (NAEI, 2005).

Pollutant	Estimated Uncertainty (%)
PM_{10}	-20 to +50
$PM_{2.5}$	-20 to +30
$PM_{1.0}$	-10 to +20
$PM_{0.1}$	+/- 10
Sulphur Dioxide	+/- 3
Oxides of Nitrogen	+/- 8
NMVOCs	+/- 10
Ammonia	+/- 20

There is uncertainty in both the aggregated emission factors and activity data used to estimate emissions i.e. the imprecision and error to be expected from the application of an ‘average’ emission factor or activity statistic to estimate emissions from a specific sector - an artificial grouping of ‘similar’ sources.

The uncertainty is partly the result of how emission factors are developed and applied. In the case of primary particulate matter, the expanded statistical uncertainty is made up of: between plant variance, within plant variance, and uncertainties associated with the measurement methodology used and the aggregation of data. The measurement data in Annex 1 illustrates the variability in emission factors that occurs from between plant variance.

Process measurements, from which emission factors are developed at individual facility level, are subject to both systematic and random errors in the determination of mass concentration, mass emission, size distribution, and analytical errors etc.

In addition bias may exist in emission factors arising from:

1. Assumptions made about the abatement used on ‘typical’ industrial installations. For example emission factors ‘age’, the factors widely used in the Guidebook and hence by many countries as default emission factors in their national inventories become out of date. Recent measurement work suggests that they may overestimate emissions from the industrial processes subject to more modern industrial emissions regulation. They may, however, still be fully representative for older plant, small plant, or for poorer fuels;
2. Assumptions about the relationship between TSP and PM10/$PM_{2.5}$. The technical literature is comprehensive for TSP and the data quality can be good if measurements have been made using the international standard methods that are available (typically the 95% confidence limit ~10%). But a variety of methods are used for particle size fractionation and as yet there are no harmonised international standards to ensure comparability. Published measurement data for PM10 is sparse, that for $PM_{2.5}$ emissions more so. An added complication is that the methodology for the

determination of TSP differs from that of PM10 and $PM_{2.5}$ and so the two need not correlate directly.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The stack emission factors described in the Guidebook, and all the PM_{10} emission factors, are based whenever possible on measurements. Particle measurements have often been made on the mass of total particulate matter and then converted to PM_{10} based either on the size distribution of the sample collected or, more usually, on size distributions given in the literature. There may be secondary sources of particulate matter, that are diffuse or fugitive in nature e.g. emissions from coke ovens, stockpiles, ash handling etc. These emissions are difficult to measure and in some cases it is likely that no entirely satisfactory measurements have ever been made, in many cases estimates of emissions from such sources are missing.

There is very little published data suitable for emission inventory compilation. I.e. representative data of known quality relating a) quantities of (particulate) material released to b) the activity associated with the release of that pollutant. Suitable data and associated information would record the determination of mass emissions rates using standardized measurement methods or calculation-based methods. Ideally such methods would cover the planning and execution of the data collection programme including: the selection of sampling methodology, choice of equipment, suitable working procedures, the calculation of representative emissions rates, the selection of matching activity data, the determination of sampling/measurement uncertainty, and the reporting of information in a form that is suitable for calculating emissions factors.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Combustion plants should be considered as point sources if plant specific data are available. Otherwise national emissions should be disaggregated on the basis of plant capacity, employment or population statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

Combustion processes can be considered as a continuous process however individual combustion plant may have daily and/or seasonal temporal profiles.

14 ADDITIONAL COMMENTS

See chapter B111.

15 SUPPLEMENTARY DOCUMENTS

Digest of UK Energy Statistics

Recommendations for the Update and Improvement of Existing $PM_{2.5}$ Split Factors – Note from Pacific Environmental Services to US EPA 29 September 2003

IIASA RAINS data

16 VERIFICATION PROCESSES

The applicability of the emission factors quoted, in Section 8 above, for use with highly regulated plant may be verified using the measurement data listed in Annex 1.

17 REFERENCES

EMEP/CORINAIR Emission Inventory Guidebook – 2005, EEA (European Environment Agency) Chapter B111

IPPC Best Available Techniques Reference Document on the Production of Iron and Steel, December 2001, http://eippcb.jrc.es

IPPC Best Available Techniques Reference Document on Large Combustion Plants, December 2001, http://eippcb.jrc.es

IPPC Best Available Techniques Reference Document on the Production of Pulp and Paper, December 2001, http://eippcb.jrc.es

NAEI (2005) UK National Atmospheric Emissions Inventory: UK Emissions of Air Pollutants 1970 to 2003, October 2005

US EPA (1996) Compilation of Air Pollutant Emission Factors Vol.1 Report AP-42 (5th ed.)

US EPA (2003) $PM_{2.5}$ Source Profiles
http://www.epa.gov/ttn/chief/emch/speciation/index.html

Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE AND SOURCE

Version: 1

Date:	Aug 2006
Source:	R. Stewart AEA Technology The Gemini Building Didcot, OXON OX11 0QR

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Robert Stewart

AEA Technology Environment
The Gemini Building
Didcot
OXON
OX11 0QR

Tel: +44 870190 6575
Fax: +44 870190 6318
Email: robert.stewart@aeat.co.uk

Ute Karl

French-German Institute for Environmental Research
University of Karlsruhe
Hertzstr 16
D-76187 Karlsruhe
Germany

Tel: +49 721 608 4590
Fax: +49 721 75 89 09
Email: ute.karl@wiwi.uni-karlsruhe.de

ANNEX 1A – SUMMARY OF RECENT MEASURED PM_{10} DATA ON COMBUSTION SOURCES

Combustion Type	**Process**	**Size indication**	**Fuel**	**Abatement Measures**	**PM_{10} Emission Factor or concentration**	**Units**	**Source[6]**	**CEPMEIP Factor**	**CEPMEIP Units**
Coal	Combustion Plant	180 MW	dry brown coal	ESP horizontal, scrubber	1.44	g/GJ	LAU	30.00	g/GJ
		146 MW	brown coal briquette, Limestone	ESP horizontal, drying desulphurisation	1.35	g/GJ	LAU		g/GJ
		119 MW	raw brown coal	ESP horizontal, desulph., NOx removal	6.13	g/GJ	LAU	30.00	g/GJ
		1000MW	hard coal	ESP, desulphurisation, NOx removal	0.33	g/GJ	LAU	25.00	g/GJ
		1000MW	hard coal	ESP, desulphurisation, NOx removal	0.30	g/GJ	LAU	25.00	g/GJ
		-	sub-bituminous coal	ESP	11.00	mg/MJ	NRCAN	25.00	g/GJ
		-	lignite	ESP	1.80	mg/MJ	NRCAN	30.00	g/GJ
		-	75% lignite/25% bituminous	ESP	1.10	mg/MJ	NRCAN		
		120 MW	Powdercoal	ESP	51.30	mg/Nm3	VITO	70.00	g/GJ
		-	lignite	Fabric filter, desulphurisation	0.1	mg/m3	TESO	8.00	g/GJ

---

[6] LAU: Christian Ehrlich, Wolf-Dieter Kalkoff, Günter Noll Landesamt für Umweltschutz Sachsen-Anhalt D-06009 Halle PF 200841 ehrlich@LAU.MLU.LSA-NET.DE
NRCAN: Dr. S. Win Lee, Senior Research Scientist, Clean Electric Power Generation, CANMET Energy Technology Centre-Ottawa, Natural Resources Canada, Ottawa. Canada. K1A 1M1, E-mail: swlee@nrcan.gc.ca
VITO: Ive Vanderreydt ive.vanderreydt@vito.be
TESO: Vladimír Bureš, Technical Services of Air Protection Prague Jenecska 146/44, 161 00 Prague 6, email: bures@teso.cz and Jan Velíšek email: velisek@teso.cz

Combustion Type	**Process**	**Size indication**	**Fuel**	**Abatement Measures**	**PM$_{10}$ Emission Factor or concentration**	**Units**	**Source[6]**	**CEPMEIP Factor**	**CEPMEIP Units**
				system					
		-	lignite	ESP, desulphurisation system	1.3	mg/m3	TESO	30.00	g/GJ
		-	hard coal	Fabric filter	7.5	mg/m3	TESO	6.00	g/GJ
		-	lignite	ESP, desulphurisation system	0.4	mg/m3	TESO	30.00	g/GJ
	Dry Bottom Ash Furnace	-	hard coal	ESP	24.4	mg/m3	TESO	25.00	
		-	lignite	ESP, desulphurisation system	1.5	mg/m3	TESO	30.00	g/GJ
		-	lignite, heavy fuel oil	ESP, desulphurisation system, fabric filter	0.2	mg/m3	TESO		
		-	lignite	ESP, desulphurisation system	14.9	mg/m3	TESO	80.00	g/GJ
		-	hard coal	ESP	0.2	mg/m3	TESO	25.00	g/GJ
		-	hard coal	Fabric filter	0.8	mg/m3	TESO	6.00	g/GJ
		-	hard coal	Fabric filter	0.2	mg/m3	TESO	6.00	g/GJ
		-	coal	ESP	1.5	mg/m3	TESO	25.00	g/GJ
	Grate and Dry Bottom Ash Furnace	-	lignite	ESP, desulphurisation system	1.2	mg/m3	TESO	80.00	g/GJ
	Grate Boiler	-	hard coal	Fabric Filter	0.7	mg/m3	TESO	6.00	g/GJ
	Grate Firing	-	lignite	ESP	6.8	mg/m3	TESO	30.00	g/GJ
	Boiler for Pulverised Solid Fuel	-	hard coal, light fuel oil	ESP	22.8	mg/m3	TESO		
		-	hard coal, lignite	ESP, desulphurisation	6.3	mg/m3	TESO	25.00	g/GJ

Combustion Type	Process	Size indication	Fuel	Abatement Measures	PM_{10} Emission Factor or concentration	Units	Source[6]	CEPMEIP Factor	CEPMEIP Units
				system					
		-	lignite	ESP, desulphurisation system	1.9	mg/m3	TESO	30.00	g/GJ
		-	lignite	ESP, desulphurisation system	4.2	mg/m3	TESO	30.00	g/GJ
		-	hard coal	Fabric filter	0.1	mg/m3	TESO	6.00	g/GJ
	Fluidised bed boiler	-	lignite	ESP, desulphurisation system, fabric filter	2.5	mg/m3	TESO	8.00	g/GJ
		-	lignite	Fabric filter, desulphurisation system	0.9	mg/m3	TESO	8.00	g/GJ
		-	hard coal, blast furnace gas	ESP	0.2	mg/m3	TESO		
		-	hard coal, blast furnace gas	ESP	0.4	mg/m3	TESO		
		-	hard coal, coke oven gas, blast furnace gas	ESP	4.3	mg/m3	TESO		
	Combustion Plant	10 MW	heavy oil	additive	12.33	g/GJ	LAU	15.00	g/GJ
		10 MW	heavy oil	additive	12.95	g/GJ	LAU	15.00	g/GJ
		10 MW	heavy oil, urea	additive, SNCR	15.29	g/GJ	LAU	15.00	g/GJ
		10 MW	heavy oil, urea	additive, SNCR	18.04	g/GJ	LAU	15.00	g/GJ
		20 t/h steam	heavy oil	SNCR	1.86	g/GJ	LAU	3.00	g/GJ
		270 MW	heavy oil	NOx removal	5.75	g/GJ	LAU	3.00	g/GJ
		270 MW	heavy oil	additive, NOx removal	4.49	g/GJ	LAU	3.00	g/GJ
		270 MW	heavy oil	NOx removal	4.79	g/GJ	LAU	3.00	g/GJ
		270 MW	heavy oil	additive, NOx removal	4.65	g/GJ	LAU	3.00	g/GJ

Combustion Type	**Process**	**Size indication**	**Fuel**	**Abatement Measures**	**PM_{10} Emission Factor or concentration**	**Units**	**Source[6]**	**CEPMEIP Factor**	**CEPMEIP Units**
		-	residual oil	-	29.00	mg/MJ	NRCAN	20.00	g/GJ
		-	heavy fuel oil, natural gas	-	6.80	mg/m3	TESO		
		-	heavy fuel oil, gas fuels	-	15.30	mg/m3	TESO		
	Combustion Plant	1.4 MW	saw chips, saw dust	cyclone	100.37	g/GJ	LAU	70.00	g/GJ
		1.4 MW	saw chips, saw dust	cyclone	75.87	g/GJ	LAU	70.00	g/GJ
		0.8 MW	saw chips, saw dust	cyclone	102.81	g/GJ	LAU	70.00	g/GJ
		3 MW	hogged wood	cyclone	96.32	g/GJ	LAU	70.00	g/GJ
		2.3 MW	rest of chipboards	multicyclone	119.09	g/GJ	LAU	70.00	g/GJ
		1.1 MW	piece of wood, saw chips	cyclone	131.93	g/GJ	LAU	70.00	g/GJ
		2 MW	hogged wood, wood waste	ESP	21.41	g/GJ	LAU	70.00	g/GJ
		7.9-9.5 MW	wood, wood chips	ESP	7.53	g/GJ	LAU	70.00	g/GJ
		7.9-9.5 MW	natural gas, wood, wood chips	ESP	7.41	g/GJ	LAU	70.00	g/GJ
		15 MW	hogged wood, rest wood, wood chips	ESP	3.22	g/GJ	LAU	70.00	g/GJ
		1.5 MW	hogged wood	chimney gas condensation, multi-cyclone	17.30	g/GJ	LAU	70.00	g/GJ
		1.5 MW	hogged wood	chimney gas condensation, multi-cyclone	21.05	g/GJ	LAU	70.00	g/GJ
		31 t/h steam	matured wood	cyclone, fabric	4.72	g/GJ	LAU	70.00	g/GJ

Combustion Type	**Process**	**Size indication**	**Fuel**	**Abatement Measures**	**PM_{10} Emission Factor or concentration**	**Units**	**Source[6]**	**CEPMEIP Factor**	**CEPMEIP Units**
				filter, NO_x removal					
	Grate Boiler		bark, natural gas	ESP	4.90	mg/m3	TESO		
Waste	hazardous waste incineration plant	-	hazardous waste	fabric filter, desulphurisation system	10.30	mg/m3	TESO		
	waste incineration plant	-	municipal solid waste	ESP, desulphurisation system	0.90	mg/m3	TESO	100.00	g/tonne
	home heating boiler	-	mixture of fuels and household waste	-	39.90	mg/m3	TESO		
	old growth , shredder	30 t/h	lumber, demolition wood, timber waste	fabric filter	2.71	g/tonne	LAU		

ANNEX 1B – SUMMARY OF RECENT MEASURED $PM_{2.5}$ DATA ON COMBUSTION SOURCES

Combustion Type	**Process**	**Size indication**	**Fuel**	**Abatement Measures**	**$PM_{2.5}$ Emission Factor or concentration**	**Units**	**Source**	**CEPMEIP Factor**	**CEPMEIP Units**
Coal	Combustion Plant	180 MW	dry brown coal	ESP horizontal, scrubber	1.20	g/GJ	LAU	14.00	g/GJ
		146 MW	brown coal briquette, Limestone	ESP horizontal, drying desulphurisation	1.09	g/GJ	LAU		g/GJ
		119 MW	raw brown coal	ESP horizontal, desulph., NOx removal	4.15	g/GJ	LAU	14.00	g/GJ
		1000MW	hard coal	ESP, desulphurisation,	0.26	g/GJ	LAU	12.00	g/GJ

Combustion Type	**Process**	**Size indication**	**Fuel**	**Abatement Measures**	**$PM_{2.5}$ Emission Factor or concentration**	**Units**	**Source**	**CEPMEIP Factor**	**CEPMEIP Units**
				NOx removal					
		1000MW	hard coal	ESP, desulphurisation, NOx removal	0.23	g/GJ	LAU	12.00	g/GJ
		-	sub-bituminous coal	ESP	8.30	mg/MJ	NRCAN	3.00	g/GJ
		-	lignite	ESP	1.20	mg/MJ	NRCAN	3.00	g/GJ
		-	75% lignite/25% bituminous	ESP	28.10	mg/MJ	NRCAN		
		120 MW	Powdercoal	ESP	30.24	mg/Nm3	VITO	17.00	g/GJ
		-	lignite	Fabric filter, desulphurisation system	0.1	mg/m3	TESO	6.00	g/GJ
		-	lignite	ESP, desulphurisation system	1.3	mg/m3	TESO	14.00	g/GJ
		-	hard coal	Fabric filter	7.4	mg/m3	TESO	5.00	
		-	lignite	ESP, desulphurisation system	0.4	mg/m3	TESO	14.00	g/GJ
	Dry Bottom Ash Furnace	-	hard coal	ESP	9.6	mg/m3	TESO	12.00	
		-	lignite	ESP, desulphurisation system	1.3	mg/m3	TESO	14.00	g/GJ
		-	lignite, heavy fuel oil	ESP, desulphurisation system, fabric filter	0.2	mg/m3	TESO		
		-	lignite	ESP, desulphurisation system	12.3	mg/m3	TESO	20.00	g/GJ
		-	hard coal	ESP	0.2	mg/m3	TESO	12.00	
		-	hard coal	Fabric filter	0.6	mg/m3	TESO	5.00	

Combustion Type	**Process**	**Size indication**	**Fuel**	**Abatement Measures**	**$PM_{2.5}$ Emission Factor or concentration**	**Units**	**Source**	**CEPMEIP Factor**	**CEPMEIP Units**
		-	hard coal	Fabric filter	0.2	mg/m3	TESO	5.00	
		-	coal	ESP	1.4	mg/m3	TESO	12.00	g/GJ
	Grate and Dry Bottom Ash Furnace	-	lignite	ESP, desulphurisation system	0.5	mg/m3	TESO	20.00	g/GJ
	Grate Boiler	-	hard coal	Fabric Filter	0.6	mg/m3	TESO	5.00	g/GJ
	Grate Firing	-	lignite	ESP	6	mg/m3	TESO	14.00	g/GJ
	Boiler for Pulverised Solid Fuel	-	hard coal, light fuel oil	ESP	20.8	mg/m3	TESO		
		-	hard coal, lignite	ESP, desulphurisation system	5.9	mg/m3	TESO		
		-	lignite	ESP, desulphurisation system	1.9	mg/m3	TESO	14.00	g/GJ
		-	lignite	ESP, desulphurisation system	4.1	mg/m3	TESO	14.00	g/GJ
		-	hard coal	Fabric filter	0.1	mg/m3	TESO	5.00	g/GJ
	Fluidised bed boiler	-	lignite	ESP, desulphurisation system, fabric filter	1.2	mg/m3	TESO	6.00	g/GJ
		-	lignite	Fabric filter, desulphurisation system	0.8	mg/m3	TESO	6.00	g/GJ
		-	hard coal, blast furnace gas	ESP	0.4	mg/m3	TESO		
		-	hard coal, blast furnace gas	ESP	0.1	mg/m3	TESO		
		-	hard coal, coke oven gas, blast furnace gas	ESP	4.1	mg/m3	TESO		

Combustion Type	Process	Size indication	Fuel	Abatement Measures	$PM_{2.5}$ Emission Factor or concentration	Units	Source	CEPMEIP Factor	CEPMEIP Units
Oil	Combustion Plant	10 MW	heavy oil	additive	10.30	g/GJ	LAU	10.00	g/GJ
		10 MW	heavy oil	additive	9.18	g/GJ	LAU	10.00	g/GJ
		10 MW	heavy oil, urea	additive, SNCR	12.21	g/GJ	LAU	10.00	g/GJ
		10 MW	heavy oil, urea	additive, SNCR	13.12	g/GJ	LAU	10.00	g/GJ
		20 t/h steam	heavy oil	SNCR	1.38	g/GJ	LAU	11.00	g/GJ
		270 MW	heavy oil	NOx removal	4.69	g/GJ	LAU	2.50	g/GJ
		270 MW	heavy oil	additive, NOx removal	4.15	g/GJ	LAU	2.50	g/GJ
		270 MW	heavy oil	NOx removal	4.41	g/GJ	LAU	2.50	g/GJ
		270 MW	heavy oil	additive, NOx removal	4.23	g/GJ	LAU	2.50	g/GJ
		-	residual oil	-	28.10	mg/MJ	NRCAN	10.00	g/GJ
		-	heavy fuel oil, natural gas	-	6.70	mg/m3	TESO		
		-	heavy fuel oil, gas fuels	-	15.20	mg/m3	TESO		
Waste	Combustion Plant	1.4 MW	saw chips, saw dust	cyclone	71.66	g/GJ	LAU	55.00	g/GJ
		1.4 MW	saw chips, saw dust	cyclone	52.25	g/GJ	LAU	55.00	g/GJ
		0.8 MW	saw chips, saw dust	cyclone	65.47	g/GJ	LAU	55.00	g/GJ
		3 MW	hogged wood	cyclone	90.13	g/GJ	LAU	55.00	g/GJ
		2.3 MW	rest of chipboards	multi-cyclone	91.92	g/GJ	LAU	55.00	g/GJ
		1.1 MW	piece of wood, saw chips	cyclone	80.80	g/GJ	LAU	55.00	g/GJ
		2 MW	hogged wood, wood waste	ESP	16.10	g/GJ	LAU	55.00	g/GJ
		7.9-9.5 MW	wood, wood chips	ESP	5.49	g/GJ	LAU	55.00	g/GJ

Combustion Type	**Process**	**Size indication**	**Fuel**	**Abatement Measures**	**$PM_{2.5}$ Emission Factor or concentration**	**Units**	**Source**	**CEPMEIP Factor**	**CEPMEIP Units**
		7.9-9.5 MW	natural gas, wood, wood chips	ESP	5.21	g/GJ	LAU	55.00	g/GJ
		15 MW	hogged wood, rest wood, wood chips	ESP	1.95	g/GJ	LAU	55.00	g/GJ
		1.5 MW	hogged wood	chimney gas condensation, multi-cyclone	17.25	g/GJ	LAU	55.00	g/GJ
		1.5 MW	hogged wood	chimney gas condensation, multi-cyclone	20.46	g/GJ	LAU	55.00	g/GJ
		31 t/h steam	matured wood	cyclone, fabric filter, NO_x removal	1.85	g/GJ	LAU	55.00	g/GJ
		-	wooden briquettes	-	12.10	mg/m3	TESO	135.00	g/GJ
	Grate Boiler		bark, natural gas	ESP	4.80	mg/m3	TESO		
Waste	hazardous waste incineration plant	-	hazardous waste	fabric filter, desulphurisation system	8.80	mg/m3	TESO		
	waste incineration plant	-	municipal solid waste	ESP, desulphurisation system	0.80	mg/m3	TESO	100.00	g/tonne
			municipal solid waste	ESP	1.80	ng/Nm3	VITO	101.00	g/tonne
	home heating boiler	-	mixture of fuels and household waste	-	34.60	mg/m3	TESO		
	old growth , shredder	30 t/h	lumber, demolition wood, timber waste	fabric filter	0.49	g/tonne	LAU		

SNAP CODE:	**010104 & 010105** **010204 & 010205** **010404 & 010405** **020104 & 020105** **020203 & 020204** **020303 & 020304** **030104 & 030105**
SOURCE ACTIVITY TITLE:	**COMBUSTION IN ENERGY & TRANSFORMATION INDUSTRIES** ***Particulate emissions from gas turbines and internal combustion engines***
NOSE CODE:	**101.01** **101.02**
NFR CODE:	**1 A 1 a,b,c** **1 A 2 a-f** **1 A 4 b,c,i**
ISIC	**3510**

1 ACTIVITIES INCLUDED

This supplement covers emissions of particulate matter (PM) released from combustion processes within the energy and transformation industries by internal combustion engines - gas turbines and reciprocating engines . This supplement includes guidance on estimating total PM (TSP), PM_{10} and $PM_{2.5}$ emissions from these sources. Information related to the estimation of emissions of other pollutants from this sector is given in chapter B111.

2 CONTRIBUTION TO TOTAL EMISSION

The contributions of PM_{10} and $PM_{2.5}$ emissions from combustion plant to total emissions in countries according to the CORINAIR90 inventory are indicated in Table 2.1.

Table 2.1 Contribution to total particulate matter emissions from 2004 EMEP database (WEBDAB)

NFR Sector	Data	PM_{10}	$PM_{2.5}$	TSP
1 A 1 a - Public Electricity and Heat Production[a]	No. of countries reporting	26	26	27
	Lowest Value	0.2%	0.2%	0.2%
	Typical Contribution	11.7%	10.1%	12.8%
	Highest Value	48.8%	47.8%	48.4%
1 A 2 - Manufacturing Industries and Construction[b]	No. of countries reporting	26	26	26
	Lowest Value	0.7%	0.6%	0.6%
	Typical Contribution	9.0%	9.5%	7.9%
	Highest Value	20.7%	22.1%	25.7%
1 A 4 a - Commercial / Institutional[c]	No. of countries reporting	23	23	23
	Lowest Value	0.1%	0.1%	0.1%
	Typical Contribution	3.9%	3.4%	4.5%
	Highest Value	19.3%	22.2%	29.5%
1 A 4 b - Residential[d]	No. of countries reporting	3	2	3
	Lowest Value	2.0%	6.5%	3.7%
	Typical Contribution	14.9%	26.2%	10.8%
	Highest Value	36.6%	45.8%	15.4%
1 A 4 b i - Residential plants[e]	No. of countries reporting	23	23	23
	Lowest Value	2.7%	5.8%	0.8%
	Typical Contribution	28.3%	33.1%	22.0%
	Highest Value	67.1%	74.6%	53.2%
1 A 5 a - Other, Stationary (including Military)[f]	No. of countries reporting	7	7	7
	Lowest Value	0.0%	0.0%	0.0%
	Typical Contribution	0.1%	0.1%	0.1%
	Highest Value	0.5%	0.4%	0.6%

[a] Includes contribution from Chapter 112

[b] Includes contributions from Chapter 112 and 316 (SNAP 030106)

[c] Includes contribution from Chapter 112 and 216 (SNAP 020205)

[d] Includes contribution from Chapter 810

[e] Includes contribution from Chapter 112

[f] Includes contribution from Chapter 112 and 216 (SNAP 020106)

3 GENERAL

3.1 Description

This supplement considers emissions of PM generated by internal combustion engines including gas turbines and reciprocating engines. Reciprocating engines include compression ignition (CI) and spark ignition (SI) technologies. Other emissions from this source category are considered in B111.

3.2 Definitions

See B111.

3.3 Techniques

See B111 for more information on combustion plant types and fuels.

Gas turbines range in size from <100kW electrical generation (microturbines) to over 250 MW electrical generation. The most common primary fuel is natural gas but gas oil and a range of derived fuels are also used.

Diesel compression engines also range from a few kW to about 50 MW electrical generation. The most typical fuel is gas oil but, various derived fuels can be used and heavy fuel oil is used on some large units. Dual fuel engines burn natural gas or derived gases with a small quantity of gas oil.

3.4 Emissions

Internal combustion engines use liquid or gaseous fuels and particulate emissions result mainly from combustion of the fuels.

Combustion of liquid fuels can generate solid residues which may be deposited within exhaust ducts oron heat exchanger surfaces (soot and fly ash). Suspended ash material in exhaust gases may be retained by particulate abatement or other emission abatement equipment (abatement residues). Material which remains in the flue gases beyond the abatement equipment and passes to the atmosphere is primary PM. Secondary PM is formed by chemical and physical processes after discharge to atmosphere and is NOT considered here.

3.5 Controls

Particulate emission reduction is not usually associated with combustion of gaseous fuels except where derived fuels are used (in which case filtering or other treatment of the fuel gas is the preferred approach). Particulate abatement equipment may be used with oil fuels and can include, fuel pre-treatment to reduce mineral content (particularly for heavy fuel oil), diesel particle filters (on smaller units) or more traditional emission abatement equipment. . N.B. Emission concentrations of TSP from compression ignition engines associated with Best Available Techniques (BAT) as defined by EU Integrated Pollution Prevention and Control regulations are 30 mg m^{-3} for gas oil and 50 mg m^{-3} for heavy fuel oil.

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.
Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.
Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the Tier 1 simpler methodology, where limited information is available, a default emission factor can be used together with activity information for the country or region of interest with limited or no specification on the type of technology or the type and efficiency of control equipment. For a Tier 2 approach an approximation may be made of the most representative technologies, thereby allowing the use of more appropriate default factors if more detailed activity data are available.

Consequently the simplest methodology (Tier 1) is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = \text{AR} \times \text{EF}$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

The Tier 2 methodology is a modified version of this basic equation:

$$\text{Emission} = \sum((\text{AR}_1 \times \text{EF}_1) + (\text{AR}_2 \times \text{EF}_2) + \ldots(\text{AR}_n \times \text{EF}_n))$$

Default emission factors for this purpose are provided in Sections 8.1 and 8.2.

---

[1] The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tier 3) to estimate emissions of pollutants from combustion plant >50 MW_{th} is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

In many countries, operators of combustion plant >50MWth will report emissions to comply with regulatory requirements and this data can be used to help compile the national inventory.

The recommended detailed methodology to estimate emissions of PM from combustion activities is based on measurements and/or estimations using technology-specific emission factors.

Information on the type of the process and activity data, for example combustion and abatement technologies, is required to assign appropriate emission factors.

6 ACTIVITY STATISTICS

Activity statistics for energy consumption or other relevant national activity data for estimating emissions using the simpler estimation methodology (Tiers 1 and 2) are available from national statistics.

The detailed methodology (Tier 3) requires more detailed information such as the amount and types of fuel consumed within individual combustion plant or industry sectors. These data are not always easily available although in many countries operators do report fuel use for emission trading or other legislative requirements.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 2 on energy, Chapter 1.

7 POINT SOURCE CRITERIA

Large combustion plants are regarded as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Default Emission Factors For Use With Simpler Methodology (Tier 1)

Fuel	Technology	**Emission factor, $g.GJ^{-1}$**			Notes
		TSP	**PM_{10}**	**$PM_{2.5}$**	
Hard Coal		-	-	-	Not applicable
Brown Coal		-	-	-	Not applicable
Other solid fuels		-	-	-	Not applicable

Natural gas	Gas turbines	0.9	0.9	0.9	US EPA
	Spark ignition	18	18	18	US EPA 2 stroke lean burn, 4 stroke lean burn is 0.04 gGJ^{-1}.
Derived gases	Gas turbine	11	11	11	Based on US EPA Landfill gas
Heavy fuel oil	Diesel	28	23	22	US EPA factor for diesel engines
Other liquid fuels	Gas turbine	2.0	2.0	2.0	US EPA factor for PM applied to other fractions
	Diesel	28	23	22	US EPA
Biomass	Gas turbine	11	11	11	Landfill gas
	Gas turbine	5.7	5.7	5.7	Anaerobic digester gas

8.2 Reference Emission Factors For Use With Tier 2 Methodology

Tables 8.2a-z contain reference particulate emission factors for fuel combustion in various technologies with different types of abatement.

Table 8.2a Emission factors for gas turbines combustion processes

Fuel	NAPFUE	NFR Codes	Activity description	Activity detail	Emission factor, g.GJ^{-1}			Notes
					TSP	PM_{10}	$PM_{2.5}$	
Natural gas					0.9	0.9	0.9	Sierra (234 tests), assumes all PM2.5
Gas oil					3	3	3	Sierra (15 tests), assume all PM2.5

Table 8.2b Emission factors for compression ignition combustion processes

Fuel (IPCC Cat)	NAPFUE	NFR Code	Activity description	Activity detail	Emission factor g GJ^{-1}			Reference/Comments
					TSP	PM_{10}	$PM_{2.5}$	
Natural gas			Dual fuel engine, gas with HFO		11	11	11	LCP BREF, assumed all PM2.5
Heavy fuel oil			Diesel engine		50	41	39	LCP BREF, 'BAT' US EPA profile applied
			Diesel engine		<64	53	50	LCP BREF, US EPA profile applied, applicable to older equipment
Gas oil			Diesel engine	<0.02% S	<26	21	20	LCP BREF, US EPA profile
			Diesel engine		<17	14	14	Smaller unit with diesel particulate filter, US EPA profile

9 SPECIES PROFILES

The US EPA (2003) undertook a review of species profiles within $PM_{2.5}$ and reports particle size distribution data for a variety of fuels and combustion and abatement technologies. Some of these data are dated and have high uncertainty ratings. Profiles of other materials are not available.

Table

Profile ref	**Profile name**	**Component**				
		POA	**PEC**	**GSO4**	**PNO3**	**Other**
22002	Residual Oil Combustion	0.1075	0.0869	0.5504	0.0005	0.2547
22003	Distillate Oil Combustion	0.0384	0.0770	0.3217	0.0024	0.5605
22004	Natural Gas Combustion	0.6000	0.0000	0.2000	0.0055	0.1945

Notes:
POA - Primary organic aerosol derived from organic carbon
PEC Elemental Carbon
GSO4 - Sulphate
PNO3 - Nitrate
Other – Remainder of PM2.5 material emitted.

Note that the data are derived from a variety of sources including dilution tunnel measurements and may not be directly comparable with filterable $PM_{2.5}$.

10 UNCERTAINTY ESTIMATES

The overall 'Uncertainty' in national emission inventories may be significant – as illustrated in Table 9.1.

Table 9.1 Uncertainty estimate for selected pollutants in the UK air emission inventory (NAEI, 2005).

Pollutant	Estimated Uncertainty (%)
PM_{10}	-20 to +50
$PM_{2.5}$	-20 to +30
$PM_{1.0}$	-10 to +20
$PM_{0.1}$	+/- 10
Sulphur Dioxide	+/- 3
Oxides of Nitrogen	+/- 8
NMVOCs	+/- 10
Ammonia	+/- 20

There is uncertainty in both the aggregated emission factors and activity data used to estimate emissions i.e. the imprecision and error to be expected from the application of an 'average' emission factor or activity statistic to estimate emissions from a specific sector - an artificial grouping of 'similar' sources.

The uncertainty is partly the result of how emission factors are developed and applied. In the case of primary particulate matter, the expanded statistical uncertainty is made up of: between plant variance, within plant variance, and uncertainties associated with the measurement methodology used and the aggregation of data. The measurement data in Annex 1 illustrates the variability in emission factors that occurs from between plant variance.

Process measurements, from which emission factors are developed at individual facility level, are subject to both systematic and random errors in the determination of mass concentration, mass emission, size distribution, and analytical errors etc.

In addition bias may exist in emission factors arising from:

1. Assumptions made about the abatement used on 'typical' industrial installations. For example emission factors 'age', the factors widely used in the Guidebook and hence by many countries as default emission factors in their national inventories become out of date. Recent measurement work suggests that they may overestimate emissions from the industrial processes subject to more modern industrial emissions regulation. They may, however, still be fully representative for older plant, small plant, or for poorer fuels;

Assumptions about the relationship between TSP and PM_{10}/$PM_{2.5}$. The technical literature is comprehensive for TSP and the data quality can be good if measurements have been made using the international standard methods that are available (typically the 95% confidence limit ~10%). But a variety of methods are used for particle size fractionation and as yet there are no harmonised international standards to ensure comparability. Published measurement data for PM10 is sparse, that for $PM_{2.5}$ emissions more so. An added complication is that the methodology for the determination of TSP differs from that of PM10 and $PM_{2.5}$ and so the two need not correlate directly.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Published $PM_{2.5}$ emission factor information for stationary engines is sparse. It is difficult to form a representative estimate the emissions likely to arise from the range of engine/fuel combinations commonly encountered. Further work is required to develop a more complete range of emission factors.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Combustion plants should be considered as point sources if plant specific data are available. Otherwise national emissions should be disaggregated on the basis of plant capacity, employment or population statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

Combustion processes can be considered as a continuous process however individual combustion plant may have daily and/or seasonal temporal profiles.

14 ADDITIONAL COMMENTS

See chapter B111 and B111 (S2) for measurement data in Annex 1.

15 SUPPLEMENTARY DOCUMENTS

None

16 VERIFICATION PROCESSES

Published $PM_{2.5}$ emission data for stationary engines is sparse.

17 REFERENCES

AEAT CCGT Measurement data

Digest of UK Energy Statistics

England, G.C., “Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Final Report, 2004.”

EMEP/CORINAIR Emission Inventory Guidebook – 2005, EEA (European Environment Agency) Chapter B111

IIASA RAINS data

IPPC Best Available Techniques Reference Document on Large Combustion Plants, December 2001, http://eippcb.jrc.es

IPCC Guidance document

NAEI (2005) UK National Atmospheric Emissions Inventory: UK Emissions of Air Pollutants 1970 to 2003, October 2005

US EPA (1996) Compilation of Air Pollutant Emission Factors Vol.1 Report AP-42 (5th ed.)

US EPA (2003) $PM_{2.5}$ Source Profiles
http://www.epa.gov/ttn/chief/emch/speciation/index.html

Recommendations for the Update and Improvement of Existing PM2.5 Split Factors – Note from Pacific Environmental Services to US EPA 29 September 2003

Rentz, O.; Karl, U.; Peter, H. Determination and evaluation of emission factors for combustion installations in Germany for the years 1995, 2000 and 2010. French-German Institute for Environmental Research University of Karlsruhe (TH), Dec 2002.

Rubenstein, G. Gas Turbine PM Emissions – Update. Sierra Research, June 2003 Paper to ASME/IGTI Turbo-Expo, Atlanta 2003

18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE AND SOURCE

Version:	1
Date:	Aug 2006

Source: R. Stewart
AEA Technology
The Gemini Building
Didcot,
OXON
OX11 0QR

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Robert Stewart

AEA Technology Environment
The Gemini Building
Didcot
OXON
OX11 0QR

Tel: +44 870190 6575
Fax: +44 870190 6318
Email: robert.stewart@aeat.co.uk

Jozef Pacyna

NILU - Norwegian Institute of Air Research
PO Box 100
N-2027 Kjeller
Norway

Tel: +47 63 89 8155
Fax: +47 63 89 80 50
Email: jozef.pacyna@nilu.no

SNAP CODES: (See below)

SOURCE ACTIVITY TITLE: COMBUSTION IN ENERGY & TRANSFORMATION INDUSTRIES
Combustion Plants as Area Sources

The following activities are taken into account when combustion plants are treated collectively as area sources. Boilers, furnaces (except process furnaces), gas turbines and stationary engines which may also be considered individually as point sources are covered by this chapter as well as by chapter B111 on ”Combustion Plants as Point Sources”.

SNAP97 Codes	NOSE CODE	NFR CODE	**Combustion plants as area sources**								
			Boilers/furnaces							Gas turbines	Stationary engines
			Thermal capacity [MW]	Public power and cogeneration plants	District heating	Industrial combustion	Commercial and institutional combustion	Residential combustion	Agriculture forestry and fishing		
01 01 02	101.02	1 A 1 a	≥ 50	X							
01 02 02	101.02	1 A 1 a	and		X						
01.03.02	101.02	1 A 1 b				X					
01.04.02	101.02	1 A 1 c				X					
01.05.02	101.02	1 A 1 c				X					
02 01 02	101.02	1 A 4 a	< 300				X				
02 02 01	101.02	1 A 4 b i						X			
02 03 01	101.02	1 A 4 c i							X		
03 01 02	101.02	1 A 2 a-f				X					
01 01 03	101.03	1 A 1 a	< 50	X							
01 02 03	101.03	1 A 1 a			X						
01 03 02	101.03	1 A 1 b				X					
01 04 02	101.03	1 A 1 c				X					
01 05 02	101.03	1 A 1 c				X					
02 01 03	101.03	1 A 4 a					X				
02 02 02	101.03	1 A 4 b i						X			
02 03 02	101.03	1 A 4 c i							X		
03 01 03	101.03	1 A 2 a-f				X					
01 01 04	101.04	1 A 1 a	Not							X	
01 02 04	101.04	1 A 1 a	Rele							X	
02 01 04	101.04	1 A 4 a	-vant							X	
02 02 03	101.04	1 A 4 b i								X	
02 03 03	101.04	1 A 4 c i								X	
03 01 04	101.04	1 A 2 a-f								X	

SNAP97 Codes	**Combustion plants as area sources**										
	NOSE CODE	NFR CODE	Boilers/furnaces							Gas turbines	Stationary engines
			Thermal capacity [MW]	Public power and cogeneration plants	District heating	Industrial combustion	Commercial and institutional combustion	Residential combustion	Agriculture forestry and fishing		
01 01 05	101.05	1 A 1 a	Not Relevant								X
01 02 05	101.05	1 A 1 a									X
02 01 05	101.05	1 A 4 a									X
02 02 04	101.05	1 A 4 b i									X
02 03 04	101.05	1 A 4 c i									X
03 01 05	101.05	1 A 2 a-									X

X : indicates relevant combination

1 ACTIVITIES INCLUDED

This chapter covers emissions from combustion plants treated collectively as area sources. However, e.g. if only a few units exist and thus only little data is available, the individual approach may be preferable also for small combustion plants.

The subdivision of the SNAP activities according to CORINAIR90 concerning combustion plants takes into account two criteria:

- the economic sector concerning the use of energy:
  - public power and co-generation,
  - district heating,
  - commercial, institutional and residential combustion,
  - industrial combustion,
    (Note: process furnaces are allocated separately.)
- the technical characteristics:
  - the installed thermal capacity,
    - ≥ 50 to < 300 MW,
    - < 50 MW,
  - other combustion technologies,
    - gas turbines,
    - stationary engines.

The emissions considered in this section are released by a controlled combustion process (boiler emissions, furnace emissions, emissions from gas turbines or stationary engines) and are mainly characterised by the types of fuels used. Furthermore, a technical characterisation of the combustion sources may be integrated according to the size and type of plants as well as on primary or secondary reduction measures.[1] Solid, liquid or gaseous fuels are used; whereby solid fuels comprise coal, coke, biomass and waste (as far as waste is used to generate heat or power). In addition a non-combustion process can be a source of ammonia emissions; namely the ammonia slip in connection with some NO_x abatement techniques.[1]

2 CONTRIBUTION TO TOTAL EMISSIONS

The contribution of area source emissions released by combustion plants to the total emissions in the countries of the CORINAIR90 inventory reported as areas sources is given as follows:

Table 1: Contributions of emissions from combustion plants as area sources to the total emissions of the CORINAIR90 inventory reported as area sources. See chapter ACOR for further information on CORINAIR 90 emissions for these SNAP activities taking point and area sources together

		Contribution to total emissions [%]							
Source category	SNAP code	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
≥ 300 MW	01 01 01 01 02 01 03 01 01	0	0	0	0	0	0	-	0
50-300 MW	01 01 02 01 02 02 02 01 02 02 02 01 02 03 01 03 01 02	12.1	10.0	1.0	0.1	2.3	9.3	3.3	0.5
< 50 MW	01 01 03 01 02 03 02 01 03 02 02 02 02 03 02 03 01 03	71.3	46.7	41.1	7.2	49.8	66.4	21.8	0.7
Gas turbines	01 01 04 01 02 04 02 01 04 02 02 03 02 03 03 03 01 04	0.1	2.0	0.03	0.03	0.1	1.0	0.2	-
Stationary engines	01 01 05 01 02 05 02 01 05 02 02 04 02 03 04 03 01 05	0.6	2.0	0.2	0.02	0.1	0.4	0.2	0

---

[1] Note: Small combustion installations are seldomly equipped with secondary measures.

- : no emissions are reported as area sources

0 : emissions are reported, but the exact amount is under the rounding limit

Plants with a thermal capacity < 50 MW are the major contributors. In particular, the contribution of small units in „Commercial, institutional and residential combustion" with a thermal capacity < 50 MW (SNAP 020002) is significantly high: SO_x 37.0 %, NO_x 24.2 %, NMVOC 39.6 %, CH_4 6.9 %, CO 46.3 %, CO_2 44.4 %, N_2O 14.7 % and NH_3 0.6 % (related to total emissions of CORINAIR90 reported as area sources).
In the literature concerning heavy metal emissions in Europe, area source emissions are not reported separately. In order to show the relevance of the sector residential combustion, the share of the emissions of different heavy metals from this sector in the total emission in Germany is shown as an example in Table 2.

Table 2: Contribution of heavy metal emissions from residential combustion to national total emissions of former West Germany /1/

	Contribution in [wt.-%]	
Pollutant	**1982**	**1990**
As	5.8	15
Cd	3	4.4
Cr	n.d.	n.d.
Cu	4.2	6.4
Hg	1.9	2.8
Ni	4.5	7.7
Pb	0.2	0.4
Se	0.8	3.1
Zn	0.4	0.7

n.d. : no data are available

For Cd and Hg data are also available for Austria. The contribution to total emissions in 1992 was for Cd 38.4% and for Hg 27.8% /2/. The contribution of area sources, such as residential combustion, to total emissions has increased during recent years. This is caused by the fact that large emitters have been equipped with improved dust control facilities in Germany as well as in Austria, and hence the contribution from larger sources has been reduced.

For Particulate Matter:
Combustion Plants < 50 MW (boilers) are now covered in the new supplementary chapter Particulate emissions from smaller Combustion Plants (<50MWth) B111(S1).

Combustion Plants >= 50 and < 300 MW (boilers) are now covered in the new supplementary chapter Particulate emissions from large Combustion Plants (>50MWth) B111(S2).

Gas Turbines are now covered in the new supplementary chapter Particulate emissions from gas turbines and internal combustion engines B111(S3).

3 GENERAL

3.1 Description

The emissions considered in this chapter are generated in boilers or in gas turbines and stationary engines regardless of the allocation of combustion plants to SNAP activities. In addition, residential combustion is relevant for this chapter. Emissions from process furnaces and from waste incineration are excluded.

3.2 Definitions

Integrated Coal Gasification Combined Cycle Gas Turbine (IGCC)	gas turbine fuelled by gas which is a product of a coal gasification process.
Boiler	any technical apparatus in which fuels are oxidised in order to generate heat for locally separate use.
Co-generation plant	steam production in (a) boiler(s) for both power generation (in a steam turbine) and heat supply.
Combined Cycle Gas Turbine (CCGT)	gas turbine combined with a steam turbine. The boiler can also be fuelled separately.
Furnace	fireplace in which fuels are oxidised to heat the direct surroundings.
Plant	element of the collective of emission sources (e.g. residential combustion) treated as an area source.
Stationary engines	spark-ignition engines or compression-ignition engines.

3.3 Techniques

3.3.1 Medium-sized combustion plants - boilers, gas turbines, stationary engines - (thermal capacity ≥ 50 and < 300 MW)

For the combustion of solid, liquid and gaseous fuels in medium-sized combustion plants techniques are used which have already been described in Section 3.3 of chapter B111 on “Combustion Plants as Point Sources”.

3.3.2 Small-sized combustion plants - boilers and furnaces - (thermal capacity < 50 MW)

Small sized combustion plants are divided here into industrial combustion and non-industrial combustion:

- Industrial combustion:
  The techniques used for the combustion of solid, liquid and gaseous fuels in industrial combustion plants have already been described in Section 3.3 of chapter B111 on

"Combustion Plants as Point Sources". The share of combustion techniques used is different: for the combustion of solid fuels mainly grate firing and stationary fluidised bed combustion are applied.

- Non-industrial combustion:
  Non-industrial combustion which includes other small consumers and residential combustion, is characterised by a great variety of combustion techniques.

  For the combustion of solid fuels e.g. mainly grate firing units are installed which can be distinguished by the type of stoking and the air supply. For example, in manually fed combustion units (such as single stoves) emissions mainly result from frequent start-ups/shut-downs; automatically fed combustion units are mainly emission relevant when the fuel is kept glowing. Normally, older combustion installations release more emissions than modern combustion installations. Furthermore, combustion installations which often operate with reduced load conditions are highly emission relevant: this operation mode occurs frequently in the case of over-dimensioned combustion units. /4, 5/

  For the combustion of liquid and gaseous fuels, in principle similar technologies are applied, such as those described in chapter B111 on "Combustion Plants as Point Sources" (Section 3.3).

3.4 Emissions

Relevant pollutants are sulphur oxides (SO_x), nitrogen oxides (NO_x), carbon dioxide (CO_2), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), methane (CH_4) and heavy metals (arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se), zinc (Zn) and in the case of heavy oil also vanadium (V)). Emissions of nitrous oxide (N_2O) and ammonia (NH_3) are normally of less importance.

The main influencing parameters which determine the emissions and species profiles of some pollutants are given in Sections 3.4 and 9 of chapter B111 on "Combustion Plants as Point Sources". In particular for small combustion installations (e.g. residential combustion) emissions of NMVOC and CO can occur in considerable amounts; these emissions are mostly released from inefficiently working stoves (e.g. wood-burning stoves). VOC emissions released from domestic wood-fired boilers (0.5 - 10 MW) can be significant. Emissions can be up to ten times higher at 20 % load than those at maximum load /29/.

The emissions are released through the stack. The relevance of fugitive emissions (from seals etc.) can be neglected for combustion installations. Due to the fact that most references do not clearly distinguish between SO_x and SO_2, for the following sections it can be assumed that SO_2 includes SO_3, if not stated otherwise.

3.5 Controls

3.5.1 Medium-sized combustion plants - boilers, gas turbines, stationary engines - (thermal capacity ≥ 50 and < 300 MW)

It can be assumed, that the smaller the combustion installation considered are, the lower is the probability to be equipped with secondary measures. For cases where abatement technologies for SO_2, NO_x or heavy metals (controlled as particulates) are installed, the corresponding technical details are given in Section 3.5 of chapter B111 on "Combustion Plants as Point Sources". For SO_2 abatement in Germany, larger boilers are mainly controlled by the limestone wet scrubbing process. In the case of smaller facilities dry sorption processes are preferred.

3.5.2 Small-sized combustion plants - boilers and furnaces - (thermal capacity < 50 MW)

Small-sized combustion plants have been split into industrial combustion and non-industrial combustion:

- Industrial combustion:

  For cases where abatement technologies for SO_2, NO_x or heavy metals are installed the corresponding technical details are given in Section 3.5 of chapter B111 on "Combustion Plants as Point Sources". If NO_x reduction measures are installed mostly primary reduction measures (e.g. low NO_x burner) are applied.
- Non-industrial combustion:
  For small consumers / residential combustion only primary emission control measures are relevant. Emission reduction is mainly achieved by optimised operation conditions (older installations) and improved combustion efficiencies (modern installations).

4 SIMPLER METHODOLOGY

For combustion plants treated as area sources only a simpler methodology is given; a detailed methodology is not applicable (see Section 5). Here "simpler methodology" refers to the calculation of emissions based on emission factors and activities and covers all relevant pollutants (SO_2, NO_x, NMVOC, CH_4, CO, CO_2, N_2O, heavy metals). Emissions of NH_3 are of less relevance (they are only released as ammonia slip in connection with secondary measures for NO_x abatement).

The annual emission E is determined by an activity A and an emission factor:

$$E_i = EF_i \cdot A \qquad (1)$$

E_i annual emission of pollutant i
EF_i emission factor of pollutant i
A annual activity rate

The activity rate A and the emission factor EF_i have to be determined on the same level of aggregation depending on the availability of data. The activity A should be determined within the considered territorial unit by using adequate statistics (see also Section 6). The activity should refer to the energy input of the emission sources considered (fuel consumption in [GJ]). Alternatively, secondary statistics (surrogate data) can be used for the determination of the fuel consumption [GJ]. The quality of surrogate data can be characterised by two criteria:

- level of correlation
  The surrogate data should be directly related to the required data (e.g. fuel consumption of households derived from heat demand of households).

- level of aggregation
  The surrogate data should be provided on the same level of aggregation (e.g. spatial, sectoral and seasonal resolution).

Examples for activity rate and surrogate data and origins of possible inaccuracies are listed in the following:

- annual fuel consumption (recommended activity rate):
  - Statistics concerning the annual fuel consumption are often not further specified for different economic branches, and emission source categories, respectively. Furthermore, no technical split can be provided.
- annual fuel production [Gg], e.g. production of hard coal, lignite, natural gas:
  - The specifications of the fuel used (e.g. different types of coal) are not given. For the conversion of the unit [Gg] into unit [GJ] only an average heating value can be used.
- density of population, number of households:
  - Population statistics correspond to a very high level of aggregation. Further information has to be used (e.g. percentages of fuel consumed) in order to determine the activity rate for small consumers (e.g. residential combustion). In particular for fuels which are distributed by pipelines (e.g. natural gas) this assessment leads to an uncertainty in the activity rate determined.
- number of enterprises, number of employees, turnover of enterprises [Mio ECU]:
  - The statistical data on enterprise level are often allocated to the economic sector (e.g. “Production and Distribution of Electric Power, Production and Distribution of Steam, Hot Water, Compressed Air, District Heating Plants” /EUROSTAT, see Section 6/). On the other hand, emission factors are specified with regard to the type of fuel and often also to the type of boiler used.
- heat consumption:
  - The specific heat consumption per capita (e.g. [J/employee], [J/inhabitant]) or related to the area heated (e.g. [J/building], [J/m²]) can be determined by using area and branch specific data (e.g. differentiation between branches, number of employees, number of inhabitants).

The emission factor EF_i should be calculated as a mean value of all combustion installations within the territorial unit considered. In practice, a limited number of installations are selected to determine a representative emission factor which is applied to the total population of the installations considered. Usually, such emission factors are only specified as a function of fuel characteristics. However, further parameters should be taken into account, in particular the technology distribution as well as the size and age distribution of the boilers. Furthermore, evidence has been given that emissions are significantly affected by the operating conditions (e.g. inefficiently working stoves).

The emission factor EF_i (see Equation (1)) takes into account abatement measures (primary and secondary). If not stated otherwise the emission factors presented refer to full load conditions.

In the following a calculation procedure for SO_2 emission factors is proposed according to Equation (2):

$$EF_{SO_2} = 2 \cdot \overline{C}_{S_{fuel}} \cdot (1 - \overline{\alpha}_s) \cdot \frac{1}{\overline{H}_u} \cdot 10^6 \qquad (2)$$

EF_{SO_2}	emission factor for SO_2 [g/GJ]
$\overline{C}_{S_{fuel}}$	average sulphur content of fuel (in mass S/mass fuel [kg/kg])
$\overline{H}_u$	average lower heating value [Mg/kg]
$\overline{\alpha}_s$	average sulphur retention in ash [ ]

In cases where secondary reduction measures are installed, the reduction efficiency has to be integrated by applying one of the following assumptions:

- if the total population of combustion installations is equipped with secondary measures, a mean reduction efficiency of these measures should be used;
- if only few combustion installations are equipped with secondary measures, either these installations should be treated separately or the mean reduction efficiency should be calculated with regard to the total population.

Reduction efficiencies for different individual secondary measures are given in Tables 10 and 11 in chapter B111 on “Combustion Plants as Point Sources”.

Equation (2) can be used for all fuels, but for liquid and gaseous fuels the sulphur retention in ash α_s is not relevant. If certain input data of Equation (2) are not available, provided default values based on literature data can be used:

$\overline{C}_{S_{fuel}}$	sulphur contents of different fuels see Table 4[2] (in Section 8),
$\overline{\alpha}_S$	sulphur retention in ash of different types of boiler see Table 8[2] in chapter B111 on “Combustion Plants as Point Sources“,
$\overline{H}_u$	lower heating values of different types of fuels see Table 21[2] in chapter B111 on “Combustion Plants as Point Sources“.

For other pollutants, according to Equation (1) fuel and technology specific emission factors EF_i are given in Tables 5 - 12 based on literature data; for activity data see Section 6.

5 DETAILED METHODOLOGY

For combustion plants a detailed methodology means the determination of emissions based on measured data. This is not applicable to area sources as only few emission sources are monitored directly.

---

[2] A mean value has to be calcutated with regard to the area concerned.

6 RELEVANT ACTIVITY STATISTICS

The following gives a list of available statistics on a national level for the determination of fuel consumption, installed capacities, socio-economic data, etc.:

- Office for Official Publication of the European Communities (ed.): Annual Statistics 1990; Luxembourg; 1992
- Statistical Office of the European Communities (EUROSTAT) (ed.): CRONOS Databank; 1993
- OECD (ed.): Environmental Data, Données OCDE sur l'environnement; Compendium; 1993
- Commission of the European Communities (ed.): Energy in Europe; 1993 - Annual Energy Review; Special Issue; Brussels; 1994
- EUROSTAT (ed.): Panorama of EU Industry'94; Office for official publications of the European Communities; Luxembourg; 1994

A brief discussion of potential surrogate data for the determination of the activity rate is given in Section 4.

7 POINT SOURCE CRITERIA

This section is not relevant since this chapter only covers area sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Medium-sized combustion plants (thermal capacity ≥ 50 and < 300 MW)

For medium combustion installations, emission factors for the pollutants NO_x, NMVOC, CH_4, CO, CO_2, N_2O and heavy metals are given in Tables 24 - 31 in chapter B111 on "Combustion Plants as Point Sources".

8.2 Small-sized combustion plants (thermal capacity < 50 MW)

Tables 4 - 12 contain emission factors for all pollutants except for SO_2 where sulphur contents of different fuels are given. All emission factor tables have been designed in a homogeneous structure: Table 3 provides a split of combustion techniques (types of boilers, etc.); this standard table has been used for all pollutants. The selection of fuels is based on the CORINAIR90 inventory.

For small-sized combustion installations, emission factors are given related to the type of fuel consumed and, if useful, related to technical specifications based on literature data. These emission factors normally refer to stationary operating conditions. Modifications are indicated as footnotes (instationary conditions e.g. due to manually fed boilers, etc.).

The sequence of the following emission factor tables is:

Table 3: Standard table for emission factors for different pollutants

Table 4: Sulphur contents of selected fuels

Table 5: NO_x emission factors [g/GJ]

Table 6: NMVOC emission factors [g/GJ]

Table 7: CH_4 emission factors [g/GJ]

Table 8: CO emission factors [g/GJ]

Table 9: CO_2 emission factors [kg/GJ]

Table 10: N_2O emission factors [g/GJ]

Table 11: NH_3 emission factors [g/GJ]

Table 12: Heavy metal emission factors (mass pollutant/mass fuel [g/Mg])

Table 3: Standard table of emission factors for the relevant pollutants

Fuel category1)				NAPFUE code1)	P12)	no technical specification	Technical specification									
							Industrial combustion							Non-industrial combustion		
							no specification10)	DBB3)	WBB4)	FBC5)	GF6)	GT7)	Stat. E.8)	no specification	Small consumers	Residential combustion9)
s	coal		no specification	-												
s	coal	hc11)		101 - 103												
s	coal	bc11)		106												
...	...	...	...	...												
s	biomass		wood	111												
...	...		...	...												
s	waste		municipal	114												
...	...		...	...												
l	oil		no specification	-												
l	oil		residual	201												
...	...		...	...												
g	gas		no specification	-												
g	gas		natural	301												
...	...		...	...												

1) the fuel category is based on the NAPFUE-code

2) P1 = sulphur content of fuel

3) DBB = Dry bottom boiler

4) WBB = Wet bottom boiler

5) FBC = Fluidised bed combustion

6) GF = Grate firing; ST1, ST2 = Type of stoker

7) GT = Gas turbine

8) Stat. E. = Stationary engine

9) A differentiation between old and modern techniques can be made for the ranges of emission factors given so that e.g. the smaller values relate to modern units.

10) Here only related to combustion in boilers; gas turbines and stationary engines are excluded.

11) hc = hard coal, bc = brown coal

Table 4: Sulphur contents of selected fuels

Fuel category				NAPFUE code	Sulphur content of fuel	
					range	unit
s	coal	hc	coking, steam, sub-bituminous	101 - 103	0.4 - 6.2	wt.-% (maf)
s	coal	bc	brown coal/lignite	105	0.4 - 6.2	wt.-% (maf)
s	coal	bc	briquettes	106		
s	coke	hc, bc	coke oven, petroleum	107, 108, 110	0.5 - 1 [1][2]	wt.-% (maf)
s	biomass		wood	111	< 0.03[1]	wt.-% (maf)
s	biomass		peat	113		
s	waste		municipal	114		
s	waste		industrial	115		
l	oil		residual	203	0.3[3] - 3.5[4]	wt.-%
l	oil		gas	204	0.08 - 1.0	wt.-%
l	oil		diesel	205		
l	kerosene			206		
l	gasoline		motor	208	< 0.05[5]	wt.-%
g	gas		natural	301		
g	gas		liquified petroleum gas	303		
g	gas		coke oven	304		
g	gas		blast furnace	305		
g	gas		refinery	308	<= 8[6]	$g \cdot m^{-3}$
g	gas		gas works	311		

[1] Marutzky 1989 /25/

[2] Boelitz 1993 /24/

[3] Personal communication Mr. Hietamäki (Finland)

[4] Referring to NL-handbook 1988 /26/ the range is 2.0 - 3.5

[5] $\alpha_S = 0$

[6] NL-handbook 1988 /26/

Table 5: NO$_x$ emission factors [g/GJ]

Fuel category				NAPFUE code	no technical specification	Technical specification									
						Industrial combustion							Non-industrial combustion		
						no specification	DBB	WBB	FBC	GF	GT	Stat. E.	no specification	Small consumers	Residential combustion
s	coal		no specification	-											60-232***
s	coal	hc	coking, steam, sub-bituminous	101, 102, 103	50 - 668[11]	155[13]							50[1][2]	150[9]	50[9]
s	coal	bc	brown coal/lignite	105	7.5 - 604[11]								12[2] - 100[1]		
s	coal	bc	briquettes	106	17 - 300[11]										100[9]
s	coke	hc,bc	coke oven, petroleum	107, 108, 110	13 - 323[11]								45	50[9][10]	50[9][10]
s	biomass		wood	111	130 - 968[11]	206[13]				100-300*, 30-120**			12 - 80[1]	75[9]	50[9], 147-200[4]
s	biomass		peat	113	130 - 240[11]								100[1]		
s	waste		municipal	114	140 - 280[11]										
s	waste		industrial	115	100 - 193[11]										
s	waste		wood	116	80 - 258[11]										
s	waste		agricultural	117	80 - 100[11]										
l	oil		no specification	-									50[2]		
l	oil		residual	203	98 - 520[11]	165[13]					350[12]	75 - 1,889[12]			
l	oil		gas	204	55 - 1,624[11]	70[13]					100 - 531[12]	80 - 1,493[12]	50[1], 51[4]	48[9]	47[9]
l	oil		diesel	205	300 - 373[11]						380[12]	840[12],[13]			
l	kerosene			206	45 - 100[11]						120[12]	45 - 1,038[12]	50[1]		
l	gasoline		motor	208	80[11]							375[12]			
l	naphtha			210	24 - 1,085[11]										
g	gas		no specification	-									30[2]-50[3]		
g	gas		natural	301	32 - 307[11]	62[13]					81 - 360[12], 165[13][14]	75 - 1,200[12], 165[13]	50[1]	38[9]	30[8], 46[9]
g	gas		liquified petroleum gas	303	18 - 105[11]						120[12]		50[1],	57[9]	47[4], 69[9]
g	gas		coke oven	304	2 - 399[11]						250[12]		50[1]	38[9]	46[9]
g	gas		blast furnace	305	25 - 1,520[11]						250[12]				
g	gas		waste	307	52 - 238[11]										
g	gas		refinery	308	65 - 155[11]						55 - 357[12]				
g	gas		biogas	309	4 - 132[11]										
g	gas		from gas works	311	50 - 411[11]								50[1]		

[1] CORINAIR 1992 /8/

[2] LIS 1977 /15/

[3] UBA 1981 /21/, Kolar 1990 /14/

[4] Radian 1990 /18/, IPCC 1994 /12/

[5] spruce wood

[6] chip board, phenol bonded

[7] chip board, urea bonded

[8] LIS 1987 /16/

[9] UBA 1995 /23/

[10] coke from hard coal

[11] CORINAIR90 data of combustion plants as area sources

[12] CORINAIR90 data, area sources

[13] UBA 1995 /30/

[14] at 50 % load: 130 g/GJ

* 100[3][5], 120[3][6], 300[3][7] for underfeed stoker

** 30[3][5], 80[3][6], 120[3][7] for overfeed stoker

*** 60[8], 149[4], 232[4]

Table 6: NMVOC emission factors [g/GJ]

Fuel category				NAPFUE code	no technical specification	Technical specification									
						Industrial combustion							Non-industrial combustion		
						no specification	DBB	WBB	FBC	GF	GT	Stat. E.	no specification	Small consumers	Residential combustion
s	coal		no specification	-											
s	coal	hc	coking, steam, sub-bituminous	101, 102, 103	1-511[5]								400[1] - 600[2]		50[3]
s	coal	bc	brown coal/lignite	105	1-800[5]										
s	coal	bc	briquettes	106	1.5-700[5]								150[1] [2]		225[3]
s		hc,bc	coke oven, petroleum	107,108, 110	0.5-700[5]								12[2]		225[3] [4]
s	biomass		wood	111	7-1,000[5]								150[2] - 800[1]		480[3]
s	biomass		peat	113	3-600[5]								150[1]		
s	waste		municipal	114	9-70[5]										
s	waste		industrial	115	0.5-134[5]										
s	waste		wood	116	48-600[5]										
s	waste		agricultural	117	50-600[5]										
l	oil		no specification	-									15[2]		
l	oil		residual	203	2.1-34[5]						3 - 4[6]	1.4 - 103.7[6]			
l	oil		gas	204	1.5-116[5]						0.7 - 5[6]	1.5 - 250[6]	15[1]		1.5[3]
l	oil		diesel	205	1.5-2.5[5]						5[6]	3.5[6]			
l	kerosene			206	1-14[5]						1[6]	1.5 - 244[6]	15[1]		
l	gasoline		motor	208	2[5]							437[6]			
l	naphtha			210	1-5[5]										
g	gas		no specification	-									1.5[2]		
g	gas		natural	301	0.3-205[5]						0.1 - 5.7[6]	0.3 - 47[6]	10[1]		2.5[3]
g	gas		liquified petroleum gas	303	0.3-14[5]						1[6]				3.5[3]
g	gas		coke oven	304	0.3-12[5]						2[6]		25[1]		2.5[3]
g	gas		blast furnace	305	0.2-1.5[5]										
g	gas		waste	307	2-16[5]										
g	gas		refinery	308	0.3-2.5[5]						2[6]				
g	gas		biogas	309	2.4-10[5]										
g	gas		from gas works	311	0.6-10[5]								25[1]		

[1] CORINAIR 1992 /8/

[2] LIS 1977 /15/

[3] UBA 1995 /23/

[4] coke from hard coal

[5] CORINAIR90 data, combustion plants as area sources with a thermal capacity of > 300, 50 - 300, < 50 MW

[6] CORINAIR90 data, area sources

Table 7: CH_4 emission factors [g/GJ]

Fuel category				NAPFUE code	no technical specification	Technical specification									
						Industrial combustion							Non-industrial Combustion		
						no specification	DBB	WBB	FBC	GF	GT	Stat. E.	no specification	Small consumers	Residential combustion
s	coal		no specification	-											
s	coal	hc	coking, steam, sub-bituminous	101, 102, 103	2 - 511$^{4)}$										450$^{2)}$
s	coal	bc	brown coal/lignite	105	0.2 - 532$^{4)}$										
s	coal	bc	briquettes	106	1 - 350$^{4)}$										225$^{2)}$
s	coke	hc,bc	coke oven, petroleum	107, 108, 110	1.5 - 200$^{4)}$										225$^{2) 3)}$
s	biomass		wood	111	21 - 601$^{4)}$										74-200$^{1)}$, 320$^{2)}$
s	biomass		peat	113	5 - 400$^{4)}$										
s	waste		municipal	114	6 - 32$^{4)}$										
s	waste		industrial	115	0.3 - 38$^{4)}$										
s	waste		wood	116	30 - 400$^{4)}$										
s	waste		agricultural	117	10 - 400$^{4)}$										
l	oil		no specification	-											
l	oil		residual	203	0.1 - 10$^{4)}$						1 - 3$^{5)}$	0,02 - 7,5$^{5)}$			
l	oil		gas	204	0.1 - 19$^{4)}$						1 - 20,9$^{5)}$	0,04 - 14$^{5)}$			3.5$^{2)}$, 5$^{1)}$
l	oil		diesel	205	1.5 - 2.5$^{4)}$							3,5$^{5)}$			
l	kerosene			206	0.02 - 7$^{4)}$						1$^{5)}$	0,02 - 7,4$^{5)}$			
l	gasoline		motor	208	1							49$^{5)}$			
l	naphtha			210	0.02 - 5$^{4)}$										
g	gas		no specification	-									1$^{1)}$		
g	gas		natural	301	0.3 - 205$^{4)}$						0,3 - 22,5$^{5)}$	0,02 - 153$^{5)}$			2.5$^{2)}$
g	gas		liquified petroleum gas	303	0.02 - 6$^{4)}$						1$^{5)}$				1.1$^{1)}$, 1.5$^{2)}$
g	gas		coke oven	304	0.02 - 12$^{4)}$						2$^{5)}$				2.5$^{2)}$
g	gas		blast furnace	305	0.02 - 4$^{4)}$										
g	gas		waste	307	0.4 - 2.5$^{4)}$										
g	gas		refinery	308	0.02 - 2.5$^{4)}$						2$^{5)}$				
g	gas		biogas	309	0.4 - 10$^{4)}$										
g	gas		from gas works	311	0.6 - 10$^{4)}$										

$^{1)}$ Radian 1990 /18/, IPCC 1994 /12/

$^{2)}$ UBA 1995 /23/

$^{3)}$ coke from hard coal

$^{4)}$ CORINAIR90 data, combustion plants as area sources with a thermal capacity of > 300, 50 - 300, < 50 MW

$^{5)}$ CORINAIR90 data, area sources

Table 8: CO emission factors [g/GJ]

					no technical specification	Technical specification									
						Industrial combustion						Non-industrial Combustion			
Fuel category				NAPFUE code		no specification	DBB	WBB	FBC	GF	GT	Stat. E.	no specification	Small consumers	Residential combustion
s	coal		no specification	-						178-196*, 100[2]-107[6]			185[5]		160-3,580**
s	coal	hc	coking, steam, sub-bituminous	101, 102, 103	9 - 5,000[11]	73[13]								500[9]	4,800[9]
s	coal	bc	brown coal/lignite	105	4 - 6,000[11]										
s	coal	bc	briquettes	106	11 - 5,200[11]								7,000[7]		4,300[9]
s	coke	hc,bc	coke oven, petroleum		2 - 5,500[11]									1,000[9] [10]	4,800[9] [10]
s	biomass		wood	111	82 - 10,000[11]	627[13]							7,000[7]	3,600[9]	5,790[9]
s	biomass		peat	113	65 - 10,000[11]										18-18,533***
s	waste		municipal	114	33 - 2,188[11]										
s	waste		industrial	115	15 - 510[11]										
s	waste		wood	116	61 - 8,500[11]										
s	waste		agricultural	117	200 - 8,500[11]										
l	oil		no specification	-									70[8]		
l	oil		residual	203	29 - 1,754[11]	10[13]					10 - 30.4[12]	11.7 - 438[12]	20[2]		13[4]
l	oil		gas	204	5.3 - 547[11]	10[13]					10 - 123[12]	12 - 691[12]		41[9]	43[9]
l	oil		diesel	205	12 - 547[11]						12[12]	190[12],[13]			
l	kerosene			206	3 - 151[11]						12[12]	3.4 - 669[12]			
l	gasoline		motor	208	12[11]										
l	naphtha			210	0.2 - 89[11]										
g	gas		no specification	-									70[8]		10[4]
g	gas		natural	301	2.4 - 500[11]	10[13]					8-123[12], 10[13][14]	2.4-335[12], 136[13]	252)	41[9]	25-250***
g	gas		liquified petroleum gas	303	3.3 - 250[11]									41[9]	10[4], 53[9]
g	gas		coke oven	304	3.3 - 279[11]						13[12]			41[9]	53[9]
g	gas		blast furnace	305	3 - 279[11]						13[12]				
g	gas		waste	307	8.8 - 27[11]										
g	gas		refinery	308	3.3 - 279[11]						2[12]				
g	gas		biogas	309	7.8 - 41[11]										
g	gas		from gas works	311	6.4 - 225[11]										

[1] EPA 1987 /10/, CORINAIR 1992 /8/

[2] CORINAIR 1992 /8/ for overfed stoker

[3] OECD 1989 /31/, CORINAIR 1992 /8/

[4] Radian 1990 /18/, IPCC 1994 /12/

[5] EPA 1987 /10/, CORINAIR 1992 /8/

[6] EPA 1985 /9/, CORINAIR 1992 /8/ for overfeed stoker

[7] LIS 1987 /16/

[8] LIS 1977 /15/

[9] UBA 1995 /23/

[10] coke from hard coal

[11] CORINAIR90 data, combustion plants as area sources with a thermal capacity of > 300, 50 - 300, < 50 MW

[12] CORINAIR90 data, area sources

[13] UBA 1995 /30/

[14] at 50 % load: 76 g/GJ

* 178[1], 190[2], 196[3] for underfeed stoker

**160[3], 484[4], 1,500[5], 1,607[6], 2,000[2], 3,400[3], 3,580[4]

*** 18[4], 53[9],4,949[4], 6,002[4], 18,533[4]

**** 25[2], 200[2], 250[2] (cooker)

Table 9: CO_2 emission factors [kg/GJ]

Fuel category				NAPFUE code	Emission factors value	range	remarks
s	coal		no specification	-			
s	coal	hc	coking, steam, sub-bituminous	101, 102, 103	94[6]	93 - 99[5], 55.9 - 106.8[2]	
s	coal	bc	brown coal/lignite	105		74 - 105.5[5], 67.5 - 116[2]	
s	coal	bc	briquettes	106	97[6]	97 - 113[3], 85.6 - 110.9[2]	
s	coke	hc,bc	coke oven, petroleum	107, 108, 110	105[6]	96 - 122[1][4], 85.6 - 151[2]	
s	biomass		wood	111		100 - 125[1] [4], 83 - 322.6[2]	
s	biomass		peat	113		98 - 115[2]	
s	waste		municipal	114		109 - 141[1], 15 - 117[2]	
s	waste		industrial	115		20 - 153.3[2]	
s	waste		wood	116		83 - 92[2]	
s	waste		agricultural	117		69 - 100[2]	
l	oil		no specification	-			
l	oil		residual	203		76 - 78[3] [4], 64 - 99[2]	
l	oil		gas	204	74[6]	73 - 74[5], 69 - 97[2]	
l	oil		diesel	205		73 - 74[2] [4]	
l	kerosene			206	73[5]	67.7 - 78.6[2]	
l	gasoline		motor	208	71[2], 73[5]	71 - 74[1][3][4]	
l	naphtha			210	73[3]	72.1 - 74[2]	
g	gas		no specification	-			
g	gas		natural	301	56[6]	55 - 61[3] [4] [5], 52 - 72[2]	
g	gas		liquified petroleum gas	303	65[6]	55 - 75.5[2]	
g	gas		coke oven	304	44[6], 49[5]	44 - 192[2]	
g	gas		blast furnace	305		105 - 290[2]	
g	gas		waste	307		62.5 - 87.1[2]	
g	gas		refinery	308		55 - 66[2]	
g	gas		biogas	309		60 - 103.4[2]	
g	gas		from gas works	311		52 - 56[2]	

[1] Schenkel 1990 /20/

[2] CORINAIR90 data, combustion plants as area sources with a thermal capacity of > 300, 50 - 300, < 50 MW

[3] IPCC 1993 /11/

[4] Kamm 1993 /13/

[5] BMU 1994 /7/

[6] UBA 1995 /30/

Table 10: N_2O emission factors [g/GJ]

Fuel category				NAPFUE code	no technical specification	Technical specification									
						Industrial combustion							Non-industrial combustion		
						no specification	DBB	WBB	FBC	GF	GT	Stat. E.	no specification	Small consumers	Residential combustion
s	coal		no specification	-											
s	coal	hc	coking, steam, sub-bituminous	101, 102, 103	5 - 30[1]										
s	coal	bc	brown coal/lignite	105	1.4 - 18.2[1]										
s	coal	bc	briquettes	106	1.4 - 14[1]										
s	coke	hc,bc	coke oven, petroleum	107, 108, 110	1.4 - 14[1]										
s	biomass		wood	111	1.6 - 20[1]										
s	biomass		peat	113	2 - 14[1]										
s	waste		municipal	114	4[1]										
s	waste		industrial	115	2 - 5.9[1]										
s	waste		wood	116	4[1]										
s	waste		agricultural	117	1.4 - 4[1]										
l	oil		no specification	-											
l	oil		residual	203	0.8 - 46.5[1]						2.5 - 25[2]	1.1 - 2.1[2]			
l	oil		gas	204	0.6 - 17.8[1]						0.5 - 25[2]	0.6 - 14[2]			
l	oil		diesel	205	2 - 15.7[1]						15.7[2]	2 - 4[2]			
l	kerosene			206	2 - 14[1]						14[2]	2[2]			
l	gasoline		motor	208	14[1]							2[2]			
l	naphtha			210	12[1]										
g	gas		no specification	-											
g	gas		natural	301	0.1 - 14[1]						0.1-3[2]	0.1-3[2]			
g	gas		liquified petroleum gas	303	1 - 14[1]						14[2]				
g	gas		coke oven	304	1 - 12[1]						3[2]				
g	gas		blast furnace	305	0.8 - 34.6[1]						3[2]				
g	gas		waste	307	3.7 - 5[1]										
g	gas		refinery	308	1.5[1]						3[2]				
g	gas		biogas	309	1.5 - 3.7[1]										
g	gas		from gas works	311	2 - 3[1]										

[1] CORINAIR90 data, combustion plants as area sources with a thermal capacity of > 300, 50 - 300, < 50 MW

[2] CORINAIR90 data, area sources

Table 11: NH_3 emission factors [g/GJ]

Fuel category				NAPFUE code	no technical specification	Technical specification	
						Gas turbines	Stationary engines
s	coal		no specification	-			
s	coal	hc	coking, steam, sub-bituminous	101, 102, 103	0.14 - 0.48[1]		
s	coal	bc	brown coal/lignite	105	0.01 - 0.86[1]		
s	coal	bc	briquettes	106	0.01 - 0.86[1]		
s	coke	hc,bc	coke oven, petroleum	107, 108, 110	0.01 - 0.86[1]		
s	biomass		wood	111	5 - 9[1]		
s	biomass		peat	113			
s	waste		municipal	114			
s	waste		industrial	115			
s	waste		wood	116			
s	waste		agricultural	117			
l	oil		no specification	-			
l	oil		residual	203	0.01[1]		
l	oil		gas	204	0.01 - 2.68[1]		0.1 - 0.2[1]
l	oil		diesel	205			
l	kerosene			206			0.2[1]
l	gasoline		motor	208			
l	naphtha			210			
g	gas		no specification	-			
g	gas		natural	301	0.15 - 1[1]		
g	gas		liquified petroleum gas	303	0.01[1]		
g	gas		coke oven	304	0.87[1]		
g	gas		blast furnace	305			
g	gas		waste	307			
g	gas		refinery	308			
g	gas		biogas	309	15[1]		
g	gas		from gas works	311			

[1] CORINAIR90 data, combustion plants as area sources with a thermal capacity of > 300, 50 - 300, < 50 MW

Table 12: Heavy metal emission factors (mass pollutant/mass fuel [g/Mg])

Fuel category			NAPFUE code	Heavy metal element	no technical specification	Technical specification							
						Industrial combustion					Non-industrial combustion		
						no specification	DBB	WBB	FBC	GF	no specification	Small consumer	Residential combustion
s	coal	hc	101/102	Mercury		1.7 g/TJ[2]							0.3[1]
				Cadmium		0.1 g/TJ[2]							0.15[1]
				Lead		6.0 g/TJ[2]							2.5[1]
				Copper		3.1 g/TJ[2]							1.2[1]
				Zinc		10.5 g/TJ[2]							1[1]
				Arsenic		3.2 g/TJ[2]							1.2[1]
				Chromium		2.3 g/TJ[2]							0.9[1]
				Selen		0.5 g/TJ[2]							0.15[1]
				Nickel		4.4 g/TJ[2]							1.8[1]
s	coal	bc	105	Mercury		4.4 g/TJ[2]		╳					0.1[2]
				Cadmium		0.4 g/TJ[2]							0. 04[2]
				Lead		3.9 g/TJ[2]							0.24[2]
				Copper		2.0 g/TJ[2]							
				Zinc		10.6 g/TJ[2]							0.14[2]
				Arsenic		4.2 g/TJ[2]							
				Chromium		3.1 g/TJ[2]							
				Selen									
				Nickel		3.9 g/TJ[2]							
l	oil, heavy fuel		203	Mercury		0.15-0.2[1]	╳	╳	╳	╳			╳
				Cadmium		0.1-1[1]							
				Lead		0.6-1.3[1]							
				Copper		0.05-1[1]							
				Zinc		0.02-0.2[1]							
				Arsenic		0.14-1[1]							
				Chromium		0.2-2.5[1]							
				Selen		0.003-1[1]							
				Nickel		17-35[1]							
g	gas		301	Mercury			╳	╳	╳	╳			

[1] Winiwarter 1995 /6/

[2] Jockel 1995 /1/

9 SPECIES PROFILES

For species profiles of selected pollutants see Section 9 in chapter B111 on “Combustion Plants as Point Sources”.

10 UNCERTAINTY ESTIMATES

Uncertainties of emission data result from inappropriate emission factors and from missing statistical information on the emission generating activity. Those discussed here are related to emission factors. Usually uncertainties associated with emission factors can be assessed by comparing them with emission factors obtained by using measured data or other literature data. However, at this stage, the available emission factors based on literature data are often poorly documented without a specification concerning the area of application. A range of emission factors, depending on the parameters available (as given in chapter B111 on “Combustion Plants as Point Sources“, Section 10), can therefore not be given here.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Weakest aspects discussed here are related to emission factors.

The average emission factor of a territorial unit should integrate the diversity of the combustion techniques installed within the territorial unit. Therefore, the number and diversity of the selected combustion installations for the calculation of the average emission factor should correspond with the number and diversity of the installations within the territorial unit (target population). Further work should be carried out to characterise territorial units with regard to the technologies in place (technology distribution, age distribution of combustion technique, etc.).

For all pollutants considered, neither qualitative nor quantitative load dependencies have yet been integrated into the emission factors. In particular for oil, coal and wood fired small stoves, increased emissions occur due to a high number of start-ups per year (e.g. up to 1,000 times a year) or due to load variations (e.g. manual furnace charging). Emissions from residential firing can be highly relevant (e.g. combustion of wood in the Nordic countries, in particular for VOC and CO emissions). Further work should be invested to clarify this influence with respect to the emission factors published.

For the weakest aspects related to the determination of activities based on surrogate data see Section 4. Uncertainty estimates of activity data should take into account the quality of available statistics. In particular, emissions from the combustion of wood in single stoves may increase as some national statistics have underestimated wood consumption to date /3/.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Spatial disaggregation of annual emission data (top-down approach) can be related

- for industrial combustion e.g. to the number of industrial employees in industrial areas and
- for residential combustion e.g. to the number of inhabitants in high density and low density areas and to the type of fuel.

In general the following disaggregation steps for emissions released from residential combustion can be used /cf. 27/:

- differentiation in spatial areas, e.g. administrative units (country, province, district, etc.), inhabited areas, settlement areas (divided in high and low density settlements),
- determination of regional emission factor per capita depending on the population density and the type of fuel used.

For emissions released from industrial combustion, spatial disaggregation takes into account the following steps:

- differentiation in spatial areas with regard to industrial areas,
- determination of emission factors related to the number of industrial employees.

13 TEMPORAL DISAGGREGATION CRITERIA

Temporal disaggregation of annual emission data (top-down approach) provides a split into monthly, weekly, daily and/or hourly emission data. For annual emissions released from combustion plants as area sources this data can be obtained for:

- industrial combustion by using in principle the disaggregation criteria and the procedure as described in Section 13 of chapter B111 on “Combustion Plants as Point Sources” by taking into account the number of plants in the area considered.
- non-industrial combustion (small consumer/residential combustion) by using a relation between the consumption of fuel and the heating degree-days.

The disaggregation of annual emissions released from non-industrial combustion (small consumers/residential combustion) has to take into account a split into:

- summer and winter time (heating periods),
- working days and holidays and
- daily fluctuations of load

for the main relevant fuels and, if possible, for the main relevant combustion techniques (manually fed stoves, etc.)

The procedure of disaggregation consists of the following step-by-step approach /cf. 28/:

- determination of the temporal variation of the heat consumption (based e.g. on user behaviour),

- determination of the fuel consumption e.g. by using statistics for district heat or consumption of gas, by using fuel balances for the estimation of coal and wood consumption (e.g. as given in /3/),
- correlation of the heating degree-days with the consumption of fuel (e.g. for gas, district heat). Typical heating degree-days are available in statistics. The correlation can be linear as given e.g. in /28/.
- determination of the relative activity (e.g. fuel consumption per hour per day) by using adequate statistics.

This approach makes it possible to determine annual, weekly and/or daily correction factors. For the determination of hourly emissions the following Equation (3) /cf. 28/ can be given as an example:

$$E_H(t) = \frac{E_A}{8{,}760\left[h\right]} \cdot f_a(t) \cdot f_w(t) \cdot f_d(t) \quad (3)$$

E_H	emission per hour(s) [Mg/h]
E_A	annual emission [Mg]
f_a	annual correction factor [ ]
f_w	weekly correction factor [ ]
f_d	daily correction factor [ ]
t	time

The constant (8,760 h) in Equation (3) represents the number of hours per year.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

As outlined in chapter B111 on ”Concepts for Emission Inventory Verification“ different verification procedures can be used. The aim of this section is to select those which are most adequate for emission data from combustion plants as area sources. Verification procedures considered here are principally based on the verification of emission data on a territorial unit level (national level).

The annual emissions related to a territorial unit can be compared to independently derived emission estimates. These independent emission estimates can be obtained by using econometric relations between annual emissions and exogenous variables, such as population equivalents, number of households, fossil fuel prices, etc.

Another possibility is to make emission density comparisons of e.g. emissions per capita or emissions per GDP between countries with comparable economic structures.

17 REFERENCES

/1/ Jockel, W.; Hartje, J.:Die Entwicklung der Schwermetallemissionen in der Bundesrepublik Deutschland von 1985-1995; Forschungsbericht 91-104 03 524, TÜV Rheinland e. V. Köln; 1995

/2/ Stobbelaar, G.: Reduction of Atmospheric Emissions under the terms of the North Sea Action Programme, Report Lucht 102; Ministry of Housing, Physical Planning and Environment; The Netherlands; 1992

/3/ Gerhold, S: Stoffstromrechnung: Holzbilanz 1955 bis 1991; in: Statistische Nachrichten; 47(1992)8; S. 651 - 656; published in Austria

/4/ Baumbach, G.; Angerer, M.: Schadstoffemission gewerblicher und industrieller Holzverbrennung; Erfassung des Stands der Technik und Möglichkeiten zur Emissionsminderung; Projekt Europäisches Forschungszentrum für Maßnahmen zur Luftreinhaltung (PEF) Bericht Nr. 103; Institut für Verfahrenstechnik und Dampfkesselwesen; Universität Stuttgart; 1993

/5/ Struschka, M; Straub, D.; Baumbach, G.: Schadstoffemissionen von Kleinfeuerungsanlagen, Derzeitiger Stand - Möglichkeiten zur Schadstoffminderung - Zukünftige Förderschwerpunkte; Institut für Verfahrenstechnik und Dampfkesselwesen - Abt.: Reinhaltung der Luft; Stuttgart; 1988

/6/ Winiwarter, Wilfried; Schneider, Manfred: Abschätzung der Schwermetallemissionen in Österreich; Umweltbundesamt (Hrsg.); Wien; 1995

/7/ Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (ed.): Umweltpolitik - Klimaschutz in Deutschland, Erster Bericht der Regierung der Bundesrepublik Deutschland nach dem Rahmenübereinkommen der Vereinten Nationen über Klimaänderungen; 1994

/8/ CITEPA: CORINAIR Inventory-Default Emission Factors Handbook (second edition); CEC - DG XI (ed.); 1992

/9/ US-EPA (ed.): Compilation of Air Pollutant Emission Factors; Stationary Point and Area Sources; Fourth Edition; 1985

/10/ US-EPA (ed.): Criteria Pollutant Emission Factors for the NAPAP Emission Inventory; EPA/600/7-87/015; 1987

/11/ IPCC/OECD (ed.): Joint Work Programme on National Inventories of Greenhouse Gas Emissions: National GHG-Inventories (ed.): Transparency in estimation and reporting; Parts I and II; Final report of the workshop held October 1, 1992 in Bracknell (U.K.); published in Paris; 1993

/12/ IPCC/OECD (ed.): Greenhouse Gas Inventory Reference Manual; First Draft, Volume 3; 1994

/13/ Kamm, Klaus; Bauer, Frank; Matt, Andreas: CO-Emissionskataster 1990 für den Stadtkreis Karlsruhe; in: WLB - Wasser, Luft und Boden (1993)10; S. 58 ff.

/14/ Kolar, Jürgen: Stickstoffoxide und Luftreinhaltung; Springer Verlag Berlin, Heidelberg; 1990

/15/ Landesanstalt für Immissionsschutz des Landes NRW (ed.): Emissionsfaktoren für Feuerungsanlagen für feste Brennstoffe; in: Gesundheits-Ingenieur 98(1977)3; S. 58 - 68

/16/ Landesanstalt für Immissionsschutz des Landes NRW (ed.): Erstellung eines Emissionskatasters und einer Emissionsprognose für Feuerungsanlagen im Sektor Haushalte und Kleinverbraucher des Belastungsgebietes Ruhrgebiet Ost; LIS Bericht Nr. 73; 1987

/17/ Mobley, J.D.; Jones G.D.: Review of U.S. NO_x abatement technology; Proceedings: NOx-Symposium Karlsruhe 1985 B1/B 74

/18/ Radian Corporation (ed.): Emissions and Cost Estimates for Globally Significant Anthropogenic Combustion Sources of NO_x, N_2O, CO and CO_2; Prepared for the Office of Research and Development; U.S. Environmental Protection Agency; Washington D.C.; 1990

/19/ Ratajczak, E.-A.; Akland, E.: Emissionen von Stickoxiden aus kohlegefeuerten Hausbrandfeuerstätten; in: Staub, Reinhaltung Luft; 47(1987)1/2, S. 7 - 13

/20/ Schenkel, W.; Barniske, L.; Pautz, D.; Glotzel, W.-D.: Müll als CO-neutrale Energieresource; in: Kraftwerkstechnik 2000 - Resourcen-Schonung und CO-Minderung; VGB-Tagung 21./22.2.1990; S. 108

/21/ Umweltbundesamt (ed.): Luftreinhaltung 1981; Berlin; 1981

/22/ Umweltbundesamt (ed.): Jahresbericht 1985; Berlin; 1986

/23/ Mr. Schäl (Umweltbundesamt Berlin); personal communication, April 10, 1995; based on "3. Bericht der Interministeriellen Arbeitsgruppe "CO_2-Reduktion"

/24/ Boelitz, J.; Esser-Schmittmann, W.; Kreusing, H.: Braunkohlenkoks zur Abgasreinigung; in: EntsorgerPraxis (1993)11; S. 819 - 821

/25/ Marutzky,R: Emissionsminderung bei Feuerungsanlagen für Festbrennstoffe; in: Das Schornsteinfegerhandwerk (1989)3; S. 7 - 15

/26/ Ministry of Housing, Physical Planning and Environment (ed.): Handbook of Emission Factors, Stationary Combustion Sources, Part 3; The Netherlands, The Hague; 1988

/27/ Loibl, W.; Orthofer, R.; Winiwarter, W.: Spatially Disaggregated Emission Inventory for Anthropogenic NMVOC in Austria; Seibersdorf; 1993

/28/ Winiwarter, W.; Kopsca, A.; Loibl, W.: Zeitliche Disaggregation von Emissionsinventuren; OE FZS-A--2490; Seibersdorf (Austria); 1993

/29/ Gustavsson, L.; Karlsson, M.-L.; Wallin, P.-A.: Emissions from Biomass Combustion; Swedish National Testing Research Institute; 1993

/30/ Mr. Beckers (Umweltbundesamt Berlin); Personal communication; August 22, 1995

/31/ OECD Environment Directorate (ed.): Greenhouse Gas Emissions and Emission Factors; 1989

18 BIBLIOGRAPHY

Additional literature is related to combustion:

Struschka, M.; Angerer, M.; Straub, D.: Schadstoffemissionen von Kachel-Grundöfen; VDI Reihe 5: Umwelttechik, Nr. 82; Düsseldorf; 1991

Umweltbundesamt, Austria (ed.): Entwicklung und fortschrittlicher Stand der Technik zur Emissionsminderung von Stickoxiden und Schwefeloxiden aus Feuerungsanlagen im Leistungsbereich von 3 bis 50 MW; Expertenhearing Laxenburg 18/19 November 1992; Wien; 1993

Engewald, W.; Knobloch, Th.; Efer, J.: Flüchtige organische Verbindungen in Emissionen aus dem Hausbrand von Braunkohle; in: UWSF-Z. Umweltchem. Ökotox. 5 (1993) 6; S. 303-308

Institut Français de l´Energie (ed.): Reduction of Emissions of Air Pollutants from New and Existing Combustion Installations less than 50 MW (th); Draft final report; Contract no: B6611-90-011041; 1991

Jockel, W.; Hartje, J.: Datenerhebung über die Emissionen umweltgefährdender Schwermetalle; im Auftrag des Umweltbundesamtes FB: 91-104 02 588; Berlin; 1991

Kolar, J.: Stickstoffoxide und Luftreinhaltung; Berlin; 1989

Allhorn, H.; Breme, V.; Strehler, A.;Rogenhofer, H.; Kraus, U.; Hellwig, M.; Schulze Lammers, P.: Verfeuerung von Stroh als Briketts in Kleinanlagen (Hausbrand) und über Großballen in Großanlagen (Brennereien, Gärtnereien) ab 500 kW Heizleistung; Kurzfassung; KfA Jülich/TU München; Bundesministerium für Forschung und Technologie (ed.); Bonn; 1987

Deutsche Gesellschaft für Mineralölwissenschaft und Kohlechemie e.V. (DGMK) (ed.): Untersuchungen über das Brennverhalten von heutigen und zukünftigen Heizölen in Heizkesseln mit Ölzerstäubungsbrennern; Projekt 185; Hamburg; 1984

Rentz, O.; Holtmann, T.; Oertel, D.; Obermeier, A. et al.: Konzeption zur Minderung der VOC-Emissionen in Baden-Würtemberg; Umweltministerium Baden-Würtemberg (ed.); Heft 21; Karlsruhe; 1993

19 RELEASE VERSION, DATE AND SOURCE

Version : 3.1

Date : December 1995

Source : Otto Rentz; Dagmar Oertel
University of Karlsruhe (TH)
Germany

Updated with particulate matter details by:
Mike Woodfield
AEA Technology
UK
December 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Ute Karl

French-German Institute for Environmental Research
University of Karlsruhe
Hertzstr 16
D-76187 Karlsruhe
Germany

Tel: +49 721 608 4590
Fax: +49 721 75 89 09
Email: ute.karl@wiwi.uni-karlsruhe.de

Annex 1: List of abbreviations

A_i	Activity rate of the emission source i
bc	Brown coal
CCGT	Combined Cycle Gas Turbine
CFBC	Circulating Fluidised Bed Combustion
DBB	Dry Bottom Boiler
E	Emission
EF_i	Emission factor of the emission source i, e.g. in [g/GJ]
f_a	Annual correction factor [ ]
f_d	Daily correction factor [ ]
f_w	Weekly correction factor [ ]
FBC	Fluidised Bed Combustion
g	Gaseous state of aggregation
GF	Grate Firing
GT	Gas Turbine
H	Lower heating value of fuel
hc	Hard coal
IGCC	Integrated Coal Gasification Combined Cycle Gas Turbine
l	Liquid state of aggregation
PFBC	Pressurised Fluidised Bed Combustion
s	Solid state of aggregation
S	Sulphur content of fuel
Stat. E.	Stationary Engine
t	Time
WBB	Wet Bottom Boiler

SNAP CODE:

010104
010204
010304
010404
010504
020104
020203
020303
030104

SOURCE ACTIVITY TITLE: **COMBUSTION IN ENERGY &TRANSFORMATION INDUSTRIES**
Gas Turbines

NOSE CODE: **101.04**

NFR CODE:

1 A 1 a
1 A 1 b
1 A 1 c
1 A 2 a-f
1 A 4 a
1 A 4 b i
1 A 4 c i

The emission factors for these activities are actually contained in Chapters B111 and B112.

For particulate matter emissions please see chapter B111 (S3) Particulate emissions from gas turbines and internal combustion engines[1].

1 RELEASE VERSION, DATE AND SOURCE

Version: 3
Date: September 2006

Source: Carlo Trozzi
Techne Consulting
Italy

2 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Carlo Trozzi
Techne Consulting
Via G. Ricci Curbastro, 34

---

[1] Updated with particulate matter details by: Mike Woodfield, AEA Technology, UK, December 2006

Roma, Italy

Tel: +39 065580993
Fax: +39 065581848
Email: carlo.trozzi@techne-consulting.com

SNAP CODE : **030106**

SOURCE ACTIVITY TITLE: **COMBUSTION IN BOILERS, GAS TURBINES & STATIONARY ENGINES**
Other Stationary Equipments

NOSE CODE:

NFR CODE: **1 A 2 a-f**

The chapter B216 covers emissions from small combustion installations, excluding industrial sources, with a thermal capacity ≤ 50 MWth. However, some industrial sources of a lower capacity might have very similar emission characteristics to the ones described them in the category "medium size boilers". As long as there is no complete guidebook chapter addressing small industrial sources the data presented in chapter B216 might be used also as defaults for these sources.

1. RELEASE VERSION, DATE AND SOURCE

Version: 2
Date: September 2006

Source: Carlo Trozzi
Techne Consulting
Italy

2. POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Carlo Trozzi
Techne Consulting
Via G. Ricci Curbastro, 34
Roma, Italy

Tel: +39 065580993
Fax: +39 065581848
Email: carlo.trozzi@techne-consulting.com

SNAP CODE: **030203**

SOURCE ACTIVITY TITLE: **PROCESS FURNACES WITHOUT CONTACT**
Blast Furnaces Cowpers

NOSE CODE: **104.12.01**

NFR CODE: **1 A 2 a**

ISIC: **2410**

1 ACTIVITIES INCLUDED

This chapter covers emissions released from the industrial combustion of blast furnace gas in cowpers (cupolas or hot stoves).

Other emissions of blast furnaces are covered by the following SNAP-codes of the category "Processes in Iron and Steel Industries and Collieries".

- Blast furnace charging	SNAP code 040202, see chapter B422
- Pig iron tapping	SNAP code 040203, see chapter B423

Figure 1 gives a key plan of a blast furnace process including a blast furnace cowper.

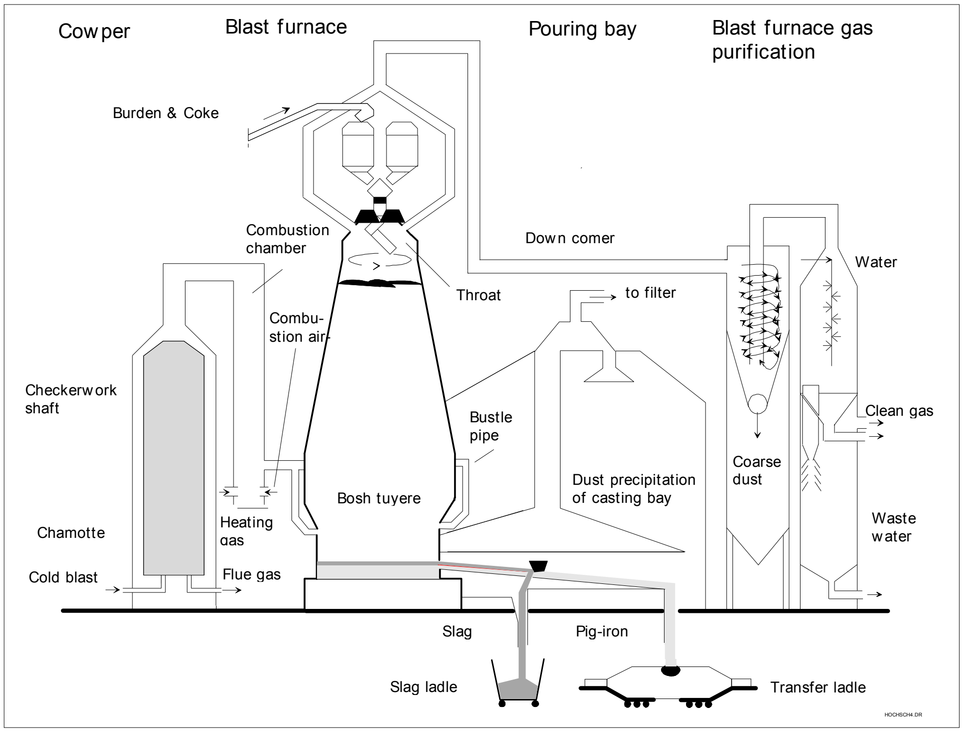


Figure 1: Flow diagram of the blast furnace process /cf. 9/

2 CONTRIBUTION TO TOTAL EMISSIONS

The contribution of emissions released from blast furnace cowpers to total emissions in countries of the CORINAIR'90 inventory is given as follows:

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**										
Blast Furnaces Cowpers	030203	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Typical contribution		0.1	0.2	0	0	1.6	1.3	0.1	-	0.092	0.171	0.201
Highest value										0.235	0.413	0.444
Lowest value										0.005	0.012	0.020

* for total blast furnace process (cowpers, charging and tapping), EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
\- = no emissions are reported

3 GENERAL

3.1 Description

Here, the blast furnace is described as a whole in order to understand the role of the blast furnace cowpers or hot stove within the overall process[1]. Detailed information concerning emissions other than from blast furnace cowpers is given in chapters B422 and B423.

The blast furnace operates as a countercurrent process. Iron ore sinter and size-graded iron ore, coke and limestone are charged as necessary into the top of the furnace. Preheated air is introduced through a large number of water-cooled nozzles at the bottom of the furnace (tuyeres) and passes through the descending charge. Carbon monoxide is produced, which reacts with the heated charge to form molten high-carbon iron, slag and blast furnace gas. /2, 7/ The molten iron and slag are periodically discharged from tap holes.

3.2 Definitions

Blast furnace	refractory-lined shaft furnace. The ore and the preheated air (coming from the cowper) are charged countercurrently (see also section 3.3). In a blast furnace the iron ore is reduced to pig iron by using the reaction of coke (coming from the coke oven plant) and oxygen as energy source, producing CO as reduction agent (for further details see chapters B422 and B423).
Cowpers	process unit, which is fired by blast furnace gas for indirect preheating of air.

3.3 Techniques

Blast furnace gas (off-gas) released at the top of the furnace is collected and is used as fuel for the cowpers. Typical fuels used for the cowpers are natural gas, coke oven gas and blast furnace gas. But also liquid fuels can be used which require different types of burner. In some countries (e.g. Sweden) a blend of coke oven and blast furnace gas is used as fuel /5/.

In order to facilitate the combustion of blast furnace gas, dust removal is necessary. In most cases a cyclone and a one or two-stage cleaning device are installed. The primary cleaner is normally a wet scrubber which removes 90 % of the particulates. The secondary cleaner is normally a high-energy wet scrubber (usually a venturi) or an electrostatic precipitator. Cleaned blast furnace gas contains less than 0.05 g/m^3 of particulates. /2, 3/

3.4 Emissions

Blast furnace gas contains about 21 - 28 % CO, inert components (50 % N_2, 23 % CO_2), some sulphur compounds and high amounts of dust (from iron ore, sinter and coke) /cf. 7, 8/. CO_2 originates from the complete oxidation of carbon in the blast furnace. Some blast furnace cowpers use a blend of blast furnace gas and alternative fuels. The most common alternative is coke oven gas, but also natural gas can be used.

---

[1] For a more detailed explanation of the functioning of cowpers see the chapter 7.1.2 on hot stoves in the BREF on Production of Iron and Steel production.

Relevant pollutants are carbon monoxide (CO) and carbon dioxide (CO_2). Sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and CH_4) and nitrous oxide (N_2O) are of less relevance. Emissions of dust which may contain heavy metals, are also of relevance /cf. 3/. Emissions of ammonia (NH_3) are not relevant. Emissions of carbon monoxide (CO) occur due to incomplete combustion of blast furnace gas components.

3.5 Controls

Due to the low relevance of SO_2 and NO_x emissions, reduction measures for these pollutants are normally not installed.

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[2]:

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (A) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The annual emission is determined according to Equation (1) by an activity and an emission factor:

$$E_i = EF_i \cdot A \tag{1}$$

E_i annual emission of pollutant i
EF_i emission factor of pollutant i

---

[2] The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

A activity

The activity A and the emission factor EF_i have to be determined on the same level of aggregation by using available data. The CORINAIR90 methodology requires for blast furnace cowpers activity data, which is related to fuel consumption in [GJ/a].

Here, it is assumed, that the required activity data (according to CORINAIR90) are not available (see Equation (1)). In practice, statistics (see also Section 6), which often provides only the production of pig iron in [Mg/a], have to be used.

In order to approximate activity data referring to the energy input into blast furnace cowpers in [GJ/a] the specific blast furnace gas consumption and the lower heating value have to be taken into account as given e.g. in Equation (2):

$$A_{COR} = F \cdot H_u \cdot A_{Stat} \qquad (2)$$

A_{COR} activity in CORINAIR-compatible unit (energy input [GJ])
F specific blast furnace gas consumption (blast furnace gas/pig iron produced [m^3/Mg pig iron])
H_u lower heating value of coke oven gas [GJ/m^3]
A_{stat} activity directly obtained from statistics (pig iron production [Mg])

For the determination of the energy input only the gas consumption by the blast furnace cowpers has to be taken into account. The production of blast furnace gas can be given as about 1,300 to 2,000 m^3/Mg crude steel. About 25 % of the blast furnace gas obtained is used for the cowpers /4/. Country specific conditions have to be taken into account, e.g. one of the two Swedish iron and steel plants uses 46 % of the blast furnace gas produced and 18 % of the coke oven gas produced for combustion in cowpers /5/. Blast furnace gas has a lower heating value of about 2,790 to 3,350 kJ/m^3 /2/.

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8.1.

5 Detailed methodology

The detailed methodology (equivalent to Tier 3), to estimate emissions of gaseous pollutants from the cowpers is based on measurements or estimations using plant specific emission factors .

Here, CORINAIR90 compatible activity data for blast furnace cowpers (related to the type of fuel consumed in [GJ/a]) are directly available (Equation (1)).

Guidance on determining plant specific emission factors is given in the Measurement Protocol Annex.

5.1 Emission factors

Emission factors for SO_2, NO_x, NMVOC and CH_4, CO, CO_2, and N_2O in mass pollutant/mass product [g/Mg] and in mass pollutant/energy input [g/GJ] are given in Table 8.1 (see Section 8) based on literature data.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of pig iron, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics.

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities of pig iron produced by various types of industrial technologies employed in the blast furnace process at plant level. This data is however not always easily available.

Statistics concerning the fuel consumption of blast furnace cowpers are not available.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

Integrated iron and steel plants with a production capacity of more than 3 million Mg/a have to be treated as point sources according to the CORINAIR90 methodology. Blast furnace cowpers included in these integrated iron and steel plants have to be considered as parts of the point source.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

The following Table 8.1 contains emission factors for blast furnace cowpers. Blast furnace cowpers are mostly fired by blast furnace gas; other types of fuel, which have been reported in CORINAIR90, are given in footnotes. A blend of blast furnace gas and coke oven gas is not taken into account.

Table 8.1: Emission factors for blast furnace cowpers

Type of fuel$^{1)}$			NAPFUE code	Emission factors						
				SO_2 [g/GJ]	NO_x [g/GJ]	NMVOC$^{4)}$ [g/GJ]	$CH_4$$^{4)}$ [g/GJ]	CO$^{5)}$ [g/GJ]	$CO_2$$^{3)}$ [kg/GJ]	N_2O [g/GJ]
g	gas	natural	301	0.5 - 8$^{2)}$	15 - 50$^{2)}$	2.5 - 5$^{2)}$	2.5 - 5$^{2)}$	10 - 200$^{2)}$	55 - 56$^{2)}$	1.5 - 3$^{2)}$
g	gas	coke oven	304	12 - 25$^{2)}$	15 - 146$^{2)}$	2.5 - 6.2$^{2)}$	2.5 - 112$^{2)}$	10 - 70$^{2))}$	42 - 46$^{2)}$	1 - 3$^{2)}$
g	gas	blast furnace	305	0.93 - 56$^{2)}$	13 - 145$^{2)}$	5 - 6.2$^{2)}$	112$^{2)}$	10 - 69$^{2)}$	100 - 290$^{2)}$	1 - 3$^{2))}$

$^{1)}$ The following fuels have been reported within CORINAIR90, but it can be assumed, that their relevance is very low:

sub-bituminous coal: NAPFUE 103; NMVOC 10; CH_4 10; CO 15; N_2O 12 [g/GJ]$^{2)}$

coke oven coal: NAPFUE 107; NO_x 141; NMVOC 2; CH_4 0.03; CO 120; CO_2 15 10^3-108 10^3; N_2O 3 [g/GJ]$^{2)}$

residual oil: NAPFUE 203; SO_2 223-305; NO_x 112-521; NMVOC 3; CH_4 3-112; CO 13-15; CO_2 76 10^3 -78 10^3; N_2O 2.8-14 [g/GJ]$^{2)}$

gas oil: : NAPFUE 204; NMVOC 2.5-6.2; CH_4 2.5; CO 12; CO_2 74 10^3; N_2O 14 [g/GJ]$^{2)}$

$^{2)}$ CORINAIR90 data

$^{3)}$ CO_2: 367 - 385 kg/Mg pig iron: conventional blast furnace (1989) /6/

$^{4)}$ VOC: 198 g/Mg iron: conventional blast furnace, average /6/

$^{5)}$ CO: 640 - 5,023 g/Mg product: conventional blast furnace process (1989) /6/

Particulate matter emissions from the hot stoves total less than 10 mg/Nm3. This is equivalent to approximately 3-6 g/t pig iron produced (10). No information is available on particle size distribution; ‘expert judgement’ would be to assume all PM is $PM_{2.5}$ (that is use PM factor for TSP, PM10 and $PM_{2.5}$ and is consistent with chapter B111 on gas-fired combustion sources,

For emission factors on particulate matter (TSP, PM_{10} and $PM_{2.5}$) from CEPMEIP (11) from the whole blast furnace operation see chapters 422 on blast furnace charging and 423 on pig iron tapping.

9 SPECIES PROFILES

Species profiles for oxides of sulphur and nitrogen are comparable to those released from combustion installations. Details can be found in chapter B111 “Combustion Plants as Point Sources” (Section 9).

10 UNCERTAINTY ESTIMATES

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Weakest aspects discussed here are related to emission factors and activities.

At this stage emission factors are only applicable when using 100 % blast furnace gas. Further work should be invested toward providing activity data for a representative split of the fuel gases used and in providing corresponding emission factors e.g. for a blend of blast furnace and coke oven gas. CORINAIR90 data can only be used in order to give a range of emission factors.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Not applicable.

13 TEMPORAL DISAGGREGATION CRITERIA

Temporal disaggregation of annual emission data (top-down approach) would provide a split into monthly, weekly, daily and/or hourly emission data. Temporal disaggregation of annual emissions released from blast furnace cowpers can be obtained by taking into account the

- time of operation, and
- variation of load depending on the demand for iron and steel.

Data for the annual time of operation in iron and steel plants should take into account that

- iron and steel plants produce during the whole year and blast furnace gas is continuously released.

Data for the variation in the demand for iron and steel can only be obtained directly from plant operators.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

No supplementary documents.

16 VERIFICATION PROCEDURES

As outlined in the chapter on “Concepts for Emission Inventory Verification” different verification procedures can be recommended. Verification procedures considered here are principally based on the verification of emission data on a national level and on a plant level.

Emission data for blast furnace cowpers can be verified on territorial unit level (e.g. national level) by comparing the annual emissions related to a territorial unit to independently derived emission estimates (e.g. obtained by using population equivalents). Another possibility is the use of emission density comparisons of e.g. emissions per capita or emissions per GDP between countries with comparable economic structures.

Verification on a plant level takes into account e.g. the number of blast furnace cowpers within the iron and steel plants considered. The verification on a plant level relies on comparisons between calculated emissions/emission factors and those derived from emission measurements.

17 REFERENCES

/1/ CITEPA (ed.): CORINAIR - Emission Factor Handbook; Paris; 1992

/2/ US-EPA (ed.): Compilation of the Pollutant Emission Fraction; Version 1; Stationary Point and Area Sources; 1986; AIR CHIEF Version 2.0 Beta; 1992

/3/ Economic Commission of Europe (ed.): Task Force on Heavy Metals Emissions; State-of-the-Art Report; Prague; 1994

/4/ Krumm, Wolfgang: Mathematische Modellierung und Optimierung der Energieverteilung im integrierten Hüttenwerk; in: Energieerzeugung VDI; Düsseldorf (Germany); 1989

/5/ Ms. Froste, Mr. Kvist, Mr. Lannerblom: Personal communication; 1995

/6/ Annema, J. A.; Albers, R. A. W.; Boulan, R. P.: Productie van Primair Ijzer en Staal; RIVM-report 736301131; RIZA-report 92.003/31; 1992

/7/ Parker, Albert (ed.): Industrial Air Pollution Handbook; Maidenhead (England); 1978

/8/ Havenaar, P.; Santen, D. J.; Verrier, K.: Blast furnace gas fired co-generation plant; in: Combustion Technology 1994, VGB Technische Vereinigung der Großkraftwerkbetreiber e.V. (ed.), Essen (Germany); 1994

/9/ Rentz, O.; Püchert, H.; Penkuhn, T.; Spengler, T.: Produktionsintegriertes Stoffstrommanagement in der Eisen- und Stahlindustrie; Konkretisierung des § 5 Abs. 1 Nr.3 BImSchG; Umweltbundesamt Berlin (ed.); Deutsch-Französisches Insitut für Umweltforschung; Karlsruhe; 1995 (to be published)

/10/ IPPC Best Available Techniques Reference Document on the Production of Iron and Steel, December 2001, http://eippcb.jrc.es

/11/ Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

No additional documents.

19 RELEASE VERSION; DATE AND SOURCE

Version: 2.1

Date: December 1995

Source: Otto Rentz, Dagmar Oertel
University of Karlsruhe (TH)
Germany

Updated with emission factors (CEPMEIP) for particulates by:
Tinus Pulles and Wilfred Appelman
TNO
The Netherlands
June 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Ute Karl

French-German Institute for Environmental Research
University of Karlsruhe
Hertzstr 16
D-76187 Karlsruhe
Germany

Tel: +49 721 608 4590
Fax: +49 721 75 89 09
Email: ute.karl@wiwi.uni-karlsruhe.de

SNAP CODE: **030204**

SOURCE ACTIVITY TITLE : **PROCESS FURNACES WITHOUT CONTACT**
Plaster Furnaces

NOSE CODE: **104.11.01**

NFR CODE: **1 A 2 f**

ISIC: **2394**

1 ACTIVITIES INCLUDED

This chapter covers emissions released from plaster furnaces as part of the production of plaster, depending on the technology applied (see Section 3.3).

Basic steps of a typical gypsum manufacturing process, producing crude gypsum, is shown as an example in Figure 1. In this process gypsum is crushed, dried, ground, and calcined.

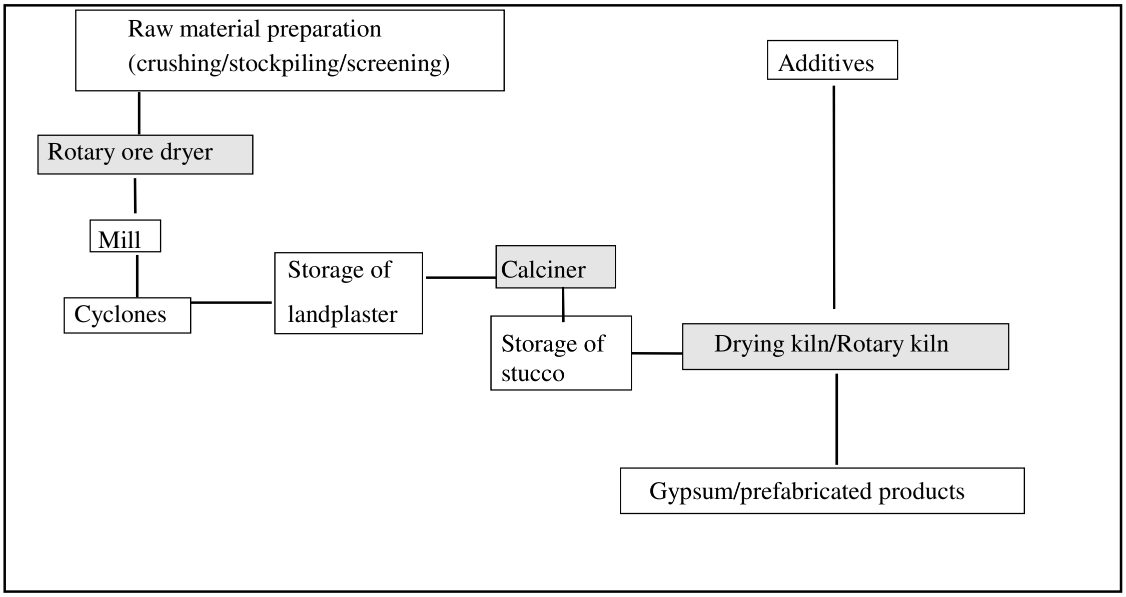


Figure 1: Basic steps of gypsum manufacturing process

Only combustion emissions are considered in this chapter (marked process steps in Figure 1).

2 CONTRIBUTION TO TOTAL EMISSIONS

The contribution of emissions released from plaster furnaces to the total emissions of the CORINAIR90 inventory is given as follows.

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**										
Plaster Furnaces	030204	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Typical contribution		0	0	-	-	0	0	0.1	-	0.050	0.046	0.021
Highest value										0.201	0.179	0.079
Lowest value										0.004	0.003	0.001

* EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
= no emissions are reported

3 GENERAL

3.1 Description

Gypsum (calcium sulphate dihydrate $CaSO_4 \cdot 2\ H_2O$) is a naturally occurring mineral which is processed into a variety of products such as a Portland cement additive, soil conditioner, industrial and building plasters or gypsum wallboard /1/.

Gypsum ore, from quarries and underground mines, is crushed and stockpiled near a plant. As needed, the stockpiled ore is further crushed and screened. If the moisture content of the mined ore is greater than about 0.5 wt.-%, the ore must be dried in a rotary dryer or a heated roller mill. Ore dried in a rotary dryer is conveyed to a roller mill. The ground gypsum leaves the mill in a gas stream and is collected in a product cyclone. Ore is sometimes dried in the roller mill by heating the gas stream, so that drying and grinding are accomplished simultaneously and no rotary dryer is needed. The finely ground gypsum ore is known as landplaster, which may also be used as a soil conditioner. /3/

3.2 Definitions

Plaster, gypsum	These expressions are often used synonymously. In this chapter plaster is used for dehydrated landplaster (produced at lower temperatures of ca. 200 °C) and gypsum is used for calcinated landplaster (produced at higher temperatures of ca. 900 °C).

3.3 Techniques

In order to obtain boiled plaster (calcium sulphate semihydrate $CaSO_4 \cdot \frac{1}{2}\ H_2O$), the gypsum ($CaSO_4 \cdot 2\ H_2O$) must be partially dehydrated at a temperature of about 120 °C. After further dehydration of the boiled plaster at a temperature of about 200 °C, stucco is obtained. Then after calcination at a temperature of about 1,300 °C building plaster is formed.

Two different combustion techniques are used: kettle calciners (combustion without contact between product and flue gas), and rotary kilns (combustion with contact between product and flue gas). In practice, plaster is obtained by dry processing in kettle calciners at a temperature of about 120 to 180 °C. α-Gypsum is also obtained by dry processing mostly within directly fired rotary kilns at a temperature of about 300 - 900 °C.

Normally, plaster is fed to kettle calciners or flash calciners, where it is heated to remove three-quarters of the chemically bound water to form stucco. Calcination occurs at approximately 120 to 150 °C and 1 Mg of gypsum calcines to about 0.85 Mg of stucco. /1/
In kettle calciners, the plaster or the gypsum is indirectly heated by hot combustion gas passed through flues in the kettle and the stucco product is discharged into a "hot pit" located below the kettle. Kettle calciners may be operated in either batch mode or continuous mode. In flash calciners, the plaster or the gypsum is in direct contact with hot gases and the stucco product is collected at the bottom of the calciner. /1/

Some plants use residual fuel oil, but the majority uses clean fuels such as natural gas or distillate fuel oil. /3/ For the heating of rotary kilns shell burners are installed which are fed by gas or oil.

3.4 Emissions

Particulate matter is the dominant pollutant in gypsum processing plants; combustion sources emit mainly gaseous pollutants. Here only emissions released from plaster furnaces are considered.

Relevant pollutants are sulphur oxides (SO_x), nitrogen oxides (NO_x) and carbon dioxide (CO_2). Emissions of volatile organic compounds (non-methane VOC and methane (CH_4)), carbon monoxide (CO) and ammonia (NH_3) are of less relevance. Normally, emissions of nitrous oxide (N_2O) are not relevant[1]. Emissions of heavy metals are of less relevance.

Emissions of sulphur dioxide (SO_2) in the flue gas of plaster furnaces depend on the sulphur content of the fuel used and are mostly relevant for the production of calcinated plaster. For the case of combustion with contact in rotary kilns a sulphur retention of SO_2 occur at higher temperatures.

The formation of nitrogen oxides (NO_x) can be split into "fuel-NO", "thermal-NO" and "prompt-NO" as discussed in the chapter "Combustion Plants as Point Sources" (Section 3). For the production of gypsum the dominating NO_x formation mechanism mainly depends on the operation temperature.

Emissions of heavy metals depend on the type of fuel used and are only relevant when using heavy fuel oil. Most heavy metals (As, Cd, Cr, Cu, Ni, Pb, Zn, V) are normally released as compounds (e.g. as chlorides) in association with particulates (see also chapter B111 on "Combustion Plants as Point Sources" (Section 9). In the case of combustion with contact in

---

[1] The amount of N_2O reported in CORINAIR90 (see Table 1) is considered to be too high.

rotary kilns the intake by the feed material has to be considered too, but also a heavy metal retention in the raw material occurs.

3.5 Controls

SO_2 emissions of plaster furnaces are only controlled by the use of low sulphur fuels (e.g. switch from oil to gaseous fuels containing less sulphur).

For the control of NO_x emissions from plaster furnaces only primary measures are relevant (e.g. optimisation of furnace conditions and/or burners).

For the control of particulate matter fabric filters are often used. Electrostatic precipitators (ESP) are installed at rotary ore dryers, roller mills, kettle calciners and conveying systems. Although rotary ore dryers may be controlled separately, emissions from roller mills and conveying systems are usually controlled jointly with kettle calciner emissions. Moisture in the kettle calciner exit gas improves the ESP performance by lowering the resistivity of the dust. /cf. 3/

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[2]:

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

---

[2] The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

Emission = AR x EF

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tiers 3), to estimate emissions of gaseous pollutants from the gypsum production is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

Emission factors for the pollutants SO_2, NO_x, NMVOC, CH_4, CO, CO_2 and N_2O are given in Table 8.1 (see Section 8) based on literature data depending on the type of fuel used. Emission factors related to the product are given in footnotes.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of gypsum, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics.

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities of gypsum produced by various types of industrial technologies employed in the gypsum industry at plant level. This data is however not always easily available.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 "Choice of activity statistics".

7 POINT SOURCE CRITERIA

Plaster furnaces should be considered as area sources. Gypsum plants are considered as point source according to the CORINAIR90 methodology, only if the whole plant emits more than 1,000 Mg/year of SO_2, NO_x, NMVOC or NH_3. In this case, plaster furnaces within a gypsum plant have to be reported collectively as part of a gypsum plant.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

The following Table 8.1 contains emission factors for the relevant pollutants based on literature data. Oil and gas are mainly used as fuels, but in several plants solid fuels are burned.

Table 8.1: Emission factors for plaster furnaces

Type of fuel				NAPFUE code	Emission factors						
					SO_2 [g/GJ]	NO_x[5] [g/GJ]	NMVOC[6] [g/GJ]	CH_4 [g/GJ]	CO [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]
s	coal	hc	sub-bituminous	102	680[3]	249[3]	15[3]	15[3]	79[3]	98[3]	14[3]
s	coal	hc	coke oven coal	107	0.4 - 436[3]	0.3 - 249[3]	15[3]	15[3]	22 - 1,534[3]	105[3]	14[3]
s	coke		petroleum	110	275[3]	249[3]	1.5[3]	1.5[3]	79[3]	97[3]	14[3]
s	biomass		wood	111	5.2[3]	249[3]	48[3]	32[3]	1,429[3]	92[3]	4[3]
l	oil		residual	203	1,260 - 1,323[3]	150 - 249[3]	3[3]	3[3]	79[3]	76[3]	14[3]
l	oil		gas	204	305[3]	249[3]	1.5[3]	1.5[3]	79[3]	73[3]	14[3]
g	gas		natural	301	[4]	249[3]	4[3]	4[3]	83[3]	55[3]	3[3]
-	not specified		-	-		800-1,400[1][2] g/Mg product					

[1] EPA /2/

[2] 800 g/Mg for rotary ore dryer, 1,400 g/Mg for continuous kettle calciner and flash calciner

[3] CORINAIR90 data

[4]	SO_x	9,611	g/Mm^3 fuel	Mineral products, process heaters (NAPFUE 301) /2/
[5]	NO_x	800	g/Mg product	Gypsum, rotary ore dryer /2/
		1,400	g/Mg product	Gypsum, continuous kettle calciner and flash calciner /2/
[6]	VOC	2	g/Mg product	Gypsum, rotary ore dryer, (NAPFUE 301) /2/
		10	g/Mg product	Gypsum, continuous kettle calciner and flash calciner (NAPFUE 301) /2/
		33.6	g/m^3 fuel	Mineral products, process heaters, (NAPFUE 203) /2/

The following Table 8.2 contains emission factors for particulates for gypsum production, derived from the CEPMEIP database (4).

Table 8.2: Emission factors for gypsum production; whole process, including plaster furnaces (CEPMEIP)

Abatement	**unit**	**TSP**	**PM10**	**PM2-5**	**Uncertainty-factor**
Control of fugitive emission	kg/ton gypsum	0.05	0.025	0.0075	5
Uncontrolled	kg/ton gypsum	0.1	0.04	0.01	5

NOTE: The uncertainty range (95% confidence) in the emission factor is expressed as a factor. The lower limit of the uncertainty range can be found by dividing the emission factor by the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example (first row in Table 8.2): The uncertainty in the emission factor for $PM_{2.5}$ with control of fugitive eission sources is 5. The emission factor with uncertainty range will therefore be 0.0075 kg gram per tonne gypsum with an uncertainty range of 0.0015 (0.0075 / 5) to 0.0375 (0.0075 x 5).

9 SPECIES PROFILES

For combustion without contact species profiles for oxides of sulphur and nitrogen are comparable to those released from combustion installations. Details can be found in chapter B111 on “Combustion Plants as Point Sources” (Section 9).

10 UNCERTAINTY ESTIMATES

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Weakest aspects discussed here are related to emission factors and activities. CORINAIR90 data can only be used to give a range of emission factors. Further work should be invested to develop emission factors by taking into account technical or fuel dependent parameters.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Spatial disaggregation can be achieved by the relation to the number of industrial employees in industrial areas, the number of plants in the area considered, etc.

13 TEMPORAL DISAGGREGATION CRITERIA

Temporal disaggregation of annual emission data (top-down approach) provides a split into monthly, weekly, daily and/or hourly emission data. Temporal disaggregation of annual emissions released from plaster furnaces can be obtained by taking into account the

- time of operation and
- variation of load.

Data for the annual time of operation should take into account, that

- plants produce plaster during the whole year,
- the production of plaster in kettle calciners is a discontinuous process.

The load of a gypsum plant is determined by the variation of production due to varying demand for products. Information concerning the variation in the demand for plaster can only be obtained directly from plant operators.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

No supplementary documents.

16 VERIFICATION PROCEDURES

As outlined in the chapter on “Concepts for Emission Inventory Verification”, different general verification procedures can be recommended. Verification procedures for activity data and emission factors can be related on a national level and on a plant level.

Emission data for plaster furnaces can be verified on a territorial unit level (e.g. national level) by comparing the annual emissions related to a territorial unit to independently derived emission estimates (e.g. obtained by using population equivalents). Another possibility is the use of emission density comparisons of e.g. emissions per capita or emissions per GDP between countries with comparable economic structures.

Verification on a plant level takes into account e.g. the number of plaster furnaces within the plants considered. The verification on a plant level relies on comparisons between calculated emissions/emission factors and those derived from emission measurements.

17 REFERENCES

/1/ US-EPA (ed.): Compilation of Air Pollutant Emission Factors, Vol. 1: Stationary Point and Area Sources, 1985; AIR CHIEF Version 2.0 Beta; 1992

/2/ EPA (ed.): AIRS Facility System, EPA-Document 450/4-90-003; Research Triangle Park; 1990.

/3/ US-EPA (ed.): AP42-CDrom; 1994

/4/ Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

No additional documents.

19 RELEASE VERSION, DATE AND SOURCE

Version: 2.1

Date: December 1995

Source: Otto Rentz, Dagmar Oertel
University of Karlsruhe
Germany

Updated with emission factors (CEPMEIP) for particulates by:
Tinus Pulles and Wilfred Appelman
TNO
The Netherlands

May 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Ute Karl

French-German Institute for Environmental Research
University of Karlsruhe
Hertzstr 16
D-76187 Karlsruhe
Germany

Tel: +49 721 608 4590
Fax: +49 721 75 89 09
Email: ute.karl@wiwi.uni-karlsruhe.de

SNAP CODE: **030205**

SOURCE ACTIVITY TITLE: **PROCESS FURNACES WITHOUT CONTACT**
Other Furnaces

NOSE CODE: **104.01.01**

NFR CODE: **1 A 2 f**

A specific methodology for these activities has not been prepared because the contribution to total national emissions is thought to be currently insignificant, i.e. less than 1% of national emissions of any pollutant.

If you have information contrary to this please contact the expert panel leaders.

These activities are not believed to be a significant source of $PM_{2.5}$ (as of December 2006)

Updated with particulate matter details by:
Mike Woodfield
AEA Technology
UK
December 2006

Leaders of the Combustion and Industry Expert Panel

Jozef Pacyna
NILU - Norwegian Institute of Air Research, PO Box 100, N-2007 Kjeller, Norway
Tel: +47 63 89 8155
Fax: +47 63 89 80 50
Email: jozef.pacyna@nilu.no

Panagiota Dilara
Emissions and Health Unit, Institute for Environment and Sustainability (IES), European Commission, Joint Research Centre, I-21020 Ispra (VA), Italy
Tel: +39 0332 789207
Fax: +39 0332 785869
Email: panagiota.dilara@jrc.it

Pieter van der Most
HIMH-MI-Netherlands, Inspectorate for the Environment, Dept for Monitoring and Information Management, PO Box 30945, 2500 GX Den Haag, The Netherlands
Tel: +31 70 339 4606
Fax: +31 70 339 1988
Email: pieter.vandermost@minvrom.nl

SNAP CODE: **030301**
040209

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Sinter and Pelletizing Plants
Sinter and Pelletizing Plants (Except Combustion 030301)

NOSE CODE: **104.12.02**
105.12.09

NFR CODE: **1 A 2 a**
2 C 1

ISIC: **2410**
2420

1 ACTIVITIES INCLUDED

The sinter process is an ore pre-treatment step in the production of iron, non-ferrous metals and other special materials.

This chapter does not address sinter plants in the non-ferrous metal industry; these plants should be covered by the chapters in SNAP 040300.

With respect to the iron and steel industry, this chapter only addresses travelling grate sintering which is by far the most important technique for iron ore sintering. The discontinuous pan sintering process as well as the rotary kiln process are now used at very few plant and are not discussed here. In addition, other agglomeration processes like pelletisation, briquetting and nodulisation are not considered here.

2 CONTRIBUTION TO TOTAL EMISSION

Table 2.1: Contribution to total emissions of the CORINAIR 90 inventory (*up to 28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%] (including emissions from nature)**										
Sinter Plants		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Typical contribution	030301	1.3	1.0	0.1	0.1	4.9	0.4	-	-	1.82	1.96	2.97
Highest value										5.13	5.37	9.09
Lowest value										0.245	0.234	0.321

* EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

Emissions of heavy metals and POPs from sinter plants are also relevant but limited information is available.

Table 2.2 gives the contribution of sinter plant to total emissions of heavy metals and POPs from the OSPARCOM-HELCOM-UNECE emission inventory. For many heavy metals and POPs, but particularly in the case of PCDD/Fs, contribution to total emission may vary significantly from country to country and could be large (up to 50%).

Sinter plant are unlikely to be a significant source of sulphurhexafluoride (SF_6), hydrofluorocarbons (HFCs) or perfluorocarbons (PFCs), (ETC/AEM-CITEPA-RISOE 1997, ref. 30).

Table 2.2: Contribution to total POP and heavy metal emissions of the OSPARCOM-HELCOM-UNECE emission inventory *(up to 39 countries)*

Source-activity	**SNAP-code**	**Contribution to total emissions (including emissions from nature) [%]**										
		As	Cr	Cu	Pb	Cd	Hg	Ni	Zn	PCBs	PCDD/Fs	PAH
Sinter plant	030301 / 040209	1.0	2.9	2.3	2.8	3.2	1.6	1.2	0.8	0.5	15	0

3 GENERAL

3.1 Description of activities

The sintering process is a pretreatment step in the production of iron where fine particles of metal ores are agglomerated by combustion. Agglomeration of the fine particles is necessary to increase the passageway for the gases during the blast furnace process. The strength of the particles is also increased by agglomeration.

The activities in the sinter plants include:

- treatment of the ores by crushing and sieving;
- mixing of treated ores, coke and flux compounds;
- combustion and agglomeration of a mixture of crushed ores, coke, small sintered agglomerates and flux compounds;
- sieving of the sintered agglomerates;
- cleaning of the combustion off-gases;
- transport and handling operations occurring between the above mentioned activities.

3.2 Definitions

Mixing of the ores	The ores are mixed with residual material, fuel (coke, breeze), and flux compounds. This is necessary for preparing the ore for the sintering process.
Crushing process	The ores are crushed to increase the contact area for the sintering. The sinter cake is crushed to improve the transportation to the furnace blasting process.

Sieving process	The crushed ores are sieved to prevent the ores which require further crushing from entering the sinter process. The crushed sinter cakes are sieved to prevent small sintered particles entering the furnace process.
Sintering process	During sintering ore particles, flux compounds and other material are agglomerated by the combustion of the coke / breeze. The temperature must stay below the melting temperature of the metals in the ores.
Air cleaning process	The air of the combustion and cooling process is cleaned by removing dust and sometimes other pollutants.
Basicity of sinter mixture	Basicity of the mixture may be an important parameter influencing the emissions of SO_2. It is defined by relation of the following compounds (fractions expressed as weight %): basicity = $(CaO + MgO)/(SiO_2 + Al_2O_3)$
POM	Polycyclic organic matter

3.3 Techniques used during the sintering process

The sintering process is used for several primary metal production processes, each having different designs. During sintering, fine-grained, smeltable ores, in particular iron ore, are agglomerated into compact lumps **by heating nearly to the melting or softening point**. Melting tends to occur at the grain boundaries leading to a caking of the material.

Before the sintering, the various substances are first mixed and, if desired, granulated. The iron ores are agglomerated on conveyor sinter installations, the conveyor belts consist of a large number of wagons. These wagons that have been linked up as an endless conveyor belt which can be as big as 4 m in width and 100 m in length. The fine ore to be sintered is moistened and fed on to the circulating grid together with coke breeze and additives such as limestone, quick lime, olivine or dolomite. Burners above a heat-resistant grate belt heat the material to the required temperature (1100-1200 °C). This causes the fuel in the mixture to be ignited. The combustion then is self supporting and provides sufficient heat, 1300 to 1480 °C, to cause surface melting and agglomeration of the mix. The carbon burns with the aid of the air sucked through the grid into the mixture, resulting in the flame front being moved through the sintering bed. On the underside of the sinter strand a series of windboxes is situated that draw combusted air down through the material bed into a common duct, leading to gas cleaning devices (ref. 1). The sintering processes are completed once the flame front has passed through the entire mixed layer and all fuel has been burnt.

The fused sinter is discarded at the end of the sinter strand, where it is crushed and screened. Undersize sinter is recycled to the mixing mill and goes back to the strand. The remaining sinter product is cooled in open air or in a circular cooler with water sprays or mechanical fans. The cooled sinter is crushed and screened for a final time, then the fines are recycled, and the product is sent to the blast furnaces to be charged (ref. 1).

The most common types of sinter coolers used include circular or straight line moving beds, quiescent beds, or shafts. Air or water is used as the cooling medium in these coolers, with air being prevalent in newer plants and water being dominant in older plants (refs. 2, 3).

Technical data which are typical for the plants operating in W-Europe are listed in Table 3.1:

Table 3.1: Range of technical parameters of European sinter plants

Parameter	**Range**	**Ref.**
width [m]	2,5-4,5	(ref. 4)
area [m²]	50-400 (1)	(ref. 4)
specific flue gas flows [m³/t sinter]	1800-2000	(ref. 5)
flue gas flows [million m³/h]	up to 1.5	(ref. 4)
height of sinter layer	ca. 250 -650 mm	(ref. 6)
coke input [kg/ton sinter]	38-55	

(1) some small installations are reported to be in operation in Poland, another one in Germany (sintering of iron containing return and filter materials)

The sinter plant plays a central role in an integrated iron and steel works for making use of production residues which would have to be disposed otherwise. Slags from steel production, filter dusts of diverse flue gas cleaning systems (including those applied to the sinter plant itself) and various iron-containing materials from residue treatment are recycled in the sinter plant. Recycling may lead to an enrichment of relevant compounds, particularly heavy metals. Some residue materials like roll mill scale may be contaminated with organic compounds (oils), being precursors for PAH and PCDD/F formation. An example of input material composition is shown in the Table 3.2 below.

Table 3.2: Example of input material composition to sinter plant

Material	% [(1)]
hematite	81.3
magnetite	2.7
returns	7.9
pellet abrasions	2.2
blast furnace dust	0.3
steel work dust	0.6
roll scale	1.3
limestone	9.4
olivine	3.5
coke breeze	5

[1] related to dry mixture

Chlorine compounds can enter into the sinter installation by means of the additive coke slack as well by the ore from its natural chloride contents. Furthermore, returned materials such as certain filter particles, scale and sludges from waste water treatment, which are added to the materials to be sintered, can also increase the chlorine content of the substances used. This is reflected in the waste gases from sinter installations which contain inorganic gaseous chlorine compounds.

An alternative process is pelletisation, where no combustion is necessary.

By 2010 a new technology called "converted blast furnace" or "melting-reduction technology" is expected to be operational. For this process sintering, pelletisation, and coke input will no longer be necessary (ref. 7).

3.4 Emissions

3.4.1 Emitted compounds

Of the 8 CORINAIR standard gaseous compounds, all except ammonia are known to be emitted by sinter plants.

- SO_2 emissions mostly originate from sulphur contained by the coke used as fuel. Actual emissions may be further dependent on the basicity of the mixture. With CaO dominated mixtures SO_2 production is decreased by increasing basicity. From MgO dominated mixtures about 97% of the sulphur content is converted to SO_2. The major fraction of the total SO_2 emission is generated in the hot part of the sinter belt (near the end), (ref. 5).
- Nitrogen oxides are mainly emitted as NO due to rapid downcooling of the flue gases. NO_X emissions originate from nitrogen contained in coke (ca. 80%) and iron ore (ca. 20%), (ref. 5).
- Raw materials contain heavy metals (HM). Dust emissions are generally associated with HM emission. During the sintering process some of the HM may be volatilised or converted into volatile compounds (e.g. chlorides) and can therefore be found in the flue

gas. This mainly concerns Zn, Pb, and Cd. Arsenic is emitted in gaseous form as As_2O_3, passing the dry gas cleaning facilities which are usually operated at 120 °C. Since these volatile compounds form or adsorb to fine particles which are removed by the gas cleaning facilities, they may be accumulated during the sinter return cycle. Moreover, fine particles passing the filters may have a much higher content of these metals than the raw gas dust or the sinter mixture (ref. 5).

- Polycyclic organic material (POM), eg. PAH and PCDD/F, may be formed from chlorine and precursor compounds like oily additives. Potentially, POM emissions may be released from the sinter machine windbox, from the sinter machine discharge point, and from sinter product processing operations (i.e. crushing, screening, and cooling). Because of the high temperatures used in sintering operations, it is probable that sinter plant POM emissions are in both gaseous and particulate matter forms (refs. 2, 8).
- Emissions of fluorides (sintering of ores recovered in Sweden) and hydrochloric acid (use of seawater moistening or coke treatment) have been observed (ref. 4)

3.4.2 Emission points

At a sinter plant, emissions may occur as (‘direct’) stack emissions and - to a minor degree - as fugitive (‘indirect’) emissions during all process steps mentioned above.

- Ambient air is sucked by several windboxes through the mixture to support the combustion process on the sinter belt. After passage of the belt the flue gases are collected, dedusted and released through the main stack.
- The main process steps (like coke crushing, raw material handling, belt charging and discharging, sintering) are usually done within encapsulated or semi-encapsulated housings. The housings may be equipped with suction hoods connected via flue gas cleaning devices to the main stack or to separate stacks. Thus, there may be more than one stack emission point at a given sinter plant.
- Fugitive dust emissions may arise during handling and transportation of the raw materials and of the cooled sinter as well as during maintenance and accidental interrupts of the cyclones or filters. More important, due to the strong thermal convection in the sinter hall’ fugitive emissions through leakages in the roof are likely to occur particularly at the end of the sinter belt.

3.4.3 Abatement measures

Gaseous compounds
Limited information is available about specific control measures for gaseous emissions. A desulphurisation facility is operated at a German plant (ref. 9). Measures for SO_2 and NOx reduction are known from plants operated in Japan (ref. 4).

Dust
Abatement measures are directed to dust emissions. In principle, reduction of dust emission also leads to reduction of emissions for those compounds being bound to particulates. Sinter strand windbox emissions commonly are controlled by cyclone cleaners followed by a dry or wet electrostatic precipitator (ESP), high pressure drop wet scrubber, or baghouse. Crusher and hot screen emissions are usually controlled by hooding and a baghouse or scrubber.

Usually horizontal dry electrostatic precipitators are used; however, less efficient mechanical dedusting devices (e.g cyclone batteries) might be installed in old sinter plants if only protection of the blower wheel rather than environmental protection is intended. Some sinter plants located in CIS countries are reported to have only this low standard abatement technology, others are equipped with wet venturi washers (ref. 10).

POM
Since being identified as a relevant source of dioxins and furans some sinter plants have been equipped with special abatement technologies (e.g. ‘Airfine-system’, Austria; injection of activated charcoal or open hearth coke in connection with fabric filter) or optimised dedusting facilities (‘MEEP’ = ESP with rotating electrode), (ref. 6).

4 SIMPLER METHODOLOGY

4.1 Calculation of emission

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes (“activity rates”) and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.
Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.
Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

---

[1] The term “Tier” is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

Emission = AR x EF

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8.1.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tiers 3), to estimate emissions of gaseous pollutants from the cement production is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

An extensive measuring programme involving off-gas measurements at all relevant emission points is essential to get a clear picture of the actual emissions. Emission measurements should be performed at least at the main stacks connected to the windboxes of the sinter strand and to the hot crushing / sieving facility. This is particularly important concerning emissions of dioxins and furans since there is no way to date to estimate the emissions from different operating conditions.

Reference emissionfactors for comaprison with users own data are provided in Section 8.2.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of cement, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics. Standard international compilations of production statistics are available from

- EUROSTAT , Brussels (Iron and Steel, Yearly statistics, Theme 4, Series C);
- the International Iron and Steel Institute , Brussels;
- Wirtschaftsvereinigung Stahl, PO Box 10 54 64, 40045 Düsseldorf, Germany (Statistical Yearbook Iron and Steel Industry);
- National Statistical Yearbooks.

More details of these example data sources for activity statistics are given in Section 17 (References).

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities produced by various types of industrial technologies employed in industry at plant level. This data is however not always easily available.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

Sinter plants usually are part of large integrated iron and steel plants connected to high chimneys (> 100 m), and should be regarded as point sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Default emission factors for iron ore sinter plants - simple methodology

Table 8.1a: Emission factors for iron ore sinter plants

Pollutant	Emission factor	Units
Particulate matter Total suspended particulate	2	kg/t sinter
PM_{10}	0.8	kg/t sinter
$PM_{2.5}$	0.5	kg/t sinter
Arsenic	0.05	g/t sinter
Cadmium	0.08	g/t sinter
Chromium	0.5	g/t sinter
Copper	0.7	g/t sinter
Mercury	0.05	g/t sinter
Nickel	0.24	g/t sinter
Lead	4	g/t sinter
Selenium	0.02	g/t sinter
Zinc	0.9	g/t sinter
Dioxins and furans	15	µgTEQ/t sinter
Hexachlorobenzene	32	µg/t sinter
Polychlorinated biphenyls	200	µg/t sinter
Polyaromatic hydrocarbons	200	mg/t sinter

8.2 Emission Factors for Use With Detailed Methodology

This section provides reference emission factors for comparison with users own data.

The following emission factors are given in ref. 28 as recommended values for emission estimation concerning the compounds covered by the Corinair '90 inventory; they are based on the results reported by different sources in Western Europe and the U.S.A. (Annex 1); Emission factors reported for other sinter processes, other countries and additional compounds are given in Annex 1.

Since no assessment of uncertainty is given, data quality rating is generally assumed to be C.
N.B. It is assumed that the emission factors given in the following table were derived originally by relating the entire emission of a pollutant within a time period to the typical input of the mentioned fuels within the same time period, regardless of whether combustion of the fuel really causes any emission of the pollutant. While this procedure leads to chemically inconsistent emission factors it still enables the rough calculation of the entire emission of a plant when just knowing the input amount of one of the fuels used.

Table 8.2a: Emission factors for gaseous compounds

Compound	**Emission factor**	**Abatement type**	**Abatement efficiency**	**Fuel type (NAPFUE code)**
	[mg/GJ]		[%]	
SO_x	499	Uncontrolled	N/A	Coke breeze (107)
	658	Uncontrolled	N/A	Heating oil heavy (203)
	1410	Uncontrolled	N/A	heating oil light (204)
	4680	Uncontrolled	N/A	natural gas (301)
	5490	Uncontrolled	N/A	coke oven gas (304)
	8600	Uncontrolled	N/A	blast furnace gas (305)
		plus scrubber	90	all fuels
NO_x	500	Uncontrolled	N/A	Coke breeze (107)
	134	Uncontrolled	N/A	Heating oil heavy (203)
	100	Uncontrolled	N/A	heating oil light (204)
	530	Uncontrolled	N/A	natural gas (301)
	2350	Uncontrolled	N/A	coke oven gas (304)
	8050	Uncontrolled	N/A	blast furnace gas (305)
		low NOx technology	30	all fuels
		secondary measures (SCR)	70	all fuels
MMVOC	50	uncontrolled or with controls for SO_x and/or NO_x only	N/A	Coke breeze (107)
	5	uncontrolled or with controls for SO_x and/or NO_x only	N/A	Heating oil heavy (203)
	1.5	uncontrolled or with controls for SO_x and/or NO_x only	N/A	heating oil light (204)
	14	uncontrolled or with controls for SO_x and/or NO_x only	N/A	natural gas (301)
	26	uncontrolled or with controls for SO_x and/or NO_x only	N/A	coke oven gas (304)
	0.25	uncontrolled or with controls for SO_x and/or NO_x only	N/A	blast furnace gas (305)
CH_4	50	uncontrolled or with controls for SO_x	N/A	Coke breeze (107)

Compound	**Emission factor**	**Abatement type**	**Abatement efficiency**	**Fuel type (NAPFUE code)**
	[mg/GJ]		[%]	
		and/or NO_x only		
	4	uncontrolled or with controls for SO_x and/or NO_x only	N/A	Heating oil heavy (203)
	1.5	uncontrolled or with controls for SO_x and/or NO_x only	N/A	heating oil light (204)
	14	uncontrolled or with controls for SO_x and/or NO_x only	N/A	natural gas (301)
	257	uncontrolled or with controls for SO_x and/or NO_x only	N/A	coke oven gas (304)
	257	uncontrolled or with controls for SO_x and/or NO_x only	N/A	blast furnace gas (305)

N/A = not applicable, Data Quality = C

Table 8.2a: (continued) Emission factors for gaseous compounds

Compound	**Emission factor**	**Abatement type**	**Abatement efficiency**	**Fuel type (NAPFUE code)**
	[mg/GJ]		[%]	
CO	10500	uncontrolled or with controls for SOx and/or NOx only	N/A	Coke breeze (107)
	14	uncontrolled or with controls for SOx and/or NOx only	N/A	Heating oil heavy (203)
	13	uncontrolled or with controls for SOx and/or NOx only	N/A	heating oil light (204)
	2160	uncontrolled or with controls for SOx and/or NOx only	N/A	natural gas (301)
	35000	uncontrolled or with controls for SOx and/or NOx only	N/A	coke oven gas (304)
	84000	uncontrolled or with controls for SOx and/or NOx only	N/A	blast furnace gas (305)
	109000	uncontrolled or with controls for SOx and/or NOx only	N/A	Coke breeze (107)
	78000	uncontrolled or with controls for SOx and/or NOx only	N/A	Heating oil heavy (203)
	74000	uncontrolled or with controls for SOx and/or NOx only	N/A	heating oil light (204)
	55500	uncontrolled or with controls for SOx and/or NOx only	N/A	natural gas (301)
	46000	uncontrolled or with controls for SOx and/or NOx only	N/A	coke oven gas (304)
	200000	uncontrolled or with controls for SOx and/or NOx only	N/A	blast furnace gas (305)
	4	uncontrolled or with controls for SOx and/or NOx only	N/A	Coke breeze (107)
	10	uncontrolled or with controls for SOx and/or NOx only	N/A	Heating oil heavy (203)
	12	uncontrolled or with controls for SOx and/or NOx only	N/A	heating oil light (204)
	3	uncontrolled or with controls for SOx and/or NOx only	N/A	natural gas (301)
	2.3	uncontrolled or with controls for SOx and/or NOx only	N/A	coke oven gas (304)
	3	uncontrolled or with controls for SOx and/or NOx only	N/A	blast furnace gas (305)

N/A = not applicable

Data Quality = C

Table 8.2b: Emission factors for dust

Process	Emission factor [kg dust/ Mg sinter]	Data quality	Abatement type	Abatement efficiency	Country	Ref
Sintering	4	C	Unabated	0	D	ref. 5
Cooling	3.5	C	Unabated	0	D	ref. 5
Sintering	14	E	Cyclones	60-70 %	CIS	ref. 29
Cooling	3	E	Cyclones	60-70 %	CIS	ref. 29
Sintering	0.3	C	ESP	>90 %	EU	ref. 16
Cooling	0.05	C	multi cyclone,	>90 %	EU	ref. 16
Handling	0.1	D	ESP, bag filters	> 90 %	EU	ref. 16
crushing, blending, sintering	0.25	D	“after abatement”	N/A	EU	ref. 31
Cooling	0.2	D	Cyclones	N/A	EU	ref. 31
Cooling	0.06	D	bag filters	N/A	EU	ref. 31
Windbox	5.56	B	Uncontrolled	N/A	US	ref. 1
Windbox	4.35	A	Uncontrolled (after coarse particles removal)	N/A	US	ref. 1
Windbox	0.8	B	ESP (dry)	N/A	US	ref. 1
Windbox	0.085	B	ESP (wet)	N/A	US	ref. 1
Windbox	0.235	B	Venturi scrubber	N/A	US	ref. 1
Windbox	0.5	B	Cyclone	N/A	US	ref. 1
Sinter discharge	3.4	B	Uncontrolled	N/A	US	ref. 1
Sinter discharge	0.05	B	Baghouse	N/A	US	ref. 1
Sinter discharge	0.295	A	Venturi scrubber	N/A	US	ref. 1
windbox and discharge	0.15	A	Baghouse	N/A	US	ref. 1

Table 8.2b: (continued) Emission factors for dust / particulate matter (CEPMEIP)

Process type	**Abatement**	**Unit**	**TSP**	**PM_{10}**	**$PM_{2.5}$**	**Uncertainty**
Agglomeration plants: sinter	(multi-) Cyclone control only	kg/ton sinter	2	0.8	0.5	2
Agglomeration plants: sinter	Conventional installation with ESP	kg/ton sinter	0.6	0.3	0.25	2
Agglomeration plants: sinter	Fabric filter, high efficiency wet scrubbing or high efficiency ESP BAT	kg/ton sinter	0.2	0.1	0.1	2

NOTE: The uncertainty range (95% confidence) in the emission factor is expressed as a factor. The lower limit of the uncertainty range can be found by dividing the emission factor by the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example (first row in table): The uncertainty in the emission factor for $PM_{2.5}$ from an plant with multicyclone only is 0.5 kg/ton sinter. The emission factor with uncertainty range will therefore be 0.5 kg per tonne sinter with an uncertainty range of 0.25 (0.5/2) to 1 (0.5x2).

8.2c Heavy metal emission

The following factors are based on the emission factors shown in Annex 1. They may be applied to estimate emissions from sinter plants in the western European countries that are commonly equipped with dedusting facilities. For calculation of the possible emission range refer to the values tabled in Annex 1. In view of the higher dust emission reported for sinter plants located in the CIS, higher emissions (about factor 2-3) of heavy metals are likely there.

Table 8.2c: Emission factors for heavy metals

Process	**Compound**	**Emission factor [g/ GJ sinter]**	**Data quality**
stack emission	As	0.05	C
	Cd	0.2	C
	Cr	0.2	C
	Cu	0.4	C
	Hg	0.05	C
	Ni	0.2	C
	Pb	8	C
	Se	0.02	C
	Zn	1	C

8.2d POP emissions

Since data on other POP were not available, only emissions of PCDD/Fs are included. Refer to Annex 1 to calculate potential emission range. It should be noticed that extremely high emissions from single plants may dominate the national emission. Therefore the simpler methodology should be applied cautiously.

Table 8.2d: Emission factors for PCDD/Fs

Compound	**Process**	**Emission factor** [1] **[µg I-TEQ/ Mg sinter]**	**Data quality**	**Abatement type**	**Abatement efficiency**	**Country /region**
PCDD/F	sintering	6	C	dedusting, ESP	0% [2]	WEu
PCDD/F	cooling	1	C	dedusting, ESP or cyclones	0% [2]	WEu
PCDD/F	sintering	1.5	D	'MEEP' (Moving ESP)	30-70%	D
PCDD/F	sintering	0.5	D	injection of adsorbents/fabric filters	up to 90%	D
PCDD/F	sintering	0.3	C	high performance washer (Airfine)	90%	A

[1] = Note that measurements have shown that there is a significant temporal variation in PCDD/F emissions from sinter plant (about a factor of 2). Also, at one German plant very high PCDD/F emissions were measured (nearly 100 µg I-TEQ/ Mg sinter), showing that variation between plant is likely.

[2] = no significant differences in PCDD/F content measured in raw and clean gas (ref. 6).

9 SPECIES PROFILES

As mentioned in section 3.4 the heavy metal profile of the dust emitted from the hot sintering and crushing/sieving processes are not necessarily related to the profile of the raw materials due to volatilisation and accumulation of some compounds. The following enrichment factors have been observed (ref. 5) :

Table 9.1: Enrichment factors for heavy metals at sinter plant

	Zn	**Pb**	**Cd**
$C_{\text{filter dust}}/C_{\text{Sinter mixture}}$	5	450	30
$C_{\text{clean gas dust}}/C_{\text{Sinter mixture}}$	20	1,300	90

PCDD/F profile information is available from a recent German study (ref. 6). Table 9.2 gives average mass fractions for PCDD/F homologues as revealed by measurement results obtained from 3 plants (5 measurements).

Table 9.2: Species data for PCDD/F from sinter plant

Homologue	**Range [%]**	**mean [%]**
TetraCDF	37-46	40
PentaCDF	26-32	28.5
HexaCDF	10-13	12
HeptaCDF	3.5-5	4
OctaCDF		0.5
TetraCDD	1-5	2
PentaCDD	4-6	4.5
HexaCDD	3-8	5
HeptaCDD	2-4	3
OctaCDD	0-2	1.5

The European IPPC Bureau (ref. 31) includes a graph showing the grain size and weight distribution of dust, based on samples from a number of sinter strands. There are two distinct maxima, one in the range 0.1 – 3 µm, one close to 100 µm. Particles smaller than 0.1 µm and between 3 µm and 80 µm make up a much smaller fraction of the total. The coarse dust can be separated in ESPs with high efficiency. However, the composition of the fine dust, alkali chlorides, reduces the efficiency of ESPs.

The EPA's AP-42 document (ref. 1) gives size distributions for particulate matter emitted from the various stages of sinter production. These are reproduced in Table 9.3.

Table 9.3: Particle size distributions and size-specific emission factors (ref. 1)

Process	**Abatement technology**	**Particle size (µm)**	**Cumulative mass % < stated size**	**Cumulative mass emission factor (kg/t)**	**Quality rating**
Windbox	uncontrolled (leaving gate)	0.5	4	0.22	D
		1	4	0.22	
		2.5	6.5	0.28	
		5	9	0.5	
		10	15	0.83	
		15	20	1.11	
			100	5.56	
Windbox	ESP (wet)	0.5	18	0.015	C
		1	25	0.021	
		2.5	33	0.028	
		5	48	0.041	
		10	59	0.05	
		15	69	0.059	
			100	0.085	
Windbox	Venturi scrubber	0.5	55	0.129	C
		1	75	0.176	
		2.5	89	0.209	
		5	93	0.219	
		10	96	0.226	
		15	98	0.23	
			100	0.235	
Windbox	cyclone	0.5	25	0.13	C
		1	37	0.19	
		2.5	52	0.26	
		5	64	0.32	
		10	74	0.37	
		15	80	0.4	
			100	0.5	
Windbox	baghouse	0.5	3	0.005	C
		1	9	0.014	
		2.5	27	0.041	
		5	47	0.071	
		10	69	0.104	
		15	79	0.119	
			100	0.15	
Discharge breaker and hot screens	baghouse	0.5	2	0.001	C
		1	4	0.002	
		2.5	11	0.006	
		5	20	0.01	
		10	32	0.016	
		15	42	0.021	
			100	0.05	

10 UNCERTAINTY ESTIMATES

The main uncertainty relates to the emission factors. The data quality for all emission factors given in this chapter is from C to E. Emissions are likely to vary greatly between different plant and some emission factors are likely to vary by a factor of at least 10. More information is required on the variation of emissions with different types and sizes of process, different abatement etc.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Knowledge on abatement techniques, dust removal efficiencies and operating techniques is limited. Emission of PCDD/F may depend strongly on operation conditions and raw material composition; hence, estimation may be very uncertain and measurements are required so that a realistic understanding of the emissions can be developed. Data for other POP remain to be collected.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

This section is not relevant because sinter plant are part of large integrated iron and steel works and therefore should be considered as point sources.

13 TEMPORAL DISAGGREGATION CRITERIA

Sintering can be considered as a continuous process. However, emissions may vary with time (e.g. due to changes in raw material composition)

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

- Environmental Protection Agency: Compilation of Air Pollutant Emission Factors (AP 42);
- PARCOM-ATMOS Emission Factors Manual;
- Holtmann T., Rentz O., Samaras Z. Zachariadis T., Kulcke K, K.-H. Zierock: Development of a Methodology and a Computer Model for Forecasting Emissions from Relevant Mobile and Stationary Sources, Final Report 1995 (study on behalf of EC, DG XI,, Brussels).

16 VERIFICATION PROCEDURES

Verification of the emissions can be done roughly for metal emissions by calculating the emissions using the factors from section 8 and comparing the results with a mean profile of the ore used. A mass balance over the entire plant may also be a useful check. In case of PCDD/Fs verification can only be done by measurements.

17 REFERENCES

1. US-EPA (ed.) AP 42 CD-ROM, 1994
2. Kelly M.E.: Sources and Emissions of Polycyclic Organic Matter. EPA Report No. 450/5-83-010b. US EPA, Research Triangle Park, North Carolina. 1983, pp. 5-58 to 5-62
3. GCA Corporation. Survey of Cadmium Emission Sources. EPA Report No. 450/3-81-013. Office of Air Quality and planning Standards, US EPA. Research Triangle Park, North Carolina, 1981.
4. R. Bothe: Umweltproblematik bei der Eisenerzsinterung; Diss. RWTH Aachen 1993
5. O. Rentz, Schleef H.-J., Dorn R., Sasse H., Karl U.: Emission Control at Stationary Sources in the Federal Republic of Germany. Report No. 104 02 360, Umweltbundesamt berlin, 1997
6. Theobald, W.: Ermittlung und verminderung der Emissionen von halogenierten Dioxinen und Furanen aus thermischen Prozessen: Untersuchung der Emissionen polychlorierter Dioxine und -furane und von Schwermetallen aus Anlagen der Stahlerzeugung. Report No. 104 03 365/01, Umweltbundesamt Berlin, 1995
7. Annema J.A., Albers R.A.W., Boulan R.P.: Produktie van Promair Ijzer en Staal. RIVM-report 736301131; RIZA-report 92,003/31, 1992
8. Siebert, P.C. et al.: Prel. Assessment of Sources, Control and Pop. Exposure to Airborne POM as Indicated by Benzo(a)pyrene (BaP). EPA Contract 68-02-2863, Research Triangle Park, North Carolina, 1978, pp. 78-79
9. Lüngen, H., Theobald W.: Umweltschutz an europäischen Sinteranlagen und Hochöfen, Stahl und Eisen 111 (1991), Nr. 12, S. 97-104
10. pers. communication from Kakareka S. (Institute for problems of Use of Natural resources & Ecology - Belarusian National Academy of Sciences, Minsk)
11. Bouscaren m.R. (1992): Corinair Inventory, Default emission Factors handbook, Second Ed.; Commission of the European Communities, Paris, 1992
12. EPA: AIRS Facility Subsystem, EPA Doc. 450/4-90-003, Research Triangle park, North Carolina, 1990
13. CORINAIR 1990 Inventory, March 1995
14. pers. Communication from B. Bretschneider (Czech Hydrometeorological Institute, Prague)
15. pers, communication from J. Fudala, Institute for Ecology of Industrial Areas, Katowice, Poland

16. European Commission, DG XI: Technical Note on the Best Available technologies to Reduce Emissions into the Air from Sinter plants, Pelletisation Plants and Blast furnaces. Third draft, Oct. 1992

17. Umweltbundesamt, Berlin: Comments on draft report of the PARCOM-Atmos Emission Factors Manual, 1992

18. Jockel W., Hartje J. Datenerhebung über die Emissionen umweltgefährdender Schwermetalle. Research report 91-104 02 588, TÜV Rheinland, Köln

19. Bouchereau J. M.: Estimation des emissions atmospheriques de metaux lourds en france pour le Cr, le Cu, le Ni, le Pb et le Zn. CITEPA, Paris, 1992

20. 9th Mtg. Working group Atm. Input. Of Poll. To Convention Waters, London, 5-8 Nov. 1991: Compilation of the comments on the report emission factors for air pollutant emissions, Annex 2

21. 9th Mtg. Working group Atm. Input. Of Poll. To Convention Waters, London, 5-8 Nov. 1991: Compilation of the comments on the report emission factors for air pollutant emissions, Annex 3

22. British iron and Steel Producers Association, pers. Communication to A.G. Salway, AEA Technology, UK

23. Dioxin data of CORINAIR '94 Inventory

24. U. Quaß, M. Fermann, H. Gliwa, G. Bröker: Identification of Relevant Industrial Sources for Dioxins and Furans, First Draft of Final Report addressed to European Commission, DG XI

25. H. J. Bremmer et al.: Emissions of Dioxins in The Netherlands, RIVM/TNO report 770501018, 1994

26. The Swedish Dioxin Survey, Draft version 1996

27. A Review of Dioxin Emissions in the UK. Report No. DOE/HMIP/RR/95/004,

28. Holtmann T., Rentz O., Samaras Z. Zachariadis T., Kulcke K, K.-H. Zierock: Development of a Methodology and a Computer Model for Forecasting Emissions from Relevant Mobile and Stationary Sources, Final Report 1995 (study on behalf of EC, DG XI,, Brussels)

29. Annual Report on the Belarusion Contribution To EMEP 1996. Meteorological Synthesizing Center - East, Minsk-Moscow, jan. 1997

30. ETC/AEM-CITEPA-RISOE (1997) Selected nomenclature for air pollution for CORINAIR94 inventory (SNAP 94), version 0.3 (Draft)

31. European IPPC Bureau (2000) Integrated Pollution Prevention and Control (IPPC): Best Available Techniques Reference Document on the Production of Iron and Steel, March 2000. Published by European Commission, Directorate General JRC, Joint Research Centre, Institute for Prospective Technological Studies (Sevilla), European IPPC Bureau. Available from the Internet http://eippcb.jrc.es, e-mail eippcb@jrc.es

32. Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP),

In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

Example data sources for activity statistics

Eurostat, Yearly Statistics, Theme 4: Energy and Industry, Series C : Accounts, surveys and statistics. Available from Office des publication officielles des Communautes Europeennes, 2, rue mercier, 2985 Luxembourg, Tel +352 499 281

Eurostat Information Office, Jean Monnet Building B3/88, L-2920 Luxembourg, Tel +352 4301 34567, Fax +352 4364 04

Eurostat Data Shop, Rue de la Loi 130, B-1049 Bruxelles, Tel +32 2 299 6666 Fax +32 2 295 0125

Statistisches Jahrbuch der Stahlindustrie. Published annually by Verlag Stahleisen, PO Box 10 51 64, D-40042, Dusseldorf, Contact Stahl Informations-Zentrum, PO Box 10 48 42, D-40213 Dusseldorf, Tel +211 829 0, Fax +211 829 231

International Iron and Steel Institute, Rue Colonel Bourg 120, B-1140 Bruxelles, Tel +32 2 726 5095, Fax +32 2 726 4012

19 RELEASE VERSION, DATE AND SOURCE

Version 3.1

Date June 2000

Source: JJM Berdowski, PFJ van der Most, JM Slager
TNO-MEP
The Netherlands

Updated by: Dr Ulrich Quaß
Landesumweltamt Nordrhein-Westfalen
Germany

Further update by:
Martin Peirce
AEA Technology Environment
UK

Updated with emission factors (CEPMEIP) for particulates by:
Tinus Pulles and Wilfred Appelman

TNO
The Netherlands
May 2006

20 POINT OF ENQUIRY

Any comments on this chapter should be directed to:

Panagiota Dilara

Emissions and Health Unit
Institute for Environment and Sustainability (IES)
European Commission
Joint Research Centre
I-21020 Ispra (VA)
Italy

Tel: +39 0332 789207
Fax: +39 0332 785869
Email: panagiota.dilara@jrc.it

ANNEX 1 - BACKGROUND EMISSION MEASUREMENT INFORMATION

Emissions of gaseous compounds

Process type	**Iron ore sinter plants**								**Sintering of special materials**	
References	(ref. 11)	(ref. 7)		(ref. 12)		(ref. 13)	(ref. 14)	(ref. 15)	(ref. 7)	
Country or region	Int.	NL		USA		EU	Cz	P	NL	
Abatement	unknown	unabated	with abatement (abatement details unknown)	unknown		unknown	unknown	unknown	unabated	abated
Dimension	g/Mg product	g/Mg crude steel		g/Mg product		g/GJ (NAPFUE 107) (6)	g/GJ	g/Mg	g/Mg crude steel	
SO_X	2,000	857	86	1,250 (2)	70 (3)				1,181	118 (7)
SO_2						233-632		1200		
NO_X	1,500	388	66			300-702	137.9		450	90 (8)
NMVOC	108 (1)					8.5.	14.2	100	347	
VOC		254		700 (2)	25 (4)					
CH_4	292 (1)					15	38.4			
CO	20,000-40,000	15,367		22,000 (2)		272		12000	23,000	
CO_2		163,265				106			221,000	
N_2O						4				
Fluoride (5)		11.6	2					5 6)		
HCl (5)		47	9							

[1] = general, 73 % CH_4 for VOC as 400 g/Mg; [2] = windbox; [3] = cooler; [4] = general for sinter process; [5] = dim: g/Mg sinter; [6] = in the document referred to also emission factors for other fuels are given (NAPFUE 203,204,301,304,305); [7] = with lime scrubber; [8] = with SCR

Dust emissions

[kg dust/Mg sinter produced]

Process type	**Iron ore sinter plants**														
References	(ref. 5)				(ref.10)	(ref. 7)		(ref.16) (6)			(ref. 31)				
Country or region	D				CIS	NL		D;I,B			EU				
Abatement (dust)	unabated		Two field ESP	ESP + fabric filter (3)	unknown (4)	unabated	abated	Dry ESP (3-4 fields)	multi cyclones	dry ESP (2-3 fields) or bag filters	“after abatement”	“after abatement”	“after abatement”	cyclones	bag filters
Dust	2-6 (1)	3-4 (2)	0.135-0.6	<0.006	10-24 (5)	0.675	0.165	0.12-0.34 (7)	0.03-0.12 (8)	0.05-0.2 (9)	< 0.0045	0.09-0.44	0.009-0.25	0.09-0.41	0.037-0.1

[1] = windbox emissions; [2] = crushing and screening; [3] = with injection of lignite activated charcoal and lime; [4] = see description given in 3.4.3; [5] = without sinter cooler 10-18 kg/t;

[6] = values calculated from given concentrations with spec flue gas flow; [7] = sintering process, Q_S assumed to be 2000 m³/Mg; [8] = Sinter cooling air (on strand) , Q_S assumed to be 700 m³/Mg; [9] = Sinter handling, Q_S assumed to be 1000 m³/Mg

Heavy metal emissions

[g/Mg sinter produced]

Process type	**Iron ore sinter plants**										
References	ref. 17	ref.18 $^{(1)}$	ref.18 $^{(2)}$	ref.19	ref. 20	ref. 21	ref. 7		ref. 5	ref. 6	ref. 22
Country or region	D	D		F	Int.	Int.			D $^{(4)}$	D $^{(3)}$	UK $^{(4)}$
Abatement (dust)	electro-filters	electro-filters		electro-filters	electro-filters	cyclones	unabated	abated	electro-filters	electro-filters	unknown
Compound											
Arsenic (As)	-	0.025	0.009	-	-		0.05	0.01	0.026	0-0.038	
Cadmium (Cd)	-	3*10^{-4}	0.09	-	0.02-0.12	0.08	0.13	0.03	0.058	0.024-0.228	0.022
Chromium (Cr)	-	0.13	0.09	0.56	-	-	0.05	0.01	0.161	0.016-0.514	
Copper (Cu)	1	0.25	0.36	0.23	-	-	0.13	0.03	0.437	0.176-0.656	

n.r.a.= No range available

[1] = Diffuse sources, cold; [2] = Abated process emissions; [3]= calculated from given concentrations and spec. flue gas flow, [4]= calculated from reported annual emission with sinter production data

Heavy metal emissions (continued)

[g/Mg sinter produced]

Process type	Iron ore sinter plants										
References	ref.17	ref.18 (1)	ref.18 (2)	ref.19	ref. 20	ref. 21	ref. 7		ref. 5	ref. 6	ref. 22
Country or region	D	D		F	Int.	Int.			D (4)	D (3)	UK (4)
Abatement (dust)	electro-filters	electro-filters		electro-filters	electro-filters	cyclones	unabated	abated	electro-filters	electro-filters	unknown
Compound											
Mercury (Hg)	-	$6*10^{-5}$	0.01	-	-	-	0.04	0.01	0.012	0.010-0.106	
Nickel (Ni)	-	0.19	0.14	1.0	-	-			0.240	0.008-0.378	
Lead (Pb)	9	0.13	4.5	2.1	-	15.3	9.92	2.48	2.990	0.360-4.106	0.73
Selenium (Se)	0.02	$1*10^{-4}$	0.019	-	-	-			0.022		
Zinc (Zn)	-	0.13	0.9	2.1	-	-	0.37	0.09	0.678		
Manganese (Mn)									0.966	0.128-1.754	

n.r.a.= No range available

[1] = Diffuse sources, cold; [2] = Abated process emissions; [3]= calculated from given concentrations and spec. flue gas flow, [4]= calculated from reported annual emission with sinter production data

POP emissions

Data are available only for PCDD/Fs

µg I-TEQ/tonne of sinter produced (1)

Process type	**Iron ore sinter plants**									**Sintering of special materials**		
References	ref. 23		ref. 24	ref. 6			ref.25	ref. 26 (2)	ref. 27	ref.24 (8)	ref.25(9)	ref.25(10)
Country or region	A		D	D			NL	S	UK	D	NL	NL
Abatement (dust)	electro-filters	high performance wet scrubbing (‘Airfine’)	electro-filters	Moving electrofilters (‘MEEP’)	fabric filter, activated charcoal	fabric filter, hearth oven coke	electro-filters	electro-filters	electro-filters	electro-filter	fabric filter	washer
PCDD/Fs	4-5 (7)	0.4-1.0	1.3-27.7 (3) 5.9 (4) 0.88 (6)	1.4 (7)	0.24-4.95 (7)	0.04-4.2 (7)	0.3-17	1-2.8	1.2-9	338	0.3	4.5

[1] = I-TEQ: International toxicity equivalents according to NATO/CCMS; [2] = value given in N-TEQ (Toxicity equivalents, nordic model); [3] = windboxes, range except one-case maximum: 94.8 µg I-TEQ/t; [4] = typical value; [6] = sinter cooler; [7] = calculated from reported concentrations and estimate of specific flue gas volume (2000 m^3/t); [8] = sintering of iron containing residue materials; [9] = prod. of artificial gravel; [10] = prod. of phosphates

SNAP CODE : **030302**

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Reheating Furnaces Steel and Iron

NOSE CODE: **104.12.03**

NFR CODE: **1 A 2 a**

1 ACTIVITIES INCLUDED

The reheating furnaces are part of the production of primary iron and steel. A detailed description of non-combustion processes in iron and steel industries and collieries can be found in chapters B146 and B422 up to B428. However, in the following, if useful for description, also non-combustion process steps are mentioned.

2 CONTRIBUTION TO TOTAL EMISSION

The emissions of heavy metals from reheating furnaces at iron and steel production plants are relevant on a national level. Emissions of other substances only give a local contribution. For heavy metal emissions, specific figures on relative contributions for this source activity are not available. The average relative contribution from the total iron and steel production industry to the total emission of heavy metals has been presented for European countries in table 1. The data in table 1 is according to Baart *et al.* (1995) [1].

Table 1: Average relative contribution of the production of iron and steel to the total emission of heavy metals in European countries

Compound	Total iron & steel production (%)
Cadmium	22
Chromium	36
Copper	16
Nickel	14
Lead	12
Zinc	33

For emissions other than heavy metals, the contribution from reheating furnaces in steel and iron production to total emissions in countries of the CORINAIR90 inventory is given in table 2.

Table 2:Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**								
		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	PM*
Reheating Furnaces Steel and Iron	030302	0.3	0.3	0	0	0.2	0.6	0.1	-	0

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported
* = PM (inclusive of TSP, PM_{10} and $PM_{2.5}$) is <0.1% of total PM emissions

3 GENERAL

3.1 Description of activities

Reheating furnaces prepare cool iron material for further processing by an appropriate temperature increase. In soaking pits, ingots are heated until the temperature distribution over the cross section of the ingots is acceptable and the surface temperature is uniform for further rolling into semifinished products (blooms, billets and slabs). In slab furnaces, a slab is heated before being rolled into finished products (plates, sheets or strips). [2]

3.2 Definitions

3.3 Techniques

The type of reheating furnace depends on the site and nature of the intermediate product and the subsequent processing. Coal-fired furnaces are now comparatively rare. Reheating furnaces are normally fired by gas or oil. [3]

3.4 Emissions

Pollutants released are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2) and nitrous oxide (N_2O). According to CORINAIR90 the main relevant pollutants are SO_x, NO_x and CO_2 (see also table 2). The emissions are released through the stack.

Emissions of sulphur dioxides (SO_x) are directly related to the sulphur content of the fuel. Reheating furnaces are normally fed by low sulphur gas (blast furnace gas, desulphurised coke oven gas or natural gas) or by oil [3].

Nitrogen oxides (NO_x) are formed within the combustion process by conversion of fuel-nitrogen and nitrogen of the combustion air.

Carbon dioxide (CO_2) is a main product of the combustion process and is directly related to the carbon content of the fuel.

3.5 Controls

Emissions are reduced by preceding cleaning of the used blast furnace gas and coke oven gas. No information is available for treatment of exhaust gases from reheating furnaces. [2]

4 SIMPLER METHODOLOGY

The emissions. are inventoried using the default emission factors provided in Table 8.1. These emission factors represent the high end of typical emission factors, and assume limited control technology is in place.

N.B There are no emission factors available for $PM_{2.5}$. The source is <0.1% of the total PM emissions for most countries.

5 DETAILED METHODOLOGY

If an extensive measuring programme is available the emission of heavy metals can be calculated on the basis of the measurements of the dust emission and the composition of compounds over the total process. Reference emission factors are provided for comparison with user's own data in Table 8.2.

Should a key source analysis indicate this to be a major source of particulate matter (TSP, PM_{10} or $PM_{2.5}$) then installation level data should be collected using a measurement protocol such as that illustrated in Measurement Protocol Annex.

6 ACTIVITY STATISTICS

Standard energy consumption statistics (IEA, UN, International Iron and Steel Institute etc.)

7 POINT SOURCE CRITERIA

The iron and steel plants from which the reheating furnaces are a part are connected to high chimneys (> 100 meter), and can be regarded as point sources . They can be considered to be point sources at a national as well as on a regional level.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Simpler Methodology

A summary of default emission factors using the simpler methodology for estimating emissions from ordinary steel and iron production are provided in Table 8.1.

8.2 Detailed Methodology

For emissions other than heavy metals, table 8.2 contains fuel use related reference emission factors for reheating furnaces in steel and iron production based on CORINAIR90 data in g/GJ. Technique related emission factors, mostly given in other units (e.g. g/Mg product), are listed in footnotes. In case of using production statistics the specific energy consumption (e.g.

GJ/Mg product) has to be taken into account. The specific energy consumption is process and country specific; within CORINAIR 90 a value of 100 GJ/Mg product has been reported.

Table 8.1 Default emission factors - simpler methodology

Pollutant	**Emission factor**	**Units**
PM10	650	g/tonne steel
Arsenic	1.44	mg/tonne steel
Cadmium	0.48	mg/tonne steel
Chromium	24	mg/tonne steel
Copper	24	mg/tonne steel
Mercury	0.5	mg/tonne steel
Lead	38	mg/tonne steel
Zinc	84	mg/tonne steel
Dioxins and furans	0.2	μgTEQ/tonne cement
Hexachlorobenzene	11	μg/tonne cement
Polyaromatic hydrocarbons	24000	mg/tonne steel

Table 8.2 Emission factors for reheating furnaces in steel and iron production – detailed methodology

								Emission factors				
	Fuel			NAPFUE -code	SO_2 [g/GJ]	NO_x [g/GJ]	NMVOC [g/GJ]	CH_4 [g/GJ]	CO [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]	NH_3 [g/GJ]
S	coal	hc	Coking	101			$15^{1)3)}$	$15^{1)}$	$12^{1)}$	$94^{1)}$	$3^{1)}$	
S	coal	hc	Steam	102	$992^{3)}$	$150^{3)}$	$15^{1)}$	$15^{1)3)}$	$120^{1)}$, $70^{3)}$	$94^{1)}$, $98^{3)}$	$14^{3)}$	
S	coal	hc	sub-bituminous	103	$1,267^{3)}$	$100^{3)}$	$4^{3)}$	$4^{3)}$	$20^{3)}$	$52^{3)}$	$3^{3)}$	
S	coal	bc	brown coal/lignite	105	$2,358^{3)}$	$150^{3)}$	$20^{3)}$	$100^{3)}$	$18^{3)}$	$86^{3)}$	$3^{3)}$	
S	coke	hc	coke oven	107	$351^{3)}$	$150^{3)}$	$15^{1)3)}$	$15^{1)3)}$	$70^{1)3)}$	$108^{1)}$, $105^{3)}$	$3^{1)}$, $14^{3)}$	
S	coke	bc	coke oven	108	$650^{3)}$	$150^{3)}$	$8^{3)}$	$15^{1)}$	$18^{3)}$	$86^{3)}$	$3^{3)}$	
S	coke		Petroleum	110	$2,000^{3)}$	300	$1.5^{3)}$	$1.5^{3)}$	$70^{3)}$	$97^{3)}$	$10^{3)}$	
L	oil		Residual	203	$1,323^{1)}$ $143\text{-}1,503^{3)}$	$100\text{-}240^{3)}$	$3\text{-}5^{1)}$ $3^{3)}$	$3\text{-}5^{1)3)}$	$15^{1)}$, $12\text{-}15^{3)}$	$76\text{-}78^{1)}$ $73\text{-}78^{3)}$	$3\text{-}14^{1)}$ $2\text{-}14^{3)}$	
L	oil		Gas	204	$94\text{-}1,410^{3)}$	$80\text{-}100^{3)}$	$2.5^{1)}$ $1.5^{3)}$	$2.5^{1)}$, $1.5^{3)}$	$12^{1)3)}$	$74^{1)}$ $69\text{-}74^{3)}$	$3^{1)}$ $2\text{-}14^{3)}$	
L	oil		shale-oil	211	$503^{1)}$	$158^{1)}$			$13^{1)}$			
G	gas		Natural	301	$0.87\text{-}58^{1)}$ $0.3\text{-}58^{3)}$	$58\text{-}187^{1)}$ $58\text{-}125^{3)}$	$2.5\text{-}4^{1)}$ $1\text{-}4^{3)}$	$2.5\text{-}4^{1)}$ $1\text{-}5^{3)}$	$5.5\text{-}13^{1)}$ $8\text{-}25^{3)}$	$55\text{-}56^{1)}$ $52\text{-}57^{3)}$	$1.5\text{-}3^{1)}$ $0.8\text{-}3^{3)}$	
G	gas		liquified petroleum gas	303	$0.04^{3)}$	$100^{3)}$	$2.1^{3)}$	$0.9^{3)}$	$13^{3)}$	$65^{3)}$	$1\text{-}3^{3)}$	
G	gas		coke oven	304	$23\text{-}715^{1)}$ $60^{3)}$	$84\text{-}207^{1)}$ $85^{3)}$	$2.5^{1)3)}$	$2.5^{1)3)}$	$12\text{-}17^{1)}$ $15^{3)}$	$42\text{-}46^{1)}$ $45^{3)}$	$3^{1)}$, $1^{3)}$	
G	gas		blast furnace	305	$57\text{-}831^{1)}$ $18\text{-}830^{3)}$	$145\text{-}831^{1)}$ $25\text{-}830^{3)}$	$0.25\text{-}2.5^{3)}$		$12\text{-}69^{1)}$ $10\text{-}14^{3)}$	$192^{1)3)}$ $290^{3)}$	$3^{1)}$, $1\text{-}2.4^{3)}$	
G	gas		coke oven and blast furnace gas	306	$0.53^{1)}$	$151^{1)}$		$0.25\text{-}2.5^{3)}$	$14^{1)}$	$205^{1)}$		
-	not specified		-	-	$400^{2)}$	$400^{2)}$	$5^{2)}$					

$^{1)}$ CORINAIR90, point sources (preliminary data)
$^{2)}$ EPA 1990 [4]
$^{3)}$ CORINAIR90 data, area sources, (preliminary data)

9 SPECIES PROFILES

The origin of the heavy metals emission is the dust production. The emission factors as presented are therefore related to the profile of the dust. This profile however is dependent on the ores used.

10 UNCERTAINTY ESTIMATES

Not available.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The weakest aspects discussed here are related to emission factors and activities.

The fuel specific emission factors provided in table 3 are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of emission factors with respect to point and area sources. Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges.

Uncertainties also occur concerning the activity covered due to the fact, that a single fuel (e.g. oil) or a mixture of blast furnace and coke oven gas can be used. Further work should be invested in a representative split of fuel gases used (activity data) and in providing corresponding emission factors e.g. for a blend of blast furnace and coke oven gas.

For heavy metals, knowledge on emission factors, abatement techniques, dust removal efficiencies and operating techniques is very limited; measurement data of composition of dust is poor.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

13 TEMPORAL DISAGGREGATION CRITERIA

Iron and steel production is a continuous process.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

Not available.

16 VERIFICATION PROCESSES

Verification of the emissions can be done for metal emissions by calculating the emissions using the factors from the PARCOM ATMOS manual and comparing the results with a mean profile of the ore used. A mass balance over the entire plant may also be a useful check.

17 REFERENCES

[1] A.C. Baart, J.J.M. Berdowski, J.A. van Jaarsveld; Calculation of atmospheric deposition of contaminants on the North Sea; IWAD; ref. TNO-MW-R 95/138; TNO MEP; Delft; The Netherlands; 1995

[2] US-EPA (ed.): AP 42 CD-Rom; 1994

[3] Parker, Albert (ed.): Industrial Air Pollution Handbook; Maidenhead,

Berkshire (England); 1978

[4] EPA (ed.): AIRS Facility Subsystem, EPA-Doc: 450/4-90-003, Research Triangle Park, March 1990

18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE, AND SOURCE

Version : 3

Date : December 2001

Source : Dick Heslinga
TNO
The Netherlands

Supported by: Otto Rentz, Dagmar Oertel
University of Karlsruhe (TH)
Germany

Updated with particulate matter details by:
Mike Woodfield
AEA Technology
UK
December 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Pieter van der Most

HIMH-MI-Netherlands
Inspectorate for the Environment
Dept for Monitoring and Information Management
PO Box 30945
2500 GX Den Haag
The Netherlands

Tel: +31 70 339 4606
Fax: +31 70 339 1988
Email: pieter.vandermost@minvrom.nl

SNAP CODE: **030303**

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Grey Iron Foundries

NOSE CODE: **104.12.04**

NFR CODE: **1 A 2 a**

ISIC: **2410**

1 ACTIVITIES INCLUDED

This chapter covers emissions released from combustion processes within grey iron foundries. The grey iron foundries are in general part of production processes for a wide range of metal products. A detailed description of non-combustion processes in iron and steel industries and collieries can be found in chapters B146 and B422 up to B428.

2 CONTRIBUTION TO TOTAL EMISSIONS

The contribution of emissions released from grey iron foundries to total emissions in countries of the CORINAIR90 inventory is given as follows:

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**										
Grey Iron Foundries	030303	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Typical contribution		0	0	0	0	1.4	0.1	-	-	0.141	0.086	0.021
Highest value										0.255	0.152	0.032
Lowest value										0.076	0.051	0.012

* contribution of pig iron foundries to total national emissions ,exluding agricultural soils, EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006)
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
\- = no emissions are reported

For heavy metal emissions, no specific figures for this source activity are available. The average relative contribution from the total iron and steel production industry and the production of pig iron to the total emission of heavy metals has been presented for European countries in Table 2.2. Grey iron foundries can be considered a part of the production of pig iron. The data in Table 2 is according to Baart *et al.* (1995). /1/

Table 2.2: Average relative contribution of the production of iron and steel and the production of pig iron to the total emission of heavy metals in European countries.

Compound	**Total iron & steel production (%)**	**Pig iron production (%)**
Cadmium	22	-
Chromium	36	3.7
Copper	16	-
Nickel	14	3.0
Lead	12	-
Zinc	33	-

- = not available

3 GENERAL

3.1 Description of activities

Foundry activities are generally part of the following type of industrial activities:

- Malleable foundries
- Nodular foundries, for instance:
  - machine construction
  - automobile and bicycle industry
- Lamellar foundries, for instance:
  - sewer pipe foundries, accessories for tubes
  - tubes for heating purposes
  - machine construction parts
  - automobile industry
- Steel foundries

The activities of the foundries can be seperated in five parts:

- pretreatment of shot metals
- production of casting models
- smelting of metals with flux compounds and treatment of smelt
- casting of metal smelt in casting models
- treatment of castings

The activities, the composition, the scaling and the use of raw materials of the foundries depend strongly on the products made by the foundries and on economic aspects. The casting process is described in Section 3.3.

3.2 Definitions

Pretreatment of the raw materials	Some raw materials need to be pretreated since they are not always suitable for the casting process.
Smelting process	The shot metals and flux compounds are mixed with cokes and heated by combustion of the cokes to a temperature above the melting point of iron (»1500 °C). These processes can be either batchwise, or continuous.
Production of casting models	A casting model is made of sand with a chemical binding agent, or of clay bounded sand. The shape of the casting model is the inverse of the casting to be produced. The casting model can only be used once, because after solidification of the metal smelt the casting will be destroyed.
Metal smelt	The shot metals used in the smelting process contain mainly iron. Since shot materials are used the iron may be contaminated with other metals.
Treatment of the metal smelt	The treatment of the metal smelt is a process intended to increase the quality of the smelt. Increase of quality is necessary for the casting process or the properties of the product.
Casting process	The casting process is the pouring of the drained off metal smelt in a casting process and the solidification of the metal smelt.

3.3 Techniques

The casting starts with the pretreatment of the metals. This pretreatment consists of breaking big parts of shot metals, and mixing the metals with the flux compounds. Three types of smelt ovens are commonly used: dome ovens, electro ovens and tumbler ovens. These ovens are described in Section 3.3.1.

After the metal smelt is drained from the ovens, the quality of the smelt can be improved by deslagging with slag binding compounds, desulphurating with fine cokes and calcium carbide, inoculation with ferro alloys (based on ferro silica) and nodulisation with magnesium.

The drained metal smelt is casted in a casting model. The casting method is specific for the products. The production of the casting models is described in paragraph 3.3.2. After solidification of the metal smelt the casting model is removed. Cleaning of the casting is generally done by shot peening. Besides shot peening the casting can be been grinded, rolled, chopped and milled. Sometimes the castings will also be treated by glowing, or hardened, tared, red-leaded, painted or lacquered.

3.3.1 Smelt ovens

Dome oven	The dome oven is a continuous operating installation. In the shaft the smelt aggregate is accumulated via an opening in the side wall. Alternately the cokes and the metals are added. During the filling of the shaft the cokes are lighted and the metal smelts and flows into the oven.
Electro oven	The metals and flux compounds are smelted by electric lighting of the petrol cokes. The process is discontinu.
Tumbler oven	The tumbler oven is heated by an oil lighted flame. The metals direct heated by the flame will melt. The turning of the tumbler assures that the metals will be heated on both sides.

3.3.2 Production of casting models

The casting models can be classified in two categories, namely the clay bounded sand models for the light casting production and the models of sand with a chemical hardener. The clay bounded sand model is strengthened by compression. The sand contains concrete, water and coal powder for the production of a smooth structure on the the casting. The casting model made of sand with the chemical agent is also strengthened by compressing during which process the chemicals are polymerized in the sand.

3.4 Emissions

The main emissions of the casting process are emissions of dust and gaseous compounds. The emissions occur during the smelting process, the production of the casting model and the treatment of the castings. The main emission is dust which contains metal oxides like iron and silica oxide. Also some solvents may be part of the emissions into air.

The emissions of dust depend strongly on the type of oven used for the smelting process and quality of the process management.

Gaseous compounds released are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (N_2O) and ammonia (NH_3). The emissions are released through the stack. According to CORINAIR90 the main relevant pollutants are CO and CO_2 (see also table 1).

Coke burned in cupola furnaces produces several pollutants. Incomplete combustion of coke causes carbon monoxide emissions and the coke sulphur content gives rise to sulphur dioxide emissions. /3/

Electric arc furnaces produce CO emissions which result from combustion of graphite from electrodes and carbon added to the charge. Hydrocarbons (NMVOC) result from vaporisation and incomplete combustion of oil residues remaining on the scrap iron charge. /3/

Electric induction furnaces release negligible amounts of hydrocarbon and carbon monoxide emissions. /3/

3.5 Controls

Possible areas for improvement in emission control are:

• Dome oven	Treatment of off-gas with bagfilters and electrofilters
• Electro oven	Treatment of off-gas with bagfilters or electrofilters
• Tumbler oven	Treatment of off-gas with bagfilters, use of low sulphur containing oil, lime injection combined with bagfilters
• Smelt treatment	Treatment of off-gas with bagfilters
• Sand preparation	Use of bagfilters and wet scrubbers
• Model production	Good humidity control. For the sand model production with the chemical hardened binding resin the choice of the resin can influence the emission.

A cupola furnace typically has an afterburner as well, which achieves up to 95 % efficiency. The afterburner is located in the furnace stack to oxidise CO and burn organic fumes, tars and oils. /3/

Electric induction furnaces are typically uncontrolled since they emit negligible amounts of hydrocarbons and carbon monoxide. /cf. 2/

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes (“activity rates”) and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

---

[1] The term “Tier” is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = AR \times EF$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8.1.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tiers 3), to estimate emissions of gaseous pollutants from the iron and steel production is based on measurements or estimations using plant specific emission factors. Guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

Reference emission factors for comparison with users own data are provided in Section 8.2.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of iron, steel and malleable iron castings, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics. For energy consumption statistics, data from the IEA can be used.

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities of iron, steel and malleable iron castings produced by various types of industrial technologies employed in the iron and steel industry at plant level. This data is however not always easily available.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

Foundries can vary strongly in size. Small foundries can be treated as area source. At the national level big foundries or a concentration of foundries in a small area would be treated as point sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Default Emission Factors for use with simpler methodology.

Table 8.1: Emission factors for grey iron foundries

Pollutant	Emission Factor	Units
Arsenic	0.3	g/tonne liquid steel
Cadmium	0.1	g/tonne liquid steel
Chromium	1	g/tonne liquid steel
Copper	1	g/tonne liquid steel
Mercury	0.04	g/tonne liquid steel
Nickel	0.3	g/tonne liquid steel
Lead	3	g/tonne liquid steel
Selenium	0.01	g/tonne liquid steel
Vanadium	1	g/tonne liquid steel
Zinc	5	g/tonne liquid steel
Particulate matter*		
TSP	2 (2)**	kg / tonne cast iron
PM_{10}	0.6 (2)**	kg / tonne cast iron
$PM_{2.5}$	0.09 (2)**	kg / tonne cast iron

Source: Pacyna et al, 2002, (*) except for particulate matter , CEPMEIP [6]
** note: NOTE: The factor between brackets () represents the uncertainty (95% confidence) in the emission factor. The lower limit of the uncertainty range can be found by dividing the emission factor by the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example (emission factor for TSP): The uncertainty in the emission factor for TSP is 2 . The emission factor with uncertainty range will therefore be 2 kg per tonne cast iron with an uncertainty range of 1 (2 /2) to 4 (2 x 2).

8.2 Reference Emission Factors

Table 8.2 contains reference emissions factors for comparison with users own data. Technique related emission factors, mostly given in other units (e.g. g/Mg charged), are listed in footnotes. In case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. At this stage no data for the definition of appropriate conversion factors are available.

For the Netherlands, emission factors are calculated from measurements in mixtures consisting of 60% of hot blast air cupolas (1500 m^3 Mg^{-1} off-gases) and 40% of cold blast air off-gases (300 m^3 Mg^{-1} off-gases), using an average dust concentration of 300 mg m^{-3}. The emission factors are calculated from formula 1:

Emission $=[\mathrm{Dust}]_{\mathrm{average}} \times \mathrm{Flow}_{\mathrm{off\text{-}gases}} \times [\mathrm{Metal\ composition}]_{\mathrm{dust}}$ [Formula 1], where

$[\mathrm{Dust}]_{\mathrm{average}}$: Average dust concentration in off-gases
$\mathrm{Flow}_{\mathrm{off\text{-}gases}}$: Average flow of off-gases

[Metal composition]$_{dust}$: Average weight percentage of metal composition in dust

The emission factors are given in table 8.2.

Table 8.2: Emission factors for grey iron foundries[7)]

					Emission factors								
	Type of fuel			NAPFUE code	SO_2 [g/GJ]	NO_x [g/GJ]	NMVOC [g/GJ]	CH_4 [g/GJ]	CO [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]	NH_3 [g/GJ]
s	coal	hc	steam	102	130-160 1)	12-80 1)	15-57 1)	5-15 1)	20 1)	93-94 1)	4-5 1)	
s	coal	bc	briquettes	106	44 1)	12 1)	15-57 1)	6.3-15 1)		97 1)	3.5 1)	
s	coke	hc	coke oven	107	100-584 1) , 92-593 2)	12-220 1) , 12-45 2)	0.5-80 1)	0.5-6.3 1)	97 1)	105-110 1), 105 2)	3-4 1)	
s	coke	bc	coke oven	108	650 1)	150 1)	5 1)	15 1)	18 1)	86 1)	3 1)	
l	oil		residual	203	143-930 1)	100-175 1)	3-57 1)	3-6.3 1)	10-15 1)	73-78 1)	2-10 1)	
l	oil		gas	204	55-94 1)	50-100 1)	1.5-57 1)	1.5-8 1)	10-20 1)	74 1)	2 1)	
g	gas		natural	301	0.3-8 1), 1 2)	50-100 1) ,145 2)	2.5-57	2-6.3 1)	10-20 1), 8 2)	53-60 1), 55 2)	1-3 1)	
g	gas		liquified petroleum gas	303	0.04 1)	100 1)	2.1 1)	0.9 1)	131)	65 1)	1 1)	
g	gas		coke oven	304	12-54 1) , 54 2)	5.5-50 1) ,5 2)	2.5-80 1)	2.5-6.3 1)	10 1)	44-45 1), 45 2)	1-1.5 1)	

1) CORINAIR90 data, area sources; 2) CORINAIR90 data, point sources

3) SO_x: /1/	450	g/Mg charged	cupola furnace
	90,000	g/Mg charged	reverberatory furnace
	0	g/Mg charged	electric induction furnace
	125	g/Mg charged	electric arc furnace
4) NO_x: /1/	50	g/Mg charged	cupola furnace
	2,900	g/Mg charged	reverberatory furnace
	0	g/Mg charged	electric induction furnace
	160	g/Mg charged	electric arc furnace
5) VOC: /1/	90	g/Mg charged	cupola furnace
	75	g/Mg charged	reverberatory furnace
	0	g/Mg charged	electric induction furnace
	90	g/Mg charged	electric arc furnace
6) CO: /1/	72,500	g/Mg charged	cupola furnace
	0	g/Mg charged	reverberatory furnace
	0	g/Mg charged	electric induction furnace
	9,500	g/Mg charged	electric arc furnace

7) It is assumed, that emission factors cited within the table are related to combustion sources in grey iron foundries; other process emissions are not covered.

9 SPECIES PROFILES

The heavy metal emissions are related to the metal profile of the dust.

10 UNCERTAINTY ESTIMATES

The emission factors given are based on the data from a small number of measurements, with a rather large variation caused by individual conditions. The quality class of the emission factors other than of CORINAIR90 is estimated to be [D].

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The weakest aspect for heavy metals is the lack of data and adequate measurements.
For emissions other than heavy metals, the weakest aspects discussed here are related to emission factors.

The fuel specific emission factors provided in table 4 are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of emission factors with respect to point and area sources. Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Not applicable.

13 TEMPORAL DISAGGREGATION CRITERIA

The temporal disaggregation depends on the management of the plant. Some foundries do emit only during Mondays to Fridays from ± 7.00 hour to ± 18.00 hour and others emit continuously.

As result of market conditions a seasonal variation might be present.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

[1] Annual report of the Common Association of Dutch Foundries 1989; AVNEG; 1990
[2] AVNEG; 1990 personal communication
[3] Basic document Cadmium; Slooff, W., Ros, J.P.M.; RIVM report number 758476002; July 1987 (in Dutch)

[4] Basic report Zinc; Haskoning; 1990 (in dutch)
[5] Energy use for basic metal industry; Braun; 1990
[6] Foundries 1987-1988 (SBI 34.0); Industrial production statistics; Central Office of Statistics; 1990
[7] Air Note L214 concerning foundries (I); DHV-MT; 1990
[8] Air Note L215 concerning foundries (II); DHV-MT; 1990
[9] Emission Registration 13, Report Emission Registration Netherlands; Ministry VROM; May 1990
[10] Atmospheric data from the Emission Registration concerning ferro and non-ferro companies; RIVM; 1991
[11] Handbook of emission factors, Part 2: Industrial sources; Government Publishing Office, The Hague; 1983
[12] Handbook of Model Descriptions of atmospheric emissions from the Iron Casting Foundries; TA-Luft; 1983
[13] Die Europäische Giesserie-Industrie; Annual Statistic Report from the Association Committee of European Foundries; 1992
[14] Industrial emission in the Netherlands, 5th inventory round - 1990; Publicatiereeks Emissieregistratie; Ministry VROM; 1993
[15] Datenerhebung über die Emissionen Umweltgefärdenden Schwermetalle; Jöckel, W., Hartje, J.; Forschungsbericht 91-104 02 588 TüV Rheinland e.V. Köln; 1991
[16] Environmental Protection Agency; Compilation of air pollutant Emission Factors AP-42
[17] PARCOM-ATMOS Emission Factors Manual.

16 VERIFICATION PROCEDURES

A verification method could be the comparison of the heavy metals emissions calculated with a profile of the composition of the products.

17 REFERENCES

/1/ A.C. Baart, J.J.M. Berdowski, J.A. van Jaarsveld; Calculation of atmospheric deposition of contaminants on the North Sea; IWAD; ref. TNO-MW-R 95/138; TNO MEP; Delft; The Netherlands; 1995
/2/ EPA (ed.): AIR Facility Subsystem, EPA-Doc. 450/4-90-003, Research Triangle Park, 1990
/3/ EPA (ed.): AIR Chief; Version 4.0; 1995
/4/ Air Pollution Aspects of the Iron Foundry Industry; APTD-0806, U.S.-EPA, Research Triangle Park (NC); 1974
/5/ Pacyna et al (2002): Combustion and Industry Expert Panel Workshop, European Joint Research Centre (JRC) ISPRA 2002. Data compiled by: Paycna J, van der Most P, Hobson M, Wieser, M, Müller B, Duval L, Spezzano P, Lotz T, Kakareka S.
[6] Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE, AND SOURCE

Version: 2.2

Date: February 2003

Source: J J M Berdowski, P F J van der Most, W Mulder
TNO
The Netherlands

Supported by: Otto Rentz, Dagmar Oertel
University of Karlsruhe (TH)
Germany

Updated with emission factors (CEPMEIP) for particulates by:

Tinus Pulles and Wilfred Appelman

TNO

The Netherlands

May 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Pieter van der Most

HIMH-MI-Netherlands
Inspectorate for the Environment
Dept for Monitoring and Information Management
PO Box 30945
2500 GX Den Haag
The Netherlands

Tel: +31 70 339 4606
Fax: +31 70 339 1988
Email: pieter.vandermost@minvrom.nl

SNAP CODE: **030304**

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Primary Lead Production

NOSE CODE: **104.12.05**

NFR CODE: **2 C 5 / 1 A 2 b**

ISIC: **2420**

1 ACTIVITIES INCLUDED

The primary lead production process is defined as the production of lead from lead concentrates. A description of the process together with a brief description of the associated process steps (e.g. sintering) is provided in Section 3. Detailed descriptions of the associated process steps can be found in chapter B331.

2 CONTRIBUTION TO TOTAL EMISSIONS

The contribution of gaseous emissions released from primary lead production to total emissions in countries of the CORINAIR90 inventory is given as follows:

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**										
		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Primary Lead Production (average)	030304	0.2	0	-	-	0	0	-	-	0.011	0.020	0.016
Highest value										0.045	0.075	0.061
Lowest value										-	-	-

* EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

The contribution of heavy metal emissions from primary lead production to the total heavy metal emissions, according to IWAD [7], is given in Table 2.2.

Table 2.2: The contribution of heavy metal emissions from primary lead production to the total emissions of the IWAD study [7]

Contribution to total emissions (%)					
Cd	Cr	Cu	Ni	Pb	Zn
1.1	0	0.2	0	1.5	0.3

0 = emissions are reported, but the exact value is below the rounding limit

3 GENERAL

3.1 Description of activities

This process contains the classical steps of ore pretreatment and concentration, sintering, smelting, and product refining. Most primary lead smelters also produce other metals to a certain extent. The process route is based on sintering, reduction of sinter in a shaft furnace, and refining of bullion, either pyrometallurgically or hydrometallurgically.

In the sintering process fine particles of metal ores are agglomerated into nodules, briquettes, sinter, or pellets. Also a roasting process is involved in which lead sulphide is converted into lead oxide. Dust emissions result from handling and stockpiling of raw materials or intermediate products. Abatement methods are the use of bag filters, wet scrubbers or electrofilters.

In the smelting process ore, coke, and flux compounds are heated either in a shaft furnace or an electric furnace. Dust abatement can be provided by bag filters or electrofilters. Improved abatement is encapsulation or evacuation of the process.

The refining process is mainly directed at the removal of copper, silver, zinc, and bismuth. Dust emissions mainly occur at the treatment of the different by-product streams.

Several improved processes are either in the pilot stage, or being used at a single plant. However, no general applicable information is available yet.

3.2 Definitions

Sintering process	Agglomeration of ore particles, flux compounds and other material by the combustion of coke.
Roasting process	Oxidation of lead concentrate converting the lead sulphide to lead oxide.

3.3 Techniques

The main techniques for the smelting process are the shaft furnace and the electric furnace process. For refining the main techniques are pyrometallurgical refining and hydrometallurgical refining. Several direct smelting technologies have been under development or are being developed yet. Information about the emissions of these techniques is not yet available.

3.4 Emissions

The main emissions during the primary lead production are dust emissions.

Pollutants released are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2), and nitrous oxide (N_2O). According to CORINAIR90 the main relevant pollutants is SO_2 (see also table 2.1).

The most relevant step with regard to SO_2 emissions is the sintering process (for details see B331). However, only about 7 % of the total sulphur in the ore is emitted as SO_2. The remainder is captured by the slag. The concentration of this SO_2 stream can vary from 1.4 to 7.2 g/m^3, depending on the amount of dilution air injected to oxidise the carbon monoxide and to cool the stream before baghouse particulate removal [1].

Nearly 85 % of the sulphur present in the lead ore concentrate is eliminated in the sintering operation (see chapter B331). In handling process offgases, either a single weak stream is taken from the machine hood at less than 2 % SO_2, or two streams are taken, a strong stream (5 to 7 % SO_2) from the feed end of the machine and a weak stream (less than 0.5 % SO_2) from the discharge end. Single stream operation has been used if there is little or no market for recovered sulphur, so that the uncontrolled, weak SO_2 stream is emitted to the atmosphere.

When sulphur removal is required, however, dual stream operation is preferred. The strong stream is sent to a sulphuric acid plant, and the weak stream is vented to the atmosphere after removal of particulate [1].

Sulphur oxides are also generated in blast furnaces during the smelting process from small quantities of residual lead sulphide and lead sulphates in the sinter feed. The quantity of these emissions is a function not only of the sinter's residual sulphur content, but also of the sulphur captured by copper and other impurities in the slag [1].

3.5 Controls

The dust emissions can be abated by using fabric filters, wet scrubbers or electrofilters. Improvement can be achieved by using encapsulation or evacuation. New approaches are under development.

The SO_2 containing emissions are often used as input for sulphuric acid plants. Here, emissions from combustion and from other process steps are reconciled. Single stage sulphuric acid plants can attain sulphur oxide levels of 5.7 g/m^3, and dual stage plants can attain levels of 1.6 g/m^3. Typical efficiencies of dual stage plants in removing sulphur oxides can exceed 99 %. Other technically feasible SO_2 control methods are elemental sulphur recovery plants and dimethylamine and ammonia absorption processes [1].

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

---

[1] The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = \text{AR} \times \text{EF}$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8.1.

5 DETAILED METHODOLOGY

Information about the newer processes mentioned above is not yet available to allow a more detailed methodology to be followed. However, reference emission factors for comparison with userrs own data are provided in Section 8.2.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of lead, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics.

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities produced by various types of industrial technologies employed in the industry at plant level. This data is however not always easily available.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

The primary lead production should be treated as a point source if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Default Emission Factors for use with simpler methodology

Table 8.1: Emission factors for primary lead production

Pollutant	**Emission Factor** *Limited control*	**Emission Factor** *Abatement*	**Units**
Arsenic	3	0.5	g/tonne lead
Cadmium	10	1	g/tonne lead
Copper	10	5	g/tonne lead
Mercury	3	1	g/tonne lead
Lead	800	200	g/tonne lead
Vanadium	80	20	g/tonne lead
Particles [1]			
TSP		0.5	g/tonne lead
PM_{10}		0.4	g/tonne lead
$PM_{2.5}$		0.2	g/tonne lead

Source: Pacyna et al (2002)

1) CEPMEIP emission factors for conventional plant using ESP, settlers, scrubbers; moderate control of fugitive sources

8.2 Reference Emission Factors for Use With Detailed Methodology

The following tables provide emission factors for comparison with users own data. Emissions can vary widely depending on the ore used and the abatement measures applied as demonstrated by the reported emission factors given in Table 8.2a. The emission factors given in Table 8.2b were prepared for the PARCOM-ATMOS Emission Factors Manual 1992.

Table 8.2c contains fuel related emission factors. Technique related emission factors, mostly given in other units (e.g. g/m^3) are listed in footnotes. In case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. At this stage no data for the definition of appropriate conversion factors are available.

Table 8.2d contains emission factors for particles, total suspended particles (TSP), PM_{10} and $PM_{2.5}$. The emission factors are derived from the CEPMEIP database.

Table 8.2a: Emission factors for primary lead production (g/Mg product) as reported by several countries/authors

	Sweden [2]		**Poland [3]**			**Germany [4]**	**Pacyna [5,6]**
Compound	limited	improved	limited	improved	unabated	unknown	unknown
Arsenic	3	0.2	16-43	-	-	3	300
Cadmium	3	0.6	10-22	-	-	6	10
Copper	10	4	10	7	-	-	-
Lead	400	200	560-1200	-	-	400	3000
Mercury	-	-	-	-	-	-	3
Zinc	50	20	110	-	680	-	110

Table 8.2b: Proposed emission factors for primary lead production (g/tonne Lead)

Substance	**Emission factor**		
	limited abatement	improved abatement	unknown level of abatement
Arsenic	3	0.5	10
Cadmium	10	1	15
Copper	10	5	10
Lead	800	200	2000
Mercury	3	3	3
Zinc	80	20	100

Table 8.2c: Emission factors for primary lead production$^{6)}$

	Type of fuel			NAPFUE code	Emission factors						
					$SO_2$$^{3)}$ [g/GJ]	$NO_x$$^{4)}$ [g/GJ]	NMVOC$^{5)}$ [g/GJ]	CH_4 [g/GJ]	CO [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]
s	coal	hc	steam	102	149-520$^{1)}$	160$^{1)}$	15$^{1)}$	15$^{1)}$	100$^{1)}$	94$^{1)}$, 99$^{2)}$	4$^{1)}$
s	coal	hc	sub-bituminous	103	838$^{2)}$	39$^{2)}$					
s	coal	bc	briquettes	106	149-176$^{1)}$	140$^{1)}$	15$^{1)}$	15$^{1)}$	100$^{1)}$	97$^{1)}$	3.5$^{1)}$
s	coke	hc	coke oven	107	149-520$^{1)}$, 462-501$^{2)}$	140$^{1)}$, 35$^{2)}$	0.5$^{1)}$	0.5$^{1)}$	100$^{1)}$	100-105$^{1)}$, 105$^{2)}$	4$^{1)}$
s	coke	bc	coke oven	108	660$^{1)}$	200$^{1)}$	05$^{1)}$	0.5$^{1)}$	100$^{1)}$	100$^{1)}$	4$^{1)}$
l	oil		residual	203	149-1,470$^{1)}$	150-175$^{1)}$	4$^{1)}$	4$^{1)}$	10-15$^{1)}$	76-78$^{1)}$	2$^{1)}$
l	oil		gas	204	68-1,410$^{1)}$	70-100$^{1)}$	2.5$^{1)}$	2.5$^{1)}$	10-12$^{1)}$	73-74$^{1)}$	2$^{1)}$
g	gas		natural	301	0.4-149$^{1)}$, 371$^{2)}$	50$^{1)}$, 45$^{2)}$	2.5$^{1)}$	2.5$^{1)}$	10$^{1)}$	55-56$^{1)}$, 55$^{2)}$	1.5$^{1)}$

$^{1)}$ CORINAIR90 data, area sources (preliminary data)

$^{2)}$ CORINAIR90 data, point sources (preliminary data)

$^{3)}$ SO_x: /1/ 17,209 · S g/m³ fuel: primary metal production, process heaters, NAPFUE 204, S = sulphur content of fuel

19,006 · S g/m³ fuel: primary metal production, process heaters, NAPFUE 203, S = sulphur content of fuel

Emission factors of SO_2 given here may contain emissions from combustion of fuel as far as emissions from sintering of ore.

$^{4)}$ NO_x: /1/ 2,397 g/m³ fuel: primary metal production, process heaters, NAPFUE 204

6,591 g/m³ fuel: primary metal production, process heaters, NAPFUE 203

$^{5)}$ VOC: /1/ 24 g/m³ fuel: primary metal production, process heaters, NAPFUE 204

34 g/m³ fuel: primary metal production, process heaters, NAPFUE 203

$^{6)}$ It is assumed, that emission factors cited within the table are only related to combustion sources in primary lead production (except of SO_2); other process emissions are not covered.

Table 8.2d: Emission factors for particles for primairy lead production (kg/ton) (CEPMEIP)

Technologies	Abatement type	Unit	TSP	PM_{10}	$PM_{2.5}$	Uncertainty	Country or region
Conventional plant	ESP, settlers, scrubbers; moderate control of fugitive sources	kg/ton	0.5	0.4	0.2	4	EU (CEPMEIP)
Modern plant	fabric filters for most emission sources, BAT	kg/ton	0.12	0.114	0.06	3	EU (CEPMEIP)
Older plant	limited control of fugitive sources	kg/ton	10	3	0.6	4	EU (CEPMEIP)

NOTE: The uncertainty range (95% confidence) in the emission factor is expressed as a factor. The lower limit of the uncertainty range can be found by dividing the emission factor with the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example (first row in table 8.2d): The uncertainty in the emission factor for $PM_{2.5}$ from a conventional plant with an ESP settlers, scrubbers and moderate control of fugitive sources is 4 . The emission factor for $PM_{2.5}$ with uncertainty range will therefore be 0.2 kg per tonne with an uncertainty range of 0.05 (0.2/4) to 0.8 (0.2 x 4).

9 SPECIES PROFILES

Not applicable.

10 UNCERTAINTY ESTIMATES

The quality class of the emission factors is estimated to be about B.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The weakest aspects in the current methodology are the emission factors.

The fuel specific emission factors provided in Table 8.2c are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of emission factors with respect to point and area sources. Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Not applicable if actively treated on a point source basis.

13 TEMPORAL DISAGGREGATION CRITERIA

The primary lead production as such is a continuous process.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

- Richtlinien zur emissionsminderung in nicht-eisen-metall-industrien. Umweltbundesamt 1980.
- US-EPA (ed.): AP 42 CD-Rom; 1994

16 VERIFICATION PROCEDURES

A comparison between the profile of the calculated emissions and the composition of the ore could be used as a verification method.

17 REFERENCES

1 EPA (ed.): AIR Facility Subsystem, EPA-Doc. 450/4-90-003, Research Triangle Park, 1990.

2 Preliminary note on guidelines on measures and methods for heavy metals emissions control for the primary non-ferrous metal industry in the framework of the ECE task force “Heavy metal emissions” Presented by Sweden on meeting Berlin 21-24 january 1992.

3 Heavy metals emission to air in Poland for years 1980-1992, Hlawiczka, S., Zeglin, M., Kosterska, A., Inst. Ecol. Ind. Areas, Report 0-2.081, Katowice, 1995 (in Polish).

4 Datenerhebung über die Emissionen Umweltgefärdenden Schwermetalle; Jockel, W., Hartje, J.; Forschungsbericht 91-104 02 588, TüV Rheinland e.V. Köln; 1991.

5 Emission factors of atmospheric Cd, Pb and Zn for major source categories in Europe in 1950-1985; Pacyna, J.M.; NILU Report OR 30/91 (ATMOS 9/Info 7); 1990.

6 Survey on heavy metal sources and their emission factors for the ECE countries; Pacyna, J.M.; Proc. 2nd Mtg Task Force Heavy Metals Emissions, ECE Convention on Long-range Transboundary Air Pollution Working Group on Technology, Prague, 15-17 October 1991; page 27-55; 1990.

7 Calculation of atmospheric deposition of contaminants on the North Sea, Baart, A.C., Berdowski, J.J.M., Jaarsveld, J.A. van, Wulffraat, K.J., TNO-report TNO-MW-R 95/138, 1995.

8 Pacyna et al (2002): Combustion and Industry Expert Panel Workshop, European Joint Research Centre (JRC) ISPRA 2002. Data compiled by: Paycna J, van der Most P, Hobson M, Wieser, M, Müller B, Duval L, Spezzano P, Lotz T, Kakareka S.

9 Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 – 174

18 BIBLIOGRAPHY

No additional documents.

19 RELEASE VERSION, DATE, AND SOURCE

Version :	2.2
Date :	February 2003
Source:	J J M Berdowski, P F J van der Most, C Veldt, J P J Bloos

TNO
The Netherlands

Supported by: Otto Rentz, Dagmar Oertel
University of Karlsruhe (TH)
Germany

Updated with emission factors (CEPMEIP) for particulates by:
Tinus Pulles and Wilfred Appelman
TNO
The Netherlands
May 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Pieter van der Most

HIMH-MI-Netherlands
Inspectorate for the Environment
Dept for Monitoring and Information Management
PO Box 30945
2500 GX Den Haag
The Netherlands

Tel: +31 70 339 4606
Fax: +31 70 339 1988
Email: pieter.vandermost@minvrom.nl

SNAP CODE: **030305**

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Primary Zinc Production

NOSE CODE: **104.12.06**

NFR CODE: **1 A 2 b / 2 C 5**

ISIC: **2420**

1 ACTIVITIES INCLUDED:

The activities relevant for the primary zinc production are:

- Transport and storage of zinc ores
- Concentration of zinc ores
- Oxidation of zinc concentrates with air (roasting process)
- Production of zinc by the electrochemical or the thermal process
- After-treatment of zinc

A description of the process together with a brief description of the associated process steps (e.g. sintering) is provided in Section 3. Detailed descriptions of the associated process steps can be found in chapter B331.

2 CONTRIBUTION TO TOTAL EMISSIONS:

The contribution of gaseous emissions released from primary zinc production to total emissions in countries of the CORINAIR90 inventory is given as follows:

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	SNAP-code	Contribution to total emissions [%]										
Primary Zinc Production	030305	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Typical contribution		0.1	-	-	-	0	-	-	-	0.046	0.083	0.104
Highest value										0.116	0.194	0.236
Lowest value										0.001	0.002	0.002

* EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

The contribution of heavy metal emissions from primary zinc production to the total heavy metal emissions, according to IWAD [9], are given in Table 2.2.

Table 2.2: The contribution of heavy metal emissions from primary zinc production to the total emissions of the IWAD study [9]

Contribution to total emissions (%)					
Cd	Cr	Cu	Ni	Pb	Zn
18.0	0	0	0	0.7	25.6

0 = emissions are reported, but the exact value is below the rounding limit

3 GENERAL

3.1 Description of activities

Primary zinc is produced from ores which contain 85 wt% zinc sulphide and 8-10 wt% iron sulphide (zinc concentration about 50 wt%). The ores also contain metal sulphides such as lead, cobalt, copper, silver, cadmium and arsenic sulphide.

The ores are oxidized with air giving zinc oxide, sulphur oxide and zinc ferro. Chlorine and fluorine are removed from the combustion gas and the sulphur oxide is converted catalytically into sulphuric acid.

The electrochemical zinc production process

The roasted ores are leached in electrolytic cell acid. The zinc oxide dissolves in the acid solution, but the zinc ferro does not. After a separation step the raw zinc sulphate solution goes to the purification process and the insoluble matter to the jarosite precipitation process.

In the jarosite precipitation process, the insoluble matter of the roast is in good contact with ammonia and iron containing solution (contains also zinc and other metals) from the second leaching process. The iron precipitates, forming the insoluble ammoniumjarosite $[(NH_4)_2Fe_6(SO_4)_4(OH)_{12}]$. After separation the zinc containing solution goes to the first leaching process and the insoluble matter to a second leaching process. The insoluble matter is contacted in the second leaching process with a strong acid solution. The zinc ferro and almost all the other metals dissolve in the strong acid solution. After separation the zinc and iron containing solution is returned to the jarosite precipitation process where the iron and the insoluble matter are removed.

The raw zinc sulphate solution from the first leaching process is purified by adding zinc dust. Because of the addition of the zinc dust the metals copper, cobalt and cadmium are precipitated as metal. After filtration of the purified zinc sulphate solution the zinc electrolytic is separated from the solution. The electrolytically produced zinc sheets are melted in induction ovens and cast to blocks. The zinc alloys can also be produced by adding low concentrations of lead or aluminium.

The thermal smelting zinc production process

Roasted zinc is heated to a temperature of about 1100 °C (temperature > boiling point is needed) in the presence of anthracite or cokes. At that temperature zinc oxide is reduced and the carbon monoxide is formed from the carbon source. The carbon monoxide reacts with another molecule of zinc oxide and forms carbon dioxide:

$ZnO + C \rightarrow Zn(gas) + CO$ Reaction 1

$ZnO + CO \rightarrow Zn(gas) + CO_2$ Reaction 2

$CO_2 + C \rightarrow 2CO$ Reaction 3

Because reaction 2 is reversible (at lower temperatures zinc oxide is reformed) the concentration of carbon dioxide has to be decreased. The concentration of carbon dioxide is decreased by reaction with the carbon source.

The vaporized zinc is condensed by external condensers.

3.2 Definitions

Zinc concentrate	Enriched zinc ores which contain 85 wt% zinc sulphide and 8-10 wt% iron sulphide. The overall zinc concentration is about 50 wt%.
Roasting process	The zinc concentrate is oxidized, converting the zinc sulphide to zinc oxide, and partly to zinc ferro. The off-gas contains sulphur dioxide and traces of chlorine, fluorine and mercury. These compounds are removed by an air cleaning process (sulphur dioxide is converted into sulphuric acid). The solid product of the roasting process is called roast good.
First leaching process	The leaching process is the dissolving of the zinc oxide in an acid solution. The insoluble matter is separated and transported to the jarosite precipitation process.
Jarosite precipitation process	During the jarosite precipitation process the dissolved iron is precipitated. The iron is converted to ammoniumjarosite which does not dissolve in strong acid solution. The solution is transported back to the first leaching process and the insoluble matter (ammoniumjarosite, zinc ferro and other metals) is transported to a second leaching process.
Second leaching process	The insoluble matter of the jarosite precipitation process is contacted with a strong acid solution. The zinc ferro and several metals dissolve in the acid solution, but the jarosite does not. The solution with dissolved zinc and metals is transported back to the jarosite precipitation process and the insoluble matter is removed from the process (jarosite).

Purification process	During the purification process the traces of metal pollution in the zinc sulphate solution are removed by adding zinc dust. These metals would disturb the electrolytic separation of the zinc and decrease the quality of the electrolytic precipitate. The metals are removed by filtration from the purified zinc sulphate solution.
Electrolytic zinc production	Zinc is electrolytically separated from the purified zinc sulphate solutions. The zinc precipitates on the electrodes and can be removed as zinc sheets.
Thermal smelting process	Roasted zinc concentrates are melted at about 1100 °C in the presence of a carbon source. Zinc oxide is reduced to zinc and vaporized.
Zinc condensation	Vaporized zinc is condensed in several traps.
Casting process	The zinc sheets are melted and the zinc melt is casted in blocks which are suitable for transport.

3.3 Emissions

The emissions of particulate matter and heavy metals (zinc and cadmium) take place during the receipt and storage of the zinc ores and during the production. The receipt and storage of the zinc ore take place under a covering to reduce the emission. The emissions during production occur from tanks, ovens and separation equipment. These emissions can be decreased by changing some constructions.

The emission to the atmosphere by the thermal smelting process can be decreased by cleaning the condensed air. The thermal smelting production process leads to increased emission of metals.

Pollutants released are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic gaseous compounds (non-methane VOC and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (N_2O), and ammonia (NH_3). According to CORINAIR90 the main relevant pollutant is SO_2 (see also table 2.1).

Each of the two smelting processes (externally heated, electrothermic reduction) generates emissions along the various process steps. More than 90 % of the potential SO_2 emissions from zinc ores is released in roasters (for details see chapter B331). About 93 to 97 % of the sulphur in the feed is emitted as sulphur oxides. Concentrations of SO_2 in the off-gas vary with the type of roaster operation. Typical SO_2 concentrations for multiple hearth, suspension and fluidised bed roasters are 4.5 to 6.5 %, 10 to 13 % and 7 to 12 %, respectively [2].

Additional SO_2 is emitted from the sinter plant; the quantity depends on the sulphur content of the calcine feedstock. The SO_2 concentration of sinter plant exhaust gas ranges from 0.1 to 2.4 % [3].

3.4 Controls

Sulphur dioxide emissions from the roasting processes are often recovered at on-site sulphuric acid plants. No sulphur controls are used on the exhaust stream of sinter plants. Extensive desulphurisation before electrothermic retorting results in practically no SO_2 emissions from these devices [2,3].

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = \text{AR} \times \text{EF}$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8.1.

---

[1] The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tiers 3), to estimate emissions of gaseous pollutants from the cement production is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

If detailed information about the local situation is available this should prevail over the use of general emission factors. Reference emission fcators for comparison with users own data are provided in Section 8.2.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of primary zinc, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics.

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities of cement produced by various types of industrial technologies employed in the zinc industry at plant level. This data is however not always easily available.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

The primary zinc production plants can be considered as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Default Emission Factors for use with simpler methodology

Table 8.1: Emission factors for primary zinc production

Pollutant	**Emission Factor** *Limited control*	**Emission Factor** *Abatement*	**Units**
Arsenic	100	1	g/tonne zinc
Cadmium	100	50	g/tonne zinc
Copper	250	25	g/tonne zinc
Mercury	20	6	g/tonne zinc
Lead	500	150	g/tonne zinc
Zinc	7000	700	g/tonne zinc
Particulate matter*			
TSP		500	g/tonne zinc
PM_{10}		400	g/tonne zinc
$PM_{2.5}$		300	g/tonne zinc

Source: Pacyna et al, 2002

* CEPMEIP emission factors for a conventional plant with ESP, settlers, scrubbers; moderate control of fugitive sources. See also table 8.2d for more details and explanation on the uncertainty.

8.2 Reference Emission Factors for Use With Detailed Methodology

The emission factor for ore handling is calculated with the following formula:

Emission = $\{[\text{Mass}]_{\text{dust}} * [\text{Mass}]_{\text{ore}} * [\text{Metal compositon}]_{\text{dust}}\} * [\text{Zinc}]^{-1}_{\text{production}}$ [Formula 1],
where

$[\text{Mass}]_{\text{dust}}$:	Loss of mass during receipt of ore (weight percentage);
$[\text{Mass}]_{\text{ore}}$:	Yearly average received mass of zinc ores (tonnes);
$[\text{Metal composition}]_{\text{dust}}$:	Average weight percentage of metals in dust;
$[\text{Zinc}]_{\text{production}}$:	Total yearly produced mass zinc (tonnes).

The emission factor, summarizing all processes with vaporisation of heavy metal containing off-gas is calculated using:

Emission = $\{\text{Flow}_{\text{gas}} * d * [\text{Metal composition}]_{\text{gas}}\} * [\text{Zinc}]^{-1}_{\text{production}}$ [Formula 2],
where

$[\text{Flow}]_{\text{gas}}$:	Gas flow of a certain subprocess which emits heavy metals to air ($m^3 * year^{-1}$);
d:	Duration of the period of emission of heavy metals to air (per subprocess) (year);
$[\text{Metal composition}]_{\text{gas}}$:	Average concentration of heavy metals in emitted gas ($g\ m^{-3}$ gas);
$[\text{Zinc}]_{\text{production}}$:	Total yearly produced zinc (tonnes).

The emissions can vary widely depending on the ore used and the abatement measures applied, see Table 8.2a for reported emission factors. The emission factors given in Table 8.2b were prepared for the PARCOM-ATMOS Emission Factors Manual 1992. The factors for the emissions are based on the information from Table 8.2a. Table 8.2c contains fuel related emission factors for primary zinc production based on CORINAIR90 data in g/GJ unit. Technique related emission factors, mostly given in other units (e.g. g/Mg product) are listed in footnotes. Table 8.2d presents emissions factors from the CEPMEIP database on particulate matter emissions (TSP, PM_{10} and $PM_{2.5}$) for three different type of plants, old, conventional and modern.

Table 8.2a: Emission factors for the primary zinc production ($g.Mg^{-1}$ product) as reported by several countries/authors

	Germany [4]		**Poland [5]**		**Netherlands [6]**	**Pacyna [7,8]**	
Compound	thermal	electrolytic	thermal	electrolytic	electrolytic	thermal	electrolytic
Cadmium	100	2	13	0.4-29	0.5	500[1])	0.2
Lead	450	1	31-1000[2])	2.3-467	-	1900	-
Mercury	5-50	-	-	-	-	8	-
Zinc	-	-	420-3800	47-1320	120	16000	6

[1] with vertical retort: 200 g/Mg product; with Imperial Smelting Furnace: 50 g/Mg product.

[2] limited abatement.

Table 8.2b: Proposed emission factors for primary zinc production (g/Mg product)

Substance	**Emission factor**	
	thermal	electrolytic
Cadmium	[1]	1
Lead	500	5
Mercury	20	-
Zinc	10000	100

[1] depends on technology deployed (see Table 8.2a)

Table 8.2c: Emission factors for primary zinc production

					Emission factors						
	Fuel			NAPFUE-code	SO_2 3) [g/GJ]	NO_x 4) [g/GJ]	NMVOC 5) [g/GJ]	CH_4 [g/GJ]	CO [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]
s	coke	hc	coke oven	107	463 2)	35 2)				105 2)	
l	oil		residual	203	1,030-1,470 1)	150 1)			15 1)	76 1)	14 1)
l	oil		gas	204	1,410 1)	100 1)			12 1)	73 1)	

1) CORINAIR90 data, area sources (preliminary data)

2) CORINAIR90 data, point sources (preliminary data)

3)	SO_x: [1]	2,145,000	g/Mg conc. ore processed	multiple hearth roaster
		325	g/Mg conc. ore processed	sinter shand
		565	g/Mg conc. ore processed	vertical retort, electrothermal furnace
		202,200	g/Mg conc. ore processed	flash roaster
		111,750	g/Mg conc. ore processed	fluidised bed roaster
		17,209	g/m³ fuel	primary metal production, process heaters, NAPFUE 204
		19,006	g/m³ fuel	primary metal production, process heaters, NAPFUE 203
4)	NO_x: [1]	2,397	g/m³ fuel	primary metal production, process heaters, NAPFUE 204
		6,591	g/m³ fuel	primary metal production, process heaters, NAPFUE 203
5)	VOC: [1]	24	g/m³ fuel	primary metal production, process heaters, NAPFUE 204
		34	g/m³ fuel	primary metal production, process heaters, NAPFUE 203

Table 8.2d: Emission factors (kg/ton) for particulates for primary zinc production (CEPMEIP)

Technology	Abatement	TSP	PM_{10}	$PM_{2.5}$	Uncertainty
Conventional plant	ESP, settlers, scrubbers; moderate control of fugitive sources	0,5	0,4	0,3	4
Modern plant (BAT)	fabric filters for most emission sources	0,2	0,18	0,16	4
Older plant	Limited control of fugitive sources	6	5	4	4

NOTE: The uncertainty range (95% confidence) in the emission factor is expressed as a factor. The lower limit of the uncertainty range can be found by dividing the emission factor by the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example (first row in Table 8.2d): The uncertainty in the emission factor for $PM_{2.5}$ from a conventional plant is 4. The emission factor with uncertainty range will therefore be 0.3 kg per tonne primary zinc with an uncertainty range of 0.075 (0.3/4) to 1.2 (0.3x4).

9 SPECIES PROFILES

Since the dust emissions are related to the profile of the ore an ore composition profile could be useful.

10 UNCERTAINTY ESTIMATES

The quality class of the emission factors is estimated to be about B.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The fuel specific emission factors provided in Table 2 are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of emission factors with respect to point and area sources. Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges.

12 SPATIAL DISAGGREGATION CRITERIA

Not applicable.

13 TEMPORAL DISAGGREGATION CRITERIA

Primary zinc production is usually a continuous process.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

Environmental Protection Agency
Compilation of air pollutant emisssion factors AP-42

PARCOM-ATMOS Emission Factors Manual

16 VERIFICATION PROCEDURES

Emissions might be verified by comparing calculated emissions with the composition profile of the ore.

17 REFERENCES

1 EPA (ed.): AIR Facility Subsystem, EPA-Doc. 450/4-90-003, Research Triangle Park, 1990

2 US-EPA (ed.): AP 42 CD-Rom; 1995

3 US-EPA (ed.): AP 42 CD-Rom; 1994

4 Datenerhebung über die Emissionen Umweltgefärdenden Schwermetalle; Jockel, W., Hartje, J.; Forschungsbericht 91-104 02 588, TüV Rheinland e.V. Köln; 1991

5 Heavy metals emission to air in Poland for years 1980-1992, Hlawiczka, S., Zeglin, M., Kosterska, A., Inst. Ecol. Ind. Areas, Report 0-2.081, Katowice, 1995 (in Polish)

6 Spindocument "Productie van primair zink"; Matthijsen, A.J.C.M., Meijer, P.J.; RIVM (reportnr. 736301113); november 1992 (in Dutch)

7 Emission factors of atmospheric Cd, Pb and Zn for major source categories in Europe in 1950-1985; Pacyna, J.M.; NILU Report OR 30/91 (ATMOS 9/Info 7); 1990

8 Survey on heavy metal sources and their emission factors for the ECE countries; Pacyna, J.M.; Proc. 2nd Mtg Task Force Heavy Metals Emissions, ECE Convention on Long-range Transboundary Air Pollution Working Group on Technology, Praque, 15-17 October 1991; page 27-55; 1990

9 Calculation of atmospheric deposition of contaminants on the North Sea, Baart, A.C., Berdowski, J.J.M., Jaarsveld, J.A. van, Wulffraat, K.J., TNO-report TNO-MW-R 95/138, 1995.

10 Pacyna et al (2002): Combustion and Industry Expert Panel Workshop, European Joint Research Centre (JRC) ISPRA 2002. Data compiled by: Paycna J, van der Most P, Hobson M, Wieser, M, Müller B, Duval L, Spezzano P, Lotz T, Kakareka S.

11 Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 – 174

18 BIBLIOGRAPHY

No additional documents.

19 RELEASE VERSION, DATE, AND SOURCE

Version : 2.2

Date : February 2002

Source: J J M Berdowski, P F J van der Most, C Veldt, J P J Bloos
TNO

The Netherlands

Supported by: Otto Rentz, Dagmar Oertel
University of Karlsruhe (TH)
Germany

Updated with emission factors (CEPMEIP) for particulates by:
Tinus Pulles and Wilfred Appelman
TNO
The Netherlands
May 2006

20 POINT OF ENQURY

Any comments on this chapter or enquiries should be directed to:

Pieter van der Most

HIMH-MI-Netherlands
Inspectorate for the Environment
Dept for Monitoring and Information Management
PO Box 30945
2500 GX Den Haag
The Netherlands

Tel: +31 70 339 4606
Fax: +31 70 339 1988
Email: pieter.vandermost@minvrom.nl

SNAP CODE: **030306**

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Primary Copper Production

NOSE CODE: **104.12.07**

NFR CODE: **2 C 5 / 1 A 2 b**

ISIC: **2420**

1 ACTIVITIES INCLUDED

This chapter presents information on atmospheric emissions during the production of copper in primary smelters. More than 80 copper smelters around the world employ various conventional pyrometallurgical techniques to produce more than 90 % of the total copper production (e.g. Pacyna, 1989). Generally there are 3 steps in this process: 1) roasting of ores to remove sulphur, 2) smelting of roaster product to remove a part of the gangue for production of the copper matte, and 3) converting of the copper matte to blister copper. Atmospheric emissions of sulphur dioxide and heavy metals on fine particles occur during all the above mentioned processes.

Both emissions from fuel combustion in the primary copper plants and industrial processes are discussed here.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

Emissions of sulphur dioxide from non-ferrous metal production, particularly copper production contribute less than 10% to the total global emissions of this pollutant. However, copper smelting can be the most important source of sulphur dioxide emissions in certain regions, such as the Kola Peninsula, the Urals, the Norilsk area, and the Fergana region in Russia, Lower Silesia in Poland, and the Gijon region in Spain.

The contribution of emissions released from primary copper production to total emissions in countries of the CORINAIR90 inventory is given as follows:

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**										
Primary Copper Production	030306	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Typical contribution		0.1	0	-	-	0.2	0	-	-	0.082	0.146	0.182
Highest value										0.260	0.435	0.530
Lowest value										-	-	-

* EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
\- = no emissions are reported

Various trace elements can be measured as impurities in copper ores. During the copper production process they are emitted to the atmosphere. This process is the major source of atmospheric arsenic and copper (about 50 % of the global emissions of the element), and indium (almost 90 %), and a significant source of atmospheric antimony, cadmium and selenium (ca. 30 %), and nickel and tin (ca. 10 %) (Nriagu and Pacyna, 1988). The production of copper (and nickel) is the major source of these and other elements in regions with non-ferrous metal production. Contribution of primary copper production emissions of selected trace metals to the total emissions in Europe is presented in Table 2.2 (Pacyna, 1996).

Table 2.2: Contribution to the European emission of trace metals at the beginning of the 1990's (Pacyna, 1996)

Source-activity	SNAP-code	Contribution to the total emissions			
		As	Cd	Pb	Zn
Primary Copper Production	030306	29.4	10.5	4.8	6.2

Primary copper production is unlikely to be a significant source of sulphurhexafluoride (SF_6), hydrofluorocarbons (HFCs) or perfluorocarbons (PFCs), (ETC/AEM-CITEPA-RISOE 1997).

3 GENERAL

3.1 Description

The traditional pyrometallurgical copper smelting process is illustrated in Figure 3.1 (EPA, 1993). Typically, the blister copper is fire refined in an anode furnace, cast into "anodes" and sent to an electrolytic refinery for further impurity elimination. The currently used copper smelters process ore concentrates by drying them in fluidized bed dryers and then converting and refining the dried product in the same manner as the traditionally used process (EPA, 1993).

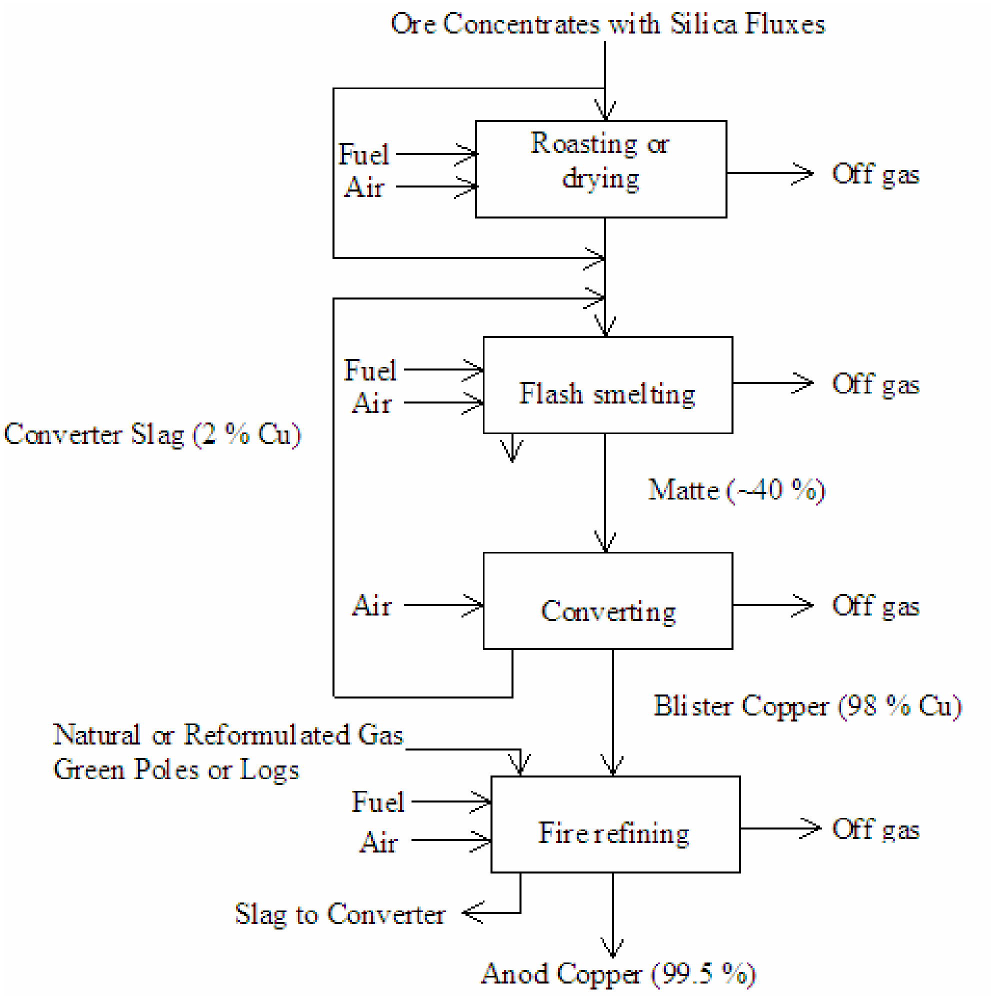
Concentrates usually contain 20-30 % Cu. In roasting, charge material of copper mixed with a siliceous flux is heated in air to about 650 C, eliminating 20 to 50 % of sulphur and portions of volatile trace elements. The roasted product, calcine, serves as a dried and heated charge for the smelting furnace.

In the smelting process, calcines are melted with siliceous flux in a flash smelting furnace to produce copper matte, a molten mixture of cuprous sulphide, ferrous sulphide, and some trace elements. Matte contains usually between 35 and 65 % of copper. Heat required in the smelting process comes from partial oxidation of the sulphide charge and from burning external fuel. Several smelting technologies are currently used in the copper industry, including reverberatory smelting, flash smelting (two processes are currently in commercial use: the INCO process and the OUTOKUMPU process), and the Noranda and electric processes.

In the reverberatory process heat is supplied by combustion of oil, gas, or pulverised coal. The temperature in the furnace can reach 1500 C. Flash furnace smelting combines the operations of roasting and smelting to produce a high grade copper matte from concentrates and flux. Most of flash furnaces use the heat generated from partial oxidation of their sulphide charge to provide much or all of the energy required for smelting. The temperature in the furnace reaches between 1200 and 1300 C. The Noranda process takes advantage of the heat energy available from the copper ore. The remaining thermal energy is supplied by oil burners, or by coal mixed with the ore concentrates. For the smelting in electric arc furnaces, heat is generated by the flow of an electric current in carbon electrodes lowered through the furnace roof and submerged in the slag layer of the molten bath (e.g. EPA, 1993; UN ECE, 1994).

Concerning emissions of air pollutants from the smelting operations, all the above described operations emit trace elements. Flash furnace smelting produces offgas streams containing high concentrations of sulphur dioxide. In contrary, electric arc furnaces do not produce fuel combustion gases, so flow rates are lower and so are the sulphur dioxide concentrations.

Figure 3.1: Typical primary copper smelter process (adapted from EPA, 1993)



The final step in the production of blister copper is converting. The rest of iron and sulphur in the matte is removed in this process leaving molten blister copper. Blister copper usually contains between 98.5 and 99.5 % pure copper with the rest consisting of trace elements, such as gold, silver, antimony, arsenic, bismuth, iron, lead, nickel, selenium, sulphur, tellurium, and zinc. There are various converting technologies applied in the copper production. The temperature in the converting furnace reaches 1100° C.

3.2 Definitions

Roasting	high-temperature process of the calcine production from ore concentrates.
Smelting	high-temperature process of the matte production from roasted (calcine feed) and unroasted (green feed) ore concentrates.
Converting	high-temperature process to yield blister copper from the matte.
Matte	impure product of smelting of sulphide ores.

3.3 Techniques

A description of primary copper process technology is given in section 3.1.

3.4 Emissions

Pollutants released are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (N_2O), trace elements, and selected persistent organic pollutants (POPs). The main relevant pollutants are SO_2 and CO, according to CORINAIR90 (see also Table 2.1) and selected trace elements. Concerning POPs, there are mostly dioxins and furans which are emitted from shaft furnaces, converters, and flame furnaces.

Primary copper smelters are a source of sulphur oxides (SO_x). Emissions are generated from the roasters, smelting furnaces, and converters (see Table 3.1). Fugitive emissions are generated during material handling operations. Remaining smelter operations use material containing very little sulphur, resulting in insignificant SO_2 emissions (EPA, 1995). Here only emissions from combustion processes with contact are relevant.

Table 3.1 shows typical average SO_2 concentrations from the various smelter units.

It can be assumed, that the SO_2 concentrations given in Table 3.1 take into account emissions from fuel sulphur and ore sulphur.

Table 3.1: Typical sulphur dioxide concentrations in off-gas from primary copper smelting sources (EPA, 1995)

Process unit	SO_2 concentration [vol.-%]
Multiple hearth roaster	1.5 - 3
Fluidized bed roaster	10 - 12
Reverberatory furnace	0.5 - 1.5
Electric arc furnace	4 - 8
Flash smelting furnace	10 - 70
Continuous smelting furnace	5 - 15
Pierce-Smith converter	4 - 7
Hoboken converter	8
Single contact H_2SO_4 plant	0.2 - 0.26
Double contact H_2SO_4 plant	0.05

3.5 Controls

Emission controls on copper smelters are employed for controlling sulphur dioxide and particulate matter emissions resulting from roasters, smelting furnaces, and converters. Control of sulphur dioxide emissions is achieved by absorption to sulphuric acid in the sulphuric acid plants, which are commonly a part of copper smelting plants. Reverberatory furnace effluent contains minimal SO_2 and is usually released directly to the atmosphere with no SO_2 reduction. Effluents from the other types of smelter furnaces contain higher concentrations of SO_2 and are treated in sulphuric acid plants before being vented. Single-contact sulphuric acid plants achieve 92.5 to 98 % conversion of SO_2 from plant effluent gas. Double-contact acid plants collect from 98 to more than 99 % of the SO_2. Absorption of the SO_2 in dimethylaniline solution has also been used in US-American smelters to produce liquid SO_2. (EPA, 1995).

Electrostatic precipitators (ESPs) are the common particulate matter control devices employed at copper smeltering facilities. The control efficiency of ESPs often reaches about 99 %. It should be added that most of the trace elements is condensed on very fine particles, e.g. <1.0 um diameter, and the control efficiency for these particles is lower, reaching about 97 % (e.g. Pacyna, 1987a).

A detailed description of control techniques and best available technologies for the primary copper production is available in UN ECE (1994).

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = \text{AR} \times \text{EF}$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8.1.

---

[1] The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tier 3), to estimate emissions of gaseous pollutants from the cement production is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

The detailed methodology to estimate emissions of trace elements from the primary copper production is similar to the simpler one. However, more information on the type of the process, e.g. roasting, smeltering, or converting, as well as on the type of the industrial technology should be made available. This information shall be used to estimate specific emissions for at least a specific industrial technology.

Measurements of the emission rate and chemical composition of fine particles with < 1.0 μm diameter are often carried out at major copper smelters worldwide. The results of these measurements are then used to estimate atmospheric emissions of several trace elements contained as impurities in copper ores.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of copper in primary smelters, suitable for estimating emissions using of the simpler estimation methodology (tier 1 and 2), is widely available from UN statistical yearbooks or national statistics. This information is satisfactory to estimate emissions with the use of the simpler estimation methodology.

The detailed methodology (tier 3) requires more detailed information. For example, the quantities produced by various types of industrial technologies employed in the copper industry at plant level. This data is however not always easily available. Therefore, the application of the detailed estimation methodology may be complicated unless the statistical data are available directly from a given smelter.

Some statistical yearbooks provide information about the production of blister copper. No information is easily available on the content of impurities in the copper ores from different mines or even mining regions.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 "Choice of activity statistics".

7 POINT SOURCE CRITERIA

Primary copper smelters should be regarded as point sources, very often high point sources, e.g. with over 100 m high stacks if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

The traditional roasters produce emissions with an average of 1 to 4 % of sulphur dioxide and 3 to 6 % of the weight of the charged concentrate as particulate. This type of roaster also produces substantial amounts of fugitive emissions. The fluid bed roaster, which is now becoming common, produces between 10 and 15 % of sulphur dioxide; up to 80 % of the calcine concentrate will leave the roaster in the flue gas (Environment Canada, 1982). The flue gases from the traditional smelter furnace contain between 1 and 2 % of sulphur dioxide, which can be increased to 2.5 % by oxygen enrichment of the air. Flash smelting produces sulphur dioxide concentrations as high as 80 % when only oxygen is used, or up to 10 to 15 % when no oxygen is used (Environment Canada, 1982). Finally, the conventional converters produce emissions with sulphur dioxide concentrations ranging from almost 0 to 10 % and averaging about 4 to 5 %. Sulphuric acid is the most common sulphur product recovered from metallurgical gases. A production schematic for single and double contact sulphuric acid plant is shown in Figure 8.1. Reference emission factors for comparison with users own data are provided in Section 8.2.

Figure 8.1: Single and double contact sulphuric acid plant schematic (adapted from Environment Canada, 1982)

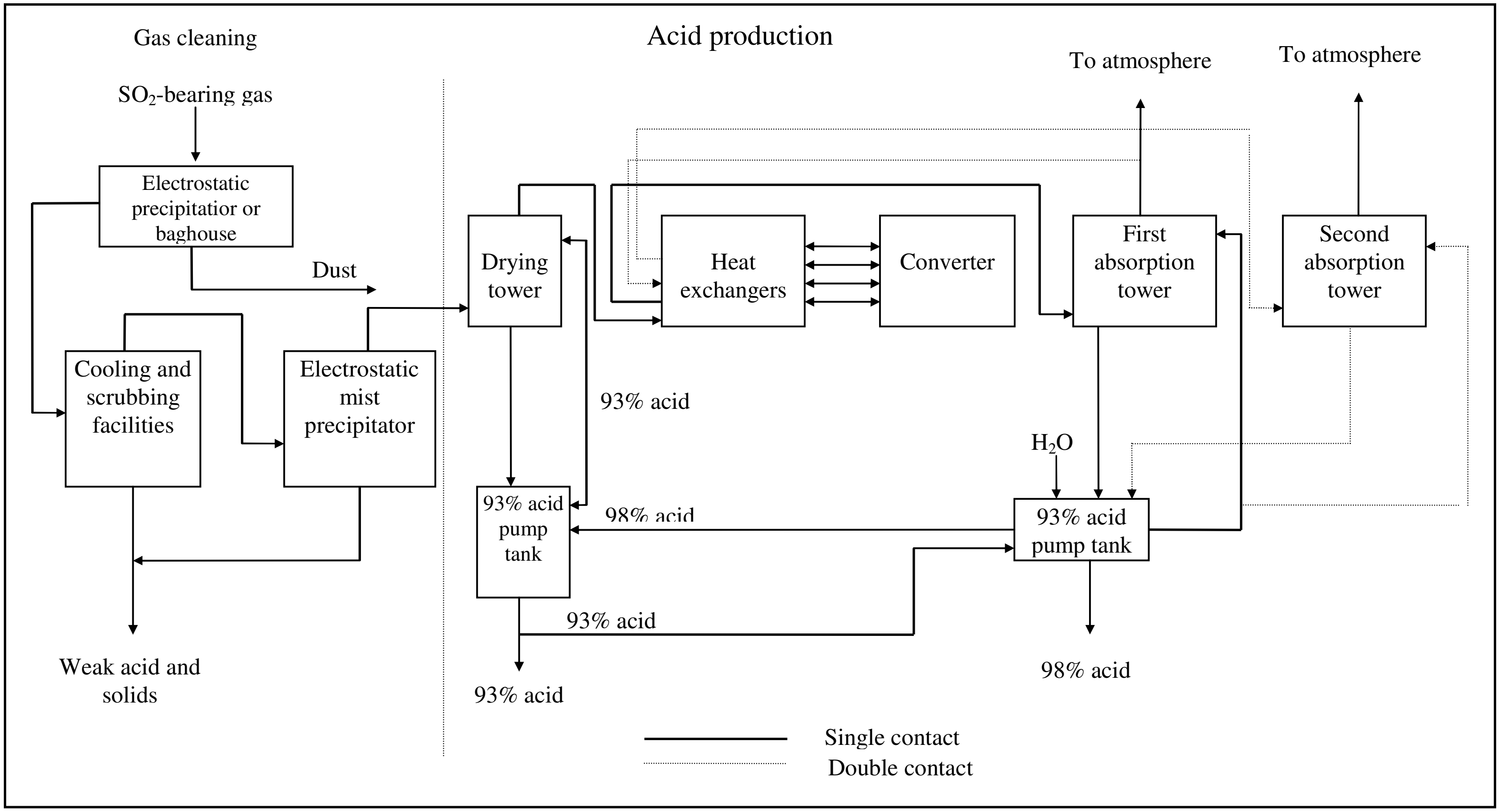


Table 8.1: Default Emission Factors for use with simpler methodology (Pacyna et al, 2002)

Pollutant	**Emission Factor** *Limited control*	**Emission Factor** *Abatement*	**Units**
Arsenic	1000	30	g/tonne copper
Cadmium	200	3	g/tonne copper
Chromium	1	0.1	g/tonne copper
Copper	4000	250	g/tonne copper
Mercury	0.1	0.1	g/tonne copper
Nickel	1500	50	g/tonne copper
Lead	2000	100	g/tonne copper
Selenium	100	15	g/tonne copper
Vanadium	7	1	g/tonne copper
Zinc	1000	200	g/tonne copper
Dioxins and furans	SS	SS	g/tonne copper
Particulate matter*			
TSP	1200		g/tonne copper
PM_{10}	960		g/tonne copper
$PM_{2.5}$	720		g/tonne copper

*CEPMEIP emission factors for a conventional plant, see also table 8.2f2 for information on uncertainty

Table 8.2a: Production data and maximum sulphur dioxide emissions for sulphuric acid processes (adopted from Environment Canada, 1982)

Sulphuric acid recovery process	SO_2 removal	SO_2 concentration in input gas (vol. %)	Maximum sulphur dioxide emissions in gas after treatment
Single contact process	97.5 %	7 %	5.7 g SO_2/m^3
	97.5 %	6 %	4.8 g SO_2/m^3 17 kg SO_2/t H_2SO_4
Double contact process	99.5 %	10 %	1.7 g SO_2/m^3 3.3 kg SO_2/t H_2SO_4
	99.5 %	6 %	1.0 g SO_2/m^3 3.3 kg SO_2/t H_2SO_4
	99.0 %	10 %	3.5 g SO_2/t H_2SO_4 6.6 kg SO_2/t H_2SO_4
	99.0 %	6 %	1.9 g SO_2/m^3 5.5 kg SO_2/t H_2SO_4

Table 8.2b: Emission factors for primary copper production based on CORINAIR90 data in [g/GJ].

Type of fuel	NAPFUE code	Emission factors SO_2 [g/GJ]	NO_x [g/GJ]	NMVOC [g/GJ]	CH_4 [g/GJ]	CO [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]
coal bc briquettes	107	$632^{2)}$	$702^{2)}$				$112^{2)}$	
oil residual	203	$419\text{-}1{,}470^{1)}$, $419\text{-}1{,}030^{2)}$	$123\text{-}150^{1)}$, $123\text{-}150^{2)}$	$7^{1)2)}$	$1^{1)}$	$5\text{-}15^{1)}$, 5-$20^{2)}$	$76\text{-}79^{1)}$, 77-$79^{2)}$	$15^{1)2)}$
oil gas	204	$1{,}410^{1)}$	$100^{1)}$			$12^{1)}$	$73^{1)}$	
Data quality rating		B	B	D	D	C	C	D

1) CORINAIR90 data, area sources
2) CORINAIR90 data, point sources

Table 8.2c: Emission factors for SO_2 in kg/tonne ore processed, unless specified otherwise (EPA, 1995)

Process type	Abatement type	Abatement efficiency	Emission Factor	Data Quality	Country or Region
Multiple hearth roaster	N/A	N/A	140.00	E	USA
Reverberatory smelting furnace after roaster	N/A	N/A	90.00	E	USA
Converter, all configurations	N/A	N/A	311.50	E	USA
Ore concentrate dryer	N/A	N/A	0.50	E	USA
Reverberatory smelting furnace with ore charge, without roasting	N/A	N/A	160.00	E	USA
Fluidized bed roaster	N/A	N/A	18.00	E	USA
Electric smelting furnace	N/A	N/A	120.00	E	USA
Flash smelting	N/A	N/A	410.00	E	USA
Roasting, fugitive emissions	N/A	N/A	0.50	E	USA
Reverberatory furnace, fugitive emissions	N/A	N/A	2.00	E	USA
Converter, fugitive emissions	N/A	N/A	65.00	E	USA
Anode refining furnace fugitive emissions	N/A	N/A	0.05	E	USA
Slag cleaning furnace, fugitive emissions	N/A	N/A	3.0	E	USA
Converter slag returns, fugitive emissions	N/A	N/A	0.05	E	USA
Slag cleaning furnace	N/A	N/A	3.75	E	USA
Reverberatory furnace with converter	N/A	N/A	160.00	E	USA
Fluidized bed roaster with reverberatory furnace and converter	N/A	N/A	180.00	E	USA
Concentrate dryer with electric furnace, cleaning furnace and converter	N/A	N/A	0.50	E	USA
Concentrate dryer with flash furnace and converter	N/A	N/A	0.50	E	USA
Multiple hearth roaster with reverberatory furnace and converter	N/A	N/A	140.00	E	USA
Fluidized bed roaster with electric furnace and converter	N/A	N/A	300.00	E	USA
Reverberatory furnace after multiple hearth roaster	N/A	N/A	90.00	E	USA
Electric furnace after concentrate dryer	N/A	N/A	120.00	E	USA
Flash furnace after concentrate dryer	N/A	N/A	410.00	E	USA
Electric furnace after fluidized bed roaster	N/A	N/A	45.00	E	USA
Primary metal production, process heaters *1	N/A	N/A	17209xS -19006xS S=Sulphur content	E	USA

*1 in g/m^3 fuel
N/A = Not available

Table 8.2d: Emission factors for NO_X in kg/tonne ore processed, unless specified otherwise (EPA, 1995)

Process type	Abatement type	Abatement efficiency	Emission Factor	Data Quality	Country or Region
Multiple hearth roaster	N/A	N/A	1.80	E	USA
Reverberatory smelting furnace after roaster	N/A	N/A	2.90	E	USA
Converter, all configurations	N/A	N/A	0	E	USA
Reverberatory smelting furnace with ore charge, without roasting	N/A	N/A	5.15	E	USA
Primary metal production, process heaters *1	N/A	N/A	2400-6600	E	USA

*1 in g/m^3 fuel
N/A = Not available

Table 8.2e: Emission Factors for VOC in g/tonne ore processed, unless specified otherwise (EPA, 1995)

Process type	Abatement type	Abatement efficiency	Emission Factor	Data Quality	Country or Region
Multiple hearth roaster	N/A	N/A	4.5	E	USA
Reverberatory smelting furnace after roaster	N/A	N/A	7.5	E	USA
Ore concentrate dryer	N/A	N/A	2.0	E	USA
Reverberatory smelting furnace with ore charge, without roasting	N/A	N/A	1.5	E	USA
Primary metal production, process heaters *1	N/A	N/A	24-34	E	USA

*1 in g/m^3 fuel
N/A = Not available

Table 8.2f1: Emission factors for particulate matter in kg/tonne ore processed, unless specified otherwise (EPA, 1995)

Process type	Abatement type	Abatement efficiency	Emission Factor	Data Quality	Country or Region
Multiple hearth roaster	N/A	N/A	22.50	E	USA
Reverberatory smelting furnace after roaster	N/A	N/A	25.00	E	USA
Converter, all configurations	N/A	N/A	18.00	E	USA
Ore concentrate dryer	N/A	N/A	5.00	E	USA
Reverberatory smelting furnace with ore charge, without roasting	N/A	N/A	25.00	E	USA
Fluidized bed roaster	N/A	N/A	27.50	E	USA
Electric smelting furnace	N/A	N/A	50.00	E	USA
Flash smelting	N/A	N/A	70.00	E	USA
Roasting, fugitive emissions	N/A	N/A	1.30	E	USA
Reverberatory furnace, fugitive emissions	N/A	N/A	0.20	E	USA
Converter, fugitive emissions	N/A	N/A	2.20	E	USA
Anode refining furnace fugitive emissions	N/A	N/A	0.25	E	USA
Slag cleaning furnace, fugitive emissions	N/A	N/A	4.00	E	USA
Slag cleaning furnace	N/A	N/A	5.00	E	USA
Reverberatory furnace with converter	N/A	N/A	25.00	E	USA
Fluidized bed roaster with reverberatory furnace and converter	N/A	N/A	27.50	E	USA
Concentrate dryer with electric furnace, cleaning furnace and converter	N/A	N/A	5.00	E	USA
Concentrate dryer with flash furnace and converter	N/A	N/A	5.00	E	USA
Multiple hearth roaster with reverberatory furnace and converter	N/A	N/A	22.50	E	USA
Fluidized bed roaster with electric furnace and converter	N/A	N/A	27.50	E	USA
Reverberatory furnace after multiple hearth roaster	N/A	N/A	25.00	E	USA
Electric furnace after concentrate dryer	N/A	N/A	50.00	E	USA
Flash furnace after concentrate dryer	N/A	N/A	70.00	E	USA
Electric furnace after fluidized bed roaster	N/A	N/A	50.00	E	USA
Fire (furnace) refining	N/A	N/A	5.00	E	USA
Reverberatory furnace after fluidized bed roaster	N/A	N/A	25.00	E	USA

N/A = Not available

Table 8.2f2: Emission factors for fine particulate matter in kg/tonne primairy copper produced (CEPMEIP)

Process type	**Abatement**	**Unit**	**TSP**	**PM_{10}**	**PM_{2-5}**	**Uncertainty**
Conventional installation	ESP and settling chambers; moderate control of fugitive emission	kg/tonne primairy copper produced	1.2	0.96	0.72	3
Modern plant (BAT)	Fabric filters for most emission sources	kg/tonne primairy copper produced	0.5	0.475	0.4	3
Older plant	Limited control of fugitive sources	kg/tonne primairy copper produced	10	3.0	1.0	3

NOTE: The uncertainty range (95% confidence) in the emission factor is expressed as a factor. The lower limit of the uncertainty range can be found by dividing the emission factor with the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example (first row in table): The uncertainty in the emission factor for $PM_{2.5}$ from a conventional plant with an ESP and settling chambers and moderate control of fugitive emission sources is 3. The emission factor for $PM_{2.5}$ with uncertainty range will therefore be 1.2 kg per tonne with an uncertainty range of 0.4 (1.2/3) to 3.6 (1.2 x 3).

A list of emission factors for several trace elements emitted from copper smelters is presented in Table 8.8. Results of measurements carried out in various countries were used to estimate these factors. The factors can be differentiated only as those relevant for a smelter with limited or improved control equipment. Limited control of emissions relates to a case of smelter equipped with ESP, the most common emission control installation in copper smelters worldwide, having control efficiency of about 99 %. Improved control of emissions relates to a case of smelter equipped with advanced emission control installation, such as high efficiency ESP, fabric filters, and/or wet scrubbers. Control efficiency of at least 99.9 % should be achieved in such smelter. It is assumed that all major copper smelters in the UN ECE region are equipped with at least limited control installations. Therefore, no uncontrolled emission factors are presented in Table 8.8.

Information available from the above mentioned measurements does not allow for further differentiation of emission factors with respect to either various industrial processes involved in the primary copper production or different production technologies used at present. Therefore, the factors in Table 8.8 can only be used in a simpler emission estimation methodology.

Table 8.2g: Compilation of emission factors for primary copper production (in g/tonne Cu produced)

Element	Global Emission Survey (Nriagu & Pacyna, 1988)	Measurements in Poland (Pacyna et al., 1981)	Measurements in Germany (Jockel and Hartje, 1991)	Measurements in Sweden (PARCOM, 1991)	Estimates in Canada (Jaques, 1987)	PARCOM program (PARCOM, 1992)	Suggested	
							Limited control	Impact control
Arsenic	1000-1500	~1000	15-45	100	600	50-100	500-1500	15-50
Chromium					1		1	?
Cadmium	200-400		3-10	15	550	6-15	200-500	3-10
Copper	1700-3600	1700-3600		300	200-12320		1500-4000	200-300
Indium	1-4						1-4	?
Manganese	100-500						100-500	?
Nickel	900				10-3410		900-3000	10-100
Lead	1300-2600	2300-3600	70	250	860-16700	250-2000	1000-4000	50-250
Antimony	50-200	~100			20		50-200	10-20
Selenium	50-150						50-150	10-20
Tin	50-200						50-200	?
Vanadium	5-10						5-10	?
Zinc	500-1000	~970		200		200-850	500-1000	100-200
Bismuth		~150					100-200	?
Mercury			0.06				?	0.10
Control	Unspecified	ESP, ca. 99% efficiency	High efficiency control equipment	Limited abatement (usually ESPs, fabric filter, wet scrubbers)	Based on questionnaires. Most plants use ESPs with 99 % efficiency	Unspecified	Common ESPs with 99% efficiency	Advanced control with at least 99.9% efficiency
Quality Data code	D	C	C	C	E	E	D	D

Concentrations of dioxins and furans in the flue gas after passing the control equipment in the primary copper production are presented in Table 8.9 after a compilation of data by the Working Group of the Subcommittee Air/Technology of the Federal Government/Federal States Emission Control Committee in Germany (Umweltbundesamt, 1996).

Table 8.2h: Concentrations of dioxins and furans in the flue gas after passing the control devices, in ng TEQ/m^{3}[*1]

Process	Emission Control Device	PCDD/F Concentration	Data Quality Code
1. Shaft furnace:		9.7	D
-old installation	Fabric filter		
-new installation	Fabric filter	1.5 - 2.0	C
2. Converter:			D
-using liquid black copper, and scrap	Fabric filter	0.16 - 0.6	
-using copper matte	ESP	0.001 - 0.005	D
3. Anode kiln	Fabric filter	0.05 -1.1	D
(flame furnace)			
4. Suspended melting	ESP	0.0001 - 0.007	D
furnace			

[*1] The toxic equivalency factor established by NATO/CCMS

In general, concentrations of dioxins and furans in the flue gas after the control device vary substantially due to the large differences in the materials used and different operational processes employed. For new installations controlled with fabric filters the concentrations would be up to 2.0 ng TEQ/m^{3}, while for older plants these concentrations can be by one order of magnitude higher.

Data from this table can be presented in a form of emission factors. These factors would range from 0.25 to 22.0 µg 1-TEQ/tonne of the copper produced.

9 SPECIES PROFILES

At present no reliable information exists on physical and chemical species of trace elements emitted during the primary copper production. It can be assumed that the majority of trace elements volatilized from the ores and then from semi-products in the production process enter the atmosphere on fine particles.

Very general information collected by Pacyna (1987b) appears to indicate that oxides and sulphates are the major chemical forms of atmospheric trace elements from the primary copper production.

10 UNCERTAINTY ESTIMATES

It is rather difficult to assess current uncertainties of emission estimates for pollutants emitted during the primary copper production. The uncertainties of sulphur dioxide emission estimates can be assessed in a similar way as the uncertainties of the estimates for the fossil fuel combustion (see chapter B111).

Recently it was concluded that up to 50 % of uncertainties can be assigned to the emission estimates of most of the trace elements emitted from major point sources in Europe (Pacyna, 1994). Similar uncertainty can be assigned for emission estimates of these compounds from the primary copper production.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Improvement of emission factors is necessary in order to obtain more accurate emission estimates for the primary copper production. This improvement should focus on preparing individual emission factors for major industrial technologies currently employed in roasting, smelting, and converting processes in the copper industry. In this way a detailed approach methodology for emission estimates can be applied. Obviously, it will be necessary to obtain relevant statistical data on the production of the calcines, matte, and blister.

The fuel specific emission factors provided in Table 8.2b are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of emission factors with respect to point and area sources. Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

National emission estimates can be disaggregated on the basis of production, population or employment statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

The primary production process is a continuous process. No temporal dissaggregation is needed.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

UN ECE State-of-the-Art Report on the Heavy Metals Emissions, the UN ECE Task Force on Heavy Metals Emissions, Prague, the Czech Republic, June 1994.

Environment Canada, Environmental Protection Service. Air Pollution Emissions and Control Technology: Primary Copper Industry. Economic and Technical Review Report EPS 3-AP-82-4, Air Pollution Control Directorate, July 1982.

16 VERIFICATION PROCEDURES

Estimated emission factors could be best verified by measurements at plants using different industrial technologies.

17 REFERENCES

Environment Canada (1982) Air pollution emissions and control technology: primary copper industry. Environment Canada, Environmental Protection Service, Economic and Technical Review Report EPS 3-AP-82-4, Ottawa, Canada.

EPA (1993) Locating and estimating air emissions from sources of mercury and mercury compounds. The U.S. Environmental Protection Agency, EPA-454/R-93-023, Research Triangle Park, NC.

EPA (1995) AP 42 CD-Rom. The U.S. Environmental Protection Agency, Research Triangle Park, NC.

ETC/AEM-CITEPA-RISOE (1997) Selected nomenclature for air pollution for CORINAIR94 inventory (SNAP 94), version 0.3 (Draft).

Jaques A.P. (1987) Summary of emissions of antimony, arsenic, cadmium, copper, lead, manganese, mercury and nickel in Canada. Environment Canada, Conservation and Protection, Environmental Analysis Branch, Ottawa, Canada.

Jockel W. and Hartje J. (1991) Datenerhebung uber die Emissionen Umweltgefahrdenden Schwermetalle, Forschungsbericht 91-104 02 588, TUV Rheinland, Cologne, Germany.

Nriagu J.O. and Pacyna J.M. (1988) Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature, 333, 134-139.

Pacyna et al (2002): Combustion and Industry Expert Panel Workshop, European Joint Research Centre (JRC) ISPRA 2002. Data compiled by: Paycna J, van der Most P, Hobson M, Wieser, M, Müller B, Duval L, Spezzano P, Lotz T, Kakareka S.

Pacyna J.M. (1987a) Methods for air pollution abatement. In: E.E. Pickett, ed. Atmospheric Pollution, Hemisphere Publ. Corp., Washington DC.

Pacyna J.M. (1987b) Atmospheric emissions of arsenic, cadmium, lead and mercury from high temperature processes in power generation and industry. In: T.C. Hutchinson and K.M. Meema, eds., Lead, Mercury, Cadmium and Arsenic in the Environment, Wiley, Chichester, the United Kingdom.

Pacyna J.M. (1989) Technological parameters affecting atmospheric emissions of trace elements from major anthropogenic sources. In: J.M. Pacyna and B. Ottar, eds., Control and Fate of Atmospheric trace Metals, Kluwer Academic Publ., Dordrecht, the Netherlands.

Pacyna J.M. (1994) Emissions of heavy metals in Europe. In: Background Document for the EMEP Workshop on European Monitoring, Modelling and Assessment of Heavy Metals and Persistent Organic Pollutants, Beekbergen, the Netherlands, 3-6 May, 1994.

Pacyna J.M. (1996) Atmospheric emissions of heavy metals for Europe: Improvements, Updates, Historical Data and Projections. A report for the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Pacyna J.M., Zwozdziak A., Zwozdziak J. and Matyniak Z. (1981) Physico-chemical transformations of pollutants in the individual environmental media. Techincal University of Wroclaw, Report SPR-14/81, Wroclaw, Poland (in Polish).

PARCOM (1991) Report of the 9th Meeting of the Working Group on Atmospheric Input of Pollutants to Convention Waters, London, 5-8 November, 1991.

PARCOM (1992) Emission Factor Manual PARCOM-ATMOS. Emission factors for air pollutants 1992. P.F.J. van der Most and C. Veldt, eds., TNO Environmental and Energy Research, TNO Rept. 92-235, Apeldoorn, the Netherlands.

Umweltbundesamt (1996) Determination of requirements to limit emissions of dioxins and furans. Report from the Working Group of the Subcommittee Air/Technology of the Federal Government/ Federal States Emission Control Committee, Texte 58/95, Umweltbundesamt, Berlin.

UN ECE (1994) State-of-the-art report on heavy metals emissions. UN Economic Commission for Europe, Convention on Long-range Transboundary Air Pollution, Task Force on Heavy Metals Emissions, Prague, the Czech Republic.

UN (1995) Statistical Yearbook. Fortieth Issue. United Nations Department for Economic and Social Information and Policy Analysis. New York, NY.

Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

No additional documents to those in Section 17.

19 RELEASE VERSION, DATE AND SOURCE

Version :	2.3
Date :	20 February 2003
Original author:	Jozef M Pacyna

Norwegian Institute for Air Research (NILU)
Norway

Supported by : Otto Rentz, Dagmar Oertel
University of Karlsruhe (TH)
Germany

Updated with emission factors (CEPMEIP) for particulates by:
Tinus Pulles and Wilfred Appelman
TNO
The Netherlands
May 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Jozef Pacyna

NILU - Norwegian Institute of Air Research
PO Box 100
N-2027 Kjeller
Norway

Tel: +47 63 89 8155
Fax: +47 63 89 80 50
Email: jozef.pacyna@nilu.no

SNAP CODE: **030307**

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Secondary Lead Production

NOSE CODE: **104.12.08**

NFR CODE: **1 A 2 b**

ISIC: 2420

1 ACTIVITIES INCLUDED

This chapter presents information on atmospheric emissions during the production of lead in secondary lead smelters. There are more than 200 secondary lead smelters in the world and a similar number of refineries, producing about 40% of the total lead production (Pacyna, 1989). Various furnaces, including blast, reverberatory and kettle-type ones, are employed in several production processes, such as storage battery production, lead alkyl manufacture, the manufacture of collapsible tubes, ammunition and plumbing equipment, coating of electrical cables and the casting, grinding, and machining of lead alloys, such as brasses and bronzes, in foundries, etc. This chapter describes the methods to estimate emissions of atmospheric pollutants during the secondary lead recovery from products such as battery plates, cable sheathing, type metal, and various slags and drosses.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

The contribution of emissions released from secondary lead production to total emissions in countries of the CORINAIR90 inventory is given as follows:

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**										
Secondary Lead Production		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Typical contribution	030307	0	-	-	-	-	-	-	-	0.010	0.018	0.014
Highest value										0.026	0.038	0.033
Lowest value										0.000	0.000	0.000

* EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
\- = no emissions are reported

There are several trace elements that can be emitted during the secondary lead production. However, these emissions are not very significant on a global scale. Nriagu and Pacyna (1988) concluded that secondary lead production contributes well below 1 % of the total atmospheric emissions of lead, antimony, selenium, and zinc. The estimated contribution of both primary and secondary lead production to European emissions is given in table 2-2. However, a secondary lead smelter or refinery can be an important emission source on a local scale.

Table 2.2: Contribution to total heavy metal emissions of the OSPARCOM-HELCOM-UN/ECE inventory for 1990 (up to 38 countries)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**							
		As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Total Lead Production	0403pb	1.0	1.4	-	0.1	0.9	-	1.1	1.1

\- = no emissions are reported

Secondary lead production may be a source of polychlorinated dioxins and furans, depending on parameters such as the composition of the raw material (e.g. presence of PVC in battery scrap). European wide emission estimates from this sector are not available.

3 GENERAL

3.1 Description

A secondary lead smelter is defined as any plant or factory in which lead-bearing scrap or lead-bearing materials, other than lead-bearing concentrates (ores) derived from a mining operation, is processed by metallurgical or chemical methods into refined lead, lead alloys or lead oxide. The high proportion of scrap-acid batteries that is re-processed provides feed for the alloy lead market (Barbour et al., 1978).

Secondary lead can be produced using pyrometallurgical or hydrometallurgical processes. Up to now hydrometallurgical processes have only been used at a preliminary stage. The pyrometallurgical processes are subdivided as follows (Rentz et al., 1996):

- battery breaking and processing (scrap preparation),
- smelting of battery scrap materials,
- refining.

In contrast to secondary zinc and copper production, which use a great variety of secondary materials, the recycling of secondary lead materials is concentrated on the processing of scrap batteries, with a world-wide portion of about 80 %. Metal sheets, pipe scraps, sludges, drosses, and dusts play only a minor role as secondary raw materials.

Secondary lead is sometimes combined with primary material for refining. Various pyrometallurgical refining technologies can be applied, depending on the feed material and product specification.

3.2 Definitions

Secondary lead production: - production of lead from materials other than ores.

3.3 Techniques

In general, for the production of secondary lead from battery scrap *two basic process routes* are possible. One route is based on breaking up and dismantling old batteries, and separating the paste, metallics and organics. Melting and reduction is carried out afterwards in different types of furnaces with an additional refining step. The other route is characterised by the direct treatment of complete and undismantled batteries with or without sulphuric acid inside in various smelting furnaces, also with an additional refining step. In detail, in the various stages of pyrometallurgical processing the following technologies are used world-wide (Rentz et al., 1996):

Battery scrap preparation
For battery scrap preparation various processes are possible, which can be differentiated by the degree of separation of single battery components. On an industrial scale, the Penneroya process, the MA process, the Tonolli-CX, and Contibat process are used. Generally heavy metal emissions from battery scrap preparation play a minor role compared to the smelting operation. The Varta and the Bergsoe process are smelting processes carried out without an initial separation, so that the batteries are directly smelted in a furnace.

Smelting
For the industrial production of secondary lead, various kinds of smelting furnaces are employed. The short rotary furnace is the most extensively used furnace for smelting separated battery scrap materials, while long rotary kilns and reverberatory furnaces are only used in a few applications. In contrast to the short rotary kiln, the long rotary kiln is operated

continuously. Reverberatory furnaces may also be used for smelting a lead-rich slag, which has been recovered in a primary furnace. Shaft furnaces are typically used for smelting unprepared battery scrap, together with lead cable scrap, furnace slag and filter dusts.

Refining
The lead bullion from secondary lead production contains various impurities, mainly copper, antimony, and tin, which may require elimination or adjustment by refining. Generally the operations necessary for secondary lead refining are limited compared to those necessary for primary lead refining. Pre-decopperising is not necessary and only final decopperising is carried out. In addition, a removal and adjustment of antimony and the elimination of tin may be necessary.

3.4 Emissions

In the secondary lead production process various direct and fugitive heavy metal emission sources are present (Rentz et al., 1996):

From *battery scrap preparation* only small amounts of particulate heavy metals are emitted as direct emissions if single preparation devices are equipped with a special waste gas cleaning facility.

For the *smelting process*, depending on the type of furnace various kinds of fuels are used. Generally short rotary furnaces and long rotary kilns are equipped with natural gas/air burners or sometimes with oxy-fuel burners, while shaft furnaces use coke as fuel. With the generated waste gas, irrespective of which kind of furnace is used, considerable amounts of heavy metals contained in the dust, as well as certain amounts of gaseous heavy metals are released, depending on the melting temperature and the vapour pressure.

For *refining and alloying*, several kettles are installed depending on the required lead quality. Because of the ongoing reactions in the waste gas from the refining and alloying kettles various amounts of heavy metals in particulate and gaseous form may be emitted.

Fugitive emissions from secondary lead smelting are released with almost all *stockpiling, transferring, charging,* and *discharging processes* The amount and composition greatly depends on the process configuration and operation mode. Values concerning the magnitude of unabated and abated emissions have not been revealed. The smelting furnaces are connected with fugitive emissions during the *charging* of raw materials and the *discharging* of slag and lead bullion. Also the *furnace openings* may be an emission source. Fugitive emissions from refining operations arise mainly during *charging, discharging* and *metal transfer* operations. Refining vessels not covered with primary hoods, may be a further emission source.

As in many plants, direct emission sources are preferably equipped with emission reduction measures, and the fugitive emissions released into ambient air in secondary lead production are generally much higher compared to direct emissions.

By far the most important SO_2 *and* NO_x emission source during secondary lead production is the operation of the smelting furnaces. The amount of SO_2 formed is mainly determined by the amount of sulphur contained in the raw materials and in the fuel used. Although a major part of the sulphur remains in the slag formed during the smelting process, a considerable share is also converted to SO_2.

SO_2 concentrations in the off-gas from reverberatory furnaces and blast furnaces are only available on a volume-percentage basis. During tests carried out at a reverberatory furnace using natural gas as a fuel, the concentration of SO_2 in the off-gas was measured at about 0.1 vol.-%. At a blast furnace using coke as fuel an even smaller off-gas concentration in the range of about 0.03 vol.-% was measured (Rentz et al., 1996b).

The formation of polychlorinated dioxins and furans depends on a number of factors such as scrap composition, process type, temperature, etc.

3.5 Controls

Most of the secondary lead smelters are equipped with dust-removing installations, such as baghouses for the control of direct emissions. The control efficiency of these installations is often very high and can reach 99.9 %. In secondary lead production for most processes it is possible to carry out final dedusting with fabric filters. In this way clean gas dust loads in general below 5 mg/m^3(STP) are achieved. For covering direct emissions from the refining and alloying kettles, primary suction hoods are arranged above the refining and melting kettles. These hoods are also linked to fabric filters. Waste gases from the furnace and the refining kettles may be dedusted together in one filter. Electrostatic precipitators or wet scrubbers may be in use for special raw gas conditions. Wet scrubbers are sometimes in place for the control of SO_2. Fugitive particulate emissions can be collected by local systems like hoods and other suction facilities or by partial or complete enclosures (Rentz et al., 1996).
Primary measures for the control of SO_2 aim to reduce the sulphur content in the fuel and in the raw materials used. Accordingly lower SO_2 emissions occur when using natural gas instead of heavy fuel oil for short rotary, long rotary and reverberatory furnace firing. Within blast furnace operation, the use of coke with a low sulphur content reduces emissions.

Oxy-fuel burners have been used in short rotary furnaces resulting in a significant reduction of the fuel input. Accordingly, a smaller pollutant mass flow is observed, although the concentration in the off-gas may be higher than in conventional firing technologies.

Significantly lower emissions occur during secondary lead production if desulphurisation of the lead paste is carried out prior to thermal treating. Within the Engitec-CX process, for example, sulphur is removed from the electrode paste by adding NaOH or Na_2CO_3. According to an operator, a reduction of SO_2 emissions in excess of 90 % can be achieved by this measure (Rentz et al., 1996b).

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = AR \times EF$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

It should be noted that the chemical composition of input scrap is one of the most important factors affecting the amount of emissions. The chemical composition of input scrap varies considerably from one plant to another and therefore emission factors also vary. Default emission factors in accordance with the simpler methodology are proposed in section 8.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tier 3), to estimate emissions of gaseous pollutants from the cement production is based on measurements or estimations using plant specific

---

[1] The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

In this case, different emission factors for various production technologies should be used. An account of the effect of emission controls should be considered. The different emission factors will have to be evaluated through measurements at representative sites.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of of lead in secondary smelters, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics.

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities of lead produced by various types of industrial technologies employed in the secondary lead industry at plant level. This data is however not always easily available. Some information in this respect is available from the International Lead and Zinc Study Group (www.ilzsg.org).

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

Secondary lead smelters should be regarded as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Information available from the sources cited below does not allow for further differentiation of emission factors with respect to either various industrial processes involved in the secondary lead production or different production technologies used at present. Therefore, the factors in table 8-1 can only be used in a simpler emission estimation methodology applied to the whole sector. As only limited background data are available on the emission factors, such as abatement type etc, a data quality E has been assigned.

The CORINAIR methodology requires the separate reporting of combustion related emissions (SNAP 030307) and process related emissions (SNAP 040300). Table 8-1 also gives emission factors related to the energy input in [g/GJ] based on CORINAIR90 data. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 values for the specific energy consumption were reported between 38.5 and 100 GJ/Mg product.

Table 8.1: Emission factor table for secondary lead production

Compound	**Plant type**	**Emission factor**	**Data Quality**	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Country or region**	**Ref.**
SO_2	*unknown*	0.85 - 8 g/GJ	*E*	*n. a.*	*n. a.*	*natural gas*	*Europe*	*CORINAIR90*
SO_2	*reverberatory furnace*	40,000 g/Mg charged	*E*	*n. a.*	*n. a.*	*n. a.*	*U.S.A.*	*EPA 1990*
SO_2	*blast furnace (cupola)*	26,500 g/Mg charged	*E*	*n. a.*	*n. a.*	*n. a.*	*U.S.A.*	*EPA 1990*
SO_2	*pot furnace heater*	17.26 g/l burned	*E*	*n. a.*	*n. a.*	*NAPFUE 204*	*U.S.A.*	*EPA 1990*
SO_2	*pot furnace heater*	9,611 g/Mm^3 burned	*E*	*n. a.*	*n. a.*	*NAPFUE 301*	*U.S.A.*	*EPA 1990*
SO_2	*secondary metal production, process heaters*	17,209 S g/m^3 fuel	*E*	*n. a.*	*n. a.*	*NAPFUE 204*	*U.S.A.*	*EPA 1990*
SO_2	*secondary metal production, process heaters*	19,006 S g/m^3 fuel	*E*	*n. a.*	*n. a.*	*NAPFUE 203*	*U.S.A.*	*EPA 1990*
NO_x	*unknown*	60 - 110 g/GJ	*E*	*n. a.*	*n. a.*	*natural gas*	*Europe*	*CORINAIR90*
NO_x	*reverberatory furnace*	150 g/Mg charged	*E*	*n. a.*	*n. a.*	*n. a.*	*U.S.A.*	*EPA 1990*
NO_x	*blast furnace (cupola)*	50 g/Mg charged	*E*	*n. a.*	*n. a.*	*n. a.*	*U.S.A.*	*EPA 1990*
NO_x	*pot furnace heater*	2.4 g/l burned	*E*	*n. a.*	*n. a.*	*NAPFUE 204*	*U.S.A.*	*EPA 1990*
NO_x	*pot furnace heater*	2,242,573 g/Mm^3 burned	*E*	*n. a.*	*n. a.*	*NAPFUE 301*	*U.S.A.*	*EPA 1990*
NO_x	*secondary metal production, process heaters*	2,396.78 g/m^3 fuel	*E*	*n. a.*	*n. a.*	*NAPFUE 204*	*U.S.A.*	*EPA 1990*
NO_x	*secondary metal production, process heaters*	6,591.15 g/m^3 fuel	*E*	*n. a.*	*n. a.*	*NAPFUE 203*	*U.S.A.*	*EPA 1990*
VOC	*pot furnace heater*	0.024 g/l burned	*E*	*n. a.*	*n. a.*	*NAPFUE 204*	*U.S.A.*	*EPA 1990*
VOC	*pot furnace heater*	44,851 g/Mm^3 burned	*E*	*n. a.*	*n. a.*	*NAPFUE 301*	*U.S.A.*	*EPA 1990*
VOC	*secondary metal production, process heaters*	23.97 g/m^3 fuel	*E*	*n. a.*	*n. a.*	*NAPFUE 204*	*U.S.A.*	*EPA 1990*

Table 8.1 (continued)

Compound	**Plant type**	**Emission factor**	**Data Quality**	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Country or region**	**Ref.**
VOC	*secondary metal production, process heaters*	33.55 g/m^3 fuel	*E*	*n. a.*	*n. a.*	*NAPFUE 203*	*U.S.A.*	*EPA 1990*
VOC	*secondary metal production, process heaters*	44,851 g/m^3 fuel	*E*	*n. a.*	*n. a.*	*NAPFUE 301, process gas*	*U.S.A.*	*EPA 1990*
NMVOC	*unknown*	10 g/GJ	*E*	*n. a.*	*n. a.*	*natural gas*	*Europe*	*CORINAIR90*
CH_4	*unknown*	2 g/GJ	*E*	*n. a.*	*n. a.*	*natural gas*	*Europe*	*CORINAIR90*
CO	*unknown*	7 - 30 g/GJ	*E*	*n. a.*	*n. a.*	*natural gas*	*Europe*	*CORINAIR90*
CO_2	*unknown*	55 kg/GJ	*E*	*n. a.*	*n. a.*	*natural gas*	*Europe*	*CORINAIR90*
N_2O	*unknown*	3 g/GJ	*E*	*n. a.*	*n. a.*	*natural gas*	*Europe*	*CORINAIR90*
As	*unknown*	8 g/Mg Pb produced	*E*	*n. a.*	*n. a.*	*n. a.*	*Austria*	*Schneider 1994*
Cd	*unknown*	2.5-3 g/Mg Pb produced	*E*	*ESP*	*ca. 99 %*	*n. a.*	*Europe*	*Pacyna 1986, Schneider 1994*
Cu	*unknown*	1.0 g/Mg Pb produced	*E*	*ESP*	*ca. 99 %*	*n. a.*	*Canada*	*Jacques 1987*
Pb	*unknown*	770 g/Mg Pb produced	*E*	*ESP*	*ca. 99 %*	*n. a.*	*Europe*	*Pacyna 1986*
Pb	*unknown*	100-300 g/Mg Pb produced	*E*	*n. a.*	*n. a.*	*n. a.*	*Europe, Canada*	*PARCOM 1992, Schneider 1994, Env. Can. 1983*
Zn	*unknown*	150 g/Mg Pb produced	*E*	*n. a.*	*n. a.*	*n. a.*	*Austria*	*Schneider 1994*
Zn	*unknown*	300 g/Mg Pb produced	*E*	*ESP*	*ca. 99 %*	*n. a.*	*Europe*	*Pacyna 1986*
PCDD/F	*unknown*	5-35 µg I-TEQ/Mg Pb produced	*E*	*fabric filter/ lime injection - limited abatement*	*range*	*n. a*	*Europe*	*Bremmer 1995 TNO 1995*

Table 8.1 (continued)

Compound	Plant type	Emission factor	Uncertainty*	Abatement type	Abatement efficiency	Fuel type	Country or region	Ref.
TSP	Conventional plant	0.4 kg / ton sec. Pb	2	ESP, settlers, scrubbers; moderate control of fugitive sources	n.a.	n.a.	Europe	CEPMEIP
TSP	Modern plant (BAT)	0.3	2	fabric filters for most emission sources	n.a.	n.a.	Europe	CEPMEIP
TSP	Older plant	1,0	2	limited control of fugitive sources	n.a.	n.a.	Europe	CEPMEIP
PM_{10}	Conventional plant	0.32 kg / ton sec. Pb	2	ESP, settlers, scrubbers; moderate control of fugitive sources	n.a.	n.a.	Europe	CEPMEIP
PM_{10}	Modern plant (BAT)	0.285	2	fabric filters for most emission sources	n.a.	n.a.	Europe	CEPMEIP
PM_{10}	Older plant	0.7	2	limited control of fugitive sources	n.a.	n.a.	Europe	CEPMEIP

$PM_{2.5}$	Conventional plant	0.16 kg / ton sec. Pb	2	ESP, settlers, scrubbers; moderate control of fugitive sources	n.a.	n.a.	Europe	CEPMEIP
$PM_{2.5}$	Modern plant (BAT)	0.15	2	fabric filters for most emission sources	n.a.	n.a.	Europe	CEPMEIP
$PM_{2.5}$	Older plant	0.4	2	limited control of fugitive sources	n.a.	n.a.	Europe	CEPMEIP

n. a.: not available

*note: NOTE: The uncertainty range (95% confidence) in the emission factor is expressed as a factor. The lower limit of the uncertainty range can be found by dividing the emission factor by the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example: The uncertainty in the emission factor for PM2.5 from a conventional plant is 2 . The emission factor with uncertainty range will therefore be 0.16 kg per tonne secundary lead with an uncertainty range of 0.08 (0.16/2) to 0.32 (0.16 x2).

9 SPECIES PROFILES

At present no reliable information exists on physical and chemical species of trace elements emitted during the secondary lead production. It can be assumed that the majority of trace elements volatilised from scrap and other lead-containing materials enter the atmosphere on fine particles. Table 9-1 indicates the heavy metal composition of dust from various secondary lead furnaces (Rentz et al., 1996):

Table 9.1: Weight composition of dust from secondary lead furnaces

	Weight composition of dust [wt.-%]	
Short rotary furnace	As 0.002 - 0.4	Ni 0.002 - 0.01
	Cd 0.07 - 0.7	Pb 20 - 54
	Cr 0.01	Sb 0.011 - 1
	Hg 0.01	Zn 0.5
Reverberatory furnace	As 0.1 - 10	Pb 30 - 50
	Cd 0.01 - 0.5	Sb 0.1 - 40
	Cu 0.001 - 0.005	Zn 0.01 - 1
Shaft furnace	As 0.01 - 3	Pb 30 - 55
	Cd 0.5 - 10	Sb 0.1 - 3
	Cu 0.01 - 0.04	Zn 1 - 10

10 UNCERTAINTY ESTIMATES

It is difficult to assess current uncertainties of emission estimates for pollutants emitted during the secondary lead production. Recently it was concluded that up to 50 % of uncertainties can be assigned for the emission estimates of most of the trace elements emitted from major point sources in Europe (Pacyna, 1994). Higher uncertainty can be assigned for emission estimates of these compounds from the secondary lead production. Information on emission factors and statistics is more limited for the secondary lead smelters than for major point sources, such as primary smelters and power plants.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Improvement of emission factors is necessary in order to obtain more accurate emission estimates for the secondary lead production. This improvement should focus on preparing individual emission factors for major industrial technologies currently employed in the lead industry. In this way a detailed approach methodology for emission estimates can be applied. It will be necessary to obtain relevant statistical data on the production of lead in various secondary lead furnaces.

The fuel-specific emission factors provided in table 8-1, are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of values with respect to point and area sources. Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

National emission estimates can be disaggregated on the basis of production, population or employment statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

The secondary lead production is a continuous process. No temporal disaggregation is needed.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

UN ECE State-of-the-Art Report on the Heavy Metals Emissions, the UN ECE Task Force on Heavy Metals Emissions, Prague, the Czech Republic, June 1994.

Environment Canada, Environmental Protection Service. National Inventory of Sources and Emissions of Lead. Economic and Technical Review Report EPS 3-EP-83-6, Air Pollution Control Directorate, November 1983.

16 VERIFICATION PROCEDURES

Estimated emission factors could be best verified by measurements at plants using different industrial technologies.

17 REFERENCES

Barbour A.K., Castle J.F. and Woods S.E. (1978) Production of non-ferrous metals. In: Industrial Air Pollution Handbook, A. Parker (ed.), Mc Graw-Hill Book Comp. Ltd., London.

Bremmer H.J. (1995) Secundaire Non-Ferroindustrie; RIVM-report 773006174; RIZA-report 92.003/74.

Bremmer H.J., Troost L.M., Kuipers G., de Koning J. and Sein A.A. (1994). Emissions of dioxins in the Netherlands. Report No. 770501003, RIVM (Research for Man and the Environment), Bilthoven, Netherlands.

Environment Canada (1983) National Inventory of Sources and Emissions of Lead. Environment Canada, Environmental Protection Service, Economic and Technical Review Report EPS 3-EP-83-6, Ottawa, Canada.

EPA (1990) AIR Facility Subsystem, EPA-Doc. 450/4-90-003, Research Triangle Park.

ILZSG (1985) World Directory: Secondary Lead Plants. International Lead and Zinc Study Group Report, London.

Jaques A.P. (1987) Summary of emissions of antimony, arsenic, cadmium, copper, lead, manganese, mercury and nickel in Canada. Environment Canada, Conservation and Protection, Environmental Analysis Branch, Ottawa, Canada.

Leech P.K. (1993) UK atmospheric emissions of metals and halides 1970-1991. Warren Spring Laboratory Rept. LR 923, Stevenage, UK.

Nriagu J.O. and Pacyna J.M. (1988) Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature, 333, 134-139.

Pacyna J.M. (1983) Trace element emission from anthropogenic sources in Europe. Norwegian Institute for Air Research, NILU Rept. TR 10/82, Lillestrøm, Norway.

Pacyna J.M. (1989) Technological parameters affecting atmospheric emissions of trace elements from major anthropogenic sources. In: J.M. Pacyna and B. Ottar, eds., Control and Fate of Atmospheric trace Metals, Kluwer Academic Publ., Dordrecht, the Netherlands.

Pacyna J.M. (1994) Emissions of heavy metals in Europe. In: Background Document for the EMEP Workshop on European Monitoring, Modelling and Assessment of Heavy Metals and Persistent Organic Pollutants, Beekbergen, the Netherlands, 3-6

May, 1994.

PARCOM (1992) Emission Factor Manual PARCOM-ATMOS. Emission factors for air pollutants 1992. P.F.J. van der Most and C. Veldt, eds., TNO Environmental and Energy Research, TNO Rept. 92-235, Apeldoorn, the Netherlands.

Rentz O., Sasse H., Karl U., Schleef H.-J. and Dorn R. (1996) Emission Control at Stationary Sources in the Federal Republic of Germany, Volume II, Heavy Metal Emission Control, Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit, Luftreinhaltung, 204 02 360.

Rentz O., Schleef H.-J., Dorn R., Sasse H. and Karl U. (1996b) Emission Control at Stationary Sources in the Federal Republic of Germany, Volume I, Sulphur Oxide and Nitrogen Oxide Emission Control, Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit, Luftreinhaltung, 204 02 360.

Schneider M. (1994) Heavy metal emissions in Austria. Umweltbundesamt report to the UN ECE Task Force on Heavy Metals Emissions. Wien, March, 1994.

TNO (1995) Technical Paper to the OSPARCOM-HELCOM-UNECE Emission inventory of heavy metals and Persistent Organic Pollutants, Report number TNO-MAP-R95/247.

UN ECE (1994) State-of-the-art report on heavy metals emissions. UN Economic Commission for Europe, Convention on Long-range Transboundary Air Pollution, Task Force on Heavy Metals Emissions, Prague, the Czech Republic.

United Nations Industrial commodity statistics yearbook: production and consumption statistics, Department for Economic and Social Information and Policy Analysis, Statistical Division, New York, USA.

Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

No additional documents.

19 RELEASE VERSION, DATE AND SOURCE

Version :	3.1
Date :	March 1999
Updated by:	Otto Rentz; Ute Karl University of Karlsruhe (TH) Germany

Updated with emission factors (CEPMEIP) for particulates by:
Tinus Pulles and Wilfred Appelman
TNO
The Netherlands
May, 2006

Original author: Jozef M Pacyna
Norwegian Institute for Air Research (NILU)
Norway

Supported by: Otto Rentz Dagmar Oertel
University of Karlsruhe (TH)
Germany

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Ute Karl

French-German Institute for Environmental Research
University of Karlsruhe
Hertzstr 16
D-76187 Karlsruhe
Germany

Tel: +49 721 608 4590
Fax: +49 721 75 89 09
Email: ute.karl@wiwi.uni-karlsruhe.de

SNAP CODE: **030308**

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Secondary Zinc Production

NOSE CODE: **104.12.09**

NFR CODE: **1 A 2 b**

ISIC: **2420**

1 ACTIVITIES INCLUDED

Zinc is produced from various primary and secondary raw materials. The primary processes use sulphidic and oxidic concentrates, while in secondary processes recycled oxidised and metallic products mostly from other metallurgical operations are employed. This chapter includes information on atmospheric emissions during the production of secondary zinc. In practice, a clear distinction of primary and secondary zinc production is often difficult, because many smelters use both primary and secondary raw materials.

Zinc production in the western world stood at about 5.2 million tonnes in 1990. Of this, 4.73 million tonnes originate from primary resources (ores), while the balance of 0.47 million tonnes is produced at the smelters from secondary raw materials (Metallgesellschaft 1994). The production of zinc in secondary smelters is increasing in various regions of the world. This increase can be as high as 5% per year in Eastern Europe. This chapter describes the methods to estimate both combustion and process emissions of atmospheric pollutants during the secondary zinc recovery from various types of zinc scrap (e.g. Barbour et al, 1978).

2 CONTRIBUTIONS TO TOTAL EMISSIONS

There are several trace metals as well as dioxins and furans which can be emitted during the secondary zinc production process. However, heavy metal emissions from this source category are not very significant on a global scale. Nriagu and Pacyna (1988) concluded that the secondary zinc production contributes well below 1 % of the total atmospheric emissions of lead, cadmium, antimony, selenium, and zinc. A similar contribution to European atmospheric emissions from secondary zinc production was estimated at the beginning of the 1980’s (Pacyna, 1983). The estimated contribution of both primary and secondary zinc production to European emissions is given in Table 2.1 (Berdowski 1997). However, a secondary zinc smelter can be an important emission source on a local scale.

The contribution of emissions released from secondary zinc production to total emissions of those pollutants covered by the CORINAIR90 inventory is negligible (see Table 2.2).

Table 2.1: Contribution to total heavy metal emissions of the OSPARCOM-HELCOM-UNECE inventory for 1990 (up to 38 countries)

Source-activity	SNAP-code	Contribution to total emissions [%]							
		As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Total Zinc Production	0403zn	0	9.1	0	0	7.1	0	0.5	9.8

Table 2.2: Contribution to total emissions of the CORINAIR90 inventory (up to 28 countries)

Source-activity	SNAP-code	Contribution to total emissions [%]										
Secondary Zinc Production	030308	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP	PM_{10*}	$PM_{2.5*}$
Typical contribution		-	-	-	-	0	-	-	-	0.002	0.003	0.003
Highest value										0.005	0.010	0.012
Lowest value										-	-	-

* EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
\- = no emissions are reported

Secondary zinc production is unlikely to be a significant source of sulphurhexafluoride (SF_6), hydrofluorocarbons (HFCs) or perfluorocarbons (PFCs), (ETC/AEM-CITEPA-RISOE 1997).

3 GENERAL

3.1 Description

A secondary zinc smelter is defined as any plant or factory in which zinc-bearing scrap or zinc-bearing materials, other than zinc-bearing concentrates (ores) derived from a mining operation, are processed (e.g. Barbour et al., 1978). In practice, primary smelters often also use zinc scrap or recycled dust as input material.

Zinc recovery involves three general operations performed on scrap, namely pre-treatment, melting, and refining. Scrap metal is delivered to the secondary zinc processor as ingots, rejected castings, flashing, and other mixed metal scrap containing zinc (US EPA, 1995).

Scrap *pre-treatment* includes sorting, cleaning, crushing and screening, sweating, and leaching. In the sorting operation, zinc scrap is manually separated according to zinc content and any subsequent processing requirements. Cleaning removes foreign materials to improve product quality and recovery efficiency. Crushing facilitates the ability to separate the zinc from the contaminants. Screening and pneumatic classification concentrates the zinc metal for further processing. Leaching with sodium carbonate solution converts dross and skimmings to zinc oxide, which can be reduced to zinc metal (US EPA, 1995).

Pure zinc scrap is *melted* in kettle, crucible, reverberatory, and electric induction furnaces. Flux is used in these furnaces to trap impurities from the molten zinc. Facilitated by agitation, flux and impurities float to the surface of the melt as dross, and are skimmed from the surface. The remaining molten zinc may be poured into moulds or transferred to the refining operation in a molten state (US EPA, 1995).

Refining processes remove further impurities from clean zinc alloy scrap and from zinc vaporised during the melt phase in retort furnaces. Molten zinc is heated until it vaporises. Zinc vapour is condensed and recovered in several forms, depending upon temperature, recovery time, absence or presence of oxygen, and equipment used during zinc vapour condensation. Final products from refining processes include zinc ingots, zinc dust, zinc oxide, and zinc alloys (US EPA, 1995).

Generally the processes used for the recycling of secondary zinc can be distinguished by the kind of raw materials employed (Rentz et al., 1996):

Very poor oxidic residues and oxidic dusts, e.g. from the steel industry, are treated in *rotary furnaces* (Waelz furnaces), producing metal oxides in a more concentrated form. These concentrated oxides (Waelz oxides) are processed together with oxidic ores in primary thermal zinc smelters, in particular Imperial Smelting furnaces which are in use for combined lead and zinc production. In this case, a clear discrimination between primary and secondary zinc production as well as between zinc and lead production is difficult.

Metallic products prior to smelting are comminuted and sieved to separate metal grains from the oxides. Afterwards the metallic products are melted in *melting furnaces*, mainly of the induction type or muffle furnaces. Finally the molten zinc is cast and in part refined to high-purity zinc in distillation columns.

In *New Jersey retorts* it is possible to process a large variety of oxidic secondary materials together with metallic materials simultaneously. For charge preparation the oxides are mixed with bituminous or gas coal, briquetted, and coked. The briquettes together with the metallic materials are charged into the retorts. The zinc vapours from the retorts are condensed by splash-condensing.

3.2 Definitions

Secondary zinc production: - production of zinc from materials other than ores.

Other definitions are covered in Sections 3.1 and 3.3.

3.3 Techniques

A *sweating furnace* (rotary, reverberatory, or muffle furnace) slowly heats the scrap containing zinc and other metals to approximately 364°C. This temperature is sufficient to melt zinc but is still below the melting point of the remaining metals. Molten zinc collects at the bottom of the sweat furnace and is subsequently recovered. The remaining scrap metal is cooled and removed to be sold to other secondary processors (US EPA, 1995).

A more sophisticated type of sweating operation involves holding scrap in a basket and heating it in a molten salt bath to a closely controlled temperature. This yields a liquid metal, which separates downwards out of the salt, and a remaining solid of the other metals still free from oxidation. By arranging for heating to a sequence of temperatures, related to the melting point of the metals or alloys involved, a set of molten metal fractions with minimum intermixture can be obtained (e.g. Barbour et al., 1978).

For zinc production in *New Jersey retorts* the zinc containing raw materials are picked up from the stockpiling area. For some raw materials a *charge preparation* is carried out, including comminution, sieving, and magnetic separation, so that a metallic and a oxidic fraction is obtained. Furthermore, for some raw materials dechlorination is necessary. The oxidic raw materials, like dusts and zinc drosses are mixed with bituminous coal. Subsequently, the mixture which contains about 40 % zinc is briquetted together with a binding agent, coked at temperatures around 800°C in an autogenous coking furnace and then charged to the New Jersey retorts together with small amounts of pure metallic materials. By heating with natural gas and CO containing waste gases, in the retorts temperatures of around 1,100°C are achieved, so that the zinc is reduced and vaporised. Subsequently, the vaporised zinc is precipitated in splash-condensers and transferred to the foundry via a holding furnace. Here the so-called selected zinc is cast into ingots. The residues from the retorts are treated in a melting cyclone to produce lead-zinc-mix oxides and slag. Figure 3.1 shows a schematic diagram for secondary zinc production using New Jersey retorts. Potential sources of particulate and heavy metal emissions are indicated. The metallic fraction from charge preparation together with other metallic materials like galvanic drosses, scrap zinc, and scrap alloys are melted. The raw zinc is then sent to a *liquation furnace* where, in a first refining step, zinc contents from 97.5 to 98 % are achieved. The melted and refined zinc is also cast into ingots (Rentz et al., 1996).

The raw materials for *Waelz furnaces* are mainly dusts and slurry from electric arc furnaces used in the steel industry, together with other zinc and lead containing secondary materials. For transferring and charging, the dustlike secondary materials are generally pelletised at the steel plant.

After mixing, the zinc and lead containing pellets, coke as reducing agent, and fluxes are charged via a charging sluice at the upper end of the slightly sloped rotary kiln. The rotation and the slope lead to an overlaid translational and rotational movement of the charge. In a counter-current direction to the charge air as combustion gas is injected at the exit opening of the furnace. At temperatures of around 1,200°C and with residence times of around 4 hours zinc and lead are reduced and vaporised. The metal vapours are reoxidised in the gas filled space of the furnace and evacuated through the charge opening together with the waste gas. In a cleaning device, the metal oxides are collected again and as filter dust the so-called Waelz oxide with a zinc content of around 55 % and a lead content of around 10 % is generated. The Waelz oxide is subsequently charged into an Imperial Smelting furnace which is used for combined primary zinc/lead smelting. The slag from the Waelz furnace is cooled down and granulated in a water bath. Additional oil as fuel is only needed at the start-up of the furnace, while in stationary operation the combustion of the metal vapours and carbon monoxide covers the energy demand of the process (Rentz et al., 1996). A schematic representation of the Waelz process is depicted in Figure 3.2.

Secondary zinc is sometimes combined with primary material for refining. Various pyrometallurgical refining technologies can be applied, depending on the feed material and product specification. Thermal zinc refining by fractional distillation is possible in rectifying columns at temperatures around 950°C (Rentz et al., 1996).

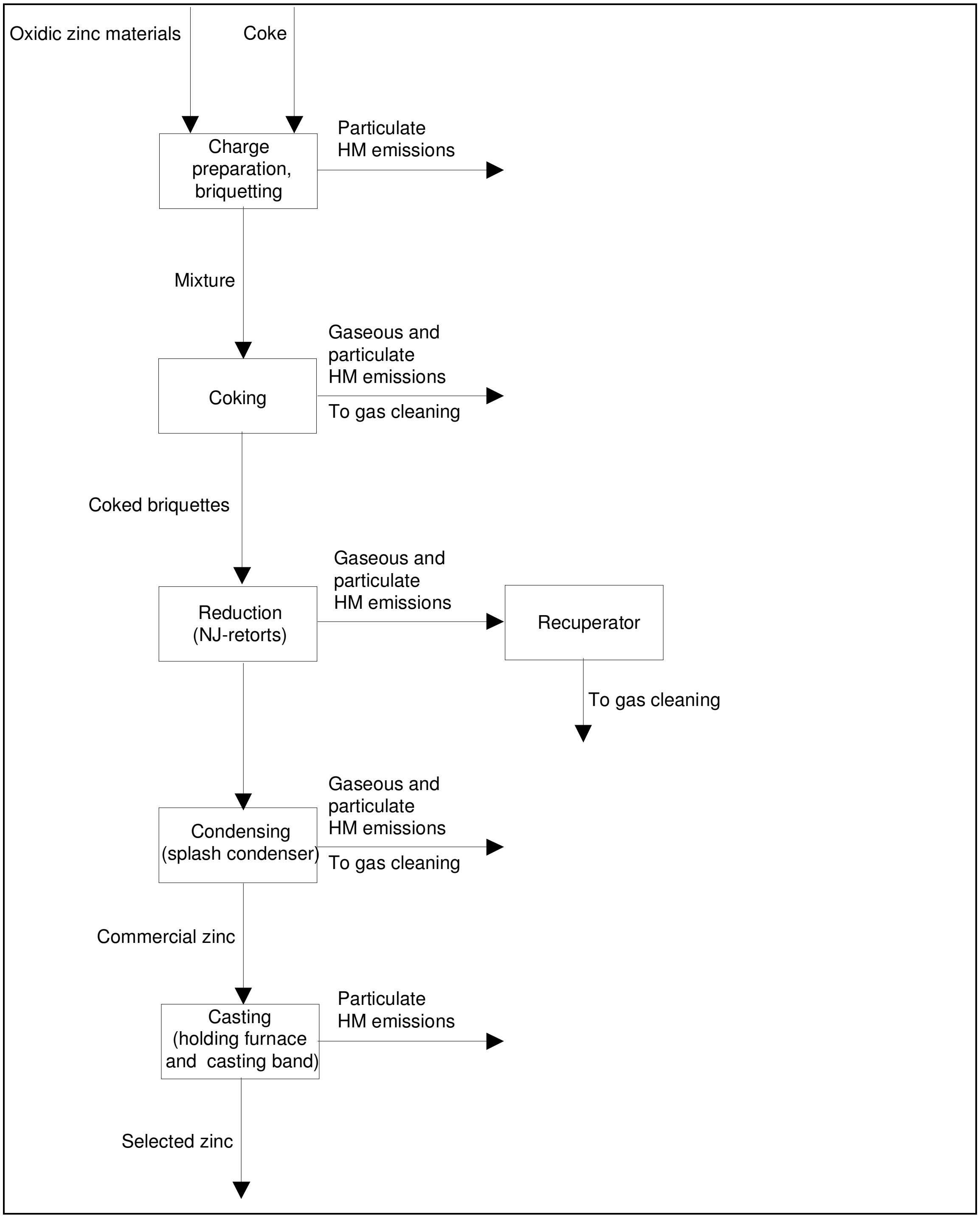


Figure 3.1: Secondary zinc production using New Jersey retorts with potential heavy metal emission sources (Rentz et al., 1996)

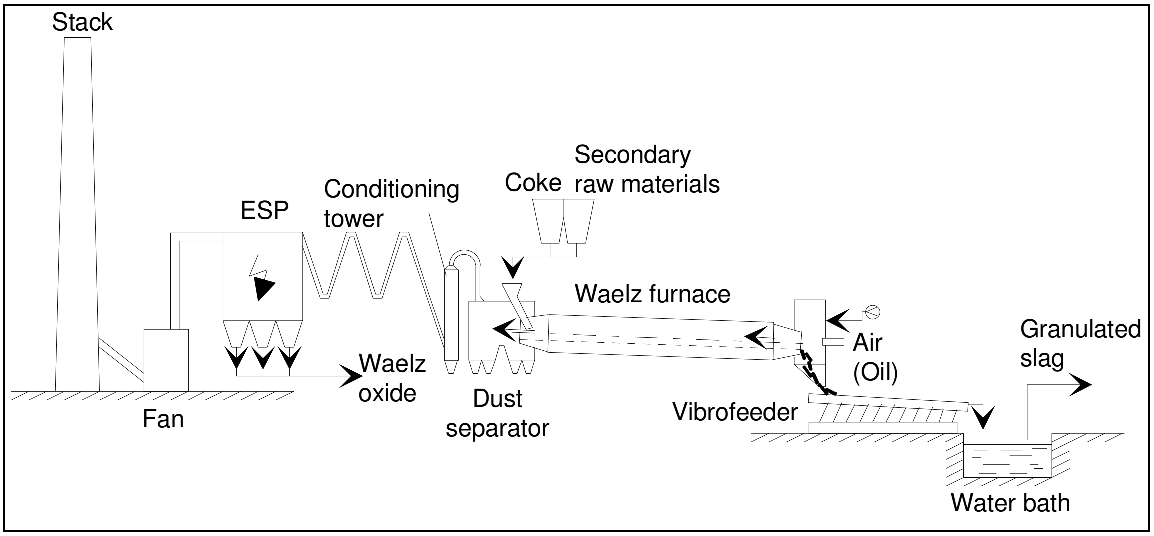


Figure 3.2: Waelz furnace with emission reduction installations (Rentz et al. 1995)

3.4 Emissions

Among the various process steps the melting furnace operation represents the most important source of atmospheric emissions. In general, continuous and periodical emissions can be distinguished. Continuous emissions are connected with the process as such, whereas periodical emissions occur e.g. during charging, heating, skimming, or cleaning operations. The most important factors influencing emissions from scrap pre-treatment and melting are:

- The composition of the raw material, in particular the content of organic and chlorinated compounds which affects the formation of dioxins and furans,
- the utilisation of flux powder ,
- the furnace type - direct heating with a mixture of process and combustion waste gases reduces the content of organic compounds released from the bath,
- the bath temperature - a temperature above 600°C creates significant emissions of zinc oxide,
- the fuel type - in general, natural gas or light fuel oil are used.

Continuous emissions from the melting furnace consist of combustion waste gases and gaseous effluents from the bath. The specific gas flow amounts to about 1,000 m^3 (STP)/Mg zinc produced.

Important periodical emissions often occur with charging and melting of the raw material. Emissions of organic compounds are mainly connected with charging operations. Furnace clearing, fluxing, ash drawing, and also cleaning operations are of minor relevance. Tapping is carried out at low temperature and therefore, no metal vapours are released.

In zinc distillation a high quality input material is used and therefore, emissions of carbon or chlorine containing compounds are low. Emissions mainly consist of zinc and zinc oxide containing particles and combustion waste gases (R. Bouscaren et. al., 1988).

3.5 Controls

Most of the secondary zinc smelters are equipped with dust removing installations, such as baghouses. In general, emission control systems vary depending on the type of scrap being processed and the products being obtained. A distinction can be made between purely oxidised, mixed oxidised/metallic and purely metallic products.

The control efficiency of dust removing installations is often very high reaching 99.9 %. Both, primary gases and fugitive dust emissions are reduced in baghouses to concentrations below 10 mg/m³.

Afterburners are reported for non-ferrous-metal industry in the USA. Also wet scrubbers may be used.

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = \text{AR} \times \text{EF}$$

---

[1] The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8.1.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tier 3), to estimate emissions of gaseous pollutants from the secondary zinc production is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

In this case, specific emission factors for the different process steps of the various production technologies should be used. An account of the effect of emission controls should be considered. The different emission factors will have to be evaluated through measurements at representative sites.

6 RELEVANT ACTIVITY STATISTICS

In many metal statistics secondary zinc production is not reported separately. The World Metal Statistics Year Book published by the World Bureau of Metal Statistics in Massachusetts, USA, reports total production of zinc without disaggregating it into primary and secondary production. The World Metal Statistics published monthly by the same organisation reports more detailed data which includes primary and secondary production for some countries and total production for others.

Information is also available from the UN statistical yearbooks (e.g. United Nations 1993). These data are satisfactory to estimate emissions using the simpler methodology.

The detailed methodology (tier 3) requires more detailed information. For example, the quantities of secondary zinc produced by various types of industrial technologies employed in the secondary zinc industry at plant level. This data is however not always easily available.
For example, the quantities of secondary zinc produced by various types of industrial technologies employed in the secondary zinc industry at plant level. Therefore, the application of the detailed estimation methodology may be complicated unless the statistical data are available directly from a given smelter. Some information in this respect is available from the International Lead and Zinc Study Group (www.ILZSG.org).

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

Secondary zinc smelters should be regarded as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

In the literature only emission factors for the simpler methodology are currently available. The CORINAIR methodology requires the separate reporting of combustion related emissions (SNAP 030308) and process related emissions (SNAP 040300). Table 8.1 also gives emission factors related to the energy input in [g/GJ] based on CORINAIR90 data. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR 90 a value for the specific energy consumption of 38.5 GJ/Mg product was reported.

Currently, a uniform emission factor for dioxin emissions from secondary zinc production cannot be given due to the enormous range of concentrations measured in the waste gases of 6 orders of magnitude. This is illustrated by results from measurements at German plants given in Tables 8.1 and 8.3 (Quaß 1997).

Table 8.1: Emission factor table for secondary zinc production

Compound	**Plant type**	**Emission factor**	**Data Quality**	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Country or region**	**Ref.**
SO_2	*unknown*	0.85 g/GJ	*E*	*n. a.*	*n. a.*	*natural gas*	*Europe*	*CORINAIR90*
SO_2	Calcining kiln	9,150g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
SO_2	Retort distillation/ oxidation	10,000g/Mg zinc oxide produced	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
SO_2	Muffle distillation/ oxidation	20,000g/Mg zinc oxide produced	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
SO_2	Secondary metal production, process heaters	17,209 · S g/m³ fuel	*E*	*n. a.*	*n. a.*	NAPFUE 204, S = sulphur content of fuel	*USA*	*US EPA (1990)*
SO_2	Secondary metal production, process heaters	19,006 · S g/m³ fuel	*E*	*n. a.*	*n. a.*	NAPFUE 203, S = sulphur content of fuel	*USA*	*US EPA (1990)*
NO_x	*unknown*	27 g/GJ	*E*	*n. a.*	*n. a.*	*coke oven coke*	*Europe*	*CORINAIR90*
NO_x	*unknown*	60 g/GJ	*E*	*n. a.*	*n. a.*	*natural gas*	*Europe*	*CORINAIR90*
NO_x	Pot furnace	950 g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
NO_x	Galvanising kettle	200 g/Mg zinc used	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
NO_x	Rotary sweat furnace	100 g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
NO_x	Retort distillation / oxidation	3,950 g/Mg zinc oxide produced	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
NO_x	Muffle distillation/ oxidation	55,000 g/Mg zinc oxide produced	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
NO_x	Process heaters in secondary metal production	2,397 g/m³ fuel	*E*	*n. a.*	*n. a.*	NAPFUE 204	*USA*	*US EPA (1990)*
NO_x	Process heaters in secondary metal production	6,591 g/m³ fuel	*E*	*n. a.*	*n. a.*	NAPFUE 203	*USA*	*US EPA (1990)*
VOC	Calcining kiln	30 g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
VOC	Concentrate dryer	2 g/Mg processed	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
VOC	Sweating furnaces (general) Kettle (pot) melting furnace	1,200 g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
VOC	Crucible melting furnace, scrap smelting	1,250 g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
VOC	Reverberatory melting furnace, scrap smelting	2,600 g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
VOC	Electric induction melting furnace, scrap melting	90 g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*USA*	*US EPA (1990)*
VOC	Process heaters in primary metal production	24 g/m³ fuel	*E*	*n. a.*	*n. a.*	NAPFUE 204	*USA*	*US EPA (1990)*

Table 8.1: continued

VOC	Process heaters in primary metal production	34 g/m³ fuel	*E*	*n. a.*	*n. a.*	NAPFUE 203	*USA*	*US EPA (1990)*
VOC	Process heaters in primary metal production	44,851 g/m³ fuel	*E*	*n. a.*	*n. a.*	NAPFUE 301, process gas	*USA*	*US EPA (1990)*
CO	*unknown*	535 g/GJ	*E*	*n. a.*	*n. a.*	*coke oven coke*	*USA*	*US EPA (1990)*
CO	*unknown*	7 g/GJ	*E*	*n. a.*	*n. a.*	*natural gas*	*Europe*	*CORINAIR90*
CO_2	*unknown*	105 kg/GJ	*E*	*n. a.*	*n. a.*	*coke oven coke*	*Europe*	*CORINAIR90*
CO_2	*unknown*	55 kg/GJ	*E*	*n. a.*	*n. a.*	*natural gas*	*Europe*	*CORINAIR90*
As	*unknown*	10 (1-20) g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*Germany (1980s)*	PARCOM/ ATMOS (1992)
Cd	*unknown*	25 (2-50) g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*Germany (1980s)*	PARCOM/ ATMOS (1992)
Cd	*unknown*	14 g/Mg zinc produced	*E*	*n. a.*	*n. a.*	*n. a.*	*Poland*	S. Hlawiczka (1995)
Hg	*unknown*	0.02 g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*Germany (1980s)*	PARCOM/ ATMOS (1992)
Pb	*unknown*	85 g/Mg zinc produced	*E*	*n. a.*	*n. a.*	*n. a.*	*Poland*	S. Hlawiczka (1995)
Pb	*unknown*	200 g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*Germany (1980s)*	PARCOM/ ATMOS (1992)
Zn	*unknown*	5,000 g/Mg product	*E*	*n. a.*	*n. a.*	*n. a.*	*Germany (1980s)*	PARCOM/ ATMOS (1992)
Zn	*unknown*	9,000 g/Mg zinc produced	*E*	*uncontrolled*	*0 %*	*n. a.*	*Europe*	PARCOM/ ATMOS (1992)
Zn	*unknown*	1,089 g/Mg zinc produced	*E*	*n. a.*	*n. a.*	*n. a.*	*Poland*	S. Hlawiczka (1995)
Zn	*unknown*	10,000 g/Mg zinc produced	*E*	*n. a.*	*n. a.*	*n. a.*	*Europe*	R. Bouscaren (1988)
PCDD/F	*Hot briquetting plant capacity 16.7 Mg Zn/h*	63.1-379 µg I-TEQ/Mg zinc produced	*E*	*controlled*	*n. a.*	*n. a.*	*Germany*	Quaß (1997)
PCDD/F	*Rotating cylinder (Waelz furnace), plant capacity 16.7 Mg Zn/h*	62.3 µg I-TEQ/Mg zinc produced	*E*	*controlled*	*n. a.*	*n. a.*	*Germany*	Quaß (1997)

n. a.: not available

Table 8.1: continued

Compound	Plant type	Emission factor	Uncertainty factor*	Abatement type	Abatement efficiency	Fuel type	Country or region	Ref.
TSP	Conventional plant	0,5 kg / Mg zinc produced	5	ESP, settlers, scrubbers; moderate control of fugitive sources	n.a.	n.a.	Europe	CEPMEIP
TSP	Modern plant (BAT)	0,5 kg / Mg zinc produced	3	fabric filters for most emission sources	n.a.	n.a.	Europe	CEPMEIP
TSP	Older plant	0,5 kg / Mg zinc produced	10	limited control of fugitive sources	n.a.	n.a.	Europe	CEPMEIP
PM_{10}	Conventional plant	0,4 kg / Mg zinc produced	5	ESP, settlers, scrubbers; moderate control of fugitive sources	n.a.	n.a.	Europe	CEPMEIP
PM_{10}	Modern plant (BAT)	0,4 kg / Mg zinc produced	3	fabric filters for most emission sources	n.a.	n.a.	Europe	CEPMEIP
PM_{10}	Older plant	0,4 kg / Mg zinc produced	10	limited control of fugitive sources	n.a.	n.a.	Europe	CEPMEIP

Table 8.1: continued

Compound	Plant type	Emission factor	Uncertainty factor*	Abatement type	Abatement efficiency	Fuel type	Country or region	Ref.
$PM_{2.5}$	Conventional plant	0,3 kg / Mg zinc produced	5	ESP, settlers, scrubbers; moderate control of fugitive sources	n.a.	n.a.	Europe	CEPMEIP
$PM_{2.5}$	Modern plant (BAT)	0,3 kg / Mg zinc produced	3	fabric filters for most emission sources	n.a.	n.a.	Europe	CEPMEIP
$PM_{2.5}$	Older plant	0,3 kg / Mg zinc produced	10	limited control of fugitive sources	n.a.	n.a.	Europe	CEPMEIP

NOTE: The uncertainty range (95% confidence) in the emission factor is expressed as a factor. The lower limit of the uncertainty range can be found by dividing the emission factor by the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example (first row in Table 8.1 on this page): The uncertainty in the emission factor for $PM_{2.5}$ from a conventional secondary zinc production plant is 5. The emission factor with uncertainty range will therefore be 0.3 kg/Mg zinc produced with an uncertainty range of 0.06 (0.3/5) to 1.5 (0.3x5).

Table 8.2: Heavy metal emission measurements

Process type:	*New Jersey retorts* *Process waste gases*	Waelz furnace Process waste gases, metal oxide recovery	Waelz furnace Furnace mouth
Country or region:	Germany	Germany	Germany
Abatement:	*Recuperator, heat exchanger, cooler, flat bag filter (polyacrylonitrile)*	*Dust separator, conditioning tower, 3-field electrostat. precip.*	*Bag filter (Nomex needlefelt)*
Waste gas stream: [m^3(STP)/h]	*124,000*	*62,000*	*9,200*
Compound:	*Clean gas [mg/m^3(STP)]*	*Clean gas [mg/m^3(STP)]*	*Clean gas [mg/m^3(STP)]*
As	*0.0009*	n. a.	n. a.
Cd	0.02	0.014	< 0.001
Cr	n. a.	n. a.	n. a.
Cu	< 0.0009	n. a.	n. a.
Hg	< 0.0009	n. a.	n. a.
Ni	n. a.	n. a.	n. a.
Pb	0.11	0.4	1.3
Zn	n. a.	1.6	3.4
Particulates	6.3	5.7	8
Reference:	Steinmann (1984)	Kola (1991)	Kola (1991)

n. a.: not available

Table 8.3: PCDD/F emission measurements

Country or region:	Germany	
Process type	**PCDD/F concentration** waste gas [ng I-TEQ/m^3]	**Mass flow** [µg I-TEQ/h]
Hot briquetting	20 - 120	1054 - 6326
Rotating cylinder	20.8	1040
Ore roasting furnace	0.0018	
Zinc melting furnace	0.042 - 0.121	0.9 - 2.7
Zinc melting furnace	0.097	5.2
Zinc melting furnace	0.028	0.3
Reference:	Bröker (1995)	

9 SPECIES PROFILES

At present little information exists on physical and chemical species of trace metals and dioxins/furans emitted during the secondary zinc production. Atmospheric emissions of various pollutants depend greatly on the degree of pre-sorting and the type and homogeneity of the scrap charged. Particles emitted during the production process contain predominantly zinc oxide, some metallic zinc, chlorides of various compounds, as well as the impurities derived from other metals in the scrap charge (Rentz et al., 1996). $ZnCl_2$ containing particulates result from the use of fluxes and granulated metal recovered from galvanic processes as a raw material. ZnO is formed from the reaction of zinc vapour with oxides at the surface. (R. Bouscaren et al., 1988).

10 UNCERTAINTY ESTIMATES

It is difficult to assess current uncertainties of emission estimates for pollutants emitted during the secondary zinc production. Recently it was concluded that up to 50 % of uncertainties can be assigned for the emission estimates of most of the trace elements emitted from major point sources in Europe (Pacyna, 1994). Much bigger uncertainty can be assigned for emission estimates of these compounds from the secondary zinc production. Information on emission factors and statistics is largely missing for the secondary zinc smelters; thus the accuracy of emission estimates for this category cannot even be compared with the accuracy of emission estimates for major point sources, such as primary smelters and power plants.

A key uncertainty is the type of abatement associated with the emission factors in section 8 which is currently not known.

Uncertainty is also increased by missing information on secondary zinc production in activity statistics. If activity rates related to the energy input are required a conversion of units is often necessary which may cause a further increase of uncertainty.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Development of emission factors for trace elements and dioxins/furanes and improvement of zinc emission factors given in section 8 is necessary in order to obtain emission estimates for the secondary zinc production. Further work is required to assess the missing parameters such as abatement type and efficiencies. The improvement should also focus on preparing individual emission factors for major industrial technologies and process units currently employed in the zinc industry. In this way a detailed methodology for emission estimates can be applied. Obviously, it will be necessary to obtain relevant statistical data on the production of zinc in various secondary zinc furnaces.

In many cases, a clear distinction between primary and secondary zinc production is not possible due to the simultaneous use of primary and secondary raw materials. In addition, a combined production of lead and zinc may occur (e. g. in IS-furnaces). Here, a double counting of emissions has to be avoided. Therefore, emissions from smelters should be reported as point sources using plant specific activity data.

The fuel specific emission factors cited from the CORINAIR90 inventory in Table 8.1 are related to both point sources and area sources without specification. It is assumed that according to the CORINAIR methodology they only include emissions from combustion (SNAP 030308). Further investigations should cover the influence of fuel characteristics and process technology on these factors for an improved discrimination between combustion and process related emissions.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

National emission estimates can be disaggregated on the basis of production, population or employment statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

The secondary zinc production is a continuous process. No temporal disaggregation is needed.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

No supplementary documents are required.

16 VERIFICATION PROCEDURES

Estimated emission factors could be best verified by measurements at plants using different industrial technologies.

17 REFERENCES

Barbour A.K., Castle J.F., and Woods S.E. (1978) Production of non-ferrous metals, Industrial Air Pollution Handbook, A. Parker (ed.), Mc Graw-Hill Book Comp. Ltd., London.

Berdowski J.J.M., Baas J., Bloos J.P.J. and Visscheldijk A.J.H (1997) The OSPARCOM-HELCOM-UNECE Emission Inventory of Heavy Metals and Persistent Organic Pollutants for 1990, TNO-MEP, Apeldoorn, the Netherlands

Bouscaren R., and Houllier C. (1988) Réduction des émissions de métaux lourds et de poussières, Technologies-efficacité-coûts, Tome 2, Métallurgie, Commission des Communautés européennes, Direction générale environnement, protection des consommateurs et sécurité nucléaire, 85-B6642-11-010-11-N

Bröker G., Bruckmann P., Geueke K.-J., Hiester E., Hoffmann, Radermacher L., and Gliwa H. (1995) "Dioxinmeßprogramm Nordrhein-Westfalen" Final report, Landesumweltamt Nordrhein-Westfalen (Ed.), 102 p.

ETC/AEM-CITEPA-RISOE (1997) Selected nomenclature for air pollution for CORINAIR94 inventory (SNAP 94), version 0.3 (Draft).

Hlawiczka S., Zeglin M., and Kosterka A. (1995) Heavy metals emission to the air in Poland for years 1980 - 1992, Inst. Ecol. Ind. Areas, Report 0-2.081, Katowice (in Polish)

ILZSG (1985) World Directory: Secondary Lead Plants, International Lead and Zinc Study Group Report, London.

Kola R., Estel R., and Steil, H. U. (1991) Abscheidung bleihaltiger Stäube mit einem Ionisationswäscher, Investitionen zur Verminderung von Umweltbelastungen, Programm des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit, Luftreinhaltung, Nr. 1108

Metallgesellschaft AG (1994) The World of Metals - Zinc, Volume 2, 1st Edition 1994, ISSN 0943-3511

van der Most P., and Veldt C. (1992) Emission Factors Manual PARCOM-ATMOS, Emission factor for air pollutants 1992, Ref.-No. 92-235

Nriagu J.O. and Pacyna J.M. (1988) Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature, 333, 134-139.

Pacyna J.M. (1983) Trace element emission from anthropogenic sources in Europe. Norwegian Institute for Air Research, NILU Rept. TR 10/82, Lillestrøm, Norway.

Pacyna J.M. (1989) Technological parameters affecting atmospheric emissions of trace elements from major anthropogenic sources, J.M. Pacyna and B. Ottar, eds., Control and Fate of Atmospheric Trace Metals, Kluwer Academic Publ., Dordrecht, the Netherlands.

Pacyna J.M. (1994) Emissions of heavy metals in Europe, Background Document for the EMEP Workshop on European Monitoring, Modelling and Assessment of Heavy Metals and Persistent Organic Pollutants, Beekbergen, the Netherlands, 3-6 May, 1994.

Quaß U. (1997) Landesumweltamt Nordrhein-Westfalen, Personal communication

Rentz O., Püchert H., Penkuhn T., and Spengler T.(1995) Stoffstrommanagement in der Eisen- und Stahlindustrie, Konkretisierung des § 5 Abs. 1 Nr. 3 Bundes-Immissionsschutzgesetz, Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit, Luftreinhaltung, Forschungsbericht 95-104 06 001

Rentz O., Sasse, H., Karl, U., Schleef, H.-J., and Dorn, R.(1996) Emission Control at Stationary Sources in the Federal Republic of Germany, Volume II, Heavy Metal Emission Control, Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit, Luftreinhaltung, 104 02 360

Steinmann U. (1984) Verminderung der Emissionen Zinkarbeit des Hüttenwerkes, Altanlagenprogramm des Bundesministers des Inneren, Luftreinhaltung, Nr. 1065

United Nations (1993) Industrial Statistics Yearbook 1991, Vol. II, Commodity Production Statistics, New York

US EPA (1990) AIR Facility Subsystem, EPA-Doc. 450/4-90-003, Research Triangle Park.

US EPA (1995) Compilation Of Air Pollutant Emission Factors, Volume I, Fifth Edition, AP-42

Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

UN ECE State-of-the-Art Report on the Heavy Metals Emissions, the UN ECE Task Force on Heavy Metals Emissions, Prague, the Czech Republic, June 1994.

US EPA (1995) Compilation Of Air Pollutant Emission Factors, Volume I, Fifth Edition, AP-42

Rentz O., Sasse, H., Karl, U., Schleef, H.-J., and Dorn, R.(1996) Emission Control at Stationary Sources in the Federal Republic of Germany, Volume II, Heavy Metal Emission Control, Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit, Luftreinhaltung, 104 02 360.

19 RELEASE VERSION, DATE AND SOURCE

Version :	2.1
Date :	1 February 1999
Updated by:	Otto Rentz, Ute Karl University of Karlsruhe (TH) Germany

Updated with emission factors (CEPMEIP) for particulates by:

Tinus Pulles and Wilfred Appelman
TNO
The Netherlands
May, 2006

Original author:	Jozef M Pacyna Norwegian Institute for Air Research (NILU) Norway
With support from:	Otto Rentz, Dagmar Oertel University of Karlsruhe (TH) Germany

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Ute Karl

French-German Institute for Environmental Research
University of Karlsruhe
Hertzstr 16
D-76187 Karlsruhe

Germany

Tel: +49 721 608 4590
Fax: +49 721 75 89 09
Email: ute.karl@wiwi.uni-karlsruhe.de

SNAP CODE: **030309**

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Secondary Copper Production

NOSE CODE: **104.12.10**

NFR CODE: **1 A 2 b**

ISIC: **2420**

1 ACTIVITIES INCLUDED

This chapter includes information on atmospheric emissions during the production of copper in secondary copper smelters. Secondary copper smelters produce about 40 % of the total copper production in the world (e.g. Pacyna, 1989). Pyrometallurgical processes are used to rework scrap and other secondary materials. As with primary copper production, final refining, where practised, is electrolytic. This chapter describes the methods to estimate emissions of atmospheric pollutants during the secondary copper recovery (e.g. Parker, 1978; UN ECE, 1994).

2 CONTRIBUTIONS TO TOTAL EMISSIONS

There are several trace elements which can be emitted during the secondary copper production. However, these emissions are not very significant on a global scale. Nriagu and Pacyna (1988) concluded that the secondary copper production contributes well below 1 % of the total atmospheric emissions of copper, lead, antimony, selenium, and zinc. Similar contribution of atmospheric emissions during the secondary copper production was estimated for the European emissions in the beginning of the 1980's (Pacyna, 1983). However, a secondary copper smelter or refinery can be an important emission source of trace element contamination on a local scale.

The contribution of emissions released from secondary copper production to total emissions in countries of the CORINAIR90 inventory is given as follows:

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**										
Secondary Copper Production	030309	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Typical contribution		0	-	0	-	0	-	-	-	0.059	0.103	0.113
Highest value										0.171	0.287	0.350
Lowest value										0.000	0.000	0.000

* EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

3 GENERAL

3.1 Description

A secondary copper smelter is defined as any plant or factory in which copper-bearing scrap or copper-bearing materials, other than copper-bearing concentrates (ores) derived from a mining operation, is processed by metallurgical or chemical process into refined copper and copper powder (a premium product).

The recycling of copper is the most comprehensive among the non-ferrous metals. The copper metal scrap can be in the form of:

- copper scrap, such as fabrication rejects, wire scrap, plumbing scrap, apparatus, electrical systems, products from cable processing,
- alloy scrap, such as brass, gunmetal, bronze, in the form of radiators, fittings, machine parts, turnings, shreddar metals, and
- copper-iron scrap like electric motors or parts thereof, plated scrap, circuit elements and switchboard units, telephone scrap, transformers, and shreddar materials.

Another large group of copper-containing materials is composed of oxidised materials, including drosses, ashes, slags, scales, ball mill fines, catalysts as well as materials resulting from pollution control systems.

The copper content of scrap varies from 10 to nearly 100% (UN ECE, 1994). The associated metals which have to be removed are mainly zinc, lead, tin, iron, nickel and aluminium as well as certain amounts of precious metals.

Depending on their chemical composition, the raw materials of a secondary copper smelter are processed in different types of furnaces, including:

- blast furnaces (up to 30% of Cu in the average charge),
- converters (about 75% Cu), and
- anode furnaces (about 95% Cu).

The blast furnace metal (“black copper”) is treated in a converter, the converter metal is refined in an anode furnace. In each step additional raw material with corresponding copper content is added.

In the blast furnace , a mixture of raw materials, iron scrap, limestone and sand as well as coke is charged at the top. Air which can be enriched with oxygen is blown through the tuyeres, the coke is burnt and the charge materials are smelted under reducing conditions. Black copper and slag are discharged from tapholes.

The converters used in primary copper smelting, working on mattes containing iron sulfide, generate surplus heat and additions of scrap copper are often used to control temperature. The converter provides a convenient and cheap form of scrap treatment, but often with only moderately efficient gas cleaning. Alternatively, hydrometallurgical treatment of scrap, using ammonia leaching, yields to solutions which can be reduced by hydrogen to obtain copper powder (e.g. Barbour et al., 1978). Alternatively, these solutions can be treated by solvent extraction to produce feed to a copper-winning cell.

Converter copper is charged together with copper raw materials in anode furnace operation. For smelting the charge, oil or coal dust is used , mainly in reverberatory furnaces. After smelting, air is blown on the bath to oxidise the remaining impurities.

Leaded brasses, containing as much as 3% of lead, are widely used in various applications and recycling of their scrap waste is an important activity. Such scrap contains usually much swarf and turnings coated with lubricant and cutting oils. Copper-containing cables and motors contain plastic or rubber insulants, varnishes, and lacquers. In such cases, scrap needs pre-treatment to remove these non-metallics. The smaller sizes of scrap can be pre-treated termally in a rotary kiln provided with an after-burner to consume smoke and oil vapors (so-called Intal process). There are also various techniques available to remove rubber and plastic insulations of cables (e.g. Barbour et al., 1978; UN ECE, 1994).

Atmospheric emissions of various pollutants are generated during all three types of processes employed in the secondary copper industry.

3.2 Definitions

Secondary copper production: - production of copper from materials other than ores.

3.3 Controls

Controls in secondary copper production should include effective dust collecting arrangements for dust from both primary exhaust gases and fugitive dust emissions. Fabric filters can be used reducing the dust emissions to below 10 mg/ m³ (UN ECE, 1994).

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers :

- Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.
- Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.
- Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = \text{AR} \times \text{EF}$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8. However, it should be noted that the chemical composition of input scrap is one of the most important factors affecting the amount of emissions. The chemical composition of input scrap varies considerably from one plant to another and so do emission factors.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tier 3), to estimate emissions of gaseous pollutants from the secondary copper production is based on measurements or estimations using plant specific emission factors. Guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of copper in secondary smelters, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics.

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities of the metal produced by various types of industrial technologies employed in the cement industry at plant level. This data is however not always easily available.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

Secondary copper smelters should be regarded as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Table 8.1 contains fuel related emission factors for secondary copper production based on CORINAIR90 data [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product, g/m^3), are listed in footnotes. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a range for the specific energy consumption of 38.5 up to 100 GJ/Mg product has been reported.

Table 8.1: Emission factors for secondary copper production[7]

		Type of fuel	NAPFUE code	Emission factors SO$_2$[2] [g/GJ]	NO$_x$[3] [g/GJ]	NMVOC[4] [g/GJ]	CH$_4$ [g/GJ]	CO [g/GJ]	CO$_2$ [kg/GJ]	N$_2$O [g/GJ]
l	oil	residual	203	495-1,470[1]	150[1]	30[1]	30[1]	15[1]	76-78[1]	2[2]
l	oil	gas	204	94-1,410[1]	100[1]	1.5[1]	1.5[1]	12[1]	73-74[1]	2[1]
g	gas	natural	301	0.28[1]	100[1]	4[1]	4[1]	13[1]	57[1], 60[5], 59[6]	1[1]
g	gas	liquified petroleum gas	303	0.04[1]	100[1]	2.1[1]	0.9[1]	13[1]	65[1]	1[1]

[1] CORINAIR90 data, point sources

[2]	SO$_x$: (EPA, 1990)	750	g/Mg charged	Scrap dryer (rotary)
		6,400	g/Mg charged	Wire burning, incinerator
		250	g/Mg charged	Crucible and pot furnace, charged with brass and bronze
		15	g/Mg charged	Electric arc furnace, charged with brass and bronze
		15	g/Mg charged	Electric induction furnace, charged with brass and bronze
		2,182	g/Mg product	Refining
		17,209 · S	g/m³ fuel	Secondary metal production, process heaters NAPFUE 204, S = sulphur content of fuel
		19,006 · S	g/m³ fuel	Secondary metal production, process heaters NAPFUE 203, S = sulphur content of fuel
[3]	NO$_x$: (EPA, 1990)	850	g/Mg charged	Wire burning, incinerator
		40	g/Mg charged	Reverberatory furnace, charged with brass and bronze
		300	g/mg charged	Rotary furnace, charged with brass and bronze
		2,397	g/m³ fuel	Secondary metal production, process heaters, NAPFUE 204
		6,591	g/m³ fuel	Secondary metal production, process heaters, NAPFUE 203
[4]	VOC: (EPA, 1990)	2	g/Mg charged	Scrap dryer (rotary)
		300	g/Mg charged	Wire burning, incinerator
		60	g/Mg charged	Sweating furnace
		223,500	g/Mg coke free charge	Cupola, charged with insulated copper or brass and scrap copper
		90	g/Mg charged	Cupola, charged with scrap copper or brass and scrap copper
		2,600	g/Mg charged	Reverberatory furnace, charged with copper / charged with brass and bronze
		1,200	g/Mg charged	Rotary furnace, charged with brass and bronze
		3,350	g/Mg charged	Crucible and pot furnace, charged with brass and bronze
		1,950	g/Mg charged	Electric arc furnace, charged with copper
		0	g/Mg charged	Electric arc furnace, charged with brass and bronze
		0	g/Mg charged	Electric induction furnace, charged with copper or brass and bronze
		24	g/m³ fuel	Secondary metal production, process heaters, NAPFUE 204
		34	g/m³ fuel	Secondary metal production, process heaters, NAPFUE 203
		44,851	g/Mm³ fuel	Secondary metal production, process heaters, NAPFUE 301

[5] CO$_2$: Locally contaminated scrap input, brass production (Bremmer, 1995)

[6] CO$_2$: Strongly contaminated scrap input, brass production (Bremmer, 1995)

[7] It is assumed, that emission factors cited within the table are related to combustion sources in secondary copper production. Footnotes may contain emission factors for total emissions (fuel and process related).

A list of emission factors for several trace elements emitted from secondary copper smelters is presented in Table 8.2. Results of measurements and estimates carried out in various countries are presented. However, in some cases the factors originate from the same sources.

Information available from the above mentioned measurements and estimates does not allow for further differentiation of emission factors with respect to neither various industrial processes involved in the secondary copper production or different production technologies used at present. Therefore, the factors in Table 8.2 can only be used in a simpler emission estimation methodology.

Table 8.2: Compilation of emission factors for secondary copper production (in g/tonne Cu produced)

Element	Estimates by Pacyna (1986)	Estimates in Canada (Jacques, 1987)	PARCOM program (PARCOM, 1992)	Estimates in the U.K. (Leech, 1993)	Estimates in Austria (Schneider, 1994)	Suggested
Arsenic					2	2
Antimony	3					3
Cadmium	4		5	5	2	2-4
Copper	150	200-400			20	20-150
Lead	50-200	230	130	130	50	50-130
Nickel		1				1
Zinc	500-1600		500	500	250	250-500
Control	ESP, ca. 99% efficiency	Based on questionnaires. Most plants use ESPs with 99% efficiency	Unspecified	Based on emission factors by Pacyna and PARCOM	Unspecified	Common ESPs with 99% efficiency

General emission factors for particulate matter for secondary copper production (all processes, CEPMEIP) are:

TSP: 1 g/kg secondary copper
PM_{10}: 0,8 g/kg secondary copper
$PM_{2.5}$: 0,6 g/kg secondary copper

The uncertainty factor in all emission factors is 10 (95% confidence)

Note: The lower limit of the uncertainty range can be found by dividing the emission factor by the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example: The emission factor for PM2.5 with an uncertainty range of 10 will therefore be 0,6 gram per kg secondary cupper with an uncertainty range of 0.06 (0.6/10) to 6 (0.6x10).

9 SPECIES PROFILES

At present no reliable information exist on physical and chemical species of trace elements emitted during the secondary copper production. It can be assumed that the majority of trace elements volatilized from scrap and other copper-containing materials enter the atmosphere on fine particles.

10 UNCERTAINTY ESTIMATES

It is difficult to assess current uncertainties of emission estimates for pollutants emitted during the secondary copper production. Recently it was concluded that up to 50 % of uncertainties can be assigned for the emission estimates of most of the trace elements emitted from major point sources in Europe (Pacyna, 1994). Even bigger uncertainty can be assigned for emission estimates of these compounds from the secondary copper production. Information on emission factors and statistics is more limited for the secondary copper smelters than for major point sources, such as primary smelters and power plants.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Improvement of emission factors is necessary in order to obtain more accurate emission estimates for the secondary copper production. This improvement should focus on preparing individual emission factors for major industrial technologies currently employed in the copper industry. In this way, a detailed methodology for emission estimates can be applied. Obviously, it will be necessary to obtain relevant statistical data on the production of copper in various secondary copper furnaces.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Not applicable.

13 TEMPORAL DISAGGREGATION CRITERIA

The secondary copper production is a continuous process. No temporal disaggregation is needed.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

The following supplementary document can be suggested:
UN ECE State-of-the-Art Report on the Heavy Metals Emissions, the UN ECE Task Force on Heavy Metals Emissions, Prague, the Czech Republic, June 1994.

16 VERIFICATION PROCEDURES

At present no specific verification procedures are available for estimation of atmospheric emissions from the secondary copper production. Estimated emission factors could be best verified by measurements at plants using different industrial technologies.

17 REFERENCES

Barbour A.K., Castle J.F. and Woods S.E. (1978) Production of non-ferrous metals. In: Industrial Air Pollution Handbook, A. Parker (ed.), Mc Graw-Hill Book Comp. Ltd., London.

Bremmer H. J.(1995) Secundaire Non-Ferroindustrie; RIVM-report 773006174; RIZA-report 92.003/74.

EPA (1990) AIR Facility Subsystem, EPA-Doc. 450/4-90-003, Research Triangle Park.

Jaques A.P. (1987) Summary of emissions of antimony, arsenic, cadmium, copper, lead, manganese, mercury and nickel in Canada. Environment Canada, Conservation and Protection, Environmental Analysis Branch, Ottawa, Canada.

Leech P.K. (1993) UK atmospheric emissions of metals and halides 1970-1991. Warren Spring Laboratory Rept. LR 923, Stevenage, UK.

Nriagu J.O. and Pacyna J.M. (1988) Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature, 333, 134-139.

Pacyna J.M. (1983) Trace element emission from anthropogenic sources in Europe. Norwegian Institute for Air Research, NILU Rept. TR 10/82, Lillestrøm, Norway.

Pacyna J.M. (1989) Technological parameters affecting atmospheric emissions of trace elements from major anthropogenic sources. In: J.M. Pacyna and B. Ottar, eds., Control and Fate of Atmospheric trace Metals, Kluwer Academic Publ., Dordrecht, the Netherlands.

Pacyna J.M. (1994) Emissions of heavy metals in Europe. In: Background Document for the EMEP Workshop on European Monitoring, Modelling and Assessment of Heavy Metals and Persistent Organic Pollutants, Beekbergen, the Netherlands, 3-6 May, 1994.

PARCOM (1992) Emission Factor Manual PARCOM-ATMOS. Emission factors for air pollutants 1992. P.F.J. van der Most and C. Veldt, eds., TNO Environmental and Energy Research, TNO Rept. 92-235, Apeldoorn, the Netherlands.

Parker A. (ed) (1978) Industrial Air Pollution Handbook, McGraw-Hill Book Comp. Ltd., London

Schneider M. (1994) Heavy metal emissions in Austria. Umweltbundesamt report to the UN ECE Task Force on Heavy Metals Emissions. Wien, March, 1994.

UN ECE (1994) State-of-the-art report on heavy metals emissions. UN Economic Commission for Europe, Convention on Long-range Transboundary Air Pollution, Task Force on Heavy Metals Emissions, Prague, the Czech Republic.

Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

No additional documents.

19 RELEASE VERSION, DATE AND SOURCE

Version : 2.1

Date :	December 1995
Source :	Jozef M Pacyna Norwegian Institute for Air Research (NILU) Norway
Supported by:	Otto Rentz, Dagmar Oertel University of Karlsruhe (TH) Germany

Updated with emission factors (CEPMEIP) for particulates by:
Tinus Pulles and Wilfred Appelman
TNO
The Netherlands
May 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Jozef Pacyna

NILU - Norwegian Institute of Air Research
PO Box 100
N-2027 Kjeller
Norway

Tel: +47 63 89 8155
Fax: +47 63 89 80 50
Email: jozef.pacyna@nilu.no

SNAP CODE: **030310**

SOURCE ACTIVITY TITLE: **PROCESSES WITHOUT CONTACT**
Secondary Aluminium Production

NOSE CODE: **104.12.11**
104.12.12

NFR CODE: **2 C 3 / 1 A 2 b**

ISIC: 2420

1 ACTIVITIES INCLUDED

This chapter includes information on atmospheric emissions during the production of Aluminium in secondary Aluminium smelters. Secondary Aluminium smelters produce about 50 % of the total Aluminium production in the United States (e.g. UN, 1994). Similar Aluminium production proportion is found in the Netherlands, France, Austria, and Italy. The secondary Aluminium industry is characterised by a large number of relatively small plants treating mostly so-called new scrap. This chapter describes the methods to estimate emissions of atmospheric pollutants during the secondary Aluminium operations (e.g. Parker, 1978).

2 CONTRIBUTIONS TO TOTAL EMISSIONS

There are various pollutants which can be emitted during the secondary Aluminium production, including smoke, acids, and particles. Major problems may arise due to emissions of Aluminium chloride and its hydrolysis product, hydrochloric acid. These emissions are not very significant on a global scale. However, a secondary Aluminium smelter can be an important emission source of pollution on a local scale.

The contribution of emissions released from secondary Aluminium production to total emissions in countries of the CORINAIR90 inventory is given as follows:

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**										
Secondary Aluminium Production	030310	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Typical contribution		0	0	0	-	-	-	-	-	0.103	0.194	0.125
Highest value										0.285	0.525	0.301
Lowest value										-	-	-

* EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
\- = no emissions are reported

Secondary Aluminium production plants have the potential to emit cadmium, hexachlorobenzene, dioxins and furans, PAHs and sulphurhexafluoride (ETC/AEM-CITEPA-RISOE 1997).

3 GENERAL

3.1 Description

A secondary Aluminium smelter is defined as any plant or factory in which Aluminium-bearing scrap or Aluminium-bearing materials, other than Aluminium-bearing concentrates (ores) derived from a mining operation, is processed into Aluminium Alloys for industrial castings and ingots. Energy for secondary refining consumes only about 5% of that required for primary Aluminium production.

In most cases, the first step in the secondary Aluminium production is removal of magnesium from the scrap charge in order to prevent off-grade castings when the refined Aluminium is cast. As much as 1% of magnesium can be found in the scrap charge and its reduction to 0.1% is necessary. This reduction can be achieved by lancing the molten charge with chlorine gas during and after the melting cycle (Barbour et al., 1978).

After pre-treatment the scrap charge is subjected to melting and demagging (chlorination). Small crucible furnaces are used to produce Aluminium Alloys for casting. Larger melting operations use reverberatory furnaces.

The final step in the production process is chlorination to obtain a high quality Aluminium product.

3.2 Definitions

Secondary Aluminium production: - production of Aluminium from materials other than ores.

3.3 Controls

Secondary Aluminium processing faces the difficult problem of suppressing emissions of corrosive Aluminium chloride associated with hydrogen chloride. Two approaches have been employed for some time to deal with the problem (Barbour et al., 1978). The Derham process uses proprietary fluxes. It claims more than 97% magnesium-chlorine efficiency for the chlorination stage at magnesium levels of less than 0.1%.

The Alcoa fumeless process depends on effecting a stoichiometric chlorination of magnesium in a multi-stage enclosed settler-reactor tank after melting and prior to casting (Barbour et al., 1978). Efficient gas-liquid contact gives a selective magnesium chlorination reaction (99% efficiency).

Afterburners are used generally to convert unburned VOC to CO_2 and H_2O. Wet scrubbers are sometimes used.

Controls in secondary Aluminium production should also include effective dust collecting arrangements for dust from both primary exhaust gases and fugitive dust emissions. Fabric filters can be used reducing the dust emissions to below 10 mg/ m³.

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

---

[1] The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

Emission = AR x EF

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8.1.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tier 3), to estimate emissions of gaseous pollutants from the cement production is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

In this case, different emission factors for various production technologies should be used. An account of the effect of emission controls should be considered. The different emission factors will have to be evaluated through measurements at representative sites.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of Aluminium in secondary smelters, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics. This information is satisfactory to estimate emissions with the use of the simpler estimation methodology.

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities produced by various types of industrial technologies employed in the secondary Aluminium industry at plant level. This data is however not always easily available.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

Secondary Aluminium smelters should be regarded as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Emissions from secondary Aluminium operations include fine particles, gaseous chlorine, and selected persistent organic pollutants.

Table 8.1 contains fuel related emission factors for secondary Aluminium production based on CORINAIR90 data in [g/GJ]. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a range for the specific energy consumption of 1.7 up to 3.5 GJ/Mg product has been reported.

Technique related emission factors, mostly given in other units (e.g. g/Mg product, g/m^3), are presented in Tables 8.2 through 8.4 for SO_x, NO_x and NMVOC, respectively. No information exists on the type and efficiency of abatement techniques, but the factors in these tables seem to be valid for emissions from uncontrolled processes.

Table 8.1: Emission factors for secondary Aluminium production (based on CORINAIR)

	Type of fuel		NAPFUE code	Emission factors						
				SO_2 [g/GJ]	NO_x [g/GJ]	NMVOC [g/GJ]	CH_4 [g/GJ]	CO [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]
l	oil	residual	203	143	100	3	5	12	73	10
l	oil	gas	204	1,410	100			12	75	
g	gas	natural	301						87-100	54-58

Table 8.2: Emission factors for SO_2 from secondary Aluminium production.

Process type	Abatement type	Abatement efficiency	Fuel type	Unit	Emission factor	Data Quality Code	Country of origin
Sweating furnace	N/A	N/A	N/A	kg/tonne Al	1.75	E	USA
Smelting Furnace:							
-crucible	N/A	N/A	N/A	kg/tonne Al	1.25	E	USA
-reverberatory	N/A	N/A	N/A	kg/tonne Al	0.45	E	USA
Burning, drying	N/A	N/A	N/A	kg/tonne Al	0.15	E	USA
Heavily contaminated scrap input	N/A	N/A	N/A	kg/tonne Al	0.54	E	USA
Pouring, casting	N/A	N/A	N/A	kg/tonne charged	0.01	E	USA
Process heaters	N/A	N/A	gas oil	kg/m^3 fuel	17.2 x S	E	USA
	N/A	N/A	residual oil	kg/m^3 fuel	19.0 x S	E	USA

N/A = Data not available
S = sulphur content of fuel

Table 8.3: Emission factors for NOx from secondary aluminium production

Process type	Abatement type	Abatement efficiency	Fuel type	Unit	Emission factor	Data Quality Code	Country or region
Sweating furnace	N/A	N/A	N/A	kg/tonne Al	0.3	E	USA
Smelting furnace							
-crucible	N/A	N/A	N/A	kg/tonne Al	0.85	E	USA
-reverberatory	N/A	N/A	N/A	kg/tonne Al	0.38	E	USA
Burning, drying	N/A	N/A	N/A	kg/tonne Al	0.25	E	USA
Annealing furnace	N/A	N/A	N/A	kg/tonne Al	0.75	E	USA
Pouring, casting	N/A	N/A	N/A	kg/tonne Al	0.005	E	USA
Slab furnace	N/A	N/A	N/A	kg/tonne Al	0.75	E	USA
Can manufacture	N/A	N/A	N/A	kg/tonne Al	0.35	E	USA
Rolling, drawing, extruding	N/A	N/A	N/A	kg/tonne Al	0.35	E	USA
Process heaters	N/A	N/A	gas oil	kg/m^3 fuel	2.4	E	USA
	N/A	N/A	residual oil	kg/m^3 fuel	6.6	E	USA

N/A = Data not available

Table 8.4: Emission factors for NMVOCs from secondary aluminium production

Process type	Abatement type	Abatement efficiency	Fuel type	Unit	Emission factor	Data Quality Code	Country or region
Sweating furnace	N/A	N/A	N/A	kg/tonne Al	1.20	E	USA
Smelting furnace							
-crucible	N/A	N/A	N/A	kg/tonne Al	1.25	E	USA
-reverberatory	N/A	N/A	N/A	kg/tonne Al	0.10	E	USA
Burning, drying	N/A	N/A	N/A	kg/tonne Al	16.00	E	USA
Foil rolling	N/A	N/A	N/A	kg/tonne Al	0.65	E	USA
Foil converting	N/A	N/A	N/A	kg/tonne Al	1.20	E	USA
Annealing furnace	N/A	N/A	N/A	kg/tonne Al	0.002	E	USA
Slab furnace	N/A	N/A	N/A	kg/tonne Al	0.002	E	USA
Pouring, casting	N/A	N/A	N/A	kg/tonne Al	0.07	E	USA
Can manufacture	N/A	N/A	N/A	kg/tonne Al	150.0	E	USA
Rolling, drawing, extruding	N/A	N/A	N/A	kg/tonne Al	0.045	E	USA
Process heaters	N/A	N/A	gas oil	kg/m^3 fuel	0.024	E	USA
	N/A	N/A	residual oil	kg/m^3 fuel	0.034	E	USA
	N/A	N/A	natural gas	kg/m^3 fuel	44.85	E	USA
	N/A	N/A	process gas	kg/m^3 fuel	44.85	E	USA

N/A = Data not available

Particle emission factors cited in CEPMEIP are presented in Table 8.5.

Table 8.5: Emission factors for fine particles from secondary aluminium production (CEPMEIP, kg/ton)

Technology	**Abatement type**	**TSP**	**PM$_{10}$**	**PM$_{2.5}$**	**Uncertainty**
Conventional plant	ESP, settlers, scrubbers; moderate control of fugitive sources	1.5	1.2	0.48	1.5
Modern plant (BAT)	fabric filters for most emission sources	1	0.9	0.405	1.5
Older plant	limited control of fugitive sources	2	1.4	0.55	1.5

NOTE: The uncertainty range (95% confidence) in the emission factor is expressed as a factor. The lower limit of the uncertainty range can be found by dividing the emission factor by the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example (first row in the table): The uncertainty in the emission factor for PM$_{2.5}$ from a conventional plant with an ESP settlers, scrubbers and moderate control of fugitive sources is 1.5. The emission factor with uncertainty range will therefore be 0.48 kgram per tonne with an uncertainty range of 0.32 (0.48/1.5) to 0.72 (0.48x1.5).

Hexachloroethane has been used in the secondary Aluminium industry and in Aluminium foundries in the form of tablets for degassing purposes in refining operations, resulting in hexachlorobenzene (HCB) emissions. An emission factor of 5 g HCB/ tonne Aluminium produced has been reported (in PARCOM, 1992).

Concentrations of dioxins and furans in the flue gas passing the control equipment in the secondary Aluminium production are presented in Table 8.6 after a compilation of data by the Working Group of the Subcommittee on Air/Technology of the Federal Government /Federal States Emission Control Committee in Germany (Umweltbundesamt, 1996).

Table 8.6: Concentrations of dioxins and furans in the flue gas after passing the control devices, in ng TEQ/m^3 *1

Process	Emission Control Device	PCDD/F Concentration	Data Quality Code
Drum furnace with convertors	Hydrated lime fabric filters	0.1 - 13.7	D
Hearth trough kiln	Hydrated lime fabric filter	0.01 - 0.7	D
Smelting and casting furnace	No treatment	0.06 - 0.09	D
Induction furnace	Fabric filters	0.01 - 0.3	D
Al smelting plant	Fabric filters	0.02 - 0.23	D

*1 TEQ = toxic equivalency factor established by NATO/CCMS

In general, concentrations of dioxins and furans in the flue gas after the control device vary substantially due to differences in operational processes employed.

Secondary Aluminium Also generates so called climate gases, including CF_4, C_2F_6, and SF_6. A temporal increase of about 2% per year in CF_4 has been measured in the global atmosphere (in Stordal and Myhre, 1991). The current concentration of SF_6 in the atmosphere is 1 to 2 ppt, and the rate of increase has recently been estimated to be 7.4 % per year in the period from 1979 to 1989 (Rinsland et Al., 1990). However, no data are available to the authors of this chapter regarding emission factors of these gases for the secondary Aluminium production.

9 SPECIES PROFILES

Not applicable.

10 UNCERTAINTY ESTIMATES

It is rather difficult to assess current uncertainties of emission estimates for pollutants emitted during the secondary Aluminium production. The uncertainties of SO2 emission estimates can be assessed in a similar way as the uncertainties of the estimates for the fossil fuel combustion (see chapter B 111).

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Improvement of emission factors is necessary in order to obtain more accurate emission estimates for the secondary aluminium production. This improvement should focus on preparing individual emission factors for major production techniques, currently employed in the secondary aluminium industry. In this way, a detailed approach methodology for emission estimates can be applied. Obviously, it will be necessary to obtain relevant statistical data on the production of aluminium in various secondary melting furnaces.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

National emission estimates can be disaggregated on the basis of production, population or employment statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

The secondary Aluminium production is a continuous process. No temporal disaggregation is needed.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

Barbour A.K., Castle J.F. and Woods S.E. (1978) Production of non-ferrous metals. In: Industrial Air Pollution Handbook, A. Parker (ed.), Mc Graw-Hill Book Comp. Ltd., London.

16 VERIFICATION PROCEDURES

Estimated emission factors could be best verified by measurements at plants using different industrial technologies.

17 REFERENCES

Barbour A.K., Castle J.F. and Woods S.E. (1978) Production of non-ferrous metals. In: Industrial Air Pollution Handbook, A. Parker (ed.), Mc Graw-Hill Book Comp. Ltd., London.

Bremmer H. J. (1995) Secundaire Non-Ferroindustrie; RIVM-report 773006174; RIZA-report 92.003/74.

Economopoulos A.P. (1993) Assessment of sources of air, water, and land pollution. A quide to rapid source inventory techniques and their use in formulating environmental control strategies. Part one: Rapid inventory techniques in environmental pollution. World Health Organization, Geneva.

EPA (1990) AIR Facility Subsystem, EPA-Doc. 450/4-90-003, Research Triangle Park.

ETC/AEM-CITEPA-RISOE (1997) Selected nomenclature for air pollution for CORINAIR94 inventory (SNAP 94), version 0.3 (Draft).

PARCOM (1992) Emission Factor Manual PARCOM-ATMOS. Emission factors for air pollutants 1992. P.F.J. van der Most and C. Veldt, eds., TNO Environmental and Energy Research, TNO Rept. 92-235, Apeldoorn, the Netherlands.

Parker A. (ed) (1978) Industrial Air Pollution Handbook, McGraw-Hill Book Comp. Ltd., London

Rinsland, C.P. Goldman, A., Murcray, F.J. Blatherwick, R.D., Kosters, J.J., Murcray, D.G., Sze, N.D. and Massie, S.T. (1990) Long-term trends in concentrations of SF_6, $CHClF_2$ and COF_2 in the lower stratosphere from analysis of high-resolution infrared solar occultation spectra. J.Geophys. Res., 95, 16477-16490.

Stordal F., and Myhre G. (1991). Greenhouse Effect and Greenhouse Warming Potential for SF6. NILU Rept. 74/91. Norwegian Institute for Air Research, Kjeller, Norway.

Umweltbundesamt (1996). Determination of requirements to limit emissions of dioxins and furnans. Report from the Working Group of the subcommitte Air/Technology of the Federal Government/Federal States Immission Control Committee, Texte 58/95, Umweltbundesamt, Berlin.

U.S. EPA (1973) Compilation of air pollutant emission factors. 2nd edition. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

UN (1994) Statistical Yearbook - 1992. United Nations, Department for Economic and Social Information and Policy Analysis, Statistical Division, New York, NY.

Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

For a detailed bibliography the primary literature mentioned in AP42 or the PARCOM-ATMOS Manual can be used.

19 RELEASE VERSION, DATE AND SOURCE

Version :	2.2
Date :	November 1997
Original author and update by:	Jozef M. Pacyna

Norwegian Institute for Air Research (NILU)
Norway

Supported by: Otto Rentz, Dagmar Oertel
University of Karlsruhe (TH)
Germany

Updated with emission factors (CEPMEIP) for particulates by:
Tinus Pulles and Wilfred Appelman
TNO
The Netherlands
May 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Jozef Pacyna

NILU - Norwegian Institute of Air Research
PO Box 100
N-2027 Kjeller
Norway

Tel: +47 63 89 8155
Fax: +47 63 89 80 50
Email: jozef.pacyna@nilu.no

SNAP CODE: **030311**
040612

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Cement
Cement (decarbonizing)

NOSE CODE: **104.11.02**
105.11.21

NFR CODE: **1 A 2 f**
2 A 1

ISIC: **2394**

1 ACTIVITIES INCLUDED

This chapter covers emissions from both the combustion and mechanical processes used to produce cement.

2 CONTRIBUTION TO TOTAL EMISSION

The contribution of gaseous emissions released from the production of cement to total emissions in countries of the CORINAIR90 inventory is presented in Table 2.1.

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory (***28 countries***)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**										
Cement	030311	SO_2	NOx	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP	PM_{10}	$PM_{2.5}$*
Typical contribution		0.8	2.3	0	0	0.2	2.1	0.3	-	11.8	5.96	3.60
Highest value										48.2	23.1	14.5
Lowest value										1.70	1.08	0.68

* EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)

\- = no emissions are reported

The emitted dust may contain heavy metals, particularly so when wastes are burnt as fuel, see Baart et al. (1995). The average relative contribution from the cement production industry to the total emission of heavy metals has been presented for European countries in Table 2.2.

Table 2.2: Average relative contribution of the production of cement to the total emission of heavy metals in European countries (Baart et al., 1995)

Compound	**Contribution (%)**
Cadmium	1.2
Chromium	1.5
Nickel	1.7
Lead	0.23

Cement production may be an important source of mercury as well as the metals presented in Table 2.2. It was estimated that on a global scale cement contributes with about 1.0 % to the total emissions of the element emitted from anthropogenic sources (Pacyna and Pacyna, 1996). However, Table 2.3 gives the contribution of cement to total emissions of heavy metals and POPs from the OSPARCOM-HELCOM-UNECE emission inventory, and the estimate for mercury is a 15 % contribution.

Table 2.3: Contribution to total POP and heavy metal emissions of the OSPARCOM-HELCOM-UNECE emission inventory (up to 39 countries)

Source-activity	**SNAP-code**	**Contribution to total emissions (including emissions from nature) [%]**										
		As	Cr	Cu	Pb	Cd	Hg	Ni	Zn	PCBs	PCDD/Fs	PAH
Cement	040612	0.5	1.2	0	0.1	0.5	15	0.3	0.3	0	0.2	0

3 GENERAL

3.1 Description

The “standard” cement is Portland cement, which accounts for about half of the EU/EEA consumption (European IPPC Bureau, 2000). The raw materials for Portland cement clinker are limestone, sand, shale, clay and iron oxide. Other cements are composite cements and blast furnace cement, which substitute blast furnace slag or other materials for a portion of the raw materials. In each case, the processing is largely the same, and the clinker is later combined with gypsum to create the final cement. The main process stages are:

- Handling of raw materials, intermediate products and final product;
- Fuel grinding if solid fuel is used;
- Kiln feed preparation;
- Pyroprocessing in a rotary kiln to form clinker;
- Clinker cooling;
- Milling (grinding and blending with gypsum).

Types of fuels used vary across the industry. Cement kilns are highly energy-intensive and fuel costs have a critical effect on profitability. Historically, some combination of coal, oil, and natural gas was used, but over the last 15 years, most plants have switched to coal.

However, in recent years a number of plants have switched to systems that burn a combination of coal and waste fuel.

3.2 Definitions

Portland cement	a type of hydraulic cement usually made by burning a mixture of limestone and clay in a kiln
Kiln	a furnace for burning fuel and cement clinker

3.3 Techniques

Portland cement can be produced either by dry or wet milling. In the case of wet milling the raw cement clinker is first mixed with water; this mixture is fired into a rotary kiln and finally milled. In the dry process the mixing with water is omitted. The dry process requires less energy than the wet process.

The raw materials are first brought to site; some will normally be conveyed from nearby quarries or open pits. The materials are then mixed, crushed and ground to produce a raw mix (raw meal) of the correct particle size and chemical properties. The raw meal is converted into cement clinker by pyroprocessing in rotary kilns. These consist of a refractory lined cylindrical steel shell slightly inclined to the horizontal and rotating at 1 – 3 rpm. Raw material is fed in at the upper end and gradually moves downward towards the lower end where there is a burner providing counter-current heating.

Most cement kilns now use the dry process, in which raw mill material is fed into the rotary kiln dry. Before passing into the kiln the material may be preheated in a vertically arrayed multi-cyclonic preheater, in which the rising hot gases exiting the kiln contact the downward flowing raw materials. Some dry processes also employ a precalciner stage beneath the preheater, just before the raw material enters the kiln. Preheaters and precalciners often have an alkali bypass between the feed end of the rotary kiln and the preheater to remove undesirable volatile components.

The use of the wet process, where the ground meal is mixed with water and fed into the kiln as a slurry, is now less common. The wet process uses about 40% more energy than the dry process.

The last stage involves cooling the clinker. As the hot clinker comes off the lower end of the kiln it is rapidly cooled by ambient air in a clinker cooler. There are many different designs of cooler, the most common of which is a travelling grate with under-grate fans that blow cool air through the clinker. Some of this air can be used for combustion, but some is vented to atmosphere or used for drying solid fuels and raw materials.

Finally, the cooled clinker is then mixed with gypsum and, for composite cements, other materials such as blast furnace slag, and ground to a fine homogeneous powder to produce the final product, which is then stored in silos prior to bulk transportation or bagging.

3.4 Emissions

Dust emissions result from activities such as handling raw materials; on site transportation; firing of clinker; milling; and shipment. The largest emission sources are the three units of kiln operation: the feed system, the fuel firing system, and the clinker cooling and handling system. The most desirable method of disposing of the collected dust is injection into the kiln burning zone and production of clinker from the dust. If the alkali content of raw materials is too high, however, some of the dust is discarded and leached before returning to the kiln. In many instances, the maximum allowable cement alkali content of 0.6 % (calculated as sodium oxide) restricts the amount of dust that can be recycled.

Nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO), and carbon dioxide (CO_2) are the primary emissions in the manufacture of portland cement. Small quantities of volatile organic compounds (NMVOC, methane (CH_4)), nitrous oxide (N_2O), and ammonia (NH_3) also may be emitted (see also Table 8.1). Emissions may also include residual materials from the fuel and raw materials or products of incomplete combustion that are considered to be hazardous. Because some facilities burn waste fuels, particularly spent solvents, in the kiln, these systems also may emit small quantities of additional hazardous organic pollutants (IPCC, 1995).

Oxides of nitrogen are generated during fuel combustion by oxidation of chemically bound nitrogen in the fuel and by thermal fixation of nitrogen in the combustion air. As flame temperature increases, the amount of thermally generated NO_x increases. The amount of NO_x generated from fuel increases with the quantity of nitrogen in the fuel. In the cement manufacturing process, NO_x is generated in both the burning zone of the kiln and the burning zone of a precalcining vessel. Fuel use affects the quantity and type of NO_x generated. There is a marked increase in the amount of oxides of nitrogen (mainly nitric oxide) that is formed at temperatures above 1,400 °C. The formation of nitric oxide is also a function of the excess air (IPCC, 1995; EPA, 1995).

Sulphur dioxide may be generated both from the sulphur compounds in the raw materials and from sulphur in the fuel. Here only emissions from combustion are taken into account originating from the sulphur in the fuel. The sulphur content of both raw materials and fuels varies from plant to plant and with geographic location. Sulphur is normally present in the form of metal sulphide and sulphates. The amount of sulphur present will vary widely according to the nature of the deposits used. During the calcining operation, sulphur dioxide is released.

Compounds of sulphur are common constituents of most fuels and levels of sulphur may be as high as 5 wt%. Sulphides and organic sulphur compounds in the raw materials will normally be oxidised to sulphur dioxide and pass through the burning zone of the kiln with the process gases. For practical purposes sulphur in the kiln exhaust may be assumed to be emitted as sulphur dioxide, although there is usually some sulphur trioxide formed. Where this sulphur dioxide is formed at temperatures lower than the calcium carbonate calcination, it will be emitted from the kiln and preheater system to a significant extent. Some absorption may take place in the precipitator or raw mill. In most circumstances, only a small fraction of the sulphur dioxide generated within the kiln from the fuel is released to atmosphere, since it is mainly incorporated into the cement clinker by chemical combination. (IPCC, 1995; EPA, 1995).

The CO_2 emissions from portland cement manufacturing are generated by two process steps: As with most high-temperature, energy-intensive industrial processes, combusting fuels to generate process energy releases substantial quantities of CO_2. Substantial quantities of CO_2 are also generated through calcining of limestone or other calcareous material. This calcining process thermally decomposes $CaCO_3$ to CaO and CO_2. The amount of CO_2 released in the calcining process is about 500 kilograms (kg) per Mg of portland cement produced. Total CO_2 emissions from the pyroprocess depend on energy consumption and generally fall in the range of 0.85 to 1.35 Mg of CO_2 per Mg of clinker. Carbon dioxide comprises at least 20 % of the dry combustion gases and is produced from the carbon content of fuels and from calcination of the calcium carbonate (IPCC, 1995; EPA, 1995). IPPC BREF document (EUROPEAN COMMISSION, 2001) report an estimated emission of CO_2 at 900 to 1000 kg/tonne clinker, related to a specific heat demand of approximately 3500 to 5000 MJ/tonne clinker, but also depending on fuel type.

Fuel combustion at portland cement plants can emit a wide range of pollutants in smaller quantities. If the combustion reactions do not reach completion, CO and volatile organic pollutants (VOC) can be emitted. Incomplete combustion also can lead to emissions of specific hazardous organic air pollutants, although these pollutants are generally emitted at substantially lower levels than CO or VOC (IPCC, 1995).

Carbon monoxide is formed by the incomplete combustion of carbonaceous fuels and even with good combustion control small amounts of carbon monoxide will be present in combustion gases. When operating near to stoichiometric conditions in the kiln, there is localised generation of carbon monoxide (HMIP, 1992).

Heavy metal emissions from cement plants depend on their content in fuels and raw materials, industrial technology (e.g. combustion temperature), and emission control measures. During the cement production process at high temperatures many heavy metals present in the fuel and the raw materials evaporate and then condense on the clinker and partly on fine particles in the flue gas. The latter portion of the metals finds its way to the atmosphere after passing through the emission control equipment.

Fluorine compounds in the feed constituents are partly volatised into gaseous acidic fluorides at the high temperatures in the kiln. However, such acidic compounds are immediately neutralised (in the form of solid calcium fluoride) by the alkaline constituents in both the clinker and the feed. Thus, 88 - 98 % of the fluoride content of the feed materials is trapped in the clinker and the remainder deposits on dust particles and is mainly removed by the dust control devices. Chlorine compounds behave in a similar manner to those of fluorine.
Some kilns do burn hazardous waste as supplemental fuel. Other types of non-hazardous liquid and solid wastes used as supplemental fuels include tyres, waste oil, and wood chips. Dioxins (PCDDs) and furans (PCDFs) were first detected in stack emissions from portland cement kilns in the early 1980s (e.g. EPA, 1994). They were detected at low concentrations and were thought to be caused by the co-firing of liquid hazardous waste with conventional fossil fuels. Recently more information has become available on the possible formation

mechanisms of dioxins in the portland cement kilns. The following mechanisms have been suggested:

- some primary combustion fuels and fuel supplements used to sustain elevated temperatures in the kiln to form clinker may also produce aromatic hydrocarbon compounds that can later become chlorinated ring structures. The oxidation of HCl gas has been shown to provide chlorine available for ring substitution;
- the chlorinated aromatic compounds may act as precursor molecules to the thermalytic formation of CDD/CDFs on the active surface of carbonaceous particles;
- de novo synthesis of CDD/CDFs on the active surface of carbonaceous particles in the presence of a catalytic agent (e.g. metal ions);
- post-kiln temperatures of the combustion gases are often within the range of temperatures that promote the continued formation of CDD/CDFs;
- co-firing of liquid hazardous organic wastes with coal and petroleum coke may lead to an increase in the amount of CDD/CDFs formed in the post-combustion zone.

3.5 Controls

Emission reduction is usually obtained by reducing the dust emissions. Electrostatic precipitators (ESPs) and fabric filters (FFs) are most widely used on both kilns and clinker coolers. For electrostatic precipitation dust concentrations of 30 - 40 mg/m^3 can be achieved. For fabric filters a value of 20 to 50 mg/m^3 is common. A few gravel bed filters have also been used to control clinker cooler emissions. Fugitive emission sources are normally captured by a ventilation system and fabric filters used to collect the dust.

A portion of heavy metals in the flue gas will also be removed with particles. However, the most volatile heavy metals are present on very fine particles, often penetrating both ESPs and FFs. It is proposed that further reduction of dust concentrations in the flue gas to 10 mg/m^3 should be achieved in order to obtain reasonable reduction of heavy metals.

Emissions of sulphur dioxide are best reduced by use of low sulphur raw materials. Removal of sulphur dioxide from the exhaust gases is possible using injection of calcium hydroxide into the air stream - after the preheater for minor reductions, or by a separate fluid bed absorber for significant reductions. However, the alkaline nature of the cement provides for direct absorption of SO_2 into the product, thereby mitigating the quantity of SO_2 emissions in the exhaust stream. Depending on the process and the source of the sulphur, SO_2 absorption ranges from about 70 percent to more than 95 percent. However, in systems that have sulphide sulphur (pyrites) in the kiln feed, the sulphur absorption rate may be as low as 70 percent without unique design considerations or changes in raw materials. Fabric filters on cement kilns are also reported to absorb SO_2 (IPCC, 1995; EPA, 1995).

Flue gas desulphurisation equipment also reduces the concentration of gaseous mercury present in the flue gas. This reduction can be as high as 50 %. Further reduction of up to 85 % can be achieved through the application of very expensive measures such as injection of activated carbon or application of activated carbon beds.

Oxides of nitrogen can be reduced by applying the following techniques (EPA, 1995):

- Use of low-NO_x-burners where practicable, the principle of which is the avoidance of localised hot spots.
- Avoidance of over-burning of the clinker. The temperature in the burning zone can be limited to that necessary to produce a free lime content which gives acceptable clinker quality. Cements kilns can be fitted with on-line oxides of nitrogen sensors which form the basis of an automatic kiln control system. The prevention of over-burning not only gives reduced oxides of nitrogen levels but also provides some worthwhile energy savings.

The formation of carbon dioxide should be minimised by the use of energy efficient systems and techniques (HMIP, 1992).

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = AR \times EF$$

---

[1] The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8.1.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tier 3), to estimate emissions of gaseous pollutants from the cement production is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

The detailed methodology to estimate emissions of trace elements from the cement production is similar to the simpler one. However, more information on the type of the process, e.g. wet and dry kilns, as well as on the type of the industrial technology should be made available. This information shall be used to estimate specific emissions for at least a specific industrial technology.

Measurements of the emission rate and chemical composition of fine particles with < 1.0 μm diameter are often carried out at major cement kilns world-wide. The results of these measurements are then used to estimate atmospheric emissions of several trace elements contained as impurities in the raw materials and fuel.

Reference emission factors for comparison with users own data are provided in Section 8.2.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of cement, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics.

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities of cement produced by various types of industrial technologies employed in the cement industry at plant level. This data is however not always easily available.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

Cement production plants are regarded as point sources if plant specific data are available. When emissions care is needed to distinguish ground level emissions (from mechanical processes) from combustion related emissions released via a chimneystack.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Default Emission Factors For Use With Simpler Methodology

A summary of default emission factors for use with a simpler methodology for estimating emissions are provided in Table 8.1a and Table 8.1b. The emission factors are mainly extracted from the Integrated Pollution Prevention and Control Reference Document on Best Available Techniques [IPPC, BREF] (European Commission, 2001). Care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030311; fuel used in the process does not have to be taken into account in 0301.

Table 8.1a: Emission Factors for Cement production

Pollutant	**Emission factor**	**Units**
Particulate matter (1)		
TSP	600	g/tonne cement
PM_{10}	510	g/tonne cement
$PM_{2.5}$	180	g/tonne cement
Nitrogen oxides		
Average (3)	2100	g/tonne of clinker (2)
BAT (3, 4)	700	g/tonne of clinker
Sulphur oxides (4)		
raw materials with little or no volatile sulphur	20	g/tonne of clinker
raw materials with high volatile sulphur		
average	2400	g/tonne of clinker
BAT (5)	600	g/tonne of clinker
Volatile organic compounds(3)	110	g/tonne clinker

(1) When information on type of facilities and abatement used is available, the corresponding emission factors for particulates (CEPMEIP) in Table 8.2g can also be used in the simple methodology. The here referred emission factor for particulate matter is for the most used technology in the EU; Conventional Cement production plant with an ESP on the main stack and smaller fabric filters for moderate control of fugitive sources

(2) Production capacities for clinker (intermediate product) and cement slightly differ and a correction factor needs to be used to transform the emission factor to cement. This factor is in order of magnitude of 0.8 [IPPC, BREF].

(2) Mean value of NOx emission measurements at more than 50 preheater rotary cement kilns from "*British Cement Association, Prevention and abatement of NOx emissions, International Cement Review, p. 51-59, October 1997*" as reported in *EUROPEAN COMMISSION, 2001*

(3) Using average of ranges in mg/m^3 and exhaust gas volumes around 2000 m^3/tonne of clinker from *EUROPEAN COMMISSION, 2001*

(4) The BAT for reducing NO_x emissions are a combination of general primary measures, primary measures to control NO_x emissions, staged combustion and selective non-catalytic reduction (SNCR) as reported in *EUROPEAN COMMISSION, 2001*"

(5) The best available techniques for reducing SO_2 emissions are a combination of general primary measures and absorbent addition for initial emission levels not higher than about 1200 mg SO_2/m^3 and a wet or dry scrubber for initial emission levels higher than about 1200 mg SO_2/m^3.

Table 8.1b: Metal and specific VOCs Emission Factors for Cement production

Pollutant	Emission factor	Units
Arsenic	0.2	g/tonne cement
Cadmium	0.01	g/tonne cement
Chromium	1	g/tonne cement
Copper	0.4	g/tonne cement
Mercury	0.1	g/tonne cement
Nickel	0.1	g/tonne cement
Lead	0.2	g/tonne cement
Selenium	0.002	g/tonne cement
Zinc	2	g/tonne cement
Dioxins and furans	0.2	µg TEQ/tonne cement
Hexachlorobenzene	11	µg TEQ/tonne cement
Polyaromatic hydrocarbons	3	mg/tonne cement
Polychlorinated biphenyls	1	µg/tonne cement

8.2 Reference Emission Factors for Use With Detailed Methodology

Table 8.2a contains reference emission factors for the production of cement based on CORINAIR90 data in [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product, g/Mg clinker), are listed in footnotes. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a value for the specific energy consumption of 13 GJ/Mg product has been reported.

In each case, care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030311; fuel used in the process does not have to be taken into account in 0301

Table 8.2a: Emission factors for the production of cement (fuel related)

Type of fuel				**NAPFUE code**	**Emission factors**						
					SO_2 [g/GJ]	**NO_x [g/GJ]**	**NMVOC [g/GJ]**	**CH_4 [g/GJ]**	**CO [g/GJ]**	**CO_2 [kg/GJ]**	**N_2O [g/GJ]**
s	coal	hc	coking	101	569$^{1)}$, 85-165$^{2)}$	701$^{1)}$, 450-709$^{2)}$		1$^{1)2)}$		86$^{1)2)}$	
s	coal	hc	steam	102	44-880$^{1)}$, 35-600$^{2)}$	150-170$^{1)}$, 0.4-575$^{2)}$	15$^{1)}$, 15-33$^{2)}$	14.7-15$^{1)}$, 0.3-15$^{2)}$	10-110$^{1)}$, 18-100$^{2)}$	93-94$^{1)}$, 78-101$^{2)}$	12$^{1)}$, 3-12$^{2)}$
s	coal	hc	sub-bituminous	103	134-154$^{1)}$, 1,260$^{2)}$	57$^{1)}$ 820-1,300$^{2)}$			22$^{1)}$	99$^{1)}$, 320-420$^{2)}$	8$^{2)}$
s	coal	hc	brown coal/lignite	105	25$^{2)}$	575$^{2)}$	15$^{2)}$	15$^{2)}$		100-113$^{2)}$	3.5$^{2)}$
s	coal	hc	briquettes	106	11$^{2)}$	575$^{2)}$	15$^{2)}$	15$^{2)}$	100-260$^{2)}$	97-98$^{2)}$	3.5$^{2)}$
s	coke	hc	coke oven	107	25$^{2)}$	575$^{2)}$	15$^{1)}$, 0.5$^{2)}$	15$^{1)}$, 0.5$^{2)}$	110$^{1)}$, 100$^{2)}$	108$^{1)}$, 100-105$^{2)}$	14$^{1)}$, 4$^{2)}$
s	coke		petroleum	110	355-511$^{1)}$, 85-1,200$^{2)}$	300-568$^{1)}$, 0.4-575$^{2)}$	1.5$^{1)}$, 1.5-15$^{2)}$	1.5$^{1)}$, 1-15$^{2)}$	10-70$^{1)}$, 15-100$^{2)}$	99-102$^{1)}$, 97-102$^{2)}$	14$^{1)}$, 3-14$^{2)}$
s	waste		municipal	115	161$^{1)}$	200$^{1)}$	15-40$^{1)}$	15-40$^{1)}$	70$^{1)}$	100-121$^{1)}$	5-12$^{1)}$
s	waste		industrial	116	135$^{2)}$	0.4-568$^{2)}$		0.2$^{2)}$	1429$^{2)}$	83$^{2)}$	4$^{2)}$
l	oil		residual	203	131-1,030$^{1)}$, 16-1,079$^{2)}$	150-220$^{1)}$, 0.4-575$^{2)}$	3$^{1)}$, 3-10$^{2)}$	1-3$^{1)}$, 1-5$^{2)}$	15-20$^{1)}$, 8-79$^{2)}$	76-79$^{1)\ 2)}$	2-15$^{1)\ 2)}$
l	oil		gas	204	4-1,410$^{2)}$	0.4-575$^{2)}$	1.5$^{1)}$, 1.5-2.5$^{2)}$	1-5$^{1)}$, 1-8$^{2)}$	12$^{1)}$, 12-79$^{2)}$	74$^{1)}$, 73-74$^{2)}$	12$^{1)}$, 2-14$^{2)}$
l	gasoline		motor	208			2.5$^{1)}$	2.5$^{1)}$	12$^{1)}$	72$^{1)}$	12$^{1)}$
l	oil		shale-oil	211						78$^{1)}$	
g	gas		natural	301	0.1-135$^{2)}$	175$^{1)}$, 60-560$^{2)}$	2.5$^{1)}$, 2.5-18.4$^{2)}$	2.5$^{1)}$, 0.4-5$^{2)}$	20$^{1)}$, 10-120$^{2)}$	53-56$^{1)}$, 55-69$^{2)}$	3$^{1)}$, 1-3.7$^{2)}$
g	gas		liquified petroleum gas	303	0.04$^{2)}$	100$^{2)}$	2.5$^{1)}$, 2.1$^{2)}$	2.5$^{1)}$, 0.9$^{2)}$	20$^{1)}$, 13$^{2)}$	65$^{1)2)}$	3$^{1)}$, 1$^{2)}$
g	gas		coke oven	304	0.6$^{2)}$	575$^{2)}$	2.5$^{2)}$	2.5$^{2)}$	10$^{2)}$	44$^{2)}$	1.5$^{2)}$
Data quality rating					B	B	D	D	C	C	D

1) CORINAIR90 data, area sources
2) CORINAIR90 data, point sources

Technique related emission factors are listed in Tables 8.2b through 8.2g for sulphur dioxide, nitrogen oxides, non-methane VOCs, CO, methane, and particulate matter. Only for particulates (Table 8.2g) some information exists on the type and efficiency of abatement techniques. All other factors in these tables seem to be valid for emissions from uncontrolled processes.

Table 8.2b: Emission factors for SO_2 from cement production

Process type	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Unit**	**Emission factor**	**Data Quality Code**	**Country or region**
Dry process kiln	N/A	N/A	N/A	kg/tonne product	5.1	E	USA
Wet process kiln	N/A	N/A	N/A	kg/tonne product	5.1	E	USA
Cement production	N/A	N/A	N/A	kg/tonne cement	0.2-0.3	E	USA
Clinker production	N/A	N/A	N/A	g/gJ	0.02-50.0	E	USA

Table 8.2c: Emission factors for NO_x from cement production

Process type	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Unit**	**Emission factor**	**Data Quality Code**	**Country or region**
Dry process kiln	N/A	N/A	N/A	kg/tonne product	1.4-2.1	E	USA
Wet process kiln	N/A	N/A	N/A	kg/tonne product	1.1-1.4	E	USA
Semi-wet process kiln	N/A	N/A	N/A	kg/tonne product	1.8	E	USA
Clinker production	N/A	N/A	N/A	g/GJ	1.2	E	USA
Clinker production (80% NO_x reduction, 20% energy saving)	N/A	N/A	N/A	kg/tonne clinker	0.6	E	USA
Cement production	N/A	N/A	N/A	g/GJ	130-220	E	USA
Cement production	N/A	N/A	N/A	kg/tonne cement	1.3-1.4	E	USA
Cement/lime industry, kiln	N/A	N/A	Natural gas	kg/GJ	1.1	E	USA
Cement/lime industry, kiln	N/A	N/A	Oil	kg/GJ	0.5	E	USA
Cement/lime industry, kiln	N/A	N/A	Coal	kg/GJ	0.5	E	USA

N/A - Data not available

Table 8.2d: Emission factors for NMVOC from cement production

Process type	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Unit**	**Emission factor**	**Data Quality Code**	**Country or region**
Dry process kiln	N/A	N/A	N/A	g/tonne product	10.0	E	USA
Cement production	N/A	N/A	N/A	kg/tonne cement	50.0	E	USA

N/A - Data not available

Table 8.2e: Emission factors for CO from cement production

Process type	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Unit**	**Emission factor**	**Data Quality Code**	**Country or region**
Cement/lime industry, kiln	N/A	N/A	Natural gas	g/GJ	83.0	E	USA
Cement/lime industry, kiln	N/A	N/A	Oil	g/GJ	79.0	E	USA
Cement/lime industry, kiln	N/A	N/A	Coal	g/GJ	79.0	E	USA

N/A - Data not available

Table 8.2f: Emission factors for CH_4 from cement production

Process type	Abatement type	Abatement efficiency	Fuel type	Unit	Emission factor	Data Quality Code	Country or region
Cement/lime industry, kiln	N/A	N/A	Natural gas	g/GJ	1.1	E	USA
Cement/lime industry, kiln	N/A	N/A	Oil	g/GJ	1.0	E	USA
Cement/lime industry, kiln	N/A	N/A	Coal	g/GJ	1.0	E	USA

N/A - Data not available

Table 8.2g: Emission factors for particles from cement production

Process type	**Abatement type**	**Abatement efficiency**	**Fuel type**	**Unit**	**Emission factor**			**Data Quality Code***	**Country or region**
					TSP	PM_{10}	$PM_{2.5}$		
Cement production (conventional plant)	ESP on main stack and smaller fabric filters for moderate control of fugitive sources	N/A	N/A	g/tonne cement	600	510	180	E (1,5)	EU (CEPMEIP)
Cement production	Limited control fugitive sources; ESP in main stack	ESP < 97%	N/A	g/tonne cement	2000	800	300	E (1,5)	EU (CEPMEIP)
Cement production (modern facility)	Addional fabric filters on the oven stack; effective control of fugitive sources	N/A	N/A	g/tonne cement	200	180	80	E (1,5)	EU (CEPMEIP)

N/A - Data not available

NOTE: The uncertainty range (95% confidence) in the emission factor is expressed as a factor. The lower limit of the uncertainty range can be found by dividing the emission factor by the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example (first row in Table 8.2g): The uncertainty in the emission factor for $PM_{2.5}$ from a conventional cement production plant with an ESP on the main stack and smaller fabric filters for moderate control of fugitive sources is 1.5. The emission factor with uncertainty range will therefore be 510 gram per tonne cement with an uncertainty range of 340 (510/1.5) to 765 (510x1.5).

The emission factors for particles are dominated by the PM emissions arising from the kilns. Emissions for manufacturing of raw material and the processing and handling of the product are significantly lower. Emission factors for milling where emissions are controlled are in the range of 4 – 14 g TSP / ton material processed (AP42, table 11.6-3).

The emission factors for heavy metals are determined by the composition of the raw material and the type of fuels used for firing. An illustration of the range of emission factors to be expected is given in Table 8.2h. This table is derived from the PARCOM-ATMOS Emission Factors Manual (van der Most and Veldt, 1992). Unfortunately, no information is available on the abatement efficiency for these data.

Table 8.2h: Examples of emission factors for heavy metals from cement production in g/Mg cement (van der Most and Veldt, 1992)

Substance	**Coal and oil fired**	**Proportion of waste oil**	**Fuel unknown**	**Fuel unknown**	**Fuel unknown**
Arsenic	-	-	-	0.012	-
Cadmium	-	-	0.04	0.008	< 0.001
Chromium	0.006-0.02	0.02-0.3	-	0.105	-
Lead	0.006	0.012-0.2	1.1	0.216	<0.033
Mercury	-	-	-	0.275	-
Nickel	-	-	-	0.111	-
Selenium	-	-	-	0.002	-
Zinc	-	-	-	0.293	0.003-0.47

- Data not available

Similar results were reported for the UK cement industry (Salway, 1997).

In the CIS countries cement plants operate mostly using the wet process, and in this way 83 % of cement is produced. Some preliminary emission factors suggested for these countries are within the ranges presented in the above tables (EMEP-MSC-E, 1997). The same can be concluded for the emission factors developed in the Netherlands.

Concentrations of dioxins and furans in the flue gas after passing the control equipment in the cement production are presented in Table 8.1b after a compilation of data by the Working Group of the Subcommittee Air/Technology of the Federal Government/Federal States Emission Control Committee in Germany (Umweltbundesamt, 1996) and information obtained from Schreiber et al. (1995), EPA (1994), and (Quass, 1997).

Emission data from kilns in operation coming from IPPC BREF document (EUROPEAN COMMISSION, 2001) is given in Table 8.2i. The emission ranges within which kilns operate depend largely on the nature of the raw materials, the fuels, the age and design of the plant, and also on the requirements laid down by the permitting authority. Mass figures are based on 2000 m^3/tonne clinker and 1 million tonnes clinker/year. Emission ranges are one-year averages and are indicative values based on various measurement techniques. O_2-content is normally 10%.

Typical kiln exhaust gas volumes expressed as m^3/tonne of clinker (dry gas, 101.3 kPa, 273 K) are between 1700 and 2500 for all types of kilns. Suspension preheater and precalciner kiln systems normally have exhaust gas volumes around 2000 m^3/tonne of clinker (dry gas, 101.3 kPa, 273 K).

There are also releases of particulates from all milling operations i.e. raw materials, solid fuel and product. There is potential for the release of particulates from any outside storage of raw materials and solid fuels as well as from any materials transport systems, including cement product loading. The magnitude of these releases can be significant if these aspects are not well engineered or maintained and being released at low level can lead to local nuisance problems.

Table 8.2i: Emission ranges from European cement kilns from IPPC BREF document (EUROPEAN COMMISSION, 2001)

Pollutant	**mg/Nm^3**	**kg/tonneclinker**	**tonnes/year**
NO_x (as NO_2)	<200–3000	<0.4-6	400-6000
SO_2	<10–3500	<0.02-7	<20-7000
Dust	5–200	0.01-0.4	10-400
CO	500–2000	1-4	1000-4000
CO_2	400-520 g/Nm^3	800-1040	0.8-1.04 million
TOC	5-500	0.01–1	10-1000
HF	<0.4-5	<0.8-10 g/t	<0.8-10
HCl	<1-25	<2-50 g/t	<2-50
PCDD/F	<0.1-0.5 ng/Nm^3	<200-1000 ng/t	<0.2-1 g/year
Metals:			
Σ(Hg,Cd,Tl)	0.01-0.3 (mainly Hg)	20-600 mg/t	20-600 kg/year
Σ(As,Co,Ni,Se,Te)	0.001-0.1	2-200 mg/t	2-200 kg/year
Σ(Sb,Pb,Cr,Cu,Mn,V,Sn,Zn)	0.005-0.3	10-600 mg/t	10-600 kg/year

9 SPECIES PROFILES

An analysis of dust emissions from clinker firing in the Netherlands gave results presented in Table 9.1. The composition is given in mg per tonne cement:

Table 9.1: Composition of dust from clinker firing

Substance	Concentration in dust (g/tonne of cement)
Antimony	6
Arsenic	4
Cadmium	6
Chromium	5
Copper	8
Lead	6.5
Mercury	9
Nickel	4
Selenium	3
Tellurium	5
Thallium	3
Uranium	3
Vanadium	5
Zinc	4

EPA (1995) gives size distributions for particulate matter emitted from various cement production processes. These are reproduced in Table 9.2. The profiles for controlled dry process kilns and controlled clinker coolers seem most appropriate for the EU and suggest that particulate matter emissions comprises about 80% PM_{10}.

Table 9.2: Particle size distributions and size-specific emission factors (EPA 1995)

Process	**Abatement technology**	**Particle size (µm)**	**Cumulative mass % less than stated size**
Kilns, wet process	Uncontrolled	2.5	7
		5	20
		10	24
		15	35
		20	57
		total	100
Kilns, wet process	ESP	2.5	64
		5	83
		10	58
		15	91
		20	98
		total	100
Kilns, dry process	Uncontrolled	2.5	18
		10	42
		15	44
		total	100
Kilns, dry process	Fabric filter	2.5	45
		5	77
		10	84
		15	89
		20	100
		total	100
Clinker coolers	Uncontrolled	2.5	0.54
		5	1.5
		10	8.6
		15	21
		20	34
		total	100
Clinker coolers	Gravel bed filter	2.5	40
		5	64
		10	76
		15	84
		20	89
		total	100

In general, no reliable information exists at present on physical and chemical species of trace elements emitted during the cement production. It can be assumed that the majority of trace elements volatilised from the raw material and fuel enter the atmosphere on fine particles.
Very general information collected by Pacyna (1987) appears to indicate that elemental forms, oxides and sulphates are the major chemical forms of atmospheric trace elements from the cement production.

10 UNCERTAINTY ESTIMATES

It is rather difficult to assess current uncertainties of emission estimates for pollutants emitted during the cement production. The uncertainties of sulphur dioxide emission estimates can be assessed in a similar way as the uncertainties of the estimates for the fossil fuel combustion (see chapter B111).

Recently it was concluded that up to 50% of uncertainties may be assigned to the emission estimates of most of the trace elements emitted from major point sources in Europe (Pacyna, 1994). Similar uncertainty can be assigned for emission estimates of these compounds from the cement production.

Uncertainties associated with the emissions of $PM_{2.5}$ are indicated in Table 8.2g.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Knowledge of abatement techniques, dust removal efficiencies and operating techniques is limited; measurement data of composition of dust is poor.

The fuel specific emission factors provided in Table 8.1 are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of emission factors with respect to point and area sources. Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges. Emission factors also need to be generated, which specifically relate to different levels of abatement on different types of plant.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Cement production plants should be considered as point sources if plant specific data are available. Otherwise national emissions should be disaggregated on the basis of plant capacity, employment or population statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

Cement production can be considered as a continuous process.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

Emission inventory in The Netherlands, 1992. Emission to air and water

Personal information and experience during emission inventories 1975 - 1995

Emission factors to be used for the building industry, TNO report 89/091

Environmental Protection Agency, Compilation of Air Pollutant Emission Factors AP 42

PARCOM-ATMOS Emission Factors Manual

16 VERIFICATION PROCESSES

Verification of the emissions can be done for metal emissions by calculating the emissions using the factors from the PARCOM ATMOS manual and comparing the results with a mean profile.

17 REFERENCES

Baart A.C., Berdowski J.J.M., van Jaarsveld J.A. (1995) Calculation of atmospheric deposition of contaminants on the North Sea; IWAD; ref. TNO-MW-R 95/138; TNO MEP; Delft; The Netherlands.

Bouscaren M. R. (1992) CORINAIR Inventory, Default Emission Factors Handbook,; second Edition, Commission of the European Communities; Paris.

EMEP-MSC-E (1997) Belarusian contribution to the EMEP. Annual Report 1996. EMEP Meteorological Synthesising Centre - East, Moscow.

EPA (1990) AIRS Facility subsystem. The U.S. Environmental Protection Agency, EPA-Doc 450/4-90-003, Research Triangle Park NC, March.

EPA (1993) Locating and Estimating Air Emissions from Sources of Mercury and Mercury Compounds. The U.S. Environmental Protection Agency, EPA-454/R-93-023, Research Triangle Park, NC, September.

EPA (1994) Estimating exposure to dioxin-like compounds. Vol. II: Properties, sources, occurrence and background exposures. The U.S. Environmental Protection Agency, EPA/600/6-88/005Cb, Washington, DC.

EPA (ed.), (1995) AP42 CD-Rom.

ETC/AEM-CITEPA-RISOE (1997) Selected nomenclature for air pollution for CORINAIR94 inventory (SNAP 94), version 0.3 (Draft).

EUROPEAN COMMISSION (2001), Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques (BREF) in the Cement and Lime Manufacturing Industries, December 2001

Hackl, A. and Mauschitz, G. (1995) Emissionen aus Anlagen der österreichischen Zementindustrie; Vienna.

Her Majesty´s Inspectorate of Pollution (HMIP) (ed.), (1992) Cement Manufacture and Associated Processes; Environmental Protection Act 1990; Process Guidance Note IPR 3/1; London.

IPCC (ed.), (1995) Greenhouse Gas Inventory Reference Manual, Volume 3.

van der Most P.F.J. and Veldt C. (1992) Emission Factors Manual. PARCOM-ATMOS-Emission factors for air pollutants 1992. TNO Rept. 92-235. TNO Environmental and Energy Research, Apeldoorn, the Netherlands

Pacyna J.M. (1987) Atmospheric emissions of arsenic, cadmium, lead and mercury from high temperature processes in power generation and industry. In: T.C. Hutchinson and K.M. Meema, eds., Lead, Mercury, Cadmium and Arsenic in the Environment, Wiley, Chichester, the United Kingdom.

Pacyna J.M. (1994) Emissions of heavy metals in Europe. In: Background Document for the EMEP Workshop on European Monitoring, Modelling and Assessment of Heavy Metals and Persistent Organic Pollutants, Beekbergen, the Netherlands, 3-6 May, 1994.

Pacyna J.M. and Pacyna P. (1996) Global emissions of mercury to the atmosphere. Emissions from anthropogenic sources. Technical Report for the Arctic Monitoring and Assessment Programme. Norwegian Institute for Air Research, Kjeller, Norway.

Passant N, Peirce M, Rudd H and Scott D (2000) UK Fine Particulate Emissions from Industrial Processes. AEA Technology report AEAT-6270, Culham UK.

Quass U. (1997) Information on dioxins/furans emissions in the German cement industry.

Salway A.G. (1997) Information on heavy metals emissions from the UK cement industry prepared by Entec company for the UK Department of the Environment.

Schreiber R.J., Evers J.J. and Winders W.H. (1995) Dioxins emissions and cement kiln operations. Organohalogen Compounds, 23, 425-429.

Smit J. R. K. (1993) Produktie van Cement; RIVM-report 73601136;RIZA-report 92.003/41; Maart.

Umweltbundesamt (1996) Determination of requirements to limit emissions of dioxins and furans. Report from the Working Group of the Subcommittee Air/Technology of the Federal Government/ Federal States Immission Control Committee, Texte 58/95, Umweltbundesamt, Berlin.

Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

For a detailed bibliography the primary literature mentioned in AP 42 or the PARCOM-ATMOS Manual can be used.

19 RELEASE VERSION, DATE AND SOURCE

Version: 2.4

Date: June 2005

Source: J.J.M. Berdowski, P.F.J.van der Most, R.Wessels Boer
TNO
The Netherlands

Supported by: Rentz, Otto; Oertel, Dagmar
University of Karlsruhe (TH)
Germany

Updated by: Jozef M. Pacyna
Norwegian Institute for Air Research (NILU)
Norway

Further update by:
Martin Pierce
AEA Technology Environment
UK

Integrated with IPPC BREF data, and updated the default emission factors for simpler methodology by:
Carlo Trozzi
Techne Consulting
Italy

Updated with emission factors (CEPMEIP) for particulates by:
Tinus Pulles and Wilfred Appelman
TNO
The Netherlands
May 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Carlo Trozzi
Techne Consulting
Via G. Ricci Curbastro, 34

Roma, Italy

Tel: +39 065580993
Fax: +39 065581848
Email: carlo.trozzi@techne-consulting.com

SNAP CODE:	**030312** **040614**
SOURCE ACTIVITY TITLE:	**PROCESSES WITH CONTACT** ***Lime*** ***Lime (decarbonizing)***
NOSE CODE:	**104.01.02**
NFR CODE:	**1 A 2 f** **2 A 2**
ISIC:	**2394**

1 ACTIVITIES INCLUDED

This chapter includes information on atmospheric emissions during lime work operations. Lime (CaO) is the high-temperature product of the calcination of limestone. The production occurs in vertical and rotary kilns fired by coal, oil or natural gas. Calcium limestone contains between 97 and 98 % of calcium carbonate on a dry basis. The rest includes magnesium carbonate, aluminium oxide, iron oxide and silica. However, some limestone contains as much as 35 to 45 % magnesium carbonate and is classified as dolomite.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

Atmospheric emissions in the lime manufacturing industry include particulate emissions from the mining, handling, crushing, screening, and calcining of the limestone and emissions of air pollutants generated during fuel combustion in kilns. These emissions are not very significant on global or even regional scale. However, lime works can be an important emission source of air pollutants on a local scale.

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**										
Lime	030312	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Typical contribution		0.1	0.2	0	0	0.3	0.3	-	-	5.98	5.24	1.85
Highest value										33.0	32.2	12.0
Lowest value										0.05	0.05	0.02

* EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

3 GENERAL

3.1 Description

Two major types of processes can be considered within the lime work operations: quarrying, crushing, and size grading of minerals and then combustion of fuels in lime kilns. Limestone quarries are usually developed in a number of benches or lifts. For primary blasting of the limestone, holes are made by drills operated by compressed air (Parker, 1978). The excavated limestone is transferred for crushing and grinding. There are several types of crushing and grinding machines to produce limestone of sizes suitable for several designs of kilns.

During the kiln operations the limestone reaches temperatures as high as 900° C, and carbon dioxide is driven off limestone to leave so-called quicklime. The quicklime descends through the cooling zone and is discharged at the base of the kiln. Obviously, various air pollutants are generated during combustion of fuels in the kiln. At present two major types of kilns are in use: vertical and rotary kilns.The vertical kilns, because of larger size of charge material, lower air velocities, and less agitation emit lower amounts of particles but higher amounts of sulfur dioxide and carbon monoxide. However, in recent years there have been important developments in the design and use of rotary kilns. They require a more carefully classified and smaller size of limestone than for the vertical kilns.

Hydrated lime is made by adding water to crushed or ground quicklime and thoroughly mixing the quicklime and the water.Milk of lime can be produced either by slaking quicklime with an excess of water or by mixing hydrated lime with water.

In Table 3.1 was reported the number of kilns for types in Europe in 1995 (EUROPEAN COMMISSION, 2001).

Table 3.1: Number of operational lime kilns, not including captive kilns, in EU Member States 1995 (EUROPEAN COMMISSION, 2001)

Country	Rotary	Annular shaft	Regener. shaft	Other shaft	Other kilns	Total
Austria	0	2	6	3	1	12
Belgium	8	5	14	0	2	29
Denmark	2	0	0	0	0	2
Finland	5	0	0	0	0	5
France	4	21	20	18	1	64
Germany	7	31	12	74	12	136
Greece	1	2	1	39	1	44
Ireland	1	0	1	3	0	5
Italy	0	5	25	30	0	60
Luxembourg	0	0	0	0	0	0
Netherlands	0	0	0	0	0	0
Portugal	0	0	2	1	9	12
Spain	4	1	21	16	0	42
Sweden	5	0	3	2	0	10
UK	8	0	7	10	1	26
Total	45	67	114	196	27	449

3.2 Definitions

Lime	the high-temperature product of the calcination of limestone.

3.3 Emissions

Pollutants released are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (N_2O) and particulate matter. According to CORINAIR90 the main relevant pollutants are SO_2, NO_x, CO and CO_2 (see also table 3).

Sulphur dioxide emissions are influenced by several factors, including the sulphur content of the fuel, the sulphur content and mineralogical form (metal sulphide like pyrite, or sulphates like gypsum) of the stone feed, the quality of lime being produced, and the type of kiln. Due to variations in these factors, plant-specific SO_2 emission factors are likely to vary significantly from the average emission factors presented here. The dominant source of sulphur emissions is the kiln's fuel, particularly coal and petroleum derived coke, where the levels of sulphur may be as high as 5 % by weight. The amount of sulphur present will vary widely according to the nature of the deposits used. During the calcining operation, sulphide and sulphates are decomposed to yield sulphur dioxide. On combustion of the fuel, the sulphur compounds present in the fuel are oxidised to sulphur dioxide, and pass through the burning zone of the kiln with the exhaust gases (EPA, 1995; HSMO, 1992).

When sulphur containing fuels are burnt, for practical purposes sulphur in the kiln exhaust may be assumed to be emitted as sulphur dioxide, although there is usually some sulphur trioxide formed. In the case of lime manufacture in shaft kilns, much of the sulphur re-combines with the burnt lime and the emissions of sulphur dioxide are subsequently reduced. In the case of rotary and rotating hearth kilns, combinations of process design and combustion conditions can be selected to ensure that most of the sulphur is expelled as sulphur dioxide in the kiln gases (HSMO, 1992).

The oxides of nitrogen are produced through the reaction of the nitrogen and oxygen in the air and through the oxidation of the nitrogen compounds contained in the fuel. There is a significant increase in the amount of oxides of nitrogen (mainly nitric oxide) which is formed at temperatures above 1,400 °C. The formation of nitric oxide is also a function of the excess air. When operating near to stoichiometric conditions in the kiln, there is localised generation of carbon monoxide. This acts as a reducing agent so that any nitric oxide which may be present is converted to nitrogen. Some oxides of nitrogen are also formed in electrostatic precipitators (HSMO, 1992).

Carbon dioxide and carbon monoxide are formed as main products of the combustion process. Carbon monoxide is formed by the incomplete combustion of carbonaceous fuels and even with good combustion control small amounts of carbon monoxide will be present in combustion gases.

The dissociation of limestone produces up to 0.75 tonne of carbon dioxide (CO_2) per tonne of quicklime, depending on the composition of the limestone and the degree of calcination.

The amount of carbon dioxide produced by combustion depends on the chemical composition of the fuel and on the heat use per tonne of quicklime, generally it is in the range 0.2 to 0.45 tonne CO_2 per tonne of quicklime (EUROPEAN COMMISSION, 2001).

3.4 Controls

Emissions of sulphur oxide can be reduced by using low sulphur fuels and by limiting the sulphur contents of the fuel and raw materials. Sulphur dioxide emissions may be further reduced if the polluting equipment is fitted to desulphurise the exhaust gases (e.g. by using a wet process) (EPA, 1995; HMSO, 1992).

The design of kiln and combustion conditions may be selected to ensure that most of the sulphur is retained in the burnt lime. In most circumstances, especially in shaft kilns, only a small fraction of the sulphur dioxide generated within the kiln (whether originating from the raw materials or from the fuel) is released to atmosphere, since it is mainly incorporated into the lime by chemical combination (HSMO, 1992).

The following techniques can be reasonably applied to reduce oxides of nitrogen discharges to the atmosphere:

- the use of low-NO_x-burners where practicable, the principle of which is the avoidance of localised hot spots, and
- the use of very finely pulverised coal so that complete combustion can be achieved with low excess air.

Modern lime works are equipped with electrostatic precipitators that remove at least 98 % of the particulate matter from exhaust gases. Other control devices are also used including multiple cyclones, wet scrubbers, and baghouses.

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes (“activity rates”) and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

---

[1] The term “Tier” is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = \text{AR} \times \text{EF}$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8.1. However, it should be admitted that the chemical composition of fuel used in kilns is one of the factors affecting the amount of these emissions.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tier 3), to estimate emissions of gaseous pollutants from the cement production is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

In this case, different emission factors for different types of kilns should be used. An account of the effect of emission controls should be considered. The different emission factors will have to be evaluated through measurements at representative sites.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of lime, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics.

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities of lime produced by various types of industrial technologies employed in the lime industry at plant level. However, in most cases, no information is available from the statistical yearbooks on the quantities of lime produced in vertical and rotary kilns.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

Lime works should be regarded as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Default Emission Factors For Use With Simpler Methodology

A summary of default emission factors for use with a simpler methodology for estimating emissions are provided in Table 8.1 and Table 8.2. The emission factors of Table 8.1 are mainly extracted from the Integrated Pollution Prevention and Control Reference Document on Best Available Techniques [IPPC, BREF] (European Commission, 2001). Care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030312; fuel used in the process does not have to be taken into account in 0301.

Table 8.1: Emission factors for lime production

Pollutant	**Emission factor**(1)	**Units**
Particulate matter(2)		
TSP	0.5	kg/Mg lime
PM_{10}	0.2	kg/Mg lime
$PM_{2.5}$	0.04	kg/Mg lime
Nitrogen oxides(3)	1,4	kg/Mg lime
Sulphur oxides (3)	1,0	kg/Mg lime
Carbon monoxide (3)	5,0	kg/Mg lime

(1) EUROPEAN COMMISSION, 2001
(2) CEPMEIP, Moderate collection of fugitive dust, for uncertainty information see table 8.2e
(3) Average value for shaft kiln, the most used (see Table 4)

8.2 Reference Emission Factors For Use With Detailed Methodology

Limited information is available on emission factors for various air pollutants emitted from lime works. A collection of emission factors was performed for World Health Organization (Economopoulos, 1993). The results of this work are presented in table 8.2a.

Table 8.2a: Emission factors for selected air pollutants emitted during lime production, in kg/Mg of lime produced, after Economopoulos (1993)

Operation	**Total suspended particles**	**SO_2**	**NO_x**	**CO**
Coal Storage and Processing (If Coal is used as fuel)				
Coal Storage				
Open Piles	0.5			
Semi-Enclosed Piles	0.25			
Compartments	0.1			
Silos	0.1			
Coal Crushing and Screening				
Uncontrolled	0.18			
Fabric Filter	0.002			
Coal Grinding				
(Semi) Direct Fired System	0.0			
Indirect Fired System				
Uncontrolled	10.0			
Fabric Filter	0.1			
Raw Material Storage	0.16			
Crushing & Screening				
Uncontrolled	1.5			
Fabric Filter	0.0005			
Crushed Material Storage				
Open Piles	1.0			
Semi-Enclosed Piles	0.5			
Compartments	0.2			
Silos	0.2			
Raw Material Conveying				
Uncontrolled	1.2			
Fabric Filter	0.01			
Raw Material Calcining				
Vertical Shaft Kiln				
Uncontrolled	3.0	0.9S	0.1	2.0
Cyclone	1.0	0.9S	0.1	2.0
Multicyclones	0.75	0.9S	0.1	2.0
Vertical Double Inclined Kilns				
Uncontrolled	10.5	0.9S	0.1	2.0
Cyclone	3.6	0.9S	0.1	2.0
Multicyclones	2.6	0.9S	0.1	2.0
Parallel Flow/Counterflow Regenerative Kilns				
Uncontrolled	8.0	0.9S	0.1	2.0
Cyclone	2.8	0.9S	0.1	2.0
Multicyclones	2.0	0.9S	0.1	2.0
Annular Kilns				
Uncontrolled	12.0	0.9S	0.1	2.0
Cyclone	4.2	0.9S	0.1	2.0
Multicyclones	3.0	0.9S	0.1	2.0

Operation	Total suspended particles	SO_2	NO_x	CO
Rotary Short Kiln/Air Suspension Preheater				
Uncontrolled	40.0	0.36S	1.5	1.0
Cyclone	14.0	0.36S	1.5	1.0
Multicyclones	9.0	0.36S	1.5	1.0
ESP	0.6	0.36S	1.5	1.0
Fabric Filter	0.2	0.36S	1.5	1.0
Rotary Long Kiln				
Uncontrolled	140.0	0.36S	1.5	1.0
Cyclone	49.0	0.36S	1.5	1.0
Multicyclones	35.0	0.36S	1.5	1.0
ESP	2.0	0.36S	1.5	1.0
Fabric Filter	0.4	0.36S	1.5	1.0
Calcimatic Kiln				
Uncontrolled	25.0	0.9S	0.1	1.0
Cyclone	8.7	0.9S	0.1	1.0
Multicyclones	6.2	0.9S	0.1	1.0
Lime Cooling				
Grate Cooler				
Uncontrolled	20.0			
Cyclone	4.0			
Multicyclones	2.0			
Fabric Filters	0.1			
Planetary, Rotary, or Vertical Shaft Coolers	0.0			
Lime Packaging/Shipping	0.12			
Lime Hydration				
Uncontrolled	35.0			
Scrubber	0.04			

"S" is the sulfur percent in the fuel.

Table 8.2b contains fuel related emission factors for lime works based on CORINAIR90 data in [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product), are listed in footnotes. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a range for the specific energy consumption of 3 up to 4.7 GJ/Mg product has been reported. In each case, care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030312.

Table 8.2b: Emission Factors for Lime Works$^{8)}$

	Type of fuel			NAPFUE code	Emission factors $SO_2$$^{3)}$ [g/GJ]	$NO_x$$^{4)}$ [g/GJ]	NMVOC$^{5)}$ [g/GJ]	$CH_4$$^{6)}$ [g/GJ]	CO$^{7)}$ [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]
s	Coal	Hc	steam	102	33-786$^{1)}$	150-340$^{1)}$	15-40$^{1)}$	0.3-15$^{1)}$	10-6000$^{1)}$	92-98$^{1)}$	4-14$^{1)}$
s	Coal	Hc	brown coal/lignite	105	25$^{1)}$, 80$^{2)}$	140$^{1)}$, 300$^{2)}$	15$^{1)2)}$	15$^{1)2)}$	100$^{1)}$, 15$^{2)}$	113$^{1)}$, 100$^{2)}$	3.5$^{1)}$, 3$^{2)}$
s	Coal	Hc	briquettes	106	11$^{1)}$	140$^{1)}$	15$^{1)}$	15$^{1)}$	6000$^{1)}$	95-981)	3.5$^{1)}$
s	coke	Hc	coke oven	107	25-400$^{1)}$	40-300$^{1)}$	0.5-15$^{1)}$	0.5-15$^{1)}$	70-6000$^{1)}$	45-200$^{1)}$	4-12$^{1)}$
s	coke	Bc	coke oven	108	650$^{1)}$	220$^{1)}$	5$^{1)}$	15$^{1)}$	90$^{1)}$	86$^{1)}$	3$^{1)}$
s	coke		petroleum	110	275$^{1)}$ 120-2,852$^{2)}$	300$^{1)}$ 200-300$^{2)}$	1.5$^{1)}$ 1.5-112$^{2)}$	1.51) 1.5-15$^{2)}$	70-75$^{1)}$ 10-133$^{2)}$	97-99$^{1)}$ 95-105$^{2)}$	10-14$^{1)}$ 3-14$^{2)}$

s	biomass	wood	111	5.2$^{1)}$	103-200$^{1)}$	48-50$^{1)}$	30-32$^{1)}$	1430-6772$^{1)}$	92$^{1)}$	4-14$^{1)}$
s	waste	industrial	116	5.2$^{1)}$	115$^{1)}$	48$^{1)}$	32$^{1)}$	1430$^{1)}$, 15$^{2)}$	83$^{1)}$ 76-92$^{2)}$	4$^{1)}$ 6-14$^{2)}$
l	oil	residual	203	47-1,470$^{1)}$ 94-1,712$^{2)}$	100-310$^{1)}$ 170-215$^{2)}$	3-4$^{1)}$ 3-46$^{2)}$	3-8$^{1)}$ 1-3$^{2)}$	12-6000$^{1)}$ 7-94$^{2)}$	73-78$^{1)}$ 75-78$^{2)}$	2-14$^{1)}$ 2.5-14$^{2)}$
l	oil	gas	204	85-305$^{1)}$ 26$^{2)}$	70-310$^{1)}$ 313$^{2)}$	1.5-2.5$^{1)}$	1-8$^{1)}$	10-20$^{1)}$, 76$^{2)}$	72-74$^{1)}$	2-14$^{1)}$
g	gas	natural	301	0.1-8$^{1)}$ 0.9$^{2)}$	50-1111$^{1)}$ 14-100$^{2)}$	2.5-10$^{1)}$ 2.5$^{2)}$	0.4-4$^{1)}$	20-6000$^{1)}$ 13-17$^{2)}$	55-56$^{1)}$ 53$^{2)}$	1-3.7$^{1)}$ 1.5$^{2)}$
g	gas	coke oven	304	15$^{2)}$	83$^{2)}$			84$^{2)}$		
g	gas	blast furnace	305	63$^{2)}$	286$^{2)}$		2.5$^{3)}$	286$^{2)}$		
g	gas	coke oven and blast furnace gas	306	328$^{2)}$	250$^{2)}$	0.8$^{2)}$	0.8$^{3)}$	15$^{2)}$	205$^{2)}$	3$^{2)}$

1) CORINAIR90 data, area sources

2) CORINAIR90 data, point sources

3)	SO_x:	4,100	g/Mg product	Calcining, vertical kiln (EPA, 1990)
		2,550	g/Mg product	Calcining, rotary kiln (EPA, 1990)
		4,100	g/Mg product	multiple hearth calciner (EPA, 1990)
4)	NO_x:	1,500	g/Mg product	General (Bouscaren, 1992)
		1,400	g/Mg product	Calcining: vertical kiln, rotary kiln and multiple hearth calciner
		1,111	g/GJ	Cement/lime industry, kilns: natural gas (IPCC, 1995)
		527	g/GJ	Cement/lime industry, kilns: oil (IPCC, 1995)
		527	g/GJ	Cement/lime industry, kilns: coal (IPCC, 1995)
5)	VOC:	10	g/Mg product	Calcining,: vertical kiln (EPA, 1990)
		30	g/Mg product	Calcining: rotary kiln (EPA, 1990)
		10	g/Mg product	Calcining: multiple hearth calciner (EPA, 1990)
6)	CH_4:	1.1	g/GJ	Cement/lime industry, kilns: natural gas (IPCC, 1995)
		1.0	g/GJ	Cement/lime industry, kilns: oil (IPCC, 1995)
		1.0	g/GJ	Cement/lime industry, kilns: coal (IPCC, 1995)
7)	CO:	83	g/GJ	Cement/lime industry, kilns: natural gas (IPCC, 1995)
		79	g/GJ	Cement/lime industry, kilns: oil (IPCC, 1995)
		79	g/GJ	Cement/lime industry, kilns: coal (IPCC, 1995)

8) It is assumed, that emission factors cited within the table are related to combustion sources in lime works. Footnotes may also include emission factors for other process emissions (e.g. calcination).

Typical emissions of NO_x and SO_2 from various types of lime kiln coming from IPPC BREF document (EUROPEAN COMMISSION, 2001) are shown in Table 8.2c for Nitrogen Oxides.

Table 8.2c: Typical emissions of NO_x, SO_x and CO from some types of lime kiln from IPPC BREF document (EUROPEAN COMMISSION, 2001)

Kiln type	**mg NO_x/ $Nm^{3\,1}$**	**Kg NO_x/ Mg lime ^{2}**	**mg SO_2/ $Nm^{3\,1}$**	**kg SO_2/ Mg lime ^{2}**	**g CO/ $Nm^{3\,1}$**	**kg CO/ Mg lime ^{2}**
Calcium quicklime, light- and hard-burned dolomite						
Mixed feed shaft kiln	<300	<1	<300	<1	12-37	42-130
Double-inclined shaft kiln	<500	<1.7	<500	<1.7	<1.4	<5
Multi-chamber shaft kiln	500-800	1.7-2.8	<500	<1.7	<1.4	<5
Annular shaft kiln	<500	<1.7	<300	<1	<1.4	<5
Parallel-flow regenerative shaft kiln	<400	<1.4	<300	<1	<1.4	<5
Other shaft kilns	<300	<1	<300	<1	<14	<50
Rotary kilns, soft burning	100-700	0.4-2.8	<800^3	<3	1.2-12	5-50
Rotary kilns, hard burning	400-1800	1.6-7	<800^3	<3	1.2-12	5-50
Travelling grate kiln	<300	<1	<300	<1	<1.3	<4
Dead-burned dolomite						
Mixed feed shaft kiln	<300	<1	<800	<1.5	37-63	70-120

Rotary kilns	2000-5000	15-45	<5000	<42.5	0.6-6	5-50

1) Emission concentrations are one year averages, and are indicative values based on various measurement techniques. O2 content normally 10%.
2) based on typical exhaust gas volumes (wet) of
3500 Nm^3/Mg of lime for shaft and travelling grate kilns,
4000 Nm^3/Mg of lime for rotary kilns calcining high-calcium limestone and dolomite,
1900 Nm^3/Mg of lime for mixed feed shaft kilns dead-burning dolomite, and
8500 Nm^3/Mg of lime for rotary kilns dead-burning dolomite.
3) May be higher with high-sulphur fuels.

Regarding PM, “dust” emissions factors from different process with and without control from the IPPC BREF document (EUROPEAN COMMISSION, 2001) are shown in Table 8.2d. For PM_{10} and $PM_{2.5}$

Table 8.2d: Typical emissions of PM from some types of lime kiln from IPPC BREF document (EUROPEAN COMMISSION, 2001)

Process	**Uncontrolled**		**Controlled**	
	mg PM/Nm^3	**kg PM/Mg lime**	**mg PM/Nm^3**	**kg PM/Mg lime**
Calcining of limestone	500 - 5000	2- 20 [1]	30-200[2]	0.1- 0.8 [1,2]
Lime hydrating	2000	1,6 [3]	20-200	0,016 - 0,16 [3,4]
Lime grinding	Not applicable[5]		20 - 50	0.03 - 0.075 [6]
Subsidiary operations [7]	Not available		Not available	

1) Based on 4000 Nm^3/Mg lime.
2) All rotary kilns are fitted with dust collection equipment, as are most shaft kilns. Because of the wide range of exhaust gas conditions, a variety of dust collectors are used, including cyclones, wet scrubbers, fabric filters, electrostatic precipitators and gravel bed filters.
3) The gaseous effluent from hydrating plants is rather small in volume; levels are around 800 m^3/Mg of hydrated lime
4) Both wet scrubbers and bag filters are used to de-dust the emission.
5) Air is drawn through all of the grinding equipment to remove ground lime of the required particle size. The product is separated from the air in bag filters, often preceded by cyclones. Thus, dust collection is an integral part of the process.
6) At a typical air flow of 1500 Nm3/Mg of lime.

May include crushing, screening, conveying, slaking, storage and discharge.

Table 8.2e: Emission factors of PM in kg/ton lime produced with different abatement technologies (CEPMEIP)

Abatement technology	**TSP**	**PM_{10}**	**$PM_{2.5}$**	**Uncertainty factor**
Effective control fugitive sources	0.3	0.15	0.03	10
Limited control fugitive sources	1.0	0.3	0.06	10
Moderate collection of fugitive dust	0.5	0.2	0.04	10

NOTE: The uncertainty range (95% confidence) in the emission factor is expressed as a factor. The lower limit of the uncertainty range can be found by dividing the emission factor by the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example (first row in Table 8.2e): The uncertainty in the emission factor for $PM_{2.5}$ with effective control of fugitive sources is 10.The emission factor with uncertainty range will therefore be 0.03 kg per ton lime produced with an uncertainty range of 0.003 (0.03 / 10) to 0.3 (0.03 x 10).

9 SPECIES PROFILES

Not available for particulate matter.

10 UNCERTAINTY ESTIMATES

It is difficult to assess current uncertainties of emission estimates for lime works operations. The difficulty results from a lack of emission measurements in these plants and thus the uncertainty of emission factors based on limited information.

11 WEAKEST ASPECTS/ PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Improvement of emission factors is necessary in order to obtain more accurate emission estimates for lime works operations. This improvement should focus on preparing individual emission factors for different types of kiln operations. In this way, a detailed methodology for emission estimates can be applied. Obviously, it will be necessary to obtain relevant statistical data.

The fuel specific emission factors provided in Table 8.2b are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of emission factors with respect to point and area sources. Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

National emission estimates can be disaggregated on the basis of production, population or employment statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

The production process in lime works is continuous.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

Parker A. (1978) Lime works. In: Industrial Air Pollution Handbook, A. Parker (ed.), Mc Graw-Hill Book Comp. Ltd., London.

16 VERIFICATION PROCEDURES

Estimated emission factors could be best verified by measurements at respective plants.

17 REFERENCES

Bouscaren M. R. (1992) CORINAIR Inventory, Default Emission Factors Handbook,; second Edition, Comission of the European Communities, Paris.

Economopoulos A.P. (1993) Assessment of sources of air, water, and land pollution. A quide to rapid source inventory techniques and their use in formulating environmental control strategies. Part one: rapid inventory techniques in environmental pollution. World Health Organization, Rept. WHO/PEP/GETNET/93.1-A, Geneva.

EUROPEAN COMMISSION (2001), Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques (BREF) in the Cement and Lime Manufacturing Industries, December 2001

EPA (1990) AIRS Facility subsystem, EPA-Doc 450/4-90-003, Research Triangle Park.

EPA (1995) AP42 CD-Rom; Research Triangle Park.

HMSO 1992 Lime Manufacture and Associated Processes; Her Majesty´s Inspectorate of Pollution, Environmental Protection Act 1990; Process Guidance Note IPR 3/1; London.

IPCC (1995) Greenhouse Gas Inventory Reference Mannual, Volume 3.

Parker A. (1978) Iron and steel works. In: Industrial Air Pollution Handbook, A. Parker (ed.), Mc Graw-Hill Book Comp. Ltd., London.

U.S. EPA (1973) Compilation of air pollutant emission factors. 2nd edition. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

UN (1994) Statistical Yearbook - 1992. United Nations, Department for Economic and Social Information and Policy Analysis, Statistical Division, New York, NY.

Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

No additional documents.

19 RELEASE VERSION, DATE AND SOURCE

Version:	2.2
Date:	June 2005
Source:	Jozef M. Pacyna Norwegian Institute for Air Research (NILU) Norway
Supported by:	Otto Rentz, Dagmar Oertel University of Karlsruhe (TH) Germany

Integrated with IPPC BREF data, and updated the default emission factors for simpler methodology by:

Carlo Trozzi
Techne Consulting
Italy

Updated with emission factors (CEPMEIP) for particulates by:

Tinus Pulles and Wilfred Appelman
TNO
The Netherlands
June 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Carlo Trozzi
Techne Consulting
Via G. Ricci Curbastro, 34
Roma, Italy

Tel: +39 065580993
Fax: +39 065581848
Email: carlo.trozzi@techne-consulting.com

SNAP CODE: **030313**

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Asphalt Concrete Plants

NOSE CODE: **104.11.04**

NFR CODE: **1 A 2 f**

1 ACTIVITIES INCLUDED

This chapter includes information on atmospheric emissions of particulate matter during the production of asphaltic concrete, a paving substance composed of a combination of aggregates uniformly mixed and coated with asphalt cement.

2 CONTRIBUTIONS TO TOTAL EMISSIONS

During the production of asphalt concrete considerable amounts of fine particles can be generated. These emissions are not very significant on global or even regional scale. However, asphalt concrete plants can be an important emission source of particles on a local scale.

Table 1:Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**								
		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	PM*
Asphalt Concrete Plants	030313	0.1	0	0	-	0	0.1	-	-	-

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported
* = PM (inclusive of TSP, PM_{10} and $PM_{2.5}$) is <0.1% of total PM emissions

3 GENERAL

3.1 Description

There are various steps in the production of asphaltic concrete. Selecting and handling the raw material is the first step in which the raw aggregates are crushed and screened at the quarries to obtain the required size distributions. The coarse aggregate usually consists of crushed stone and gravel, but waste materials, such as slag from steel mills or crushed glass, can also be used as raw material (U.S. EPA, 1973).

Plants produce finished asphaltic concrete through either batch or continuous aggregate operations. In either operation the aggregate is transported first to a gas- or oil-fired rotary dryer and then to a set of vibrating screens.

In the final operation, the aggregate and the asphalt are brought together and mixed in a batch or a special mixer.

3.2 Definitions

3.3 Controls

Rotary dryer, hot aggregate elevators, vibrating screens, as well as various hoppers, mixers and transfer points are the major sources of particulate emissions in the asphaltic concrete plants. Most of these emissions are fugitive, however, the rotary dryer is often considered as a separate source for emission control.

Various types of control installations have been used in asphaltic concrete plants, including mechanical collectors, scrubbers, and fabric filters. In some cases dual dust collection systems are used with primary and secondary collectors in order to improve the collection efficiency.

4 SIMPLER METHODOLOGY

The application of general emission factors with appropriate activity statistics can be regarded as a simple approach methodology for estimation of particulate matter emissions from the dryer exhaust from the asphaltic concrete production (See Table 8.1).

5 DETAILED METHODOLOGY

In this case, different emission factors for various production steps in the asphaltic concrete plants should be used, particularly for the rotary dryer. An account of the effect of emission controls should be considered. The different emission factors will have to be evaluated through measurements at representative sites. See Table 8.2 for particulate matter emission factors.

Should a key source analysis indicate this to be a major source of particulate matter (TSP, PM_{10} or $PM_{2.5}$) then installation level data should be collected using a protocol such as that illustrated in the Measurement Protocol Annex.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of asphaltic concrete is largely missing in the international statistical yearbooks. This information should be obtained at a national or a country district level.

7 POINT SOURCE CRITERIA

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Table 8.1 Particulate Matter Emission Factors for use with the Simpler Methodology

Activity	Abatement	Emission factor, kg/tonne material produced		
		TPM	PM_{10}	$PM_{2.5}$
Dryer plant	Uncontrolled	16	2.3	1.5
	Venturi/wet scrubber	0.06	0.05	0.03
	Fabric filter	0.013	0.0049	0.0049

There are no emission factors available for $PM_{2.5}$ Factors are estimated based on 'expert judgment' from the USEPA (AP-42) filterable PM or PM_{10} emission factors. The source is <0.1% of the total PM emissions for most countries.

Table 8.2 Particulate Matter Emission Factors for use with the Detailed Methodology

Activity	Abatement	Emission factor, kg/tonne material produced		
		TPM	PM_{10}	$PM_{2.5}$
Dryer plant (batch mix)	Uncontrolled	16	2.3	1.5
	Venturi/wet scrubber	0.06	0.05	0.03
	Fabric filter	0.013	0.0049	0.0049
Dryer plant (drum mix)	Uncontrolled	14	3.2	2.1
	Venturi/wet scrubber	0.013	0.010	0.007
	Fabric filter	0.007	0.0020	0.0013

Very limited information is available on emission factors for asphaltic concrete plants. Old data from the U.S. Environmental Protection Agency indicate (U.S. EPA, 1973) that an uncontrolled emission factor for particulate matter should not exceed 22.5 kg/tonne asphaltic concrete, assuming that at least a precleaner is installed following the rotary dryer.

Various controlled emission factors are listed in the EPA emission factor handbook (U.S. EPA, 1973) for different types of control devices including:

- 850 g particulate matter/ tonne of asphaltic concrete produced for a high-efficiency cyclone,
- 200 g particulate matter/ tonne of asphaltic concrete produced for a spray tower,
- 150 g particulate matter/ tonne of asphaltic concrete produced for a multiple centrifugal scrubber,
- 150 g particulate matter/ tonne of asphaltic concrete produced for a baffle spray tower,
- 20 g particulate matter/ tonne of asphaltic concrete produced for an orifice-type scrubber, and

- 50 g particulate matter/ tonne of asphaltic concrete produced for a baghouse.

It was also suggested that emissions from a properly designed, installed, operated, and maintained collector can be as low as 2.5 to 10 g particulate matter/ tonne of asphaltic concrete produced.

9 SPECIES PROFILES

10 CURRENT UNCERTAINTY ESTIMATES

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Improvement of emission factors is necessary in order to obtain more accurate emission estimates for asphaltic concrete plants. This improvement should focus on preparing individual emission factors for individual steps in the asphaltic concrete production. In this way, a detailed approach methodology for emission estimates can be applied. Obviously, it will be necessary to obtain relevant statistical data.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

13 TEMPORAL DISAGGREGATION CRITERIA

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

U.S. EPA (2004) Compilation of air pollutant emission factors. 5th edition. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC. http://www.epa.gov/ttn/chief/ap42/ch11/index.html

16 VERIFICATION PROCEDURES

At present no specific verification procedures are available for estimation of atmospheric emissions from the production of asphaltic concrete. Estimated emission factors could be best verified by measurements at respective plants which are often equipped with different emission control devices.

17 REFERENCES

U.S. EPA (1973) Compilation of air pollutant emission factors. 2nd edition. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

U.S. EPA (2004) Compilation of air pollutant emission factors. 5th edition. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC. http://www.epa.gov/ttn/chief/ap42/ch11/index.html

18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE AND SOURCE

Version : 1.1

Date : 2 May, 1995

Source : Jozef M. Pacyna
Norwegian Institute for Air Research (NILU)
Norway

Updated with particulate matter details by:
Mike Woodfield
AEA Technology
UK
December 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Jozef Pacyna

NILU - Norwegian Institute of Air Research
PO Box 100
N-2027 Kjeller
Norway

Tel: +47 63 89 8155
Fax: +47 63 89 80 50
Email: jozef.pacyna@nilu.no

SNAP CODE:	**030314** **030315** **030316** **030317** **040613**
SOURCE ACTIVITY TITLE:	**PROCESSES WITH CONTRACT** ***Glass Production***
NOSE CODE:	**104.11.05** **104.11.06** **104.11.07** **104.11.08** **105.11.03**
NFR CODE:	**1 A 2 f** **2 A 7**
ISIC:	**2310**

1 ACTIVITIES INCLUDED

The activities described under chapter 040613 regard the process emissions during the production of different types of glass (flat glass, container glass, glass wool and other glass {including special glass}). The activities concerned with the combustion and the resulting emissions are described in the chapters 030314, 030315, 030316 and 030317. The emissions treated in this chapter are carbon dioxide emissions from the carbonisation process and emissions of micropollutants, heavy metals and dust, partly resulting from the combustion of fossil fuels, partly from the basic materials. For micropollutants, heavy metals and dust separate emission factors for combustion and process emissions are not available. The factors given are to be used as default values for the whole process.

2 CONTRIBUTION TO TOTAL EMISSION

The contribution of emissions released from the production of glass to total emissions to air in countries of the CORINAIR90 inventory is given as follows:

Table 2.1: Contribution to total emissions to air of the CORINAIR90 inventory (28 countries)

Source-activity	SNAP-code	Typical contribution to total emissions [%] (lowest value – highest value)									
		SO_2	NO_x	NMVOC	CH_4	CO	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Flat Glass	030314	0.1	0.3	0	-	0	-	-	0.004 (0.001 - 0.008)	0.222 (0.008 - 0.74)	0.352 (0.011 - 1.073)
Container Glass	030315	0.1	0.2	0	-	0	-	-	0.113 (0.004 - 0.367)	0.222 (0.008 - 0.74)	0.352 (0.011 - 1.073)
Glass Wool	030316	0	0	-	-	-	-	-	0.022 (0 - 0.043)	0.043 (0.001 - 0.077)	0.051 (0.002 - 0.084)
Other Glass	030317	0	0.1	-	-	0	-	-	0.073 (0.032 - 0.114)	0.144 (0.059 - 0.23)	0.227 (0.121 - 0.333)

* contribution to total national emissions, excluding agricultural soils, EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006)
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

Table 2.2: Contribution to total emissions to air (OSPAR-HELCOM-UNECE Emission Inventory)

Source-activity	Contribution to total emissions [%]							
	Arsenic	Cadmium	Chromium	Copper	Mercury	Nickel	Lead	Zinc
Glass industry	1.3	1.3	0.9	0.1	0.1	0.1	0.9	0.2

Table 2.3: Contribution from the carbonisation process

Source-activity	Contribution of carbon dioxide to total emissions [%]
Glass industry	

The emission of fluorides are also important.

3 GENERAL

In the production of glass products can be distinguished, for instance flat glass, container glass, special glass, glass wool, continuous filament fibres, water glass and tableware. The smelting process for the different product groups is similar.

The production of flat glass, container glass, glass fibres and commodity glass is dominated by large multinational companies, whereas domestic glass production (manufacture of table and decorative ware) take place in small- and medium-sized enterprises. Unlike technical glass production, domestic glass production is characterised by a great diversity of products and processes, including hand forming of glass. (Rentz et al., 1991; Eichhammer et al, 1994).

3.1 Description of Activities

The manufacturing process of glass consists of the following steps (Schmalhorst E.; Ernas T., 1995; Rentz et al., 1991; Eichhammer et al, 1994):

- *Selection and controlling of raw materials.*
- *Preparation of raw materials:* preparation consists essentially of a weighing and mixing operation.
- *Melting:* the raw materials undergo fusion at high temperature in a furnace.
- *Forming:* the molten glass is given a shape and allowed to solidify (production of flat and container glass); the formation of fibres into glasswool mats is carried out (production of glasswool).
- *Curing:* the binder-coated fibreglass mat is allowed to cure (production of glasswool).
- *Annealing:* internal stresses are removed by heat treatment.
- *Finishing:* finishing includes in particular quality control and cutting (production of flat and container glass); finishing includes cooling the mat, and backing, cutting, and packaging the insulation, as well as quality control (production of glasswool); finishing includes quality control, cutting, and for hand-shaped glass, further decorative treatment such as engraving or polishing (special glass).

A large variety of glass with differing chemical composition is produced, and therefore a great diversity of raw materials is used in glass manufacturing (VDI Kommission Reinhaltung der Luft, 1997). Main raw materials are silica sand, lime, dolomite and soda for the production of soda lime glass, as well as lead oxide, potash and zinc oxide for the production of special glass (Rentz et al., 1991; UN/ECE, 1995). Glass wool is a boro-silicate glass, which is manufactured from sand, limestone, dolomite, boric-oxide and other oxides. Refining agents such as antimony oxide, nitrates, sulphates, and colouring agents like metal oxides and sulphides enter also in the composition of special glass, e.g. TV glass, crystal glass, etc. (VDI Kommission Reinhaltung der Luft, 1997).

Nowadays, approximately 85 % of the glass produced in Europe is made up of soda lime, and consists principally of flat and container glass. The remaining 15 % of the European glass production include glass wool and special glass such as hand-shaped glassware, lighting, TV-screen, optical glasses. (Abraham et al. 1997)

Recycled glass is also largely used in the manufacturing of glass and represents typically between 20 and 25 % of the quantity of melted flat glass and up to 80 % of the quantity of melted container glass. Throughout the industry, virtually all internally generated cullet is reused. The poor quality and contamination of external cullet virtually eliminates its use for flat, commodity and domestic glassware, but much external cullet (with treatment) can be used in the container glass industry. (Abraham et al. 1997)

Currently, the majority of raw material is delivered to the glass production site in a prepared form; only broken glass pieces from recycling undergo processing steps such as sieving. The different materials are weighed and mixed, and the mixed batch is transferred to the melting furnace. (Rentz et al., 1991)

3.2 Definitions

Borosilicate glass	a silicate glass that is composed of at least five percent oxide of boron and is used especially in heat-resistant glassware.
Crown glass	alkali-lime silicate optical glass having relatively low index of refraction and low dispersion value.
Fibreglass	glass in fibrous form used in making various products (as glass wool for insulation).
Flint glass	heavy brilliant glass that contains lead oxide, has a relatively high index of refraction, and is used in lenses and prisms.
Float glass	flat glass produced by solidifying molten glass on the surface of a bath of molten tin.
Glass wool	there exist two types of glass fibre products, textile and wool, which are manufactured by similar processes. Here only glasswool is taken into account: glass fibres in a mass resembling wool and being used especially for thermal insulation and air filters.
Lead glass	glass containing a high proportion of lead oxide and having extraordinary clarity and brilliance.
Optical glass	flint or crown glass of well-defined characteristics used especially for making lenses.

3.3 Techniques

For container glass production, the melting stage can be preceded by a pre-heating of the mixed batch (Rentz et al., 1991); however, this is not commonly done: around 10 batch preheaters are currently in operation world wide (Abraham et al. 1997).

The melting process is the most important step with regard to quality and quantity of glass, which depend on the furnace design (Eichhammer et al., 1994). In the melting furnaces, the glass is melted at temperatures ranging from 1,500 °C to 1,600 °C (the flame temperature achieving more than 2,000 °C) and are transformed through a sequence of chemical reactions to molten glass. Although there are many furnace designs, furnaces are generally large, shallow, and well-insulated vessels that are heated from above. In operation, raw materials are introduced continuously on top of a bed of molten glass, where they slowly mix and dissolve. Mixing is effected by natural convection, gases rising from chemical reactions, and, in some operations, by air injection into the bottom of the bed. (EPA, 1994) In the glass production, both continuously and batch-wise operated melting furnaces are in use. In large glass manufacturing installations as it is the case for flat and container glass production, and where the forming processes are fully automated, refractory lined tank furnaces are operated in the continuous mode. For the production of smaller quantities of glass, especially for hand-shaped glassware, the batch operating mode is preferred since molten glass has to be removed from the pot furnace by hand. (Eichhammer et al., 1994; VDI Kommission Reinhaltung der Luft, 1997)

Some characteristics of the above mentioned furnaces are summarised in the following table.

Table 3.4: Some characteristics of furnaces used in glass production (VDI Kommission Reinhaltung der Luft, 1997; Landesgewerbeanstalt Bayern, 1994)

Type of Furnace	**Type of Firing**	**Energy Source**	**Operating Mode**	**Capacity [Mg/d]**
Single or multi-pot	flame or electrically heated	gas, oil, electricity	batch	0.1 – 35
Day tank	flame or electrically heated	gas, oil, electricity	batch	0.1 – 3
Tank furnace	flame or electrically heated	gas, oil, electricity	continuous	2 - 900

In order to achieve a higher energy efficiency and a higher flame temperature, the combustion air is preheated. Air preheaters in use are recuperative or regenerative (Rentz et al., 1991; Nolle G., 1997; Teller A.J.; Hsieh J.Y., 1992). Glass melting furnaces use natural gas and/or oil as a fuel, since the use of hard coal or lignite would result into an import of molten ash in the glass phase, and would subsequently lead to a lower product quality and would block the refractory lattice of the regenerators or the recuperators (Rentz et al., 1991; Abraham et al. 1997). For the production of container glass, approximately 70 % of the furnaces are operating with oil and 30 % with natural gas. City gas or liquified gas are used in isolated cases (VDI, 1998).

The furnace most commonly used within flat glass production is a cross-fired furnace with regenerative preheating working in the continuous mode; very few exception with end-fired furnaces do exist in the production of printed glass (Abraham et al. 1997). In container glass production, mostly regeneratively heated furnaces are in use (Abraham et al. 1997).

Additional electric heating is frequently employed to increase output and to cope with peak-load demands. Between 5 to 30 % of the total energy is passed in the form of electrical energy directly into the glass batch through electrodes. (VDI, 1998).

Table 3.5: Specific energy demand for the production of glass

Type of Glass	Specific Energy Demand [GJ/Mg glass]
Flat glass	7
Container glass	6
Glass wool	12
Special glass	25

However, more advanced glass furnaces do exist with lower specific energy demands (for example around 4 GJ/Mg (VDI, 1998) in the production of flat glass).

Glass Wool Manufacturing Process

In the "indirect" melting process, molten glass passes to a forehearth, where it is drawn off, sheared into globs, and formed into marbles by roll-forming. The marbles are then stress-relieved in annealing ovens, cooled, and conveyed to storage or to further processing in other plants. In the "direct" glass fibre process, molten glass passes from the furnace into a refining unit, where bubbles and particles are removed by settling, and the melt is allowed to cool to the proper viscosity for the fibre forming operation (EPA, 1995).

During the formation of fibres into a wool fibreglass mat (the process is known as "forming" in the industry), glass fibres are made from molten glass, and a chemical binder is simultaneously sprayed on the fibres as they are created. Although the binder composition varies with product type, typically the binder consists of a solution of phenol-formaldehyde resin, water, urea, lignin, silane, and ammonia. Colouring agents may also be added to the binder. Two methods of creating fibres are used by the industry. In the rotary spin process, centrifugal force causes molten glass to flow through small holes in the wall of a rapidly rotating cylinder to create fibres that are broken into pieces by an air stream. This is the newer of the two processes and dominates the industry today. In the flame attenuation process, molten glass flows by gravity from a furnace through numerous small orifices to create threads that are then attenuated (stretched to the point of breaking) by high velocity, hot air, and/or a flame (EPA, 1995).

3.3.1 Gas- and Oil-Fired Glass Melting Furnaces with Regenerative Air Preheating

The common feature of all tank furnaces is a large ceramic tank which serves as a melting container. In general, tank furnaces are operated by alternating flame-heating based on the regenerative principle. (VDI, 1988)

Regenerative air preheaters use a lattice of brickwork to recover waste heat from the exhaust gas. The regenerators are made up of two chambers, each of them consisting of a refractory lattice; the chamber walls and the mentioned lattice represent the heat storing material, which transfers the heat from the waste gas to the combustion air. The waste gas is lead from the furnace to one of these chambers, whereby the lattice is warmed up. The combustion air enters the furnace via the other chamber. The combustion air flow and the waste gas flow are then reversed: the combustion air flows then through the hot chamber and is heated there, while the waste gas flows through the second chamber, reheating the refractory lattice. The temperature of the incoming air achieves up to 1,350 °C, and the waste gas leaves the regenerative chambers with a temperature of about 500 – 550 °C. (Rentz et al., 1991; VDI Kommission Reinhaltung der Luft, 1997;, Kircher U., 1993)

Depending on the arrangement of the burners and the position of the flames, one differentiates between cross-fired and end-fired tanks. (VDI, 1988) Because of the higher number of burner necks and the larger regenerator chambers, the specific energy consumption is higher for cross-fired furnaces than for comparable end-fired furnaces. (VDI Kommission Reinhaltung der Luft, 1997) Small and medium-sized tanks are built as end-fired tanks, larger ones as cross-fired burner tanks. In both arrangements, the flames flow closely over the molten glass surface and transmit heat to it, primarily by radiation. (VDI, 1988)

Cross-fired furnaces give better control of melting chamber temperatures and oxidation state and therefore predominate in the larger throughput and ”quality glass” furnaces. Cross-fired furnaces are used exclusively in float glass furnaces and in the larger container furnaces, whereas for melting surfaces up to 120 m^2 more and more are laid down as end-fired furnaces, since they show a simpler arrangement, a lower price and a higher energy efficiency than comparable cross-fired furnaces. (VDI Kommission Reinhaltung der Luft, 1997)

3.3.2 Gas- and Oil-Fired Glass Melting Furnaces with Recuperative Air Preheating

Another configuration of the tank furnace is the recuperatively heated glass melting tank. Recuperative air preheaters use most commonly a steel heat exchanger, recovering heat from the exhaust gas by exchange with the combustion air; the preheating temperature can reach up to 800 °C (VDI Kommission Reinhaltung der Luft, 1997). Here, the hot waste gas and the cold combustion air flow through two parallel, but separated ducts, and the heat exchange is performed via the separation wall. Unlike regenerative heating furnaces, the combustion is not interrupted and the waste gas is continuously recuperated via the heat exchanger. In order to achieve an optimal energy use, the recuperators are often connected to waste heat boilers for steam or hot water generation (Rentz et al., 1991; Kircher U., 1993). The lower flame temperatures achieved (compared with those from regenerative systems) eliminates them from use in the higher quality glasses (e. g. float glass) or high specific pull (many container glasses). Recuperatively heated furnaces are generally of cross-fired configuration. (Abraham et al. 1997)

3.3.3 Pot Furnaces

The use of pot furnaces is confined to manually worked specialty glasses, with intermittently operation and melting temperatures under 1,460 °C. One furnace usually is comprised of several pots permitting simultaneous melting of several types of glass. Flame-heated regeneratively and recuperatively-operated furnaces as well as electrically heated furnaces, are put to use here. City gas, natural gas, liquefied gases and light oil as well as electricity are used as heat energy. The specific heat consumption (relative to glass production) of pot furnaces is comparatively high and averages 30 GJ/Mg glass produced (Jockel W., Hartje J., 1991).

3.3.4 Electric Furnaces

Electric furnaces melt glass by passing an electric current through the melt. Electric furnaces are either hot-top or cold-top. The former use gas for auxiliary heating, and the latter use only the electric current (EPA, 1994). Electric heating is used either for additional heating (electric boost) or almost exclusively in small- and medium-sized furnaces for the manufacturing of special glass such as lighting glass, glass fibres, crystal glass (Rentz et al., 1991; Nolle G., 1997; Teller A.J.; Hsieh J.Y., 1992). One case of soda lime glass manufacturing via electric heating is currently known, but is restricted to low furnace outputs and special composition glasses (Abraham et al. 1997). Further information on electric heating is given later in this chapter.

3.4 Emissions

3.4.1 Combustion-related Emissions

Pollutants released during the manufacture of glass are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2) and nitrous oxide (N_2O). Also emissions of hydrogen chloride, hydrogen fluoride, particulate matter and heavy metals are produced by the melting process. Emissions of particulate matter can also result from handling raw materials. Heavy metals will be present in the particulate matter. According to CORINAIR90 of these, the main relevant pollutants are SO_2, NO_x, and CO_2 (see also Table 1).

The waste gases released from melting furnaces consist mainly of combustion gases generated by fuels and of gases arising from the melting of the batch, which in turn depends on chemical reactions taking place within this time. The proportion of batch gases from exclusively flame-heated furnaces represents 3 to 5 % of the total gas volume. (VDI, 1998)

Sulphur Oxides

The amount of SO_2 released during glass manufacturing is mainly determined by the sulphur content of the fuel, the sulphate content of the molten batch and the sulphur absorption ability of the glass produced (VDI, 1988; Gitzhofer K.-H., 1993).

The sulphur contained in the batch is partly bound in the glass as SO_3. Glass contains up to 0.4 wt.-% SO_3 (VDI, 1998). The SO_3-content is 5 to 10 % of the SO_2-content. The amount of SO_3 depends on the excess air and the combustion temperature. (VDI, 1988)

The SO_2 content in the off-gas is also determined by the operating conditions of the glass melting tank. With tank furnaces operated by alternating flame heating, based on the regenerative principle, an increase of the SO_2 content in the off-gas during the firing interval is observed. This is most likely due to a decrease in the sulphur absorption ability of the molten glass with an increasing temperature in the upper zone of the furnace, and evaporation of already condensed sulphurous species in the air preheater (Gitzhofer K.-H., 1993). The oxygen content in the upper zone of the furnace also has an impact on the SO_2 content of the off-gas: if the amount of excess air is decreased, in order to minimise fuel input and to suppress NO_x formation, an increase in the SO_2 content of the off-gas is observed. This is due to the fact that the sulphur absorption ability of the molten glass decreases with a decreasing oxygen content in the upper furnace zone (Gitzhofer K.-H., 1993).

Since natural gas and city gas contain only trace amounts of sulphur, a lower SO_2 content in the off-gas of glass melting tanks fired with gaseous fuels is observed compared to oil fired glass melting tanks. (Rentz et al., 1991)

Nitrogen Oxides

The relevant NO_x emission process step within the production of glass is the melting stage. NO_x emissions released by glass furnaces are nitric oxides (NO to about 90 % due to the near stoichiometric operation of the furnaces, the remainder being nitrogen dioxide NO_2). The concentrations of nitrous oxide in glass furnace waste gases are in general below the detection limit (Quirk R. , 1997).

Four main NO_x formation mechanisms exist: three of them are combustion related and include thermal, fuel and prompt NO_x formation; the fourth mechanism (the 'batch' NO_x formation) results from the use of nitrates in the raw materials for certain glasses. (Quirk R. , 1997) In the glass melting furnace, the temperature ranges from 1,500 °C to 1,600 °C (VDI Kommission Reinhaltung der Luft, 1997), leading to flame temperatures above 2,000 °C (Abraham et al. 1997). This explains the presence of high NO_x concentrations, almost exclusively due to thermal NO_x formation (according to the Zeldovich mechanism). Several parameters influence the mechanism of thermal NO_x formation: flame temperature, oxygen content in the reaction zone, and retention time of the combustion gas in high temperature zones of the flame. These parameters are in direct relation with operating parameters as for example burner and melting furnace design, amount of excess air, mixing of fuel and combustion air, etc. (Kircher U., 1993; Flamme M., 1993; Flamme M.; Haep J., 1994). Prompt NO_x is relatively small, and when firing natural gas, fuel NO_x is sensibly zero (Quirk R. , 1997).

The conversion of nitrogen compounds contained in the raw materials and in the refining agents contributes also to NO_x emissions due to the batch NO_x formation. The quantity of nitrogen oxides arising from the feed material (see also chapter B4614) will be affected by the concentration and composition of the nitrates in the feed. (Her Majesty´s Inspectorate of Pollution, 1992) For example, certain tinted glasses in the flat glass sector require the use of nitrates, which produce additional NO_x-emissions almost as great as uncontrolled emissions from a clear flat glass operation: typical emissions might be 2,500 mg/Nm^3 for clear glass, 4,000 mg/Nm^3 for tint glass (UN/ECE, 1998). It must be acknowledged that such tints are only occasionally manufactured.

When using gas fired glass melting tanks, the achieved flame temperature is higher compared to oil. As a consequence, oil fired tanks emit less NO_x than gas fired tanks. Moreover, as end-fired furnaces allow a more favourable flame characteristic than cross-fired glass melting furnaces, the first show lower NO_x emissions. Recuperative furnaces induce lower NO_x emissions than regenerative furnaces, due to their lower preheating temperature (Rentz et al., 1991; Kircher U., 1993).

Following table gives the NO_x-concentrations for some types of furnaces.

Table 3.6: NO_x Emissions for some types of furnaces (Rentz et al., 1991; Kircher U., 1993b)

Type of Furnace / Fuel	NO_x-Emission* [mg/Nm^3]
Oil fired recuperatively heated furnace	400 – 1,400
Gas fired recuperatively heated furnace	400 – 1,600
Oil fired regeneratively heated furnace	
• end-fired furnace	1,000 – 2,400
• cross-fired furnace	1,600 – 3,600
Gas fired regeneratively heated furnace	
• end-fired furnace	1,400 – 3,000
• cross-fired furnace	1,600 – 4,000

* These values refer to an O_2-content in the waste gas of 8 vol.-%.

3.4.2 Process-related Emissions

The most important source of atmospheric emissions is the hot furnace. The heavy metals from the raw materials or the fuel partly vaporize in the hot furnace. The heavy metals which are emitted to air are mainly arsenic, cadmium, chromium, lead, tin, and selenium.

If fuel oil is used in the combustion process also nickel and vanadium may be found. In south and eastern Europe fluorspar is often used in the melting process. If recycled glass originating from these countries some fluorine may be emitted.

Basic materials for glass production are silicium oxide and oxides of alkalimetals. The alcali metal oxides are produced during the process from dissociation of carbonates. The emission factors given under (Leendertse, A., 1998) are calculated from the amount of carbonates added in general in the production process of the different types of glass, assuming that all metal oxides have their origin in carbonates and that no recycled glass is added. If however oxides, hydrocarbonates, sulfates, or a relevant amount of recycled glass are used corrections must be made.

3.5 Controls

3.5.1 NO_x-Emission Reduction Measures

3.5.1.1 Primary Emission Reduction Measures

3.5.1.1.1 Lowering the Amount of Excess Air

Technical Aspects

This relatively simple measure aims at achieving near stoichiometric combustion, resulting in a lower oxygen concentration in the reaction zone, and consequently in a reduction of nitrogen oxides. Sealing of the furnace against inleaked (false) air is an additional measure to lowering the amount of excess air. NO_x emission reduction efficiencies between 30 and 70 % (depending on the initial level) are achievable (Kircher U., 1993). Further a slight decrease in specific energy consumption is observed (Abraham et al. 1997).

However, it may be noted that a move to near stoichiometric combustion can give a significant reduction in NO_x, but may lead on the other hand to an increase of the emissions of other pollutants (e. g. CO, dust) as well as to a slight increase of energy demand. Furthermore, the quality of the product and the furnace lifetime can both be influenced by the O_2-content in the upper zone of the glass melting furnace. (Rentz et al., 1991)

Side-Effects
Near stoichiometric combustion (as performed when lowering the amount of excess air) lowers the nitrogen oxides formation, but in the same time induces slightly increased emissions of measured SO_2.

3.5.1.1.2 Reduced Air Preheating

Preheaters have originally been used to improve the heat transfer from flame to batch, and have proved to lead to savings in energy consumption (Abraham et al. 1997).

Technical Aspects
By reducing the air preheating temperature, the flame temperature is reduced and consequently the formation of nitrogen oxides. Reduction of the preheating temperature can be carried out by using recuperative air preheaters instead of regenerative air preheaters (Rentz et al., 1991). However, when switching from a regenerative to a recuperative preheater, the melting capacity is reduced, inducing the need of larger facilities and thus higher costs. Furthermore, recuperative air preheaters achieve lower energy efficiencies. (Abraham et al. 1997)

Side-Effects
The use of recuperative air preheaters instead of regenerative ones results in a reduction of flame temperature and hence glass quality, pull rate and energy efficiency (Abraham et al. 1997).

3.5.1.1.3 Staged Combustion

In a classical combustion facility, the totality of fuel and air/oxygen is injected at the same place. The resulting flame is then composed of a hot and oxidising primary zone located at the flame root and a colder secondary zone located at the flame end. The primary zone generates most of the NO-emissions, which increase exponentially with the temperature, whereas the contribution of the secondary zone is rather modest. Staged combustion aims at decreasing the temperature in the primary zone. Therefore, only a part of the fuel or of the air/oxygen is injected at the burner, the rest being injected downstream of the main combustion zone.

Emission reduction rates in the range of 50 to 70 % can be achieved by combining staged combustion with other primary measures. It is estimated that about 30 to 50 % of the reduction may originate from staged combustion alone. Concentrations around 700 mg/Nm^3 may be reached in the best cases (Delacroix et al., 1996).

Air/Oxygen Staging
The KORTING air staging process (Barklage-Hilgefort, H., Sieger W., 1989) has been tested at three furnaces in Germany at the beginning of the 90s, but has been abandoned meanwhile.

Maintenance problems have appeared on the air ejector at high temperatures, and anyway this technique does not allow as good reduction efficiencies as do state-of-the-art low-NO_x burners (Delacroix et al., 1996; Kircher U.; 1995).

Oxygen staging with the Oxygen Enriched Air Staging (O.E.A.S.) process (Joshi M.L. et al.1994) is still in a state of development (three test furnaces are running in the USA) and it is therefore impossible to conclude about efficiency and applicability(Delacroix et al., 1996). Due to the high costs of oxygen, this technique will most probably not be generally applied (Abraham et al. 1997).

Fuel Staging

A lack of fuel in the primary zone decreases the flame temperature. The fuel-rich secondary zone becomes reducing, generating hydrocarbon radicals reducing NO into molecular nitrogen. About 8 to 10 % of the fuel is injected into the combustion air in the port neck, resulting in sub-stoichiometric conditions in the main flame, and therefore leading to reduced NO_x formation. The remaining fuel is injected within the furnace and ensures complete burnout. NO_x concentrations below 800 mg/m^3 have been reported with initial values between 1,800 and 2,200 mg/m^3. (Rentz et al., 1991)

Fuel staging has proven to be rather attractive: it has been implemented at 12 German glass melting tanks for nitrogen oxides abatement (Rentz et al., 1991); however, this measure is expected to be phased out with the installation of new low-NO_x burners (Abraham et al. 1997).

Side-Effects

No side-effects have been observed.

3.5.1.1.4 Flue Gas Recirculation

Technical Aspects

This technology is in principle similar to staged combustion: NO_x-emissions are reduced by lowering the flame temperature. Secondary air is mixed with a part of the flue gas, and this oxygen lacking air is injected as combustive agent in the furnace.

Three tests of flue gas recirculation have been performed in the glass production sector (Abraham et al. 1997). NO_x emission abatement rates between 16 and 44 % could be achieved, but this technology proved to be difficult to be implemented, and has meanwhile been abandoned (Delacroix et al., 1996).

Side-Effects

No side-effects have been observed, but it must be acknowledged that the experience is very limited.

3.5.1.1.5 Reburning / 3R Process

The reburning process and the 3R process are similar technologies, based on the same principle. In the literature, both processes are either considered as primary NO_x-emission reduction measures or as secondary NO_x-removal options. In the framework of this report, the reburning / 3R process will be presented as a primary measure, since it can be compared to the fuel-staging process.

Technical Aspects

In both the reburning and 3R processes, NO or its precursors (HCN, NH_y) formed in the combustion zone undergo reduction by injection of natural gas or fuel as the waste gases enter the regenerators from the melting chamber. In the 3R process, hydrocarbon fuel is injected into the waste gas downstream of the glass melting furnace tank (Shulver I.; 1994). The added fuel does not burn, but pyrolyses to form radicals converting the nitrogen oxides in the waste gas into nitrogen and water. A major advantage of this process is the possibility of using all kinds of hydrocarbon fuels (natural gas, fuel oil...) (Abraham et al. 1997), (Quirk R. , 1997). Air is added downstream of the denitrification zone to ensure burnout of residual ”fuel” fragments.

Reburning is at an experimental stage, whereas the 3R process has been installed at one German float glass production site, achieving nitrogen oxides concentrations below 500 mg/m^3 (Kircher U., 1995). According to Quirk R., 1996 and Koppang R., 1996, 3R has been successfully operated on float furnaces in Finland and California, and demonstrated on furnaces in the TV glass production (in Korea (Abraham et al. 1997)), container, and shaped glass. In all cases, a nitrogen oxides abatement up to 85 % could be achieved. One further furnace has been equipped with 3R at a float glass production site in the UK. This technology is now applied by two float glass companies in the USA (Abraham et al. 1997).

Side-Effects

As this process is based on hydrocarbon fuel injection, an increased energy consumption is to be expected. Nevertheless, this technology ensures burnout of residual fuel fragments; subsequently, achievable levels of CO may be lower than with conventional combustion. Moreover, if supplementary heat recovery is available, the additional CO_2 originating from the increased use of fuel can be compensated by the reduction that would have arisen from fossil fuel boilers or from the power station (Quirk R. , 1997).

3.5.1.1.6 Low-NO_x Glass Melting Furnaces

Technical Aspects

In recent years, new melting furnaces have been developed achieving low NO_x emissions: the FlexMelter® and the LoNOx® melter (Quirk R., 1996; Pabst R., 1994).

The LoNOx® melter is a combined electrical/fossil fuel fired melting tank with recuperative air preheating, including a batch preheating step. For this melting furnace, energy efficiency has been increased to compensate for the lower thermal efficiency of the air preheater compared with the regenerator and so the heat consumption of this modified recuperatively fired furnace can be compared to conventional regeneratively fired furnaces: waste gas from the melting furnace is first fed to the recuperative air preheater and afterwards used to preheat the cullet. Air temperatures of about 750 °C are reached (Gitzhofer K.-H., 1993). This melting furnace allows to achieve NO_x concentrations below 500 mg/m^3 in the waste gas (Flamme M.; Haep J., 1994; Kircher U., 1995; Shulver I., 1994; Pabst R., 1994). This type of low NO_x melter is exclusively used in the container glass manufacturing at about 70 – 80 % cullets undergoing preheating (Abraham et al. 1997).

The FlexMelter® has originally been developed for discontinuous production, but is operated nowadays both in the continuous and discontinuous mode. Typical applications are glass fibres for insulation, automobile lighting, and other special glass such as crystal glass. The relatively low flame temperatures from recuperative air preheaters precludes their use for typical flat glass and most container glass production (Abraham et al. 1997).

Currently, three low-NO_x melting furnaces with a total capacity of approximately 800 Mg/d glass are operated in Germany. (Abraham et al. 1997)

Side-Effects
No side-effects have been observed.

3.5.1.1.7 Oxy-Fuel Firing

Technical Aspects

By this very effective, but also very expensive technology, preheated combustion air is replaced by high purity oxygen and there is thus no need for regenerators. Even though the resulting nitrogen oxide concentration in the flue gas is higher with oxy-fuel firing, mass emissions of NO_x are lower. Therefore, the actual mass flow has to be considered. Oxy-fuel firing can be applied to pot furnaces and day tanks (UN/ECE; 1998). The conversion from air to 100 % oxygen may result in a 50 - 60 % reduction of energy consumption (UN/ECE, 1998). As regards the achievable NO_x reduction rate, (Barklage-Hilgefoot H.J.; Sieger W., 1989) quotes a 80 to 95 %-reduction for oxy-fuel firing over 100%-air firing (50 % in the worst case of existing furnaces with poor sealing conditions (UN/ECE, 1998).

About one hundred furnaces are run world-wide on the oxy-fuel mode, representing approximately 4 % of the whole glass production. Since the beginning of the 90s, oxy-fuel combustion has gained importance mainly in the USA, where it represents nowadays about 10 % of the number of glass melting furnaces. The reason why oxycombustion is so popular in the USA is mainly due to economical reasons: sometimes nitrogen can be used for non-melting applications in the factory or associated products and then the overall cost of the oxygen is reduced. Furthermore, when applying this technology, an increase in capacity can be observed as well as an improvement of the product quality (UN/ECE, 1998). In Germany, two container glass melting furnaces are operated in the oxy-fuel mode, and several others are planned, among which two special glass production sites (Rentz et al., 1991; Kircher U., 1995; Abraham et al. 1997). The application fields of oxy-combustion are basically the glass fibre, TV glass, container and special glass industries (Her Majesty´s Inspectorate of Pollution, 1992).

Besides the environmental aspect, since regenerators and recuperators can be omitted, low investment is a further advantage increasing the interest of glass producers in oxy-fuel firing. Moreover, the change from a recuperatively heated furnace to oxy-fuel firing is very easy (Abraham et al. 1997). For an energy balance, production of oxygen has to be considered, and energy savings can be achieved in the case of an effective heat recovery. It should however be mentioned that the related operating costs are higher compared to 100% air firing, due to the high price of oxygen and that this technology is not yet applicable to every field of glass production (Shulver I., 1994; Delacroix et al., 1996). Furthermore, oxy-fuel firing is not effective when nitrate containing batches are melted, since only thermal NO_x is being reduced by oxy-combustion (Quirk R. , 1996). Another problem which had been reported several times is the corrosion of the furnace superstructure and crown due to higher concentration of volatiles in the furnace. (Abraham et al. 1997)

Side-Effects

Besides NO_x, other pollutants can be abated via oxy-fuel firing: volatile components allowing substantial savings in batch materials and particulates in special glass (e. g. borosilicates). Energy savings can be expected when no consideration of the oxygen production is made. However, since electricity is required for the production of oxygen, the total energy consumption is the same as with conventional fired furnaces. (Jockel W., Hartje J., 1991; Abraham et al. 1997; Delacroix et al., 1996) Furthermore, it must be mentioned that a transfer of pollution occurs upstream towards electricity production, therefore not solving the pollution problem.

3.5.1.1.8 Electric Melting

Technical Aspects

Molten glass is an electricity conductor and thus can be heated via electrodes immersed in the bath of glass. These electrodes are generally made up of molybdenum or platinum, and are located either at the top, at the bottom or at the walls of the furnace tank. In electrically heated furnaces, no direct emissions are released. Furthermore, compared to conventional regeneratively fired furnaces, electric melting furnaces show several advantages such as good temperature control and preheating of the batch inherent to the system, but the following drawbacks should be mentioned:

- the pollution is transferred upstream, towards electricity production;
- the lifetime of an electric melting furnace is reduced compared to a conventionally fired one;
- the furnace size is limited;
- an incompatibility between glass and electrodes occur for some glass compositions;
- high operating costs related to energy costs may be expected. (VDI Kommission Reinhaltung der Luft, 1997)

Electric melting is currently limited to production of special glass, especially crystal glass, and to glass fibre production (UN/ECE, 1995; Delacroix et al., 1996).. Very small units have been constructed in the float industry for specially formulated glasses only (Abraham et al. 1997).

Side-Effects

Via electric melting, pollution is transferred upstream towards electricity production.

3.5.1.2 Secondary Emission Reduction Measures

Even though high NO_x emission reduction can be achieved by primary measures, especially via combustion modifications and the reburning/3R process, secondary measures can be used in some cases to meet more stringent standards. Proven NO_x-abatement measures in the glass industry are the selective non-catalytic (SNCR) and catalytic (SCR) reduction processes.

3.5.1.2.1 Selective Non Catalytic Reduction (SNCR)

Technical Aspects

Ammonia is injected at an over-stoichiometric ratio into the waste gas stream of the glass melting furnace within a temperature window ranging from 850 to 1,100 °C. This temperature window is the most important parameter with regard to satisfactory NO_x conversion, in parallel with avoiding an increased ammonia slip. In regenerative glass melting furnaces, the above given temperature window can generally not be met. Therefore, this secondary measure is rather suitable for recuperatively heated furnaces, although SNCR technology can be found also in regeneratively fired glass melting furnaces (Kircher U., 1993; Kircher U., 1995).

The NO_2 conversion and the NH_3 slip are function of the amount of NH_3 injected: an appropriate NH_3 distribution in the waste gas is required to obtain a satisfactory conversion rate and ammonia slip. (Rentz et al., 1991)

The SNCR process is characterised by relatively high costs with regard to a rather low NO_x-removal efficiency, typically around 50 % (Abraham et al. 1997; Quirk R. , 1997), which is not sufficient as regards European regulations.
Today in Germany, 6 glass melting plants are equipped with SNCR technology, and three further installations are planned (Kircher U., 1995). Two further installations are located in the USA, and one in Switzerland (Delacroix et al., 1996). Operational parameters of the six German plants are given in Table 3.7.

Table 3.7: Operational parameters of 6 SNCR installations in the European glass production sector (Kircher U., 1995)

Plant	1	2	3	4	5	6
Furnace	Recuperative	recuperative	recuperative	Regenerative	recuperative	regenerative
Technical / Experimental	Technical	technical	technical	Technical	technical	technical
Fuel	Natural gas	natural gas	heavy oil	natural gas / heavy oil	natural gas	natural gas
Glass	Special	special	container	Water	special	soda lime
Waste gas flow rate	10,000 m^3/h	10,000 m^3/h	25,000 m^3/h	25,000 m^3/h	10,000 m^3/h	20,000 m^3/h
Ammonia feeding	Downstream Recuperator	downstream recuperator	between two recuperators	downstream first regenerator	downstream recuperator	middle of regenerator
Dissolved / gaseous NH_3	Gaseous	gaseous	gaseous	solution	gaseous	gaseous
Start of operation	1989	1992	1992	1989 / 1990	1994	1994
Efficieny	84 %	86 %	75 %	50 – 60 %	ca. 80 %	50 – 60 %
Ammonia slip	6 mg/m^3	23 mg/m^3	< 30 mg/m^3	< 30 mg/m^3	< 30 mg/m^3	< 30 mg/m^3
NO_x content in the cleaned gas*	180 mg/m^3	470 mg/m^3	<500 mg/m^3	<800 mg/m^3	350 mg/m^3	650 mg/m^3

* These values refer to an O_2-content in the waste gas of 8 vol.-%.

Side-Effects

Neither emissions to water, nor solid waste occur. But an increase in energy consumption and an ammonia slippage can be observed. The use of ammonia on-site is a potential safety hazard.

3.5.1.2.2 Selective Catalytic Reduction (SCR)

Technical Aspects

Here, the reduction of nitrogen oxides is based on the injection of gaseous or aqueous ammonia in a near stoichiometric ratio into the waste gas of the glass melting furnace in the presence of a catalyst and within a temperature window between 300 and 400 °C. A NO_x-abatement up to 90 % can be achieved. Some years ago, in glass production, catalyst lifetime was reduced by the presence of sodium sulphate in the waste gas which blocks and poisons the catalyst, but nowadays a catalyst can already achieve up to 4 years lifetime, and therefore, SCR has reached the status of a proven technology (Kircher U.; 1995). However, the SCR applied in the glass manufacturing industry is always operated with an electrostatic precipitator, in order to achieve concentrations of soda dust below 10 mg/m^3, which may be a poison to the catalyst. For the same reason of catalyst poisoning, natural gas is preferred over oil as a fuel. (Abraham et al. 1997)

Six SCR installations at glass melting plants are implemented in Germany, mainly in the field of special glass production (e. g. TV screen glass) (Abraham et al. 1997). In Hombourg (France), a SCR facility has been started in 1997 in the float glass production (Quirk R., 1997, Genuist G., 1996).. Table 8 gives an overview of the operational parameters of SCR at six German glass production plants.

Table 3.8: Operational parameters of 6 SCR installations in the German glass production sector (Schmalhorst E., Ernas T., 1995;, Kircher U., 1995, UN/ECE, 1998)

Plant	**1**	**2**	**3**	**4**	**5**	**6**
Furnace	Regenerative	regenerative	regenerative	regenerative	regenerative	regenerative
Fuel	Natural gas	natural gas	natural gas	natural gas	natural gas	natural gas
Type of Glass	Container	special	special	container	special	special
Waste gas flow rate	50,000 m^3/h	50,000 m^3/h	40,000 m^3/h	60,000 m^3/h	40,000 m^3/h	40,000 m^3/h
Dissolved / gaseous NH_3	Solution	solution	gaseous	solution	solution	gaseous
Catalyst	Zeolithe	V_2O_5/TiO_2	V_2O_5/TiO_2	V_2O_5/TiO_2	V_2O_5/TiO_2	V_2O_5/TiO_2
Number of layers	1	1	1	2	2	1
Start of operation	1987	1989	1991	1994	1994	1994
Efficiency	55 %	75 %	70 %	76 %	n. a.	75 %
Ammonia slip	28 mg/m^3	< 30 mg/m^3	< 30 mg/m^3	2 mg/m^3	< 30 mg/m^3	< 30 mg/m^3
NO_x content in the cleaned gas	480 mg/m^3	1,000 mg/m^3	1,350 mg/m^3	500 mg/m^3	< 1,500 mg/m^3	< 1,000 mg/m^3

n. a. = data is not available

The installation at plant 1 was stopped in June 1997 in favour of primary measures (Abraham et al. 1997). The only SCR installed at a container glass production plant is currently running at PLM Glashütte Münder, where clean gas concentrations of 500 mg/Nm^3 are achieved (low NO_x burners are already installed) (Schmalhorst E., Ernas T., 1995; UN/ECE, 1998).

Side-Effects

SCR generates solid waste via deactivated catalyst, but it can often be reprocessed by the manufacturer or be used as combustion material. As for SNCR, the increased energy consumption and ammonia slippage have to be accounted for. The use of ammonia on-site is a potential safety hazard.

3.5.2 SO_x-Emission Reduction Measures

3.5.2.1 Primary Emission Reduction Measures

The most important option for the reduction of SO_2 emissions from glass melting furnaces is the use of fuels with a lower sulphur content. SO_2 emissions from gas fired glass melting tanks are lower than the emissions from oil fired furnaces, since gaseous fuels have a lower sulphur content than liquid fuels. (Rentz et al., 1991) However, the selection of fuels depends on their availability and on the furnace design in place. (VDI, 1998)

Furthermore, the melting furnace should be operated in such a way that the sulphur absorption ability of the melt is not decreased: it it thus necessary to obtain a certain oxygen concentration in the upper zone of the furnace. (Rentz et al., 1991)

3.5.2.2 Secondary Emission Reduction Measures

Emissions of sulphur oxide from the off-gases of glass melting furnaces can be removed via sorption, e.g. by supply of appropriate sorbents (dry sorbent, or calcium and sodium based sorbents). Besides sulphurous compounds, hydrogen chloride, hydrogen fluoride, and gaseous heavy metals are also removed by this process. Removal efficiency for the different compounds is mainly determined by the amount of sorbent used and by the temperature at which the reaction takes place. A higher temperature leads to higher removal rates for SO_2 and hydrogen chloride. The removal of hydrogen fluoride is slightly lower at higher temperatures. (Gitzhofer K.-H., 1993)

3.5.3 Emission Reduction Measures for Other Pollutants

Measures for decreasing air emissions from the combustion process will also result in a reduction of the heavy metal and dust emissions. Dust emissions from handling raw materials can be reduced using fabric filters or using different improved handling techniques. The emissions of carbon dioxide from the carbonisation process can be reduced by adding more recycled glass or using non-carbonate basic materials.

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes (“activity rates”) and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

---

[1] The term “Tier” is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = \text{AR} \times \text{EF}$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8.1. Note: The values given for the carbonisation process are very much dependant on the local situation and can only be used if no information is available.

5 DETAILED METHODOLOGY

The detailed methodology (equivalent to Tier 3), to estimate emissions of gaseous pollutants from the glass production is based on measurements or estimations using plant specific emission factors - Guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

Note: a detailed calculation should be based on individual plant information about the amounts of substances added. Also the amount of recycled glass used should be available. However these data are often confidential. Also fuel information and information about local abatement methods should be available.

6 RELEVANT ACTIVITY STATISTICS

Information on the production of glass, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics.

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities of glass produced by various types of industrial technologies employed in the glass industry at plant level. This data is however not always easily available.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

The production of glass is usually connected to medium size stacks that may be regarded as point sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Default Emission Factors for Use With Simpler Methodology

In Table 8.1 and Table 8.2 are reported default emission factors for glass production (including, where applicable, also emission from non-melting activities). The emission factors on Table 8.2 was elaborated from Integrated Pollution Prevention and Control Reference Document on Best Available Techniques [IPPC, BREF] (European Commission, 2001). Care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030314; fuel used in the process does not have to be taken into account in 0301.

Table 8.1: Emission factors (kg/Mg glass melted) for glass production (European Commission, 2001) (1)

Substance	Flat glass production	Container glass production	Glass wool (2)	Other (3)
NO_x	4.6	2.4	3.9	4.8
SO_x	5.3	2.5	0.23	0.7
PM	0.4	0.4	2.74	0.4
VOC			1.51	
NH_3			3.16	

(1) Emissions factors without secondary abatement
(2) Combined fossil fuel-electric melting furnace including non-melting activities
(3) Domestic soda lime-glass as reference

For carbonization process an average emission factor of 137 kg/Mg glass can be used (the value derive from the detailed methodology emission factors, an IPPC BREF evaluation of the European production composition and an IPPC BREF evaluation of post consumer cullet in production of different kinds of glass).

Table 8.2: Emission factors to air in [g/Mg glass] for heavy metals and micropollutants for glass production in general

Substance	Default value	Range
Arsenic	0.10	0.1 - 0.25
Cadmium	0.15	0.05 - 0.25
Chromium	2.5	0.5 - 5
Copper	0.5	0.4 - 1.1
Lead (1)	10	2 - 24
Mercury	0.05	0.04 - 0.07
Nickel	2	1.2 - 2.6
Selenium	20	2.5 - 24
Zinc	10	5 - 24
Dichloromethane	5	0 - 11
Fluorine	30	5 - 70
Dust	400	3 - 800

The emission of lead is mainly determined by the amount of recycled glass used (Beerkens, R.G.C., 1991).

8.2 Reference Emission Factors for Use With Detailed Methodology

The emission factors in Table 8.3a give the theoretical amount of carbon dioxide emitted. Especially for container glass the amount of recycled glass may be up to 85 %.

IPPC, BREF (European Commission, 2001) reports an average of 40% of post consumer cullet in container glass production while the total cullet introduced in flat glass furnaces is typically around 20% (process cullet and sometimes also post consumer cullet).

Table 8.3a: Theoretical process emission factors for carbon dioxide from the carbonisation process in [kg/Mg product] in relation to the alcaline content of the product

Glass type	sodium oxide (wt %)	potassium oxide (wt %)	Magnesium oxide (wt %)	calcium oxide (wt %)	barium oxide (wt %)	carbon dioxide
Container glass	12-14	0.3-0.5	0.5-3	10-12	-	171-229
Flat glass	13.6	0.3	4.1	8.6	-	210
Continuous filament fibres						
E-fibres	< 2	< 2	20-24	20-24	-	157-203
AR-fibres	13-15	13-15	4-6	4-6	-	92-172
R/S-fibres	< 1	< 1	9-16	9-16	-	71-182
D-fibres	< 4	< 4	0	0	-	0-28
C-fibres	15-20	15-20	10-30	10-30		149-470
ECR-fibres	< 1	< 1	22-27	22-27	-	173-302
A-fibres	12-15	12-15	10-15	10-15		135-270
Special glass						
CRT panel	6.6-9.4	6.6-8.4	0-1.2	0-3.2	0	78-144
CRT tube	5.8-6.7	7.8-8.1	0.6-2.2	0.9-3.8	0	91-139
Glass tube, earth alk	12.5	2.5	2	4	0	154
Glass tube, borosilicate	3.5-6.5	0.5-1.5	0.01-0.5	0.01-1	0	27-66
Borosilicateglass	3.5-6.5	0.5-1.5	0.01-0.5	0.01-1	0	27-66
Opaque lighting glass	13.6	1.8	0	9.4	0	178
Lamb bulb	3-4	1.5-2.5	0.5	0.5	0	38-49
Glass ceramic	0.5-10	0	0-1	0.5-7	0	7.5-137
Quartz	0	0	0	0	0	0
Boron crown optical	0-5	12-18	0	0-0.3	0	56-122
Fluorine crown optical	0	0	0	0	20	57
Waterglass sodium sil.	22.5-24	0	0.008	0/008	0	160-171
Waterglass potassium silicate	0	27-32	0.008	0.008	0	126-150
Glass wool	12-18	12-18	8-15	8-15	0	119-292
Stone wool	0.5-5	0.5-5	30-45	30-45	0	238-527

Table 8.3b gives emission factors for particulate matter (TSP, PM10 and PM2.5) for glass production derived from CEPMEIP.

Table 8.3b: Emission factors for particulate matter in glass production [kg/Mg glass product] (CEPMEIP)

Glastype	**Technology and abatement**	**TSP**	**PM_{10}**	**$PM_{2.5}$**	**Uncertainty**
Flat glass, blown or drawn glass and container glass	Electrically heated, ESP, scrubber or fabric filter	0.03	0.027	0.024	5
Flat glass, blown or drawn glass and container glass	Gas or fuel oil-fired, uncontrolled or limited emission control	0.5	0.45	0.4	3
Flat glass, blown or drawn glass and container glass	Uncontrolled; old plant	2	1.8	1.6	3
Glass fibres	Electrically heated, ESP	0.5	0.45	0.35	3
Glass fibres	Gas or fuel oil-fired, uncontrolled	1	0.9	0.7	2
Glass fibres	Uncontrolled; old plant:	2	1.8	1.4	3

NOTE: The uncertainty range (95% confidence) in the emission factor is expressed as a factor. The lower limit of the uncertainty range can be found by dividing the emission factor by the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example (first row in table): The uncertainty in the emission factor for $PM_{2.5}$ for flat glass production with an electrical is 5. The emission factor with uncertainty range will therefore be 0.024 kg per tonne glass with an uncertainty range of 0.048 (0.024 / 5) to 0.120 (0.024 x 5).

8.2.1 Production of Flat Glass

Reported emission levels from IPPC, BREF (European Commission, 2001) are given in Table 8.4. The table shows figures separately for unabated furnaces and furnaces with secondary abatement techniques installed. The data covers both gas and oil fired furnaces making clear float glass under normal operating conditions and includes measurements from 1996 and 1997 only. The term unabated furnaces refers to furnaces operating normally with no specific pollution control technology.

Table 8.4: Total emission ranges[1] reported for flat glass sector furnaces with primary and secondary abatement measures (European Commission, 2001)

Parameter	**Unabated Furnaces**		**Abated Furnaces Primary/Secondary Methods**	
	mg/Nm^3	**kg/t glass melted**	**mg/Nm^3**	**kg/t glass melted**
NO_x	1800 – 2870	1.7 - 7.4	495 - 1250	1.1 - 2.9
SO_x	365 – 3295	1.0 - 10.6	218 - 1691	0.54 - 4.0
PM	99 – 280	0.2 - 0.6	5.0 - 40	0.02 - 0.1
HCl	7.0 – 85	0.06 - 0.22	4.0 - 30	<0.01 - 0.08

Parameter	**Unabated Furnaces**		**Abated Furnaces** **Primary/Secondary Methods**	
	mg/Nm^3	**kg/t glass melted**	**mg/Nm^3**	**kg/t glass melted**
HF	<1.0 - 25	<0.002 - 0.07	<1.0 - 4.0	<0.002 - 0.01
Metals	<1.0 – 5.0	<0.001 - 0.015	<1.0	<0.001

[1]Reference conditions are: dry, temperature 0°C (273K), pressure 101.3 kPa, 8 % oxygen by volume.

The on-line coating processes applied to flat glass are very case specific and the raw materials used and the pollutants emitted will vary. However, emissions will typically contain acid gases (HF, HCl) and fine particulate matter (e.g. oxides of silicon and tin). This type of process is usually subject to the general local environmental legislation and abatement is installed accordingly. For example, HCl 10 mg/m3, HF 5 mg/m3, particulate 20 mg/m3, and tin compounds 5 mg/m3 (European Commission, 2001).

The range of energy consumption encountered within the sector is quite narrow, because there is relatively little variation in the type of furnace used. Energy levels for melting are typically 5.5 to 8.0 GJ/Mg of glass melted, with specific energy requirements for the process as a whole generally less than 8.0 GJ/Mg (European Commission, 2001).

For the situation in the Netherlands, the following emission factors for flat glass in kg/Mg glass was proposed:.

handling/shipping:

dust:	0.15 kg/Mg

melting oven:

SO_2	3.0 kg/Mg
CO_2	140 kg/Mg
F_g	0.055 kg/Mg
Cl_g	0.06 kg/Mg
dust	0.37 kg/Mg

fuel:

SO_2	3.0 (fuel oil) kg/Mg
CO_2	530 kg/Mg
NO_x	5.5 kg/Mg
CO	0.09 kg/Mg

Heavy metals are incorporated in the dust emissions. The available information about compositions is scarce. The only consistent information is based on the work of Jockel and Hartje (Jockel W.; Hartje J., 1991), also incorporated in the PARCOM-ATMOS Manual. This information, based on the situation in Germany, is given in Table 8.5.

Table 8.5: Emission factors for glass production in [g/Mg glass] generalised for the situation in Germany.

Substance	Emission factor [g/Mg glass]	Range [g/Mg glass]
Arsenic	0.12	0.1-0.24
Cadmium	0.15	0.06-0.24
Chromium	2.4	0.5-5
Copper	0.6	0.4-1.1
Lead	12	2-24
Mercury	0.05	0.036-0.072
Nickel	1.9	1.2-2.6
Selenium	18	2.4-24
Zinc	11	4.8-24

The following Table 8.6 contains fuel related emission factors for container glass production based on CORINAIR90 data in [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product) are listed in footnotes.

In each case, care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030314.

Table 8.6: Emission for flat glass production[6)]

Type of fuel				NAPFUE code	Emission factors						
					SO_2[3)] [g/GJ]	NO_x[4)] [g/GJ]	NMVOC[5)] [g/GJ]	CH_4 [g/GJ]	CO [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]
s	Coal	hc	Steam	102	650[1)]	300[1)]	15[1)]	15[1)]	100[1)]	93[1)]	4[1)]
s	Coal	bc	brown coal/lignite	105	500[1)]	300[1)]	15[1)]	15[1)]	100[1)]	113[1)]	3.5[1)]
s	Coal	bc	Briquettes	106	220[1)]	300[1)]	15[1)]	15[1)]	100[1)]	98[1)]	3.5[1)]
s	Biomass		Wood	111	25[1)]	130[1)]	48[1)]	32[1)]	160[1)]	105[1)]	4[1)]
l	Oil		Residual	203	930-1,470 1,400[2)]	98-1,800[1)] 180[2)]	3-4[1)] 3[2)]	3-4[1)] 3[2)]	10-320[1)] 15[2)]	72-78[1)] 78[2)]	2-14[1)] 14[2)]

Type of fuel				NAPFUE code	Emission factors						
					SO_2[3] [g/GJ]	NO_x[4] [g/GJ]	NMVOC[5] [g/GJ]	CH_4 [g/GJ]	CO [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]
l	Oil		gas	204	85-1,410[1] 600[2]	100-450[1] 180[2]	1.5-4[1] 1.5[2]	1.5-4[1] 1.5[2]	10-12[1] 12[2]	73-74[1] 74[2]	2-12[1] 12[2]
g	Gas		natural	301	0.5-8[1]	60-570[1] 100[2]	2.5-10[1] 2.5[2]	2-3[1] 2.5[2]	10-120[1] 13[2]	53-56[1] 53[2]	1-3[1] 3[2]
g	Gas		coke oven	304	12[1]	400-450[1]	2.5[1]	2.5[1]	10[1]	44-49[1]	1.5[1]

[1] CORINAIR90 data, area sources

[2] CORINAIR90 data, point sources

[3]	SO_x:	1,500	g/Mg product	Melting furnace (Loos, B. 1992)
		2,246	g/Mg product	General (EPA, 1990)
		1,675	g/Mg product	General, with venturi scrubber (EPA, 1990)
		1,182	g/Mg product	General, with low energy scrubber (EPA, 1990)
		2,800	g/Mg beaded glass	Ground cutlet beading furnace (Loos, B. 1992)
[4]	NO_x:	8.6-10	kg/Mg product	General (Bouscaren, 1992)
		2,920	g/Mg product	General (EPA, 1990)
		4,000	g/Mg product	Melting furnace (Loos, B. 1992)
		4,250	g/Mg product	Ground cutlet beading furnace
		800	g/Mg product	General, (FRG, GDR, 1990) (BUNDESUMWELTMINISTERIUM, 1994)
[5]	VOC:	50	g/Mg product	Melting furnace (Loos, B. 1992)
		150	g/Mg beaded glass	Ground cutlet beading furnace (Loos, B. 1992)

[6] It is assumed, that emission factors cited within the table are related to combustion sources in flat glass production. Footnotes may also include emission factors for other process emissions.

8.2.2 Production of Container Glass

Reported emission levels from IPPC, BREF (European Commission, 2001) are given in Table 15. The source of this table is a statistical study made among members of the container glass trade association FEVE on data from 228 fossil fuel fired furnaces, with and without electric boosting, from the entire spectrum of furnace and product types. Data refers to measurements made in 1996 and 1997. Sampling and measurement techniques are not standardised and the data can only be considered as indicative of the range of actual emissions at the time of the survey. The data for metals emissions was supplied for only 42 % of the furnaces and the metals included may differ.

About 30 % (72/228) of the container glass furnaces in the FEVE study are equipped with secondary abatement. The secondary abatement referred to is in all cases dust abatement, by an Electrostatic Precipitator or (less frequently) a bag filter, generally with upstream desulphuring. Filter dust is recycled in all cases into the glass melt, within the limits imposed by possible substitution of raw materials. Overall reduction of sulphur oxide emissions thus corresponds in current practice to the substitution of sulphate in raw materials. The desulphuring is considered as secondary abatement for other acid gases (HCl & HF) with similar limitations on the overall effect due to recycling of filter dust. Secondary abatement of NOx (by SCR) is only installed in one EU container plant (4 furnaces).

The data for Table 8.7 from the same FEVE study as for Table 8.8 report the 80 % middle range (from Percentile 10 to Percentile 90) and is an indication of the performance of the majority of EU-wide installations in 1996 – 1997.

Care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030315.

Table 8.7: Total emission ranges reported for container glass sector furnaces with primary and secondary abatement measures (European Commission, 2001)

Parameter	**Without Secondary Abatement** **With or without primary measures**		**With Secondary Abatement**	
	mg/Nm^3	**kg/t glass melted**	**mg/Nm^3**	**kg/t glass melted**
NO_x	400–5000	0.6-11.7	<400	<0.74
SO_x	100–4500	0.2-9.8	100-1637	0.2-3.4
PM	40–800	0.1-1.9	1-32	0.002-0.22
HCl	5–62	0.01-0.12	7-30	0.01-0.07
HF	1–70	≤0.16	≤1-6	≤0.02
Metals	≤1–16	≤0.017	≤1-3	≤0.003
Cullet Rate	5-95 %			
Typical Load	25-600 t/day			
Specific Energy Melting only incl. Boosting	3.2-12.2 [GJ/t]			

[1]Reference conditions are: dry, temperature 0°C (273K), pressure 101.3 kPa, 8 % oxygen by volume.

The application of hot surface coatings and cold surface treatments can give rise to emissions of fume and vapours, principally HCl and tin compounds (European Commission, 2001). The levels of emissions will vary between processes and will depend on many factors. Mass emissions are quite low due to the low amounts of substance used, and concentrations will depend heavily on the amount of extraction air applied. To date, the control of these substances seems to have concentrated on the control of workplace exposure levels.

Table 8.8: Total emission ranges reported for Middle 80 % (P10 to P90) container glass sector furnaces with primary and secondary abatement measures (European Commission, 2001)

Parameter	Without Secondary Abatement With or without primary measures		With Secondary Abatement	
	mg/Nm^3	kg/t glass melted	mg/Nm^3	kg/t glass melted
NO_x	600-2000	1.2-3.9	<400	<0.74
SO_x	250 - 3200	0.5 - 7.2	230 - 1500	0.4 - 2.8
PM	100 - 270	0.2 - 0.6	2 - 32	0.002 - 0.05
HCl	10 - 40	0.02 - 0.08	7 - 30	0.01 - 0.06
HF	1 - 11	≤0.027	≤1 - 5	≤0.011
Metals	0.2 - 8	≤ 0.016	≤ 1	≤ 0.002
Cullet Rate	18 - 80 %			
Typical Load	100 - 360 t/day			
Specific Energy Melting only incl. Boosting	3.9 - 6.4 [GJ/t]			

[1] Reference conditions are: dry, temperature 0°C (273K), pressure 101.3 kPa, 8 % oxygen by volume.

Wherever, HCl containing waste gas from hot end coating is combined with waste gas with a significant organics content, consideration must be given to the potential for the formation of dioxins and furans. The forming processes are highly mechanised which can give rise to mists of lubricating oils but these are controlled according to workplace exposure levels and do not represent a significant emission to air (European Commission, 2001).

For the situation in the Netherlands, the following emission factors for container glass can be proposed:

handling/shipping:

dust:	0.03 - 0.15 kg/Mg glass

melting oven:

SO_2	1.2 kg/Mg glass
CO_2	150 kg/Mg glass
F_g	0.014 kg/Mg glass
Cl_g	0.05 kg/Mg glass
dust	0.30 kg/Mg glass

fuel:

SO_2	3.0 (fuel oil) kg/Mg glass
CO_2	265 kg/Mg glass
NO_x	3.8 kg/Mg glass

The dust is the main source of heavy metals. The emissions are largely determined by the composition of the basic materials and the product. Jockel and Hartje (Jockel W.; Hartje J., 1991) produced some generalised emission factors for the situation in Germany. These factors, also used in the PARCOM-ATMOS Manual, are given in Table 8.9 in g/Mg glass:

Table 8.9: Emission factors for glass production in [g/Mg glass] generalised for the situation in Germany

Substance	**Emission Factor [g/Mg glass]**	**Range [g/Mg glass]**
Arsenic	0.12	0.1-0.24
Cadmium	0.15	0.06-0.24
Chromium	2.4	0.4-1.1
Copper	0.6	0.4-1.1
Lead	12	2-24
Mercury	0.05	0.036-0.072
Nickel	1.9	1.2-2.6
Selenium	18	2.4-24
Zinc	11	4.8-24

The following Table 8.10 contains fuel related emission factors for container glass production based on CORINAIR90 data in [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product) are listed in footnotes. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a range for the specific energy consumption of 6 - 100 GJ/Mg product has been reported.

In each case, care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030315.

Table 8.10: Emission factors for container glass production$^{7)}$

Type of fuel			**NAPFUE code**	**Emission factors**						
				$SO_2$$^{2)}$ [g/GJ]	**$NO_x$$^{3)}$ [g/GJ]**	**NMVOC$^{4)}$ [g/GJ]**	**$CH_4$$^{4)}$ [g/GJ]**	**CO$^{5)}$ [g/GJ]**	**$CO_2$$^{6)}$ [kg/GJ]**	**N_2O [g/GJ]**
1	oil	residual	203	143-1,470$^{1)}$	100-570$^{1)}$	3$^{1)}$	3-8$^{1)}$	12-20$^{1)}$	73-78$^{1)}$	2-10$^{1)}$

Type of fuel			NAPFUE code	Emission factors						
				SO_2[2] [g/GJ]	NO_x[3] [g/GJ]	NMVOC[4] [g/GJ]	CH_4[4] [g/GJ]	CO[5] [g/GJ]	CO_2[6] [kg/GJ]	N_2O [g/GJ]
l	oil	Gas	204	55-1,410[1]	100-570[1]	1.5[1]	1.5-8[1]	12-20[1]	73-74[1]	2[1]
g	gas	natural	301	0.3[1]	80-570[1]	2.5-4[1]	2.5-4[1]	13-176[1]	53-57[1]	1[1]
g	gas	Liquified petroleum gas	303	0.04[1]	100[1]	2.1[1]	0.9[1]	13[1]	65[1]	1[1]

[1] CORINAIR90 data, area sources

[2]	SO_x:	2,246	g/Mg product	General (EPA, 1990)
		1,700	g/Mg product	Melting furnace (Loos, B. 1992)
[3]	NO_x:	4.3-5	kg/Mg product	General (Bouscaren, 1992) (spec. fuel consumption 7.5 GJ/Mg glass)
		2,920	kg/Mg product	General (Loos, B. 1992)
		3,100	kg/Mg product	Melting furnace (Loos, B. 1992)
[4]	VOC:	100	g/Mg product	Melting furnace (Loos, B. 1992)
[5]	CO:	100	g/Mg product	Melting furnace (Loos, B. 1992)
[6]	CO_2:	423	g/Mg product	General (EPA, 1990)

[7] It is assumed, that emission factors cited within the table are related to combustion sources in container glass production. Footnotes may also include emission factors for other process emissions.

8.3 Production of Glass wool

Reported emission levels for melting from IPPC, BREF (European Commission, 2001) are given in Table 8.11 and Table 8.12. Table 8.11 shows the full range of melting emissions from glass wool plants in the EU. Care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030316.

Glass wool products usually contain a proportion of phenolic resin based binder. The binder solution is applied to the fibres in the forming area and is cross-linked and dried in the curing oven. The forming area waste gas will contain particulate matter, phenol, formaldehyde and ammonia (European Commission, 2001).

The particulate matter consists of both organic and inorganic material, often with a very small particle size. Lower levels of VOCs and amines may also be detected if they are included in the binder system. Due to the nature of the process the gas stream has a high volume and high moisture content. The releases from the oven will consist of volatile binder materials, binder breakdown products, water vapour and combustion products from the oven burners. After exiting the oven the product is cooled by passing a large quantity of air through it. This gas is likely to contain glass wool fibre and low levels of organic material. Product finishing involves cutting, handling and packaging, which can give rise to dust emissions (European Commission, 2001).

Table 8.11: Total emission ranges reported for glass wool melting activities (European Commission, 2001)

Substance	**Electric Melting Glass**		**Flame Fired Furnaces**		**Combined Fossil fuel / electrical melting**	
	mg/m3	**kg/Mg of melt**	**mg/m3**	**kg/Mg of melt**	**mg/m3**	**kg/Mg of melt**
PM	2 – 250	0.004 - 1.0	10 - 1000	0.02 - 4.0	10 - 1000	0.02 - 4.0
SO_2			20 - 1000	0.05 - 4.0	20 - 1000	0.05 - 4.0
NO_x	15 - 500	0.002 - 0.03	100 - 1500	0.5 - 6.0[1]	100 - 1500	0.5 - 6.0
HF	0.5 - 5	0.003 - 0.03	0.5 – 5	0.002 – 0.02	0.5 - 5	0.002 - 0.02
HCl	0.2 - 5	0.001 - 0.03	1 – 30	0.004 – 0.08	1 - 30	0.004 - 0.08
CO_2	30 – 150 $*10^3$	100 - 300	150-190$*10^3$	400 – 500	150-190$*10^3$	400 – 500

[1]The lower levels of NOx are from an oxy-gas fired furnace.

Table 20 shows the estimated middle 80 % middle range (from Percentile 10 to Percentile 90) and is an indication of the performance of the majority of EU-wide installations.

Table 8.12: Total emission ranges reported for Middle 80 % (P10 to P90) for glass wool melting activities (European Commission, 2001)

Substance	**Electric Melting Glass**		**Flame Fired Furnaces**		**Combined Fossil fuel / electrical melting**	
	mg/m3	**kg/Mg of melt**	**mg/m3**	**kg/Mg of melt**	**mg/m3**	**kg/Mg of melt**
PM	25 - 220	0.08 - 0.9	30 – 200	0.06 – 0.8	30 - 200	0.06 - 0.8
SO_2			20 – 100	0.05 – 0.4	20 - 100	0.05 - 0.4
NO_x	200 - 400	0.02 - 0.025	500 - 1200	2.5 - 4.8	500 - 1200	2.5 - 4.8
HF	0.5 - 1.0	0.003 - 0.006	1.0 - 5.0	0.004 – 0.02	1.0 - 5.0	0.004 - 0.02
HCl	0.5 - 1.0	0.003 - 0.006	1.0 - 15.0	0.004 – 0.04	1.0 - 15.0	0.004 - 0.04
CO_2	30 – 150 $*10^3$	100 - 300	150-190$*10^3$	400 – 500	150-190$*10^3$	400 - 500

[1]The lower levels of NOx are from an oxy-gas fired furnace.

An important factor that has a major impact on emissions from forming, curing and cooling is the level of binder applied to the product, as higher binder content products will generally result in higher emission levels. Binder derived emissions depend essentially on the mass of binder solids applied over a given time, and therefore high binder content, and to a lesser extent high density products may give rise to higher emissions (European Commission, 2001).

Table 8.13 shows the full range of emissions from downstream operations of mineral wool plants in the EU, with figures for kg/Mg of product in brackets. Table 8.14 shows the estimated middle 80 % of the range.

Table 8.13: Total emission ranges reported for glass wool after melting activities (European Commission, 2001)

Substance	**Combined fiberising, forming and curing**		**Fiberising and forming**		**Product curing**		**Product cooling**		**Product finishing**	
	mg/Nm	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**
PM	10 - 200	0.3 - 6.0	10 - 200	0.3 - 6.0	5.0 – 55	0.01 - 0.18	10 - 50	0.04 - 0.3	1.0 - 50	0.005 - 0.4
Phenol	2.0 - 50	0.05 - 1.6	2.0 - 50	0.05 - 1.5	2.0 – 40	0.004 - 0.11	1.0 - 10	0.004 - 0.06		
Formaldehyde	2.0 - 30	0.05 - 1.2	2.0 - 30	0.05 - 1.0	2.0 – 60	0.004 - 0.17	1.0 - 10	0.004 - 0.06		
Ammonia	20 - 250	0.6 - 8.8	20 - 250	0.5 - 7.6	30 – 460	0.06 - 1.9	1.0 - 50	0.004 - 0.3		
NO_x					50 – 200	0.1 - 0.6				
VOC	5.0 - 150	0.1 - 5.0	5.0-150	0.1 - 4.6	5.0 – 150	0.01 - 0.43	1.0 - 30	0.004 - 0.2		
CO^2					20 – 80 * 10^3	40 - 230				
Amines	1.0 - 40	0.1 - 1.3	5.0 - 40	0.1 - 1.2	5.0 - 20	0.01 - 0.06	1.0 - 5.0	0.004 - 0.03		

Table 8.14: Total emission ranges reported for Middle 80 % (P10 to P90) for glass wool after melting activities (European Commission, 2001)

Substance	**Combined fiberising, forming and curing**		**Fiberising and forming**		**Product curing**		**Product cooling**		**Product finishing**	
	mg/Nm	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**
PM	10 - 50	0.9 - 1.9	10 - 50	0.6 - 3.5	5.0 - 25	0.01 - 0.07	10 - 30	0.04 - 0.2	5.0 - 20	0.03 - 0.16
Phenol	5.0 - 25	0.2 - 1.3	5.0 - 25	0.1 - 0.8	5.0 - 15	0.01 - 0.04	1.0 - 5.0	0.004 - 0.03		
Formaldehyde	5.0 - 20	0.15 - 0.43	5.0 - 20	0.1 - 0.6	5.0 - 30	0.01 - 0.09	1.0 - 5.0	0.004 - 0.03		
Ammonia	40 - 150	1.8 - 5.4	40 - 150	1.0 - 4.5	50 - 200	0.1 - 0.6	2.0 - 20	0.007 - 0.12		
NO_x					50 - 150	0.1 - 0.4				
VOC	10 - 80	0.2 - 2.7	10 - 80	0.3 - 2.4	10 - 80	0.02 - 0.23	1.0 - 10	0.004 - 0.06		
CO^2					20 – 80 * 10^3	40 - 230				
Amines	5.0 - 20	0.1 - 1.0	5.0 - 20	0.1 - 0.6	5.0 - 10	0.01 - 0.03	1.0 - 5.0	0.004 - 0.03		

For the situation in the Netherlands, the following emission factors for several compounds in kg/Mg glass wool can be proposed::

handling/shipping:

dust:	0.03 - 0.15 kg/Mg glass

melting oven:

SO_2	0.5 kg/Mg glass
CO_2	450 kg/Mg glass
F_g	0.006 kg/Mg glass
Cl_g	0.01 kg/Mg glass
dust	0.04 (after dust collector) kg/Mg glass

spinning/wool manufacturing:

formaldehyde	0.9 kg/Mg glass
phenol(s)	0.3 kg/Mg glass
ammonia	4.5 kg/Mg glass
VOS	0.6 kg/Mg glass

fuel:

SO_2	5.0 (fuel oil) kg/Mg glass
CO_2	670 kg/Mg glass
NO_x	2.8 kg/Mg glass

Emissions of heavy metals may be contained in the dust. No specific information for glass wool production is available. For a first estimation the factors referred to above for flat glass and container glass may be used.

The following Table 8.15 contains fuel related emission factors for the production of glass wool based on CORINAIR90 data in [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product, g/Mg material), are listed in footnotes. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a range for the specific energy consumption of 4.3 - 100 GJ/Mg product has been reported.

In each case, care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030316.

Table 8.15: Emission factors for the production of glass wool[7]

				Emission factors						
	Type of fuel		NAPFUE code	SO_2[2] [g/GJ]	NO_x[3] [g/GJ]	NMVOC[4][5] [g/GJ]	CH_4[5] [g/GJ]	CO[6] [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]
l	oil	Residual	203	840-1470[1]	150-450[1]		8[1]	20[1]	76-77[1]	2[1]
l	oil	Gas	204	55-1410[1]	50-100[1]		81)	20[1]	73-74[1]	2[1]
g	gas	Natural	301	8[1]	60-150[1]	10[1]	2-3[1]	20-30[1]	53-55[1]	1-3[1]

[1] CORINAIR90 data, area sources (preliminary data)

[2]	SO_x:	2,246	g/Mg product	General (EPA, 1990)
		5,000	g/Mg material processed	Regenerative furnace and recuperative furnace (Bouscaren, 1992)
		20	g/Mg material processed	Electric furnace
		300	g/Mg material processed	Unit smelter furnace
[3]	NO_x:	5,400-6,000	g/Mg product	General (Bouscaren, 1992)
		2,500	g/Mg material processed	Regenerative furnace (Bouscaren, 1992)
		850	g/Mg material processed	Recuperative furnace (Bouscaren, 1992)
		135	g/Mg material processed	Electric furnace (Bouscaren, 1992)
		245	g/Mg material processed	Forming, rotary spin (Bouscaren, 1992)
		550	g/Mg material processed	Alting oven: rotary spin (Bouscaren, 1992)
		150	g/Mg material processed	Cooling (Bouscaren, 1992)
		150	g/Mg material processed	Unit smelter furnace (Bouscaren, 1992)
		1,000	g/Mg material processed	Cursing: flame attenuation (Bouscaren, 1992)
[4]	NMVOC:	5,000	g/Mg product	(Loos, B. 1992)
[5]	VOC:	100	g/Mg material processed	Regenerative furnace, recuperative furnace and electric furnace (Bouscaren, 1992)
		3,500	g/Mg material processed	Forming: rotary spin (Bouscaren, 1992)
		1,500	g/Mg material processed	Cursing oven: rotary spin (Bouscaren, 1992)
		150	g/Mg material processed	Forming: flame attenuation (Bouscaren, 1992)
		3,500	g/Mg material processed	Cursing: Flame attenuation (Bouscaren, 1992)
[6]	CO:	0-500	g/Mg glass	For electric melting (Loos, B. 1992)
		100-600	g/Mg glass	For other furnaces (Bouscaren, 1992)
		125	g/Mg material processed	Regenerative furnace (Bouscaren, 1992) and recuperative furnace (Bouscaren, 1992)
		25	g/Mg material processed	Electric furnace (Bouscaren, 1992)
		850	g/Mg material processed	Cursing oven: rotary spin (Bouscaren, 1992)
		125	g/Mg material processed	Unit melter furnace (Bouscaren, 1992)
		1,750	g/Mg material processed	Cursing: flame attenuation (Bouscaren, 1992)

[7] It is assumed, that emission factors cited within the table are related to combustion sources in glasswool production. Footnotes may also include emission factors for other process emissions.

8.4 Production of Other Glass

The emission levels from IPPC, BREF (European Commission, 2001) are given in Table 8.16 (domestic glass) and Table 8.17 (examples of special glass processes).

In each case, care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030317.

Table 8.16: Summary of emission averages and ranges reported for domestic glass furnaces (European Commission, 2001)

Substance	**Soda-lime glass**				**Lead Crystal**(1)			
	mg/m3		**kg/Mg of melt**		**mg/m3**		**kg/Mg of melt**	
	Range	**Average value**	**Range**	**Average value**	**Range**	**Average value**	**Range**	**Average value**
PM	0.5 – 400	200	0.001 – 0.8	0.4	2 - 10	5	0.001 - 0.1	0.02
SO_2	50 – 1000	250	0.1 - 2.8	0.7			0.1 - 1	0.2
NO_x	140 – 5500(2)	2300	0.9 - 11	4.8	1000 - 2000	1500	0.9 - 5.0	1
HF	<5				0.1 - 1.0	0.5	0.0002 - 0.004	0.0003
HCl	<10				0.5 - 5.0	2.0	0.001 - 0.003	0.002
Metals(3)	<5				0.05 - 0.5	0.2	0.0001 - 0.035	0.01

(1) These data relate to conventional furnaces (i.e. not electrical)
(2) Some high results relate to the use of nitrates in the batch or to other specific conditions (e.g. very low pull rate).
(3) Including lead

Table 8.17: Summary of emission factors (kg/Mg) reported for special glass specific example processes (European Commission, 2001)

Substance	**Water glass**	**TV funnel glass**	**TV panel glass**
PM	0.212	0.0061	0.0326
SO_2	1322	0.0714	0.0817
NO_x	2028	12000	2700
HF	400	0.00137	0.0013
HCl	24	0.00924	0.0026

For emissions of heavy metals some specific information are derived from the PARCOM-ATMOS Emission Factors Manual and the literature mentioned there:

- For the production of lead crystal glass an emission factor of 60 g lead/Mg product is mentioned, using bag filters as abatement method. Without abatement the emission factor is estimated to be 1% of the lead content of the glass (UK Energy Efficiency Office, 1994).
- For coloured glass an emission factor of 0.11-0.15 g cadmium/g glass is mentioned.
- For the situation in Germany some specific information is given by Jockel and Hartje (Jockel W.; Hartje J., 1991). This information is given in Table 8.18.

Table 8.18: Emission factors for heavy metals from special glass production in Germany in [g/Mg product]

Substance	Emission Factor [g/Mg product]	Range [g/Mg product]
Arsenic (lead crystal glass)	140	22-310
Arsenic (crystal glass)	96	-
Cadmium	0.15	0.06-0.24
Chromium	2.4	0.5-5
Copper	0.6	0.4-1.1
Lead (lead crystal glass)	2700	2200-3200
Lead (crystal glass)	480	-
Mercury	0.05	0.036-0.072
Nickel	1.9	1.2-2.6
Selenium	18	2.4-24
Zinc	11	4.8-24

The following Table 8.19 contains fuel related emission factors for the production of other glass based on CORINAIR90 data in [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product, g/Mg material processed), are listed in footnotes. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a range for the specific energy consumption of 25 - 6.000 GJ/Mg product has been reported.

In each case, care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030317.

Table 8.19: Emission factors for the production of other glass[6]

					Emission factors						
	Type of fuel			**NAPFUE code**	**SO_2[2] [g/GJ]**	**NO_x[3] [g/GJ]**	**NMVOC[4] [g/GJ]**	**CH_4[4] [g/GJ]**	**CO[5] [g/GJ]**	**CO_2 [kg/GJ]**	**N_2O [g/GJ]**
s	Coal	hc	steam	102	787[1]	150[1]	15[1]	15[1]	10[1]	94[1]	14[1]
s	Biomass		wood	111		200[1]	50[1]	30[1]		92[1]	14[1]
l	Oil		residual	203	960-1,470[1]	132-370[1]	3-19[1]	0.1-3[1]	15-19[1]	76[1]	14[1]
l	Oil		gas	204	138-1,410[1]	80-100[1]	2[1]	1[1]	12[1]	73[1]	14[1]
l	Kerosene			206	69[1]	80[1]	2[1]	1[1]	12[1]	71[1]	14[1]
l	Gasoline		motor	208	45[1]	80[1]	2[1]	11)	12[1]	71[1]	14[1]
g	Gas		natural	301	8-260[1]	32-622[1]	10-26[1]	0.4-3[1]	8.5-95[1]	53-56[1]	1-3.7[1]
g	Gas		liquified petroleum gas	303	2[1]	20-40[1]	1-4[1]	1-4[1]	13[1]	60-65[1]	3[1]

[1] CORINAIR90 data, area sources

[2]	SO_x:	2,246	g/Mg product	General (Loos, B. 1992)
		1,500	g/Mg material processed	Textile fiber, regenerative furnace and recuperative furnace (EPA, 1990)
		2,800	g/Mg product	Pressed and blown glass, melting furnace (EPA, 1990)
		2,800	g/Mg beaded glass	Ground cullet beading furnace (EPA, 1990)
[3]	NO_x:	3,500-6,000	g/Mg product	General (Bouscaren, 1992)
		10,000	g/Mg material processed	Textile fiber; regenerative furnace, recuperative furnace and unit smelter furnace (EPA, 1990)
		1,300	g/Mg material processed	Textile fiber; curing oven (EPA, 1990)
		4,250	g/Mg product	Pressed and blown glass, melting furnace (EPA, 1990)
		4,250	g/Mg beaded glass	Ground cullet beading furnace (EPA, 1990)
[4]	VOC:	100	g/Mg material processed	Textile fiber: regenerative furnace and recuperative furnace (EPA, 1990)
		0	g/Mg material processed	Textile fiber: unit smelter furnace (EPA, 1990)
		150	g/mg product	Pressed and blown glass, melting furnace (EPA, 1990)
		150	g/Mg beaded glass	Ground cullet beading furnace (EPA, 1990)
[5]	CO:	100	g/Mg product	Pressed and blown glass, average (Bouscaren, 1992)
		100	g/Mg product	Pressed and blown glass, melting furnace (EPA, 1990)

[6] It is assumed, that emission factors cited within the table are related to combustion sources in other glass production. Footnotes may also include emission factors for other process emissions.

9 SPECIES PROFILES

An analysis of dust emissions from a melting oven in the Netherlands is available. The major constituents from this analysis are given in g/Mg glass:

Table 9.1: Composition of dust from glass melting oven

Substance	**Concentration [g/Mg glass]**
Aluminium	1.3
Chromium	0.15
Cobalt	0.05
Copper	0.15
Iron	2.4
Lead	0.30
Manganese	0.05
Nickel	1.0
Titanium	0.08
Vanadium	1.90
Zinc	0.25

These components are present as sulphates.

10 UNCERTAINTY ESTIMATES

If the simplified approach is used the results may differ very much from the real situation. A classification C-D is appropriate in this case. If more detail about the individual plant are available the factors should be corrected e in classifications in the B to C range.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The default calculation could be very much improved if information about the basic materials used is available.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Not relevant if treated as point source. Otherwise national emissions should be disaggregated on the basis of plant capacity, employment or population statistics.

Production of special glass is usually done in small plants. They may be treated as an area source by disaggregating national emission estimates on the basis of plant capacity, employment or population statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

The production of flat glass, container glass, and glass wool can be considered as a continuous process. The production of special glass is usually a discontinuous process but no information is available on temporal profile.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

- Emission inventory in The Netherlands, 1992. Emission to air and water
- Personal information and experience during emission inventories 1975 - 1995
- Emission factors to be used for the building industry, TNO report 89/091
- Environmental Protection Agency, Compilation of Air Pollutant Emission Factors AP-42
- PARCOM-ATMOS Emission Factors Manual
- SPIN document "Productie van glas ,glasvezel, en glaswol", 1992 (in Dutch)
- LEENDERTSE, A.: Dutch notes on BAT for the Glass and Mineral Wool Industry. prepared for the Ministry of Housing, Spatial Planning and the Environment. Directorate for Air and Energy Draft version October 1998
- WESSELS BOER CONSULTANCY: Personal communication, 1998

16 VERIFICATION PROCESSES

Verification should be applied by comparing calculated emissions with measured emissions at an individual plant.

17 REFERENCES

Abraham D.; Quirk R.; de Reydellet A.; Scalet B. M.; Tackels G. (1997): Personal Communication, July 1997.

Barklage-Hilgefoot H.J.; Sieger W. (1989): Primary measures for the NO_x-Reduction on Glass Melting Furnaces, in: Glasstechnik Bericht 62,5.

Barklage-Hilgefort, H., Sieger W. (1989): Primary Measures for the NO_x Reduction on Glass Melting Furnaces, in: Glastechnische Berichte, 62,5, p. 151 – 157.

Beerkens, R.G.C. (1991): Overzicht Productie, Energieverbruik en Rookgasemissies Nederlandse Glasindustrie anno 1990; Technische Physische Dienst TNO-TUD (report number TPD-GL-RPT-91-007), January 1991 (in Dutch).

Bouscaren M. R. (1992): CORINAIR Inventory, Default Emission Factors Handbook,; second Edition, comission of the European Communities, Paris, 1992.

BUNDESUMWELTMINISTERIUM (1994) (ed.). Erster Bericht der Regierung der Bundesrepublik Deutschland nach dem Rahmenübereinkommen der Vereinten Nationen über Klimaänderungen, 1994.

Delacroix F., Delhopital G., Lalart D., Mocek L., Tackels G.(1996): Réduction des Emissions d'Oxydes d'Azote dans l'Industrie du Verre, Comité de Suivi du Verre, Arrêté du 14 Mai 1993, July 1996.

Eichhammer W.; Bradke H.; Flanagan J.; Laue H. J.; Bahm W. (1994): Energy Efficient Techniques in Domestic Glass Production, Report to European Commission Directorate-General for Energy – DG XVII, Contract No.XVII/7001/90-8, June 1994.

EPA (1990): AIRS Facility subsystem, EPA-Doc 450/4-90-003, Research Triangle Park, March 1990.

EPA (1994): AP42 CD-Rom.

EPA (1995): AP42 CD-Rom

EUROPEAN COMMISSION (2001), Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques (BREF) in the Cement and Lime Manufacturing Industries, December 2001

Flamme M. (1993): Feuerungstechnische NO_x-Minderungsverfahren, in: HVG-Fortbildungskurs 1993, Minderung der Staub- und Schadgas-Emissionen bei Glasschmelzöfen, Fachhochschule Nürnberg,.

Flamme M.; Haep J. (1994): Möglichkeiten zur Minderung der NO_x-Bildung im Bereich der Glasindustrie, in: Gaswärme International, 43,9.

Genuist G. (1996): SCR: L'expérience d'EUROGLAS dans le domaine du verre plat, in: Combustion et Procédés Industriels – Comment Réduire les Emissions d'Oxydes d'Azote, Rencontres et Journées Techniques de l'Ademe, Angers, September 1996.

Gitzhofer K.-H. (1993): Emissionen und Stand der Abgasreinigung, in: HVG-Fortbildungskurs 1993, Minderung der Staub- und Schadgas-Emissionen bei Glasschmelzöfen, Fachhochschule Nürnberg, 18./19. November 1993.

Her Majesty´s Inspectorate of Pollution (1992): Glass Manufacture and Production Glass Frit and Enamel Frit; Environmental Protection Act 1990; Process Guidance Note IPR 3/5; London, 1992.

Jockel W.; Hartje J. (1991) Datenerhebung über die Emissionen Umwelt-gefährdenden Schwermetalle. Forschungsbericht 91-1-4 02 588; TüV Rheinland e.V. Köln.

Joshi M.L., Wishnick D.B., Madrazo R. F., Benz W.H., Panahi S.K., Slavejkov A.G., Abbasi H.A., Grosman R.E., Donaldson L.W. (1994): Cost-Effective NO_x Reduction Using Oxygen-Enriched Air Staging on Regenerative Glass Furnaces, 55th Conference on Glass Problems, November 1994.

Kircher U. (1993a): NO_x-Emissionen und Stand der Minderungstechnik, in: HVG-Fortbildingskurs 1993, Minderung der Staub- und Schadgas-Emissionen bei Glasschmelzöfen, Fachhochschule Nürnberg,.

Kircher U. (1993b): NO_x-Minderung von Glasschmelzöfen, in: GASWÄRME International, 42,1/3, p. 14 - 21.

Kircher U. (1995): Present Status of NO_x Reduction by Primary and Secondary Measures in the German Glass Industry, in: Proceedings: XVII International Congress on Glass, Beijing.

Koppang R. (1996); Evaluation du Reburning sur un Four de Verre Creux de 350 Mg/j, in: Combustion et Procédés Industriels – Comment Réduire les Emissions d'Oxydes d'Azote, Rencontres et Journées Techniques de l'Ademe, Angers, September 1996.

Landesgewerbeanstalt Bayern (1994): Beurteilung von Anlagen zur Herstellung von Glas nach der 12. BImSchV, Nürnberg,.

Leendertse, A. (1998): Personal communication about the carbonization process.

Loos B. (1990): Produktie van Glas, Glas vezel en Glaswol; RIVM-report 736301115; RIZA-report 92.003/15, 1992.

Nölle G. (1978): Technik der Glasherstellung, Deutscher Verlag für Grundstoffindustrie, Leipzig,.

Pabst R. (1994): Noncatalytic Removal of Nitrogen in a Recuperative Container Glass Furnace, in: Glastechnische Berichte, 57,3.

Quirk R. (1996): Pilkington 3R Process in Glass Industry: An Update, in: Combustion et Procédés Industriels – Comment Réduire les Emissions d'Oxydes d'Azote, Rencontres et Journées Techniques de l'Ademe, Angers, September 1996.

Quirk R. (1997): Review of Controls of NO_x: Glass Opportunities – The Challenge of the Environment, in: Glass Technology, Volume 38, No. 4, August 1997.

Rentz O; Schleef H.-J.; Dorn R; Sasse H.; Karl U. (1996): Emission Control at Stationary Sources in the Federal Republic of Germany, Sulphur Oxide and Nitrogen Oxide Emission Control, UFOPLAN-Ref. No. 104 02 360, Karlsruhe, August 1996.

Schmalhorst E.; Ernas T. (1995): First Practical Experiences with an SCR DeNO_x Facility in a Container Glassworks, in: Glastechnische Berichte Glass Sci. Technol., 68,5.

Shulver I. (1994): New Developments in NO_x Control – Pilkington '3R' Process, in: Glastechnische Berichte, 67,11.

Teller A.J.; Hsieh J.Y. (1992): Glass Manufacturing, in: Buonicore A.J.; Davis T.W. (eds.): Air Pollution Engineering Manual, New York

UK Energy Efficiency Office (1994): Energy efficient environmental control in the glass industry. Good practice Guide no 127.

UN/ECE (1995): Task Force on Heavy Metal Emissions, State-of-the-Art Report–Second Edition, Prague.

UN/ECE (1998) Task Force on the Assessment of Abatement Options/Techniques for Nitrogen Oxides from Stationary Sources: Draft Background Document, French-German Institute of Environmental Research, Karlsruhe, April 1998.

VDI (1998): Emissionsminderung Glasshütten / Emission Control Glass Manufacture; VDI 2578; Düsseldorf.

VDI Kommission Reinhaltung der Luft (1997): Emissionsminderung Glashütten, VDI Richtlinie 2578, 7. Vorentwurf, in: VDI/DIN-Handbuch Reinhaltung der Luft, Volume 1, Düsseldorf, April 1997.

Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

19 RELEASE VERSION, DATE AND SOURCE

Version : 2.2

Date : June 2005

Authors : P. F. J.van der Most
Inspectorate for Environmental Protection
Netherlands

O Rentz, S Nunge
University of Karlsruhe (TH)
Germany

Integrated with IPPC BREF data, and updated the default emission factors for simpler methodology by:
Carlo Trozzi
Techne Consulting
Italy

Updated with emission factors (CEPMEIP) for particulates by:
Tinus Pulles and Wilfred Appelman
TNO
The Netherlands
May 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Carlo Trozzi
Techne Consulting
Via G. Ricci Curbastro, 34
Roma, Italy

Tel: +39 065580993
Fax: +39 065581848
Email: carlo.trozzi@techne-consulting.com

SNAP CODE: **030318**

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Mineral Wool

NOSE CODE: **104.11.09**

NFR CODE: **1 A 2 f**

1 ACTIVITIES INCLUDED

This chapter covers emissions released from combustion processes within mineral wool production.
A mixture of minerals and coke is heated until it is molten and can be spun into fibres. The fibres are treated with resins to form a wool-like product.

2 CONTRIBUTION TO TOTAL EMISSION

The contribution of fuel use related emissions released from the production of mineral wool to total emissions in countries of the CORINAIR90 inventory is minor, as indicated in table 1.

Table 1:Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**								
		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	PM*
Mineral Wool	0303018	0	0	-	-	0	0	-	-	-

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported
* = PM (inclusive of TSP, PM_{10} and $PM_{2.5}$) is <0.1% of total PM emissions

The emissions of phenol(s) is also relevant but no estimates are available at the European level.

3 GENERAL

3.1 Description of activities

Products manufactured from man-made mineral fibres (MMMF) generally consist of inorganic fibres produced from a silicate melt, and, depending on their application and use, contain binding agents, additives and filters. (VDI, 1994)

Whilst basically the melting technology closely resembles the technology commonly used in glass-works, there are considerable differences in the composition of the glass types which have to be adapted to meet the special demands made on the man-made mineral fibres with respect to processability, viscosity, melting range, hydrolytic class, heat resistance etc. In particular, special glasses containing boron and glasses with additives of volcanic rock (phonolite, basalt, diabase) are used. (VDI, 1994)

3.2 Definitions

3.3 Techniques

Cupola furnaces are used for the production of silicate melts. The starting materials for the production of MMMF are silicate rocks (e.g. basalt, diabase) or metallurgical slags with alkaline or acid additives (e.g. limestone, dolomite, sandstone). Coke, fuel oil or gas are used as fuels. (VDI, 1994)

In electric melting units, the mineral raw materials are melted by electric resistance heating. Units of fireproof (refractory) materials and water-cooled metal containers are in use. (VDI, 1994)

The silicate melt is fed either in covered or open channels (feeders, troughs) or directly to the processing units in which the fibres are produced. The most commonly employed processes are the bushing blowing process, the centrifugal process and the bushing drawing process. (VDI, 1994)

Man-made mineral fibres are generally processed by impregnation, soaking or coating and possibly with subsequent drying processes to form a wide range of finished products. (VDI, 1994)

The impregnated or coated semi-finished product is dried by intensive contact with hot air. Continuous pass driers, single or multi-layer and chamber drying kilns are used. The hot air temperature can be up to 300 °C. The hot air is generally circulated (circulation air process), whereby both direct and indirect heating (e.g. by means of heat transfer oil) processes are in use. (VDI, 1994) Hot pressing is commonly used for the manufacture of certain products, whereby the drying and hardening is performed by warming between heated moulds. (VDI, 1994)

Energy consumption is typically around 6 -10 GJ per ton produced.

3.4 Emissions

Dust emission can result from handling raw materials as well as from the melting process.

Other emissions result from the melting process, the spinning process as well as finishing the wool. Pollutants released are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2), and nitrous oxide (N_2O). According to CORINAIR90 the main relevant pollutants are SO_2, NO_x, CO and CO_2 (see also table 1).

The cupola is a source of CO, CO_2 and NO_x emissions; SO_2 and H_2S emissions also occur, because blast furnace slags contain sulphur /cf 4/.

Emissions of organic and inorganic substances arise from manufacturing products of man-made mineral fibres. The raw gas contents of the melting facilities are generally of a purely inorganic nature and free from fibrous constituents. Emissions of organic substances can arise preparating the binding agent. /cf. 3/
Where binding agents containing nitrogen (ammonia, aminoplasts) are processed, ammonia and/or organic compounds containing nitrogen may occur in the waste gases, depending on the operating conditions. /cf. 3/

No gaseous or particulate emissions arise during the actual production of the fibres (VDI, 1994).

3.5 Controls

Dust emissions from handling raw materials can be reduced using fabric filters or using different handling techniques.

Extraction systems and driers (hardening kilns, presses) should be designed with respect to the product throughput in such a way that overloading of the facilities by increased temperatures and excessive flow velocities or increased evaporation of constituents of the binding agents or the transport in the air current of droplets and fibrous dusts is prevented. (VDI, 1994)

The malodorous and organically contaminated waste gases from the drying and hardening kilns are transferred to waste gas treatment plants. Multistage wet separator systems (washers) can be used in conjunction with wet electrostatic precipitators or aerosol separators as well as catalytic and thermal post-combustion. Processes employing high-frequency drying result in neither malodorous or organic emissions. No significant dust emissions occur during the process stages drying and hardening. Waste gases are released by stack. /cf 3/

4 SIMPLER METHODOLOGY

The simpler methodology involves applying an appropriate emission factor to either production or energy consumption statistics.

N.B There are no emission factors available for $PM_{2.5}$. The source is <0.1% of the total PM emissions for most countries.

5 DETAILED METHODOLOGY

If an extensive measuring programme is available the emissions can be calculated on for an individual plant.

Should a key source analysis indicate this to be a major source of particulate matter (TSP, PM_{10} or $PM_{2.5}$) then installation level data should be collected using a measurement protocol such as that illustrated in Measurement Protocol Annex.

6 RELEVANT ACTIVITY STATISTICS

Standard production and energy statistics from national or international statistical publications.

7 POINT SOURCE CRITERIA

The production of mineral wool is a minor source of emissions and hence can be treated on an area basis. However, production usually connected to high chimneys can be regarded as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

8.1 Default Emission Factors For Use With Simpler Methodology

Table 2: Emission factors (kg/Mg product) for mineral wool production (European Commission, 2001) (1)

Substance	Emission factor
NO_x	0,73
SO_x	4,1
PM	2,49
VOC	1,51
NH_3	3,16
CO	125

(1) Cupola furnace including non-melting activities

8.2 Reference Emission Factors For Use With Detailed Methodology

Reported emission levels from Integrated Pollution Prevention and Control Reference Document on Best Available Techniques [IPPC, BREF] (European Commission, 2001) are given in Table 3 and Table 4 (for melting) and Table 5 (for non melting activities). Table 2 shows the full range of melting emissions from mineral wool plants in the EU. Table 3 shows the estimated middle 80 % middle range (from Percentile 10 to Percentile 90) and is an indication of the performance of the majority of EU-wide installations.

Following the melting stage (European Commission, 2001) the processes and environmental issues are essentially the same as in glass wool (activity 030316).

Mineral wool products usually contain a proportion of phenolic resin based binder. The binder solution is applied to the fibres in the forming area and is cross-linked and dried in the curing oven. The forming area waste gas will contain particulate matter, phenol, formaldehyde and ammonia (European Commission, 2001).

The particulate matter consists of both organic and inorganic material, often with a very small particle size. Lower levels of VOCs and amines may also be detected if they are included in the binder system. Due to the nature of the process the gas stream has a high volume and high moisture content. The releases from the oven will consist of volatile binder materials, binder breakdown products, water vapour and combustion products from the oven burners. After exiting the oven the product is cooled by passing a large quantity of air through it. This gas is likely to contain mineral wool fibre and low levels of organic material. Product finishing involves cutting, handling and packaging, which can give rise to dust emissions (European Commission, 2001).

Table 3: Total emission ranges reported for mineral wool melting activities (European Commission, 2001)

Substance	**Cupola Furnaces**		**Immersed Electric Arc Furnace**		**Flame Fired Furnaces**	
	Mg/m3	**kg/Mg of melt**	**mg/m3**	**Kg/Mg of melt**	**mg/m3**	**kg/Mg of melt**
PM	10 - 3000	0.03 - 9.0	10 - 30	0.01 - 0.03	10 - 50	0.02 - 0.1
SO_2	150 - 3500	0.4 - 10.0	1000 - 3000	1.0 - 3.0	30 - 300	0.06 - 0.6
NO_2	50 - 400	0.14 - 1.1	50 - 200	0.05 - 0.2	800 – 1500	1.6 - 3.0
HF	1 - 30	0.003 - 0.09	1 - 5	0.001 - 0.005	0.5 - 5	0.002 - 0.02
HCl	10 - 150	0.03 - 0.4	10 - 50	0.01 - 0.05	1 - 30	0.002 - 0.02
H_2S	1 - 500	0.003 - 1.4	0 - 5	0 - 0.005		
CO	10 – 100000	0.03 - 300	30 - 100	0.03 - 0.1		
CO_2	130 – 260 * 10^3	400 - 800	20 - 200* 10^3	20 - 200	150- 200* 10^3	400 - 500
Metals[1]	0.1 - 30	0.0003 - 0.09				

[1] Metals are emitted mainly as particulate matter.

Table 4: Total emission ranges reported for Middle 80 % (P10 to P90) for mineral wool melting activities (European Commission, 2001)

Substance	**Cupola Furnaces**		**Immersed Electric Arc Furnace**		**Flame Fired Furnaces**	
	Mg/m3	**Kg/Mg of melt**	**mg/m3**	**kg/Mg of melt**	**mg/m3**	**kg/Mg of melt**
PM	20 - 100	0.06 - 0.3	10 - 30	0.01 - 0.03	10 - 50	0.02 - 0.1
SO_2	400 - 2500	1.1 - 7.1	1000 - 3000	1.0 - 3.0	30 - 250	0.06 - 0.5
NO_2	80 - 250	0.25 - 0.7	50 - 200	0.05 - 0.2	1150 - 1250	2.3 - 2.5
HF	1.0 - 15.0	0.003 - 0.03	1.0 - 5.0	0.001 - 0.005	1.0 - 5.0	0.004 - 0.02
HCl	10 - 50	0.03 - 0.2	10 - 50	0.01 - 0.05	1.0 - 25	0.002 - 0.015
H_2S	1.0 - 200	0.003 - 0.6	0 - 5.0	0 - 0.005		
CO	30 - 80000	0.1 - 250	30 - 100	0.03 - 0.1		

CO_2	130 – 260 * 10^3	400 - 800	20 - 200* 10^3	20 - 200	150- 200* 10^3	400 - 500
Metals[1]	0.1 - 2.0	0.0003 - 0.006				

[1] Metals are emitted mainly as particulate matter.

An important factor that has a major impact on emissions from forming, curing and cooling is the level of binder applied to the product, as higher binder content products will generally result in higher emission levels. Binder derived emissions depend essentially on the mass of binder solids applied over a given time, and therefore high binder content, and to a lesser extent high density products may give rise to higher emissions (European Commission, 2001).

Table 5 shows the full range of emissions from downstream operations of mineral wool plants in the EU, with figures for kg/Mg of product in brackets. Table 6 shows the estimated middle 80 % of the range.

Table 5: Total emission ranges reported for mineral wool after melting activities (European Commission, 2001)

Substance	**Combined fiberising, forming and curing**		**Fiberising and forming**		**Product curing**		**Product cooling**		**Product finishing**	
	mg/Nm	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**
PM	10 - 200	0.3 - 6.0	10 - 200	0.3 - 6.0	5.0 - 55	0.01 - 0.18	10 - 50	0.04 - 0.3	1.0 - 50	0.005 - 0.4
Phenol	2.0 - 50	0.05 - 1.6	2.0 - 50	0.05 - 1.5	2.0 - 40	0.004 - 0.11	1.0 - 10	0.004 - 0.06		
Formaldehyde	2.0 - 30	0.05 - 1.2	2.0 - 30	0.05 - 1.0	2.0 - 60	0.004 - 0.17	1.0 - 10	0.004 - 0.06		
Ammonia	20 - 250	0.6 - 8.8	20 - 250	0.5 - 7.6	30 - 460	0.06 - 1.9	1.0 - 50	0.004 - 0.3		
NO_x					50 - 200	0.1 - 0.6				
VOC	5.0 - 150	0.1 - 5.0	5.0-150	0.1 - 4.6	5.0 - 150	0.01 - 0.43	1.0 - 30	0.004 - 0.2		
CO2					20 – 80 * 10^3	40 - 230				
Amines	1.0 - 40	0.1 - 1.3	5.0 - 40	0.1 - 1.2	5.0 - 20	0.01 - 0.06	1.0 - 5.0	0.004 - 0.03		

Table 6: Total emission ranges reported for Middle 80 % (P10 to P90) for mineral wool after melting activities (European Commission, 2001)

Substance	**Combined fiberising, forming and curing**		**Fiberising and forming**		**Product curing**		**Product cooling**		**Product finishing**	
	mg/Nm	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**	**mg/Nm**	**kg/Mg of product**
PM	10 - 50	0.9 - 1.9	10 - 50	0.6 - 3.5	5.0 - 25	0.01 - 0.07	10 - 30	0.04 - 0.2	5.0 - 20	0.03 - 0.16
Phenol	5.0 - 25	0.2 - 1.3	5.0 - 25	0.1 - 0.8	5.0 - 15	0.01 - 0.04	1.0 - 5.0	0.004 - 0.03		
Formaldehyde	5.0 - 20	0.15 - 0.43	5.0 - 20	0.1 - 0.6	5.0 - 30	0.01 - 0.09	1.0 - 5.0	0.004 - 0.03		
Ammonia	40 - 150	1.8 - 5.4	40 - 150	1.0 - 4.5	50 - 200	0.1 - 0.6	2.0 - 20	0.007 - 0.12		
NO_x					50 - 150	0.1 - 0.4				

VOC	10 - 80	0.2 - 2.7	10 - 80	0.3 - 2.4	10 - 80	0.02 - 0.23	1.0 - 10	0.004 - 0.06		
CO2					20 – 80 * 10^3	40 - 230				
Amines	5.0 - 20	0.1 - 1.0	5.0 - 20	0.1 - 0.6	5.0 - 10	0.01 - 0.03	1.0 - 5.0	0.004 - 0.03		

For the situation in the Netherlands, the following emission factors in kg per ton wool can be proposed:

handling/shipping:

dust:	0.5 kg per ton wool

melting oven:

SO_2	1.5 kg per ton wool
CO_2	115 kg per ton wool
CO	3.2 kg per ton wool
F_g	0.008 kg per ton wool
dust	0.06 kg per ton wool (after dust collector)

spinning/wool manufacturing:

formaldehyde	0.2 kg per ton wool
phenol(s)	0.7 kg per ton wool
ammonia	1.8 kg per ton wool
VOS	1.0 kg per ton wool

fuel:

NO_x	1.1 kg per ton wool
CO_2	450 kg per ton wool

The following Table 7 contains fuel related emission factors for the production of mineral wool based on CORINAIR90 data in [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product, g/Mg charged), are listed in footnotes. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a range for the specific energy consumption of 7 - 5.000 GJ/Mg product has been reported.
In each case, care should be taken not to double-count emissions reported in 0301 Combustion in boilers, gas turbines and stationary engines, and emissions reported here in activity 030312. Table 8 contains the AP 42 emission factors for particulate matter (US EPA, 1996).

Table 7: Emission factors for the production of mineral wool$^{7)}$

	Type of fuel			NAPFUE code	Emission factors $SO_2$$^{2)}$ [g/GJ]	$NO_x$$^{3)}$ [g/GJ]	NMVOC$^{4)}$ [g/GJ]	$CH_4$$^{4)}$ [g/GJ]	CO$^{5)}$ [g/GJ]	$CO_2$$^{6)}$ [kg/GJ]	N_2O [g/GJ]	NH_3 [g/GJ]
s	coal	hc	steam	102	584-610$^{1)}$	150-200$^{1)}$	15$^{1)}$	5-15$^{1)}$	20-97$^{1)}$	93-95$^{1)}$	3-5$^{1)}$	
s	coke	hc	coke oven	107	138-584$^{1)}$	90-100$^{1)}$	1.5-83$^{1)}$	1.5$^{1)}$	97$^{1)}$	101-110$^{1)}$	3$^{1)}$	
s	coke	bc	coke oven	108	650$^{1)}$	220$^{1)}$	5$^{1)}$	15$^{1)}$	90$^{1)}$	86$^{1)}$	3$^{1)}$	
s	biomass		wood	111	130$^{1)}$	130$^{1)}$	48$^{1)}$	32$^{1)}$	160$^{1)}$	102$^{1)}$	4$^{1)}$	

l	oil	residual	203	143-1,030[1]	100-330[1]	3[1]	3-8[1]	12-20[1]	73-78[1]	2-10[1]
l	oil	gas	204	55-94[1]	100[1]	1.5-2[1]	1.5-8[1]	12-20[1]	73-74[1]	2[1]
g	gas	natural	301	0.3-8[1]	60-250[1]	4-10[1]	2-4[1]	13-20[1]	53-57[1]	1-3[1]
g	gas	liquified petroleum gas	303	0.04[1]	100[1]	2.1[1]	0.9	13[1]	65[1]	1[1]

[1] CORINAIR90 data, area sources

[2]	SO_x:	8,480	g/Mg	(1989) (Kaskens et al., 1992)
		2,320	g/Mg	(1991) (Kaskens et al., 1992)
		10	g/Mg charged	Cupola furnace (EPA, 1990)
[3]	NO_x:	210	g/Mg	(1989) (Kaskens et al., 1992)
		200	g/Mg	(1991) (Kaskens et al., 1992)
		800	g/Mg charged	Cupola furnace (EPA, 1990)
		80	g/Mg charged	Curing furnace (EPA, 1990)
[4]	VOC:	450	g/Mg charged	Blow chamber
		500	g/Mg charged	Curing oven
[5]	CO:	8,120	g/Mg	(1989) (Kaskens et al., 1992)
		< 7,400	g/Mg	(1991) (Kaskens et al., 1992)
[6]	CO_2:	67.4	kg/Mg product	General for 1989 (Kaskens et al., 1992)
		168	kg/Mg product	General for 1991 (Kaskens et al., 1992)

[7] It is assumed, that emission factors cited within the table are related to combustion sources in mineral wool production. Footnotes may also include emission factors for other process emissions.

Table 8: AP 42 Particulate matter emission factors* for Mineral Wool (g/Mg) (US EPA, 1996)

Process	PM (g/Mg)	Rating
Cupola	8200	E
Cupola with fabric filter	51	D
Reverberatory furnace	2400	E
Batt curing oven	1800	E
Batt curing oven with ESP	360	D
Blow chamber	6000	E
Blow chamber with wire mesh filter	450	D
Cooler	1200	E

* = In the absence of more appropriate data use the AP 42 emission factors

9 SPECIES PROFILES

No general applicable profile for dust emissions available.

10 UNCERTAINTY ESTIMATES

The quality classification of the emission factors expressed per ton wool is estimated to be D.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

Knowledge about measurements related to abatement techniques is limited.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

National emission estimates can be disaggregated on the basis of plant capacity, employment or population statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

The production of mineral wool is a semi-continuous process but no further quantitative information is available.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

Emission inventory in The Netherlands, 1992. Emission to air and water.

Personal information and experience during emission inventories 1975 - 1995

Emission factors to be used for the building industry, TNO report 89/091 (1989 - in dutch)

Environmental Protection Agency

Compilation of Air Pollutant Emission Factors AP 42

16 VERIFICATION PROCESSES

Verification of the emissions can be done by comparing emission estimates with measurements at the individual plants.

17 REFERENCES

EPA (ed.): AIRS Facility Subsystem; EPA-Doc. 450/4-90-003; Research Triangle Park; 1990

EUROPEAN COMMISSION (2001), Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques (BREF) in the Cement and Lime Manufacturing Industries, December 2001

Kaskens, H. J. M.; Matthijsen, A. J. C. M.; Verburgh, J. J.: Productie van steenwol; RIVM-report 736301114; RIZA-report 92.0003/14; 1992

VDI (ed.): Emissionsminderungsanlagen zur Herstellung von Mineralfaserprodukten/Emission Control Facilities for the Production of Man-Made Mineral Fibres (MMMF); VDI 3457; Düsseldorf; 1994

US EPA (1996) Compilation of Air Pollutant Emission Factors Vol.1 Report AP-42 (5th ed.)

18 BIBLIOGRAPHY

For a detailed bibliography the primary literature mentioned in AP 42 may be used.

19 RELEASE VERSION, DATE, AND SOURCE

Version : 2.2

Date : June 2005

Source : P F J van der Most, R Wessels Boer
TNO
The Netherlands

Supported by: Otton Rentz, Dagmar Oertel
University of Karlsruhe (TH)
Germany

Integrated with IPPC BREF data, and updated the default emission factors for simpler methodology by:
Carlo Trozzi
Techne Consulting
Italy

Updated with particulate matter details by:
Mike Woodfield
AEA Technology
UK
December 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Carlo Trozzi
Techne Consulting
Via G. Ricci Curbastro, 34
Roma, Italy

Tel: +39 065580993
Fax: +39 065581848
Email: carlo.trozzi@techne-consulting.com

SNAP CODE: **030319**

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Bricks And Tiles

NOSE CODE: **104.11.10**

NFR CODE: **1 A 2 f**

1 ACTIVITIES INCLUDED

This chapter covers emissions released from combustion processes within bricks and tiles production. However, in the following if useful for description, also non-combustion emissions are mentioned.

2 CONTRIBUTION TO TOTAL EMISSION

The contribution of fuel use related emissions released from the production of bricks and tiles to total emissions in countries of the CORINAIR90 inventory is given as follows:

Table 1:Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**								
		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	PM*
Bricks and Tiles	030319	0.3	0.3	0	0	0.3	0.6	0.1	-	-

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported
* = PM (inclusive of TSP, PM_{10} and $PM_{2.5}$) is <0.1% of total PM emissions

The emission of fluorides is also relevant but no information is currently available at the European level.

3 GENERAL

3.1 Description of activities

The manufacture of bricks and related products such as clay pipe, pottery, and some types of refractory brick involves the mining, grinding, screening, and blending of the raw materials, clay with additives such as caoline or limestone, and the forming, cutting or shaping, drying or curing, and firing of the final product. /4/

To start the forming process, clay is mixed with water, usually in a pug mill. The three principal processes for forming bricks are stiff mud, soft mud, and dry press. In the stiff mud process, sufficient water is added to give the clay plasticity, and bricks are formed by forcing the clay through a die. Wire is used in separating bricks. All structural tile and most brick are formed by this process. The soft mud process is usually used with clay too wet for the stiff mud process. The clay is mixed with water to a moisture content of 20 to 30 percent, and the bricks are formed in molds. /4/

Three stages of heating are almost invariably involved /5/:

- The initial drying period, in which appreciable volumes of hot air must be passed through the setting in order to remove moisture until the ware is completely dry.
- The oxidation preheating period, in which chemically combined water is removed and oxidation of any carbonaceous matter in the green product is completed.
- The finishing period, during which the required final temperature of 950 - 1100 °C is attained and soaking time allowed to obtain uniformity of heat treatment and develop the required degree of vitrification and maturity.

3.2 Definitions

3.3 Techniques

Two types of kilns can be distinguished, the intermittent and the continuous kiln:

- Intermittent kilns (discontinuous)
  Intermittent kilns are mainly used to fire special products not amenable to continuous practice and where flexibility is of more importance than high thermal efficiency or large output of any one product. Unavoidable heat loss from the firing of these kilns is considerable /5/.

  Two main types of intermittent kiln are used in the heavy clay industry; the rectangular down-drought and the round down drought. Both muffle and open-flame conditions are used with each type. In muffle firing the gases from the fires are not allowed to make contact with the goods being fired, heat transfer being obtained almost entirely by radiation from the muffle walls. With open-flame firing, which is used to a much larger extent, all gases and flames from the fires pass through setting spaces among the ware before the combustion products are finally exhausted through the flue system. /5/

  Each kiln is usually connected to a separate stack. The draught in the kiln is controlled by means of a damper at the base of the stack. /5/

- Continuous kilns
  Continuous kilns are especially applicable to the firing of standard products where large throughput is desired. Recuperation of heat from cooling goods and from the kiln gases makes this kind of kiln more thermally efficient. The economic advantages of mass production and high thermal efficiency are obtained from the use of continuous kilns. /5/

  Two distinct firing principles are used in continuous practice. In car tunnel kilns the pre-heating, firing and cooling zones are fired and the goods travel through these zones on cars

or bogie carriages operated by an external pusher mechanism. These tunnels may be either straight or annular, a moving hearth being used in the annular kiln instead of cars. /5/
In the second type of continuous kiln the goods are set in the kiln and remain stationary while preheating, firing and cooling zones move round the kiln. With this type, one continuous tunnel may be used or the kiln system may consist of a number of transverse arch chambers connected through suitable chamber openings. /5/

Most commonly natural gas is burned to heat the ovens, but other fuels are possible. Energy consumption is typically around 2 - 2.5 GJ per ton.

3.4 Emissions

Pollutants released are dust, sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (N_2O), fluoride (F_g, Chlorine (Cl_g) and ammonia (NH_3). According to CORINAIR90 the main relevant pollutants are SO_2, NO_x, CO, and CO_2 (see also table 1).

Pollution from the brick making industry is predominantly confined to stack emissions of kiln exhaust gases. The pollutants in the exhaust gas originate mainly from impurities within the clay, although firing with coal or heavy fuel oil will make a significant contribution to the overall emissions to atmosphere. Such impurities will produce fluoride emissions from the fluorine containing components of the clay minerals; sulphur oxides from iron pyrites or other sulphur bearing minerals (e.g. sulphates); and odorous gases from organic materials occurring naturally within the clay or added to the clay during processing The sulphur content of clay varies widely, with the majority of the clays. Combustion products are emitted from the fuel consumed in the dryer and the kiln. /cf. 5/

However, natural gas is mainly employed for firing and the use of heavy oil and coal has declined. Overall, about 2 % of the sulphur oxides emitted are in the form of sulphur trioxide. Research work in the UK on sulphur dioxide emissions from tunnel kilns gave total sulphur dioxide levels up to 480 mg/m³. /cf. 4, 5/

In the combustion process, oxides of nitrogen will be produced from the oxidation of chemically bound nitrogen in the fuel, the clay and from atmospheric nitrogen. In general, the higher the temperature the greater the production of nitrogen oxides. /5/

3.5 Controls

The following main categories of techniques are available for dealing with these pollutants and may be applicable for this process: dry absorption, condensation, wet scrubbing, flue gas desulphurisation, incineration and wet/dry absorption.

- Dry Absorption :
  Most flue gas cleaning systems currently in operation within the brick industry are dry absorption based processes. Two systems are employed, packed bed filters and cloth filters.

  - Packed Bed Filters :
    In the packed bed filter system, fluoride sorption is achieved using a filter bed of granular limestone (calcium carbonate) through which the flue gas passes. Fluorine, and other pollutants are absorbed on the filter media which also allows for dust deposition, thereby avoiding the need for a separate dust filter. The efficiency of these units is generally high, with typical levels in the treated gas quoted as being: e.g. for fluorine < 5 mg/m³ as hydrogen, fluoride, sulphur trioxide 90 % removal, sulphur dioxide 10-15 % removal and particulate matter < 50 mg/m³.
  - Cloth Filters :
    Lime or hydrated lime is injected into the gas stream to absorb the gaseous fluorine and sulphur compounds. The resulting fluorspar and gypsum are then removed from the gas stream using cloth filters. The removal efficiencies for such a system are reported to be as follows: Fluorine (99 %), sulphur trioxide (75 %), sulphur dioxide (5 to 10 %) and dust (< 50 mg/m³). The main advantage of the standard cloth filter system its ability to operate in high sulphur environments, possibly up to 2,000 mg/m³ sulphur dioxide since blockage is less likely.

- Condensation :
  The principle behind these systems is to cool the gas down to such a degree that the pollutants are precipitated by condensation. The condensates so produced contain hydrofluoric and sulphuric acids which are highly aggressive. The condensates are then neutralised with castic soda or milk of lime. In practice milk of lime is usually selected because it is cheaper than caustic soda. Reported estimates of the typical removal efficiencies that can be achieved by this technique are for fluorine (90 %), sulphur trioxide (50 %) and sulphur dioxide (15 %).

- Wet scrubbing :
  Wet scrubbing systems aim to produce contact between the scrubbing liquid and the pollutant, in order to promote absorption and/or precipitation processes. Levels of efficiency of removal have been claimed for fluorine 99 %, sulphur dioxide 15 % and particulates 87 %.

- Incineration :
  Incineration of odours may also be undertaken externally to the kiln for successful removal of these odorous compounds.

- Wet/dry absorption :
  A sulphur dioxide absorber (either lime, sodium carbonate or bicarbonate solution or slurry) is injected into the exhaust gas stream upstream of any dust collection equipment. This process removes about 70 % of sulphur in the gas stream.

4 SIMPLER METHODOLOGY

The simpler methodology involves applying an appropriate emission factor to either production or energy consumption statistics.

N.B There are no emission factors available for $PM_{2.5}$. The source is <0.1% of the total PM emissions for most countries.

5 DETAILED METHODOLOGY

If an extensive measuring programme is available the emissions can be calculated on for an individual plant.

Should a key source analysis indicate this to be a major source of particulate matter (TSP, PM_{10} or $PM_{2.5}$) then installation level data should be collected using a measurement protocol such as that illustrated in Measurement Protocol Annex.

6 RELEVANT ACTIVITY STATISTICS

Standard production and energy statistics available from national or international statistical publications.

7 POINT SOURCE CRITERIA

The production of bricks and tiles can be considered as an area source. However, production is usually connected to high chimneys that can be regarded as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

For the situation in the Netherlands, the following can be proposed:

Emission factors are given for three types of clay:

class A: clay products that after firing are “red” coloured.
class B: clay products that after firing are “yellow” coloured.
class C: clay products that after firing are “white” coloured.

Table 2: Emission factors in kg per ton product:

	class A **‘red’**	**class B** **‘yellow**	**class C** **‘white**
SO_2	0.175	0.040	0.600
SO_3	0.030	0.050	0.055
dust *	0.050	0.050	0.050
F_g	0.170	0.060	0.250
Cl_g	0.040	0.035	0.110

Table 3: Emission factors in kg per m^3 of natural gas used:

	class A **'red'**	**class B** **'yellow**	**class C** **'white**
NO_x	0.0032	0.0032	0.0032
CO	0.0080	0.0100	0.0160
CO_2	2.3000	3.7000	3.0000
C_xH_y	0.0011	0.0011	0.0011

* dust consists of clay particles, the composition may vary widely.

The following Table 4 contains fuel related emission factors for the production of bricks and tiles based on CORINAIR90 data in [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product), are listed in footnotes. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a range for the specific energy consumption of 2 - 100 GJ/Mg product has been reported. Table 5 contains the AP 42 emission factors for particulate matter (US EPA, 1996).

Table 4: Emission factors for the production of bricks and tiles 7)

	Type of fuel			NAPFUE code	Emission factors SO_2 2) [g/GJ]	NO_x 3) [g/GJ]	NMVOC 4) [g/GJ]	CH_4 4) [g/GJ]	CO 5) [g/GJ]	CO_2 6) [kg/GJ]	N_2O [g/GJ]	NH_3 [g/GJ]
s	coal	hc	coking	101	159 1)	569 1)		1 1)		86 1)		
s	coal	hc	steam	102	407-787 1)	150-334 1)	15-21 1)	0.3-15 1)	10-120 1)	79-95 1)	4-14 1)	
s	coal	hc	sub-bituminous	103	170 1)	30 1)	15 1)	15 1)	50 1)	99 1)	8 1)	
s	coal	bc	brown coal/lignite	105	500-2,900 1)	140-300 1)	1.5-20 1)	1.5-100 1)	14-110 1)	86-113 1)	3-14 1)	
s	coal	bc	briquettes	106	175 1)	140 1)	15 1)	15 1)	100 1)	97-98 1)	3.5 1)	
s	coke	hc	coke oven	107	400-540 1)	140-300 1)	0.5-15 1)	0.5-15 1)	15-100 1)	100-105 1)	4-14 1)	
s	coke		petroleum	110	680 1)	200 1)	1.5 1)	1.5 1)	97 1)	102 1)	3 1)	
s	biomass		wood	111	130 1)	130-200 1)	48-50 1)	30-32 1)	160 1)	83-102 1)	4-14 1)	
l	oil		residual	203	57-1,470 1)	57-330 1)	3-57 1)	0.1-8 1)	10-234 1)	76-78 1)	2-15 1)	
l	oil		gas	204	55-1,410 1)	54-330 1)	1.5-2.5 1)	1-8 1)	10-54 1)	72-74 1)	2-14 1)	
l	kerosene			206	68.6 1)		2 1)	1 1)	12 1)	71 1)	14 1)	
l	gasoline		motor	208	44.7 1)		2 1)	1 1)	12 1)	71 1)	14 1)	
g	gas		natural	301	0.4-8 1)	50-330 1)	4-26 1)	0.4-4 1)	10-343 1)	34-66 1)	1-4 1)	
g	gas		liquified petroleum gas	303	0.04-2 1)	20-100 1)	1-4 1)	1 1)	13 1)	60-65 1)	1-3 1)	
g	gas		coke oven	304	9.6 1)	50 1)	2.5 1)	2.5 1)	10 1)	44-49 1)	1.5 1)	

1) CORINAIR90 data, area sources

2)	SO_x:	354	g/Mg	General (1992) /1/
		2,000	g/Mg product	Curing and firing, oil fired tunnel kilns /2/
		3,665	g/Mg product	Curing and firing, coal fired tunnel kilns /2/
		2,950	g/Mg product	Curing and firing, gas fired periodic kilns /2/
		6,065	g/Mg product	Curing and firing, oil fired periodic kilns /2/

3)	NO_x:	500	g/Mg product	General /3/
		120	g/Mg product	General (1992), NAPFUE 301 (94 %) /1/
		90	g/Mg product	Curing and firing, gas fired tunnel kilns /2/
		550	g/Mg product	Curing and firing, oil fired tunnel kilns /2/
		725	g/Mg product	Curing and firing, coal fired tunnel kilns /2/
		250	g/Mg product	Curing and firing, gas fired periodic kilns /2/
		810	g/Mg product	Curing and firing, oil fired periodic kilns /2/
		1,175	g/Mg product	Curing and firing, coal fired periodic kilns /2/
4)	VOC:	10	g/Mg product	Curing and firing, coal fired periodic kilns /2/
		50	g/Mg product	Curing and firing, oil fired periodic kilns /2/
		5	g/Mg product	Curing and firing, gas fired periodic kilns /2/
		5	g/Mg product	Curing and firing, coal fired tunnel kilns /2/
		35	g/Mg product	Curing and firing, coal fired tunnel kilns /2/
		15	g/Mg product	Curing and firing, coal fired tunnel kilns /2/
	NMVOC:	< 500	g/Mg product	General for porous bricks, for FRG, DN and UK, released by waste raw material /3/
5)	CO:	1,600	g/Mg product	EPA-value, ceramic industry /3/
		30	g/Mg product	Curing and firing, gas fired tunnel kilns /2/
		60	g/Mg product	Curing and firing, oil fired tunnel kilns /2/
		715	g/Mg product	Curing and firing, coal fired tunnel kilns /2/
		75	g/Mg product	Curing and firing, gas fired periodic kilns /2/
		95	g/Mg product	Curing and firing, oil fired periodic kilns /2/
		1,195	g/Mg product	Curing and firing, coal fired periodic kilns /2/
		240	g/GJ	General, (1992), NAPFUE 301 (94 %) /1/
6)	CO_2:	61	kg/GJ	General, (1992), NAPFUE 301 (94 %) /1/

7) It is assumed, that emission factors cited within the table are related to combustion sources in bricks and tiles production. Footnotes may also include emission factors for other process emissions.

Table 5: AP 42 Particulate matter emission factors* for Brick and Tiles (g/Mg) /5/

Source	PM (g/Mg)	RATING	PM_{10} (g/Mg)	RATING	$PM_{2.5}$ (g/Mg)	RATING
Primary crusher with fabric filter	ND	NA	0.295	E	ND	NA
Grinding and screening operations						
processing dry material	4250	E	265	E	ND	NA
processing wet material	12.5	E	1.15	E	ND	NA
with fabric filter	3.1	E	1.6	E	ND	NA
Extrusion line with fabric filter	1500	NA	1.8	E	ND	NA
Natural gas-fired kiln	480	D	435	D	ND	NA
Coal-fired kiln						
uncontrolled	900	B	700	C	435	D
with fabric filter	315	E	ND	NA	ND	NA
Sawdust-fired kiln	465	D	425	D	375	D
Sawdust-fired kiln and sawdust dryer	700	E	155	E	ND	NA

* = In the absence of more appropriate data use the AP 42 emission factors
ND = No data
NA = Not applicable

9 SPECIES PROFILES

A profile of the clay used would be useful. This information is not available.

10 UNCERTAINTY ESTIMATES

The quality classification of the emission factors expressed per ton product is estimated to be C.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The fuel specific emission factors provided in table 2 are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of emission factors with respect to point and area sources. Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

National emission estimates can be disaggregated on the basis of plant capacity, employment or population statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

The production of bricks and tiles can be considered as a continuous process.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

Emission inventory in The Netherlands, 1992. Emission to air and water.

Emission factors to be used for the building industry, TNO report 89/091.

Environmental Protection Agency, Compilation of Air Pollutant Emission Factors AP-42

16 VERIFICATION PROCESSES

Verification of the emissions can be done by comparing the results of the calculations with measurements at the individual plant.

17 REFERENCES

/1/ Huizinga, K.; Verburgh, J. J.; Mathijsen, A. J. C. M.: Großkeramische Industrie; RIVM-report 736301112; RIZA-report 92.003/12; 1995

/2/ EPA (ed.): AIRS Facility subsystem; EPA-Doc 450/4-90-003; Research Triangle Park; 1990

/3/ Bouscaren, M. R.: CORINAIR Inventory, Default Emission Factors Handbook; second Edition; Comission of the European Communities; Paris; 1992

/4/ EPA (ed.): AP 42 CD-Rom; 1995

/5/ Her Majesty's Inspectorate of Pollution (HMSO) (ed.): Ceramic Process; Environmental Protection Act 1990; Process Guidance IPR 3/6; London 1992

/6/ US EPA (1996) Compilation of Air Pollutant Emission Factors Vol.1 Report AP-42 (5th ed.)

18 BIBLIOGRAPHY

For a detailed bibliography the primary literature mentioned in AP 42 may be used.

19 RELEASE VERSION, DATE AND SOURCE

Version :	2.1
Date:	November 1995
Source:	J J M Berdowski, P F J van der Most, R Wessels Boer TNO The Netherlands
Supported by:	Otto Rentz, Dagmar Oertel University of Karlsruhe (TH) Germany

Updated with particulate matter details by:
Mike Woodfield
AEA Technology
UK
December 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Pieter van der Most

HIMH-MI-Netherlands
Inspectorate for the Environment
Dept for Monitoring and Information Management
PO Box 30945
2500 GX Den Haag
The Netherlands

Tel: +31 70 339 4606
Fax: +31 70 339 1988
Email: pieter.vandermost@minvrom.nl

SNAP CODE: **030320**

SOURCE ACTIVITY TITLE: **PROCESSES WITH CONTACT**
Fine Ceramics Materials

NOSE CODE: **104.11.11**

NFR CODE: **1 A 2 f**

1 ACTIVITIES INCLUDED

This chapter covers emissions released from combustion processes within the production of fine ceramics. However, in the following if useful for description, also non-combustion emissions are mentioned.

2 CONTRIBUTION TO TOTAL EMISSION

The contribution of fuel use related emissions released from the production of fine ceramics to total emissions in countries of the CORINAIR90 inventory is given as follows:

Table 1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**								
		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	PM*
Fine Ceramics Materials	030320	0.2	0.1	-	-	0.3	0.3	0.1	-	-

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported
* = PM (inclusive of TSP, PM_{10} and $PM_{2.5}$) is <0.1% of total PM emissions

3 GENERAL

3.1 Description of activities

The manufacture of ceramic clay involves the conditioning of the basic ores by several methods. These include the separation and concentration of the minerals by screening, floating, wet and dry grinding, and blending of the desired ore varieties. The basic raw materials in ceramic clay manufacture are kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) and montmorillonite [$(Mg, Ca)O \cdot Al_2O_3 \cdot 5SiO_2 \cdot nH_2O$] clays. Caoline or limestone are used as additives. The clays are refined by separation and bleaching, blended, kiln-dried, and formed into such items as whiteware, heavy clay products (brick, etc.), various stoneware, and other products such as diatomaceous earth, which is used as a filter aid. /4/

The oven temperature reaches about 1100 ^oC. Most commonly natural gas is burned to heat the ovens, but other fuels are possible. Electric heated ovens are used in small scale ovens. Usually a tunnel shaped oven is used, but other types are used as well.

3.2 Definitions

3.3 Techniques

It can be assumed, that similar techniques are in use as described in chapter B3319.

3.4 Emissions

Pollutants released are dust, sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (N_2O), fluoride (F_g), Chlorine (Cl_g) and ammonia (NH_3). According to CORINAIR90 the main relevant pollutants are SO_2, NO_x, CO, and CO_2 (see also table 1).

In the Netherlands, emissions from fine ceramic materials production represent scarcely 5 % of the emissions from bricks and tiles production /2/. The high temperatures of the firing kilns are also conductive to the fixation of atmospheric nitrogen and the subsequent release of NO_x.

It can be assumed, that formation mechanisms and formation processes of pollutants are similar to those described in chapter B3319. /cf 4/

3.5 Controls

Emission reduction techniques are almost non-existent.

4 SIMPLER METHODOLOGY

The simpler methodology involves applying an appropriate emission factor to either production or energy consumption statistics.

N.B There are no emission factors available for $PM_{2.5}$. The source is <0.1% of the total PM emissions for most countries.

5 DETAILED METHODOLOGY

If an extensive measuring programme is available, emissions can be calculated on for an individual plant.

Should a key source analysis indicate this to be a major source of particulate matter (TSP, PM_{10} or $PM_{2.5}$) then installation level data should be collected using a measurement protocol such as that illustrated in Measurement Protocol Annex.

6 RELEVANT ACTIVITY STATISTICS

Standard production and energy statistics available from national or international statistical publications.

7 POINT SOURCE CRITERIA

The production of fine ceramics is usually executed in rather small plants can be considered as area sources.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

For the situation in the Netherlands, the following can be proposed:
Emission factors are given in kg per ton product:
SO_2: 0.2 - 2.7
F_g : 0.2 - 2.8
Cl_g: 0.1
CO_2: 300 - 1600
NO_x: 0.6 - 2.0
dust *: 0.35 - 0.80

* dust consists of clay particles, the composition may vary widely.

The following Table 2 contains fuel related emission factors for the production of fine ceramics based on CORINAIR90 data in [g/GJ]. Technique related emission factors, mostly given in other units (e.g. g/Mg product), are listed in footnotes. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. Within CORINAIR90 a range for the specific energy consumption of 8.8 - 100 GJ/Mg product has been reported. Table 3 contains the AP 42 emission factors for particulate matter (US EPA, 1996).

Table 2: Emission factors for the production of fine ceramics$^{7)}$

					Emission factors							
	Type of fuel			NAPFUE code	$SO_2$$^{3)}$ [g/GJ]	$NO_x$$^{4)}$ [g/GJ]	NMVOC [g/GJ]	CH_4 [g/GJ]	CO$^{5)}$ [g/GJ]	$CO_2$$^{6)}$ [kg/GJ]	N_2O [g/GJ]	NH_3 [g/GJ]
s	coal	hc	steam	102	650$^{1)}$	160$^{1)}$	15$^{1)}$	15$^{1)}$	100$^{1)}$	93$^{1)}$	4$^{1)}$	
s	coal	hc	sub-bituminous	103	610$^{1)}$, 609$^{2)}$	40$^{1)}$, 39$^{2)}$	1.5	1.5$^{1)}$		99$^{1)2)}$	8$^{1)}$	
s	coal	bc	brown coal/lignite	105	600$^{1)}$	140$^{1)}$	15$^{1)}$	15$^{1)}$	100$^{1)}$	113$^{1)}$	3.5$^{1)}$	
s	coal	bc	briquettes	106	220$^{1)}$	140$^{1)}$	15$^{1)}$	15$^{1)}$	100$^{1)}$	98$^{1)}$	3.5$^{1)}$	
s	coke	hc	coke oven	107	145$^{1)}$, 144$^{2)}$	45$^{1)2)}$	2.5$^{1)}$	2.5$^{1)}$		105$^{1)2)}$		
s	coke	bc	coke oven	108	650$^{1)}$	220$^{1)}$	5$^{1)}$	15$^{1)}$	90$^{1)}$	86$^{1)}$	3$^{1)}$	
s	biomass		wood	111		200$^{1)}$	50$^{1)}$	30$^{1)}$		83-92$^{1)}$	4-14$^{1)}$	
l	oil		residual	203	143-1,494$^{1)}$	100-180$^{1)}$	3-4$^{1)}$	0.1-5$^{1)}$	10-15$^{1)}$	73-78$^{1)}$	2-14$^{1)}$	
l	oil		gas	204	85-1,410$^{1)}$	70-100$^{1)}$	1.5-2.5$^{1)}$	1-2.5$^{1)}$	10-12$^{1)}$	73-74$^{1)}$	2-14$^{1)}$	
l	kerosene			206	69$^{1)}$	80$^{1)}$	2$^{1)}$	1$^{1)}$	12$^{1)}$	71$^{1)}$	14$^{1)}$	
l	gasoline		motor	208	45$^{1)}$	80$^{1)}$	2$^{1)}$	1$^{1)}$	12$^{1)}$	71$^{1)}$	14$^{1)}$	
g	gas		natural	301	0.3-8$^{1)}$	44-330$^{1)}$	2.5-10$^{1)}$	0.4-4$^{1)}$	10-111$^{1)}$	53-69$^{1)}$	1-3.7$^{1)}$	
g	gas		liquified petroleum gas	303	0.04-2$^{1)}$	20-100$^{1)}$	1-2$^{1)}$	1-4$^{1)}$	13$^{1)}$	60-65$^{1)}$	1-3$^{1)}$	
g	gas		coke oven	304	0.04-12$^{1)}$	50-100$^{1)}$	2.5-4$^{1)}$	2.5-4$^{1)}$	10-13$^{1)}$	49-59$^{1)}$	1-1.5$^{1)}$	

1) CORINAIR90 data, area sources

2) CORINAIR90 data, point sources

3)	SO_x:	9,611	g/Mm³ fuel	Mineral products, process heaters, NAPFUE 301 /1/
		290	g/Mg product	General, SO_2 260 g/Mg, SO_x 30 g/Mg /2/
		210	g/Mg product	Future Value /2/
4)	NO_x:	850	g/Mg product	/2/
5)	CO:	1,600	g/Mg product	EPA value for ceramic industry
		130	g/Mg product	/2/
6)	CO_2:	255	kg/Mg product	General /2/

7) It is assumed, that emission factors cited within the table are related to combustion sources in the production of fine ceramics. Footnotes may also include emission factors for other process emissions.

Table 3: AP 42 Particulate matter emission factors* for Fine Ceramics (g/Mg) /5/

Source	PM (g/Mg)	RATING
Comminution--raw material crushing and screening line with fabric filter	60	D
Dryer	1150	E
Cooler	55	E
Granulation--natural gas-fired spray dryer		
with fabric filter	30	E
with venturi scrubber	95	D
Firing--natural gas-fired kiln	245	D
Refiring--natural gas-fired kiln	33.5	E
Ceramic glaze spray booth		

Source	**PM (g/Mg)**	**RATING**
uncontrolled	9500	E
with wet scrubber	900	D

* = In the absence of more appropriate data use the AP 42 emission factors

9 SPECIES PROFILES

A profile of the clay used might be useful. This information however is not usually available.

10 UNCERTAINTY ESTIMATES

The quality classification of the emission factors expressed per ton product is estimated to be D.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The fuel specific emission factors provided in table 2 are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of emission factors with respect to point and area sources. Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

13 TEMPORAL DISAGGREGATION CRITERIA

The production of fine ceramics can be either a continuous or a discontinuous process.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

Emission inventory in The Netherlands, 1992. Emission to air and water.

Emission factors to be used for the building industry, TNO report 89/091(1989) (in Dutch).

Environmental Protection Agency, Compilation of Air Pollutant Emission Factors AP 42

16 VERIFICATION PROCESSES

Verification of the emissions can be done by comparing the results of the calculations with measurements at the individual plant.

17 REFERENCES

/1/ EPA (ed.): AIRS Facility subsystem; EPA-Doc 450/4-90-003; Research Triangle Park; 1990
/2/ Huizinga, K.; Verburgh, J. J.; Mathijsen, A. J. C. M.; Loos, B.: Fijnkeramische Industrie; RIVM-report 736301124; RIZA-report 92.003/24; 1992
/3/ Bouscaren, M. R.: CORINAIR Inventory, Default Emission Factors Handbook; Second Edition; Comission of the European Communities; Paris; 1992
/4/ EPA (ed.): AP 42, CD-Rom, 1995
/5/ US EPA (1996) Compilation of Air Pollutant Emission Factors Vol.1 Report AP-42 (5th ed.)

18 BIBLIOGRAPHY

For a detailed bibliography the primary literature mentioned in AP 42 may be used.

19 RELEASE VERSION, DATE AND SOURCE

Version:	2.1
Date:	November 1995
Source:	J J M Berdowski, P F J van der Most, R Wessels Boer TNO The Netherlands
Supported by:	Otto Rentz, Dagmar Oertel University of Karlsruhe (TH) Germany

Updated with particulate matter details by:
Mike Woodfield
AEA Technology
UK
December 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Pieter van der Most

HIMH-MI-Netherlands
Inspectorate for the Environment
Dept for Monitoring and Information Management
PO Box 30945
2500 GX Den Haag
The Netherlands

Tel: +31 70 339 4606
Fax: +31 70 339 1988
EMAIL: PIETER.VANDERMOST@MINVROM.NL

SNAP CODE: **030321**

SOURCE ACTIVITY: **PROCESSES WITH CONTACT**
Paper-mill Industry (Drying Processes)

NOSE CODE: **104.07.01**

NFR CODE: **1 A 2 d**

1 ACTIVITIES INCLUDED

The activities described are related to the production of paper in paper mills. In this chapter only the drying process within a paper mill is taken into account. Other process emissions are covered by chapters B462, B463 and B464 respectively. However, in the following, also non-combustion emissions are mentioned.

2 CONTRIBUTION TO TOTAL EMISSIONS

The contribution of fuel use related emissions released from drying processes in paper mills to total emissions in countries of the CORINAIR90 inventory is given as follows:

Table 1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**							
		SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
Paper-mill Industry	030321	0.1	0	0	-	0	0.1	0.1	-

0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
- = no emissions are reported

This activity is not believed to be a significant source of $PM_{2.5}$ (as of December 2006).

3 GENERAL

3.1 Description of activities

After a beating process paper pulp is introduced into the paper mill in concentrations of about 1 %. Mineral pigments or fillers are added to improve the brightness, opacity, and surface smoothness. Substances added are for instance china clay, calcium sulphate, calcium carbonate, or titanium dioxide. The final drying process of the sheets consists in passing the sheets over a series of steamheated cylinders.

Paper mills produce pulp from wood, either by chemical or by mechanical processes. Other paper mills use purchased pulp, non-wood fibres, or recovered paper fibres to manufacture paper. The production of pulp and paper requires considerable amounts of steam and power.

Most mills produce their own steam in one or more industrial boilers which burn fossil fuels and/or wood residues. Mills that pulp wood with a chemical process (kraft, sulphite, soda, semi-chemical) normally combust their spent pulping liquor in a combustion unit, e.g., kraft recovery furnace, to recover pulping chemicals for subsequent reuse. These units are also capable of providing process steam and power for mill operations. (Pinkerton, 1993) Emissions from the steam generation in boilers have to be allocated to SNAP category 030100.
For the drying of 1 t of chemical pulp, 1,5 t of steam is necessary. (Ullmanns Enzyklopädie der Technischen Chemie)

3.2 Definitions

3.3 Techniques

Drying processes can be divided in the contact drying process, convective drying process and infrared drying process. The most common process used is the contact drying process, where the paper sheet is dried over a drying basket, which is fed by hot air (pressure of 1.5 - 3.5 at). The drying process of paper is influenced by the temperature of the drying basket, the thickness and density of the paper produced, the dehydrateability of the paper, etc. (Ullmanns Enzyklopädie der Technischen Chemie).

3.4 Emissions

Fuel use related pollutants released are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (non-methane VOC and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (N_2O) and ammonia (NH_3). According to CORINAIR90 the main relevant pollutants are SO_2, and CO_2 (see also table 1).

Emissions from boilers used to generate steam and power account for the majority of emissions from pulp and paper mills, with kraft pulp mill emission sources (recovery furnace, lime kiln, reduced sulphur gas oxidation) accounting for most of the remainder. It should be mentioned that a very recent analysis of SO_2 measurement data for combination boilers (boilers that co-fire coal or oil with wood residues) strongly suggests that a considerable amount of SO_2 capture occurs due to the alkaline nature of the wood ash (Pinkerton, 1993). Coal and oil combustion in boilers now accounts for 75 % of the total SO_2 emissions from paper mills (Pinkerton, 1993).

Emissions from fuel burning in boilers represent the majority of the total NO_x, while kraft pulping sources accounted for almost all of the remainder (Pinkerton, 1993). Total NO_x-emissions are affected by fuel use practices. Most mills have one or more multi-fuel boilers and fuel choices are often governed by availability and price (Pinkerton, 1993). Increased coal and wood use can result in increased NO_x-emissions, since add-on NO_x-controls are not obligatory in most areas (Pinkerton, 1993).

Releases to air that are not related to energy generation are (European Commission, 2001) mainly volatile organic compounds (VOC). This emission is usually of minor importance. Situations where emissions of volatile organic compounds need to be controlled are related to a limited number of paper mills of different types. In the exhaust air of paper mills that utilise volatile organic additives in the production process those substances are measured in low concentrations. Most volatile components of virgin pulps have been lost to atmosphere by the time that the pulp reaches the paper machine. However, in the dryer section of the paper machine or after coating the paper web is heated up to 100°C to evaporate the residual water. Apart from the water vapour also volatile components from the fibre material and from chemical additives are released. Usually no special abatement techniques for these emissions are applied in paper mills because the released loads are rather small.

Examples of operations where higher concentrations of VOCs are released are the following (European Commission, 2001):

- Coating of paper with coating colours that contain organic solvents, although the basis of coating colours is exclusively aqueous (lower concentrations of various volatile substances (as e.g. formaldehyde, alkyl substituted aromatics, lower alcohols) can be measured in the exhaust of every coating machine).
- Preparation of papers with resins and production of speciality papers by using volatile additives.

Examples of volatile organic compounds (VOCs) which are released to the atmosphere are the following (European Commission, 2001):

- Alcohols
- Formaldehyde contained in urea or melamine formaldehyde (UF/MF) resins used as wet strength agents
- Acetone and other ketones
- Phenols (only in special cases)
- Solvents used for cleaning machine fabrics (usually a minor application)
- Organic acids and residual monomers of polymers

In a few special cases particulates from some finishing operations may raise concern (European Commission, 2001).

3.5 Controls

SO_2 control systems (scrubbers, lime injection) are installed in the mills. NO_x-controls are not obligatory in most areas (Pinkerton, 1993).

The concentrations of organic substances in the exhaust air of paper mills can usually be considered as low so that no abatement technique for air emissions is required (European Commission, 2001).

The emission of some single substances of concern in the exhaust air of coating machines as e.g. acrylonitrile (occur only when acrylonitrile butadiene binder systems are used) can be avoided or reduced by careful choice of coating colour recipes. Coating colour recipes that contain carcinogenic compounds should be avoided. Formaldehyde is normally more difficult to prevent because it has different sources as wet strength agents, preservatives, biocides etc. (European Commission, 2001).

4 SIMPLER METHODOLOGY

The emissions of the paper industry as a whole might be calculated by establishing a relationship with economic statistics.

5 DETAILED METHODOLOGY

A detailed methodology is possible if sufficient measurements are available for the situation in the individual plant.

6 RELEVANT ACTIVITY STATISTICS

Production and energy consumption statistics, for instance as produced by the United Nations or IEA are available.

7 POINT SOURCE CRITERIA

Paper production plants can be considered as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

The measured concentration of total organic carbon varies significantly. Values between 2 and 135 mg/Nm3 have been measured. A specific load between 0.05 - 0.5 kg $orgC_{total}$/t of paper was determined in the exhaust of the seven investigated mills (European Commission, 2001). Formaldehyde in concentrations between 0.1 - 4.8 mg/Nm^3 have been measured (European Commission, 2001).

The following Table 2 contains fuel related emission factors for paper mills based on CORINAIR90 data in [g/GJ]. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg pulp) has to be taken into account, which is process and country specific. At this stage no data for the definition of appropriate conversion factors are available. Emissions from the steam generation in boilers have to be allocated to SNAP category 030100.

Table 2: Emission factors for paper mills[3]

					Emission factors							
	Type of fuel			NAPFUE code	SO_2 [g/GJ]	NO_x [g/GJ]	NMVOC [g/GJ]	CH_4 [g/GJ]	CO [g/GJ]	CO_2 [kg/GJ]	N_2O [g/GJ]	NH_3 [g/GJ]
s	coal	hc	steam	102	992[1]	150[1]	15[1], 5[2]	15[1], 1[2]	70[1], 20[2]	98[1], 91[2]	14[1], 75[2]	2[2]
s	coal	hc	sub-bituminous	103	992[1]	150[1]	15[1]	15[1]		99[1]	14[1]	
s	coal	hc/bc	patent fuels	104	701[1]	150[1]	15[1]	15[1]	70[1]	94[1]	14[1]	
s	biomass		wood	111	5.2[1] 343[2]	115-200[1] 972[2]	50[1]	30[1]	10[1]	92[1][2]	4-14[1]	
s	waste		wood	116	5.2[1] 0.8-20[2]	115[1] 100-117[2]	50[1] 3-10[2]	30[1] 1[2]	30[2]	83[1]	4[1] 4-25[2]	2[2]
s	sludge		sewage	118			10[2]	1[2]	30[2]		4[2]	2[2]
l	oil		residual	203	28-149[1] 168-190[2]	123-180[1]	3-7.4[1] 3[2]	1-3[1], 1[2]	5-15[1] 10[2]	76-79[1] 76[2]	2.5-14[1] 5[2]	2[2]
l	oil		gas	204	139-305[1]	80[1]	1.5-2[1]	1-1.5[1]	12[1]	73[1]	14[1]	
l	kerosene			206	69[1]	80[1]	2[1]	1[1]	12[1]	71[1]	14[1]	
l	gasoline		motor	208	45[1]	80[1]	2[1]	1[1]	12[1]	71[1]	14[1]	
g	gas		natural	301	0.5-8[1]	60-100[1]	4[1]	4[1]	13[1]	55-57[1]	2.5-3[1]	
g	gas		liquified petroleum gas	303	2[1]	20-100[2]	1[3], 2[2]	1-4[1], 1[2]	13[1], 10[2]	60-65[1],56[2]	3[1], 2[2]	

[1] CORINAIR90 data, area sources [2] CORINAIR90 data, point sources

[3] It is assumed, that emission factors cited within the table are related to combustion sources in paper mills; other process emissions are not covered.

9 SPECIES PROFILES

The species profile of emissions from combustion is dependent on the fuel used for heat generation. Releases to air that are not related to energy generation are mainly formaldehyde and acrylonitrile (European Commission, 2001).

10 UNCERTAINTY ESTIMATES

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The weakest aspects discussed here are related to emission factors from CORINAIR90.

The fuel specific emission factors provided in table 3 are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of emission factors with respect to point and area sources. Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

National emission estimates can be disaggregated on the basis of plant capacity, employment or population statistics if plant specific data are not used/available.

13 TEMPORAL DISAGGREGATION CRITERIA

Paper production is usually a continuous process.

14 ADDITIONAL COMMENTS

15 SUPPLEMENTARY DOCUMENTS

Samenwerkingsproject procesbeschrijvingen industrie Nederland (SPIN) Papier en Kartonindustrie. RIVM report 736301135 (1991)(in dutch)

16 VERIFICATION PROCEDURES

Verification may be done by comparing the calculated emissions with measurements at an individual plant.

17 REFERENCES

European Commission (2001), Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques (BREF) in the Pulp and Paper Industry, December 2001

Pinkerton, J. E. (1993), Emission of SO_2 and NO_x from Pulp and Paper Mills; in: Air & Waste; 10(1993)43; p. 1404-1407

Ullmanns Enzyklopädie der Technischen Chemie, Bd. 17, S. 531 ff.

18 BIBLIOGRAPHY

19 RELEASE VERSION, DATE AND SOURCE

Version: 2.2

Date: June 2005

Source: J J M Berdowski, P F J van der Most
TNO
The Netherlands

Supported by: Otto Rentz, Dagmar Oertel
University of Karlsruhe (TH)
Germany

Integrated with IPPC BREF data by:
Carlo Trozzi
Techne Consulting
Italy

Updated with particulate matter details by:
Mike Woodfield
AEA Technology
UK
December 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Carlo Trozzi
Techne Consulting
Via G. Ricci Curbastro, 34
Roma, Italy

Tel: +39 065580993
Fax: +39 065581848
Email: carlo.trozzi@techne-consulting.com

SNAP CODE:	**030322**
SOURCE ACTIVITY:	**PROCESSES WITH CONTACT** ***Alumina Production***
NOSE CODE:	**104.12.13**
NFR CODE:	**1 A 2 b**
ISIC:	**2420**

1 ACTIVITIES INCLUDED

This chapter covers emissions released from combustion processes within alumina production. Alumina production is an ore treatment step in the production of primary aluminium (SNAP code 040301, chapter B431).

2 CONTRIBUTION TO TOTAL EMISSIONS

The contribution of emissions related to fuel use, released from the alumina production to total emissions in countries of the CORINAIR90 inventory is minor, as indicated in Table 2.1.

Table 2.1: Contribution to total emissions of the CORINAIR90 inventory (*28 countries*)

Source-activity	**SNAP-code**	**Contribution to total emissions [%]**										
Aluminia Production	030322	SO_2	NO_x	NMVOC	CH_4	CO	CO_2	N_2O	NH_3	TSP*	PM_{10}*	$PM_{2.5}$*
Typical contribution		0	0	-	-	-	-	-	-	0.316	0.599	0.440
Highest value										1.001	2.472	1.818
Lowest value										-	-	-

* EU $PM_{2.5}$ Inventory project for EU25 for the year 2000 (TNO, 2006), contribution to total national emissions, excluding agricultural soils
0 = emissions are reported, but the exact value is below the rounding limit (0.1 per cent)
\- = no emissions are reported

3 GENERAL

3.1 Description of activities

The base ore for primary aluminium production is bauxite. Alumina is produced by the Bayer process. In this process the ore is dried, ground in ball mills, and mixed with a leaching solution of sodium hydroxide at an elevated temperature and pressure, producing a sodium aluminate which is separated from the impurities and cooled, during which the alumina precipitates. After washing to remove impurities the alumina is dried and calcined to produce a crystalline form of alumina.

3.2 Definitions

Bauxite	A hydrated oxide of aluminium consisting of 30-70 percent alumina and lesser amounts of iron, silicon and titanium.

3.3 Techniques

The calcination of the aluminium-hydroxide takes place in rotary kilns at about 1,300 °C or in fluidised bed furnaces at lower temperatures. The furnaces are fired with heavy oil and gas.

3.4 Emissions

The main emissions are dust emissions occurring during the grinding of the bauxite and the calcining of the aluminium hydroxide.

Pollutants related to fuel use are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compunds (non-methane VOC and methane (CH_4)), carbon monoxide (CO), carbon dioxide (CO_2), and nitrous oxide (N_2O). Of these, according to CORINAIR90, the main relevant pollutants are SO_2 and NO_x (see also table 1).

3.5 Controls

Dust emissions can be abated by cyclones, spray towers, floating bed scrubbers, quench towers, or electrostatic precipitators (ESP). The dust trapped in the calcining process is usually reused.

No information is available about control of gaseous emissions.

4 SIMPLER METHODOLOGY

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions.

---

[1] The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the simpler methodology (equivalent to Tiers 1 and 2), where limited information is available, a default emission factor can be used together with production capacity information for the country or region of interest without further specification on the type of industrial technology or the type and efficiency of control equipment.

Consequently the simplified methodology is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = \text{AR x EF}$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

Default emission factors for this purpose are provided in Section 8.

5 DETAILED METHODOLOGY

A detailed methodology is possible if sufficient measurements are available about the situation in an individual plant.

The detailed methodology (equivalent to Tier 3), to estimate emissions of gaseous pollutants from the primary aluminium production is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in Measurement Protocol Annex.

The detailed methodology to estimate emissions of trace elements from the primary aluminium production is similar to the simpler one. However, more information on the type of the process, as well as on the type of the industrial technology should be made available. This information shall be used to estimate specific emissions for at least a specific industrial technology.

Measurements of the emission rate and chemical composition of fine particles with < 1.0 µm diameter are often carried out at major aluminium plants world-wide. The results of these measurements are then used to estimate atmospheric emissions of several trace elements contained as impurities in the raw materials and fuel.

Reference emission factors for comparison with users own data are provided in Section 8.

6 RELEVANT ACTIVITY STATISTICS

Production and energy statistics, suitable for estimating emissions using of the simpler estimation methodology (Tier 1 and 2), is widely available from UN statistical yearbooks or national statistics.

The detailed methodology (Tier 3) requires more detailed information. For example, the quantities of primary aluminium produced by various types of industrial technologies employed in industry at plant level. This data is however not always easily available.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, volume 3 on Industrial Processes and Product Use (IPPU), chapter 2.2.1.3 " Choice of activity statistics".

7 POINT SOURCE CRITERIA

Aluminium production plants containing an alumina production department can be considered as point sources if plant specific data are available.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

For the situation in the Netherlands, the following can be proposed:
Controlled and uncontrolled emission factors for dust are available for both sectors of the Bayer process. These emission factors for dust are presented in Table 8.1. See also Table 8.3 for emission factors for dust (TSP, PM_{10} and $PM_{2.5}$).

Table 8.1: Emission factors for dust from alumina production in gram/kg aluminium produced

	Bauxite grinding	**Calcining**
Uncontrolled	3.0	100.0
Spray towers	0.5	30.0
Floating bed scrubber	0.85	28.0
Quench tower	0.5	17.0
Electrostatic precipitator	0.06	2.0

Source: EPA Compilation of air pollutant emission factors AP-42.

The following Table 8.2 contains fuel related emission factors for the alumina production based on CORINAIR90 data in [g/GJ]. In the case of using production statistics the specific energy consumption (e.g. GJ/Mg product) has to be taken into account, which is process and country specific. At this stage no data for the definition of appropriate conversion factors are available.

Table 8.2: Emission factors for the alumina production[2)]

	Type of fuel		NAPFUE code	Emission factors SO_2 [g/GJ]	 NO_x [g/GJ]	 NMVOC [g/GJ]	 CH_4 [g/GJ]	 CO [g/GJ]	 CO_2 [kg/GJ]	 N_2O [g/GJ]
l	oil	residual	203	419[1)]	123[1)]	7.4[1)]	1[1)]	5[1)]	79[1)]	
g	gas	natural	301	8[1)]	60[1)]	10[1)]	2[1)]	30[1)]	55[1)]	

[1)] CORINAIR90 data, area sources

[2)] It is assumed, that emission factors cited within the table are related to combustion sources in alumina production; other process emissions are not covered.

Following Table 8.3 contains emission factors for the primary alumina production based on CEPMEIP data in [kg/ton aluminium].

Table 8.3: Emission factors for the alumina production in g/kg primary aluminium (CEPMEIP)

Technology and abatement	**TSP**	**PM_{10}**	**$PM_{2.5}$**	**Uncertainty-factor**
Cyclones or scrubbers only; limited abatement of fugitive emission	10	6	2.7	1.5
Effective capturing fugitive sources; extensive application of fabric filters	3	2.85	1.28	2
Conventional installation: moderate collection of fugitive dust; combined usage of cyclones, ESP and scrubbers	4	3.2	1.44	1,5

NOTE: The uncertainty range (95% confidence) in the emission factor is expressed as a factor. The lower limit of the uncertainty range can be found by dividing the emission factor by the uncertainty factor, whereas the upper limit of the uncertainty range can be found by multiplying the range with the uncertainty factor. Example (first row in Table 8.3): The uncertainty in the emission factor for $PM_{2.5}$ for a plant with only cyclones or scrubbers and limited abatement of fugitive emission (first row in table) is 1.5. The emission factor with uncertainty range will therefore be 2.7 kg per tonne primary aluminium with an uncertainty range of 1.8 (2.7 / 1.5) to 4 (2.7 x 1.5).

9 SPECIES PROFILES

The species profile of the dust is directly related to the bauxite composition which may differ from location to location.

10 UNCERTAINTY ESTIMATES

The uncertainty classification of the emission factors expressed per kg aluminium is estimated to be C.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The weakest aspects discussed here are related to fuel use related emission factors.

The fuel specific emission factors provided in table 3 are related to point sources and area sources without specification. CORINAIR90 data can only be used in order to give a range of emission factors with respect to point and area sources. Further work should be invested to develop emission factors, which include technical or fuel dependent explanations concerning emission factor ranges.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

National emission estimates can be disaggregated on the basis of plant capacity, employment or population statistics.

13 TEMPORAL DISAGGREGATION CRITERIA

Alumina production is usually a continuous process.

14 ADDITIONAL COMMENTS

No additional comments.

15 SUPPLEMENTARY DOCUMENTS

Environmental Protection Agency, Compilation of Air Pollutant Emission Factors. AP-42.

16 VERIFICATION PROCEDURES

Verification may be done by comparing the calculated emissions with measurements from individual plants.

17 REFERENCES

/1/ VDI (ed.): Auswurfbegrenzung - Aluminium-Monoxidgewinnung und Aluminium-schlmelzflußelektrolyse (Entwurf); 1974

/2/ Visschedijk, A.J.H., J. Pacyna, T. Pulles, P. Zandveld and H. Denier van der Gon, 2004, Cooordinated European Particulate Matter Emission Inventory Program (CEPMEIP), In: P. Dilara et. Al (eds), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp 163 - 174

18 BIBLIOGRAPHY

No additional documents.

19 RELEASE VERSION, DATE AND SOURCE

Version: 2.1

Date: November 1995

Source: J J M Berdowski, P F J van der Most
TNO
Germany

Supported by: Otto Rentz, Dagmar Oertel
University of Karlsruhe (TH)
Germany

Updated with emission factors (CEPMEIP) for particulates by:
Tinus Pulles and Wilfred Appelman
TNO
The Netherlands
June 2006

20 POINT OF ENQUIRY

Any comments on this chapter or enquiries should be directed to:

Pieter van der Most

HIMH-MI-Netherlands
Inspectorate for the Environment
Dept for Monitoring and Information Management
PO Box 30945
2500 GX Den Haag
The Netherlands

Tel: +31 70 339 4606
Fax: +31 70 339 1988

Email: pieter.vandermost@minvrom.nl

SOURCE ACTIVITY TITLE: PROCESSES WITH CONTACT

ACTIVITY	SNAP CODE	NOSE CODE	NFR CODE
Magnesium Production (Dolomite Treatment)	**030323**	**104.12.14**	**1 A 2 b**
Nickel Production (Thermal Process)	**030324**	**104.12.15**	**1 A 2 b**
Enamel Production	**030325**	**104.09.01**	**1 A 2 f**
Other	**030326**	**104.12.16,17**	**1 A 2 f**

A specific methodology for these activities has not been prepared because the contribution to total national emissions is thought to be currently insignificant, i.e. less than 1% of national emissions of any pollutant.

If you have information contrary to this please contact the expert panel leaders.

These activities are not believed to be a significant source of $PM_{2.5}$ (as of December 2006).

Updated with particulate matter details by:
Mike Woodfield
AEA Technology
UK
December 2006

Leaders of the Combustion and Industry Expert Panel

Jozef Pacyna
NILU - Norwegian Institute of Air Research, PO Box 100, N-2007 Kjeller, Norway
Tel: +47 63 89 8155
Fax: +47 63 89 80 50
Email: jozef.pacyna@nilu.no

Panagiota Dilara
Emissions and Health Unit, Institute for Environment and Sustainability (IES), European Commission, Joint Research Centre, I-21020 Ispra (VA), Italy
Tel: +39 0332 789207
Fax: +39 0332 785869
Email: panagiota.dilara@jrc.it

Pieter van der Most
HIMH-MI-Netherlands, Inspectorate for the Environment, Dept for Monitoring and Information Management, PO Box 30945, 2500 GX Den Haag, The Netherlands
Tel: +31 70 339 4606
Fax: +31 70 339 1988
Email: pieter.vandermost@minvrom.nl