

EMISSION FACTORS MANUAL
PARCOM-ATMOS
Emission factors for air pollutants 1992

Final version

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Summary

This manual provides emission factors for emissions to air for nine heavy metals, nine organic substances and ammonia. The emission factors are presented separately for each industrial and non-industrial activity. An overview indicates for each of the nineteen substances the activities for which emission factors are available. If possible, emission factors are given related to the abatement technique. The emission factors can be used to establish emission inventories.

The report is an extension of a 1991 document prepared for PARCOM-ATMOS which was mainly based on experience from the emission inventory in the Netherlands. Comments on the 1991 report, and additional material from international sources were incorporated.

The uncertainty in the calculated emissions can be caused by the range of the emission factor but also by the limited information about for instance metal contents of fuels and ores or the part of the emissions that is airborne. Recommendations for further investigation and an estimation of priorities are given.

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1 Introduction

Deposition of atmospheric pollutants can give an important contribution to the pollution of the Northsea. The ATMOS Working Group of the Paris Commission has the task to provide a quantitative insight into the contribution of the different primary sources of air pollutants to the deposition on the Convention area. A method for providing this information is feeding the results of an emission inventory into a transport model and making calculations of the deposition on the Northsea.

At the PARCOM-ATMOS meeting in 1991 it was agreed that the available rough emission figures should be extended and completed in 1993. The best method for establishing an emission inventory is making use of detailed and frequent emission measurements. However, for most activities these measurements are not available. Therefore emission factors must be used in many situations. The Netherlands accepted the task to provide a Manual derived from a document, mainly based on directly available material from the emission inventory in the Netherlands. This document was presented to the 1991 PARCOM-ATMOS meeting (ATMOS 9/10/1). The comments received on this version enabled the authors to widen the scope and to include more material from other countries. As a result, many factors have a more solid basis compared to those in the 1991 version. Also more attention was paid to the effects of abatement technology. Though there are still many gaps in knowledge this manual provides for the activities and substances defined by ATMOS an almost complete compilation of the material available in 1992.

An emission factor is a number that establishes the relation between the quantity of a pollutant and the intensity of an activity. For industrial activities, the intensity is, in general, related to the production of a certain component. This information is usually available from various statistical sources. For non-industrial sources, a wide range of emission-determining aspects can be defined. In this report, these possibilities are limited to those information sources that should be readily available. The localisation and quantification of the diffuse sources usually will be less precise.

The available material does not allow an estimation of uncertainties in terms of percentage error or something equivalent. Instead, average values together with ranges, also depending on the applied technology are presented whenever possible.

Compared with the 1991 version [33] the accent of this manual is focused on the emission factors by activity (chapter 2). This chapter is followed by a substance-activity matrix that enables the user to find the information for a substance directed approach. Substances that might be emitted by a given activity, but for which no emission factors can be given, are indicated by brackets.

The Manual is concluded with a discussion about gaps in knowledge and some recommendations to improve this situation.

To improve the exchange of information in the future the Corinair/EMEP SNAP code 90 is added.

2 Emission factors by activity

2.1 Iron and steel production

For the production of iron and steel a sequence of processes is used. For the estimation of emissions from an individual plant information is needed about the processes in use. This chapter provides emission factors for the commonly used processes. For substances where no data were available, an emission factor was estimated, usually based on emission profiles. It will be clear that these figures, indicated by [32] give only a first approximation.

The emission factors found in literature cover a wide range. This is mainly caused either by differences in the raw materials or by the abatement technique used. Information about the composition of the ore used during the measurements is almost nonexistent in literature. Even the abatement methods used are not always given. Therefore for each process the available material is given together with a mean set of emission factors to be used if no information is available.

Because of internal recycling emissions have to be related to gross production rates [61].

The secondary iron and steel production is presented under 2.6 'Electric arc furnace'.

2.1.1 Sinter plant (snap code 3.3.1)

For Sinter plants emission factors from five different references have been found. These factors are presented in table 2.1.1 together with a mean emission factor to be used when no other information is available (in g.Mg⁻¹ sinter).

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Table 2.1.1 Emission factors for heavy metals in emitted dust from sinter-plants
(g.Mg⁻¹ sinter) (process stages not specified)

Substance	Ref. [60]	Ref. [59] 1) 2)	Ref. [56]	Ref. [15]	Ref. [51a]	Ref. [51.b]	Emission factor
Abatement	unknown	unknown	cyclones	electrofilters	electrofilters	cyclones	unknown
Arsenic	-	0.025 0.009	0.05	-	-	-	0.04
Cadmium	-	3 x 10 ⁻⁴ 0.09	0.13	-	0.02-0.12	0.08	0.1
Chromium	-	0.13 0.09	0.05	0.56	-	-	0.3
Copper	1	0.25 0.36	0.13	0.23	-	-	0.6
Mercury	-	6 x 10 ⁻⁵ 0.01	0.04	-	-	-	0.02
Nickel	-	0.19 0.14	-	1.0	-	-	0.7
Lead	9	0.13 4.5	10	2.1	-	15 ³⁾	6
Selenium	0.02	1 x 10 ⁻⁴ 0.019	-	-	-	-	0.02
Zinc	-	0.13 0.9	0.37	2.1	-	-	1.0
Particle size <10 micron	-	-	82%	-	-	-	-

1) diffuse sources, cold

2) abated process emissions

3) high lead content in ore

- not available

Abatement technology

Abatement technology is dust abatement. Fabric filters, cyclones and electrostatic precipitators are used. Abatement methods are described in reference [18]. For electrostatic precipitators lower exit concentrations than reported in this document are mentioned: 30-40 mg.m⁻³ [61].

Organic substances

Generally emissions from organic substances originate from recycled oil-bearing mill scale. Since these emissions can affect the efficiency of electrofilters and can cause glow fires in filters, presently recycling of mill scale is stopped [53 c].

Dioxine emissions: 2-3 ng TEQ.m₀⁻³ [52 b] or, with 2000 m₀³.Mg⁻¹ sinter [52 b]: 4-6 µTEQ.Mg⁻¹. Emissions can be as low as 0.1 ng TEQ.m₀⁻³. Best available technology: active carbon adsorption, cooling and filtration < 10 mg.m₀⁻³ [18].

Possible production of dioxines is mentioned in literature [52b]. The emission factors are given in table 2.1.2.

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Table 2.1.2 Emission factors for dioxines from sinter plants

Emission/m_o⁻³	Emission/M_g⁻¹ 1)
2-3 ng TEQ	4-6 µg TEQ

1) 2000 m_o³/mg⁻¹

2.1.2 Pellet plant

Pelletizing is a process that is only used in a few countries.

Table 2.1.3 Emission factors for heavy metals in emitted dust from pellet plants (g.Mg⁻¹ pellets)

Substance	Emission factor	References
Abatement	cyclones or wet scrubbers multicyclones	56 51b
Arsenic	0.04	56, 51b
Cadmium	0.01	51b
Chromium	0.04	56, 51b
Copper	0.03	56, 51b
Lead	0.05	51b
Mercury	0.02	56, 51b
Nickel	0.1	56, 51b
Particle size <10 micron	100%	56

Fabric filters are considered to be the best abatement technology as electro-precipitation is considered to be insufficient.

2.1.3 Blast furnace (snap code 3.2.3)

For blast furnaces emission factors from four different references are available. These factors are presented in table 2.1.4, in combination with a proposed mean factor.

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Abatement Technology

Table 2.1.4 Emission factors for heavy metals in emitted dust from blast furnaces (g.Mg⁻¹)

Substance	Ref. [59] ¹⁾			Ref. [51b] [65b]		Ref. [15]	Ref. [1]	Emission factor
	2)	3)	4)	2)	2)			
Abatement	unknown			bag filters		unknown	unknown	unknown
Arsenic	0.0006	0.06	0.08	-	-	-	-	0.15
Cadmium	6 × 10 ⁻⁵	0.0005	0.008	0.001	-	-	0.08	0.02
Chromium	0.03	0.1	0.08	-	-	0.16	-	0.2
Copper	0.06	0.6	0.4	-	-	0.05	-	1
Mercury	0.0012	0.018	0.007	-	-	-	-	0.02
Nickel	0.045	0.15	0.12	-	-	0.32	-	0.3
Lead	0.03	1	2	0.02	0.01	4	11	5
Selenium	3 × 10 ⁻⁵	0.03	0.013	-	-	-	-	0.04
Zinc	0.03	5	4	-	0.02	17	27	15

1) total emissions, sum of 2), 3) and 4)

2) diffuse sources, cold

3) process emissions, unabated

4) process emissions abated

- unknown

Abatement methods are electrostatic precipitators or venturiscrubbers (for furnace gases) and fabric filters (for tapping)

2.1.4 Basic oxygen furnace (snap code 4.2.6)

For basic oxygen furnaces emission factors are available from five different references.

These emission factors are presented in table 2.1.5 together with a proposed mean factor.

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Table 2.1.5 Emission factors for heavy metals in emitted dust from basic oxygen furnaces (g.Mg⁻¹ steel)

Substance	Ref. [59] ¹⁾ 2) 3)		Ref. [56]	Ref. [15]	Ref. [1]	Ref. [51b] [65b]		Emission factor
Abatement	unknown		wet scrubbers fabric filters	unknown	unknown	wet scrubbers fabric filters		unknown
Arsenic	0.0035	5 x 10 ⁻⁴	0.02	0.02	-	-	-	0.015
Cadmium	0.018	0.013	0.003	0.002-0.05	0.02	0.04	0.04	0.025
Chromium	0.35	0.15	0.04	0.07	-	-	0.026	0.5 ⁴⁾
Copper	0.1	0.03	0.04	0.25	-	-	0.066	0.15
Mercury	-	-	0.004	-	-	0.001	0.00033	0.003
Nickel	0.07	0.02	-	0.05	-	-	0.024	0.1 ⁴⁾
Lead	1.05	0.25	2.3	0.9	1.6	4	4.6	1.5
Selenium	-	-	-	-	-	-	-	0.003
Zinc	2.8	0.5	4.1	4.1	3.9	6	6.4	4
Particle size % <10 micron	-	-	100	-	-	-	-	-

1) total emissions, sum of 2) and 3)

2) process emissions, unabated

3) process emissions, abated

4) value of ref. [59] chosen because of increased use of alloyed steels

- unknown

For pretreatment and charging fabric filters are the best available technology. For cleaning of converter gas electrostatic precipitators or scrubbers are used.

2.1.5 Open hearth furnace (snap code 4.2.5)

In Western Europe this process was abandoned in 1983. Emission factors from earlier measurements are reported in reference [59]. These factors are (in g.Mg⁻¹)

Substance	Emission factor	Range
Cadmium	0.7	0.5 - 0.9
Lead	12	7 - 18

2.1.6 Electric arc furnace (snap code 4.2.7)

Emission factors were developed from two information sources. The Committee on Environmental Affairs (ENCO) of IISI completed a study in 1990 based on a questionnaire answered by 45 plants in 15 countries about the dust emission levels [54c]. This information, combined with a detailed analysis of the composition of dust from electric arc furnaces [5] resulted in emission factors well within the range of other data from literature.

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These emission factors are presented in tables 2.1.6 and 2.1.7.

The applied abatement techniques are unknown.

To illustrate the large variations that can occur, measured data from four different plants in Sweden are added to these tables.

Table 2.1.6 Emission factors for heavy metals from electric arc furnaces
(in g.Mg⁻¹ carbon steel and construction steel)

Substance	Emission factor	Range	Ref [65b]
Dust	-	-	60 ²⁾ 200 ²⁾
Arsenic	0.1	0.06 - 14	
Cadmium	0.25	0.03 - 1.5	0.043 0.043
Chromium	1	0.3 - 2	0.065 9.4
Copper	0.8	0.3 - 1	0.13 1.3
Mercury	0.15 ¹⁾	-	0.052 0.013
Nickel	0.25	0.1 - 0.6	0.043 0.43
Lead	14	5 - 20	5.0 2.1
Selenium	0.05 ¹⁾	-	
Zinc	50	20 - 90	12 34

¹⁾ Reference 32

²⁾ g.dust. Mg⁻¹ steel

Table 2.1.7 Emission factors for heavy metals from electric arc furnaces
(in g.Mg⁻¹ stainless steel)

Substance	Emission factor	Range	Ref [65b]
Dust	-	-	30 ²⁾ 900 ²⁾
Arsenic	0.015	0.01 - 0.02	
Cadmium	0.07	0.05 - 0.09	0.0025 0.29
Chromium	15	12 - 18	2.5 19.9
Copper	0.5	0.3 - 0.7	
Mercury	0.15 ¹⁾	-	0.27 0.29
Nickel	5	3 - 6	1.0 14.0
Lead	2.5	1 - 3	0.3 8.8
Selenium	0.05 ¹⁾	-	
Zinc	6	4 - 9	0.15 37.5

¹⁾ Reference 32

²⁾ g.dust.Mg⁻¹ steel

Abatement is good encapsulation and use of fabric filters: 5-10 mg.m₀⁻³ (furnace) and 10 mg.m₀⁻³ (other sources) can be achieved.

Diminishing emissions of gaseous cadmium and mercury can be achieved by improved sorting of scrap and limitations of, or bans on cadmium and mercury.

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Emission factors for organic substances are also presented in the ENCO Study [54c].

They are presented in table 2.1.8.

The factor for dioxines is too high, according to [60]; 0.07 mg TEQ.Mg⁻¹ is proposed, but this figure still might be too high [65b]. No conclusion can be drawn.

*Table 2.1.8 Emission factors for organic substances
from electric arc furnaces in mg.Mg⁻¹*

Substance	Emission factor
Chlorobenzenes	25
Chlorophenols	7
Dioxins (as TEQ) ¹⁾	4

¹⁾ proposed by ref. [60]: 0.07 TEQ.Mg⁻¹

proposed by ref. [65b]: < 0.005 TEQ.Mg⁻¹

2.1.7 Coke production

For the situation in the Netherlands (three plants) an emission factor for ammonia is derived.

Emissions of heavy metals are reported by [59]. They are from diffuse sources and are related to the composition of the coal used. Dust emissions are estimated to be 650 g.Mg⁻¹ but can be reduced to 150 g.Mg⁻¹ by good housekeeping.

Table 2.1.9 Emission factors for coke ovens (in g.Mg⁻¹ [59])

Substance	Emission factor	Range
Arsenic	0.02	
Cadmium	0.05	0.0033-0.13
Chromium	0.17	0.13-0.2
Copper	0.09	0.033-0.13
Mercury	0.03 ¹⁾	0.01-0.03
Nickel	0.065	
Lead	0.22	0.065-0.33
Zinc	0.22	0.13-0.26

¹⁾ ref. [65b]: 0.01

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2.1.8 Foundries (snap code 3.3.3)

For foundries the only reference that provided data of heavy metal emissions is [59]. Reported emission factors were calculated from a population consisting of 60% of hot blast air cupolas ($1500 \text{ m}^3 \cdot \text{Mg}^{-1}$ off gases) and 40% of cold blast air off-gases ($3000 \text{ m}^3 \cdot \text{Mg}^{-1}$ off gases). An average dust concentration of $300 \text{ mg} \cdot \text{m}^{-3}$ was taken.

These emission factors are given in table 2.1.10

Table 2.1.10 Emission factors for foundries (in $\text{g} \cdot \text{Mg}^{-1}$ [59])

Substance	Emission factor	Range
Arsenic	0.3	0.02-3.6
Cadmium	0.14	0.006-0.45
Chromium	1.1	0.09-3.0
Nickel	0.5	0.01-1.3
Lead	7.2	0.24-15
Zinc	5.0	2.4-7.2

Scrubbers and cyclones have exit dust concentrations of $> 300 \text{ mg} \cdot \text{m}^{-3}$, bagfilters perform better, with $< 50 \text{ mg} \cdot \text{m}^{-3}$. Venturiscrubbers perform in between.

2.2 Primary non-ferrous metal production

2.2.1 Primary copper production (snap code 3.3.6)

Emissions vary widely depending on the ore, the process used and the effect of dust abatement.

Emission factors are available from a Swedish plant [51b], from Germany [59] and from other literature [1, 2a]. In table 2.2.1 this information is presented.

Table 2.2.1 Emission factors for primary copper production in g.Mg^{-1} product

Substance	Ref. [51b]	Ref. [51b]	Ref. [1, 2a]	Ref. [59]	Emission factor ¹⁾	
Abatement	limited	improved	unknown		limited	improved
Arsenic	100	50	n.a.	15-45	50 (10-100)	5 (1-50)
Cadmium	15	6	200	3-10	20 (10-200)	3 (0.5-6)
Copper	300	n.a.	n.a.		300	50
Lead	250	n.a.	2000	70	100 (50-10000)	10
Zinc	200	n.a.	850		500	100
Mercury				0.06	0.1	0.1

¹⁾ Ref. [60] proposes As: 1-50; Cd: 0.5-10 and Pb 10-100 g.Mg^{-1}

n.a. not available

Limited abatement is application of fabric filters, wet scrubbers or electrofilters. Improved abatement is application of encapsulation or evacuation.

Specific abatement methods will lead to an important reduction of fugitive emissions [2b].

2.2.2 Primary lead production (snap code 3.3.4)

The emissions vary widely, depending on the ore used and the abatement measures. Emission factors are available from a Swedish plant [51b], from Germany [59] and from other literature [1, 2a]. In table 2.2.2 this information is presented, giving an indication of the range that might be expected.

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Table 2.2.2 Emission factors for primary lead production in g.Mg^{-1} product

Substance	Ref. [51b]	Ref. [51b]	Ref. [1, 2a]	Ref. [59]	Emission factor	
	limited	improved	unknown	unknown	limited	improved
Abatement						
Arsenic	3	0.2	n.a.	3	3	0.5
Cadmium	3	0.6	10	6	6	1
Copper	10	4	n.a.	n.a.	10	4
Lead	400	200	3000	400	500	200
Mercury	n.a.	n.a.	3	n.a.	3	3
Zinc	50	20	110	n.a.	80	20

n.a. not available

Limited abatement is application of fabric filters, wet scrubbers or electrofilters.
Improved abatement is application of encapsulation or evacuation.

Specific abatement methods will lead to an important reduction of fugitive emissions [2b].

2.2.3 Primary zinc production (snap code 3.3.5)

Emission factors from primary zinc production are reported for the electrolytic process [34] and for pyrometallurgical processes [1, 2a]. Ref. [59] reports both.

Table 2.2.3 Emission factors for heavy metals from primary zinc production in g.Mg^{-1}

Substance	Ref. [1, 2a]	Ref. [59]	Ref. [59]	Ref. [34]	Emission factor	
	thermal	thermal	electrolytic	electrolytic	thermal	electrolytic
Cadmium	500 ¹⁾	100	2	0.2	200	1
Lead	1900	450	1	-	500	1
Mercury	8	5-50	-	-	20	-
Zinc	16000	-	-	50	10000	50

¹⁾ with a vertical retort: 200 g.Mg^{-1} , with an improved smelting furnace 50 g.Mg^{-1}

n.a. not available

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2.2.4 Primary aluminium production (snap code 4.3.1)

The primary production of aluminium produces a small amount of dust that may contain traces of heavy metals. Emission factors have been estimated for the situation in the Netherlands [38b].

From the comments received [60, 61] it can be concluded that these values are rather high. No alternatives have been proposed.

Table 2.2.4 Emission factors for heavy metals from primary aluminium production in g.Mg⁻¹

Substance	Emission factor	Range
Cadmium	0.1	0.1-0.2
Nickel	10	0.1-20
Zinc	10	0.15-25

2.3 Secondary non-ferrous metal production

Establishing emission factors for secondary non-ferrous metals production is complicated. The reason for this is that the composition of the charge and the applied technology can differ widely.

As a first approximation a plant, equipped with a bag filter will produce about 100 g dust per ton product (range 50-150 g [51b]). The mean metal content in the dust is estimated at about 40% (range 10-70%). As to the individual secondary metal production some additional information is found in literature. These figures are given below. Abatement methods are described in ref. [2c].

2.3.1 Secondary copper (snap code 3.3.9)

Emission factors as proposed in ref. [1] are given in table 2.3.1. Other factors [59] for cadmium and lead are, however, one order of magnitude lower.

Table 2.3.1 Emission factors for the production of secondary copper in g.Mg⁻¹ product

Substance	Ref. [1]	Ref. [59]	Ref. [65b]	Emission factor
Arsenic		1.6-2.7		2
Cadmium	5	0.35-0.8		2
Copper			20	20
Lead	130	25		50
Zinc	500		150 ¹⁾	250
Dioxins				unknown (ref. 55)

¹⁾ brass production

2.3.2 Secondary lead (snap code 3.3.7)

The main application is the recycling of batteries. Emission factors are given in table 2.3.2.

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Table 2.3.2 Emission factors for the production of secondary lead in g.Mg⁻¹ product

Substance	Ref. [1]	Ref. [59]	Ref. [65b] ¹⁾	Emission factor
Arsenic	-	6-9		8
Cadmium	2.5	2-6	< 0.4	3
Lead	130	365	10-20	150
Zinc	300	-	trace	150

¹⁾ dust: 20 - 60 g.Mg⁻¹

- not available

2.3.3 Secondary zinc (snap code 3.3.8)

The main application is in the recycling of residues. Emission factors from ref. [59] are given in table 2.3.3. Ref. [1] reports 9000 g Zn.Mg⁻¹.

Table 2.3.3 Emission factors for the production of secondary zinc in g.Mg⁻¹ product

Substance	Ref. [59]	Emission factor
Arsenic	0.7	10 (1-20)
Cadmium	1.8	25 (2-50)
Mercury	0.014	0.02
Lead	11	200 (10-400)
Zinc	-	5000

These values apply to a cleaned up plant. Lead emissions before clean up were about 36 times higher.

2.3.4 Secondary aluminium (snap code 3.3.10)

Hexachloroethane is used in the secondary aluminium industry and in aluminium foundries in the form of tablets for degassing purposes in refining operations, resulting in hexachlorobenzene emissions.

The use of hexachloroethane is to be phased out by december 31 1992. [53a]
 For hexachlorobenzene and dioxin emissions have been reported [51b].
 Based on these data, emission factors are proposed in table 2.3.4.

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Table 2.3.4 Emission factors for secondary aluminium production

Substance	Emission factor
Hexachlorobenzene ¹⁾	5 g.Mg ⁻¹ aluminium
Dioxin (TEQ)	0.13 mg.Mg ⁻¹ aluminium

¹⁾ Only if hexachloroethane is still used

2.4 Combustion of fossil fuels

The emissions of micropollutants from combustion of fossil fuels are primarily controlled by the composition of the fuel. Therefore it is not possible to give general applicable emission factors. In this chapter a methodology for estimating emissions is given.

Combustion of coal

Pacyna [1] developed a methodology for the estimation of emissions of heavy metals from coal-fired power plants. This methodology can be used for PARCOM, adapted for a more detailed incorporation of national data. The emission factor for heavy metals can be calculated with

$$EF = 10^{-4} c f_a f_e (100 - \eta) \text{ mg.kg}^{-1} \text{ coal}$$

where EF = emission factor of metal in particulate matter in cleaned flue gas
 c = concentration of metal in coal (mg.kg⁻¹ coal)
 f_a = fraction of ash leaving combustion chamber as particulate matter (%ww)
 f_e = enrichment factor
 η = efficiency of dust control equipment (%)

Coal composition data should be assessed for the reference year with as much differentiation as possible with respect to sources and source types.

A good example of applying coal composition data for this purpose is the work of van der Sloot c.s. [6].

Values of f_a are reported by Pacyna [1] and [54a]:

They are given in the table below.

Fraction of ash leaving the combustion chamber (f_a)

Technology	Ref. [1]	Ref. [54a]	Proposed figure
Pulverized coal	73	70-100	80
Cyclone	14	n.a.	15
Grate firing	59	20-40	50*
Fluid bed	n.a.	15	15

n.a. = not available

* Mean value of a very wide range of application modes

Values of f_e can be taken from a literature survey and measurements [7]. These values are representative for large, pulverized coal, dry-bottom fired units with a 'cold' electrostatic precipitator.

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Enrichment factors (f_e) for different substances.

Substance	Factor	Range
Arsenic	5.5	4.5 - 7.5
Cadmium	7	6 - 9
Copper	2.3	1.5 - 3
Chromium	1.0	0.8 - 1.3
Nickel	3.3	1.5 - 5
Lead	6	4 - 10
Selenium	7.5	4 - 12
Zinc	7	5 - 9

The efficiency of dust removal can be > 99.75%, resulting in less than 20 mg of fly ash.m₀⁻³.

Some heavy metals are partly emitted in a gaseous form, due to their physical properties. The percentage that is emitted in gaseous form is given in the table below:

Substance	Percentage
Arsenic	0.5
Mercury	90
Selenium	15

An example of emission factors are given in tabel 2.4.1.

These factors can only be applied in situations where the mean fuel compositions are comparable to the situation in the Netherlands or Germany.

Table 2.4.1 Examples of emission factors for heavy metals from coal combustion in large boilers in g.Mg⁻¹ coal

The Netherlands			Germany	
Substance	Emission factor	Range	Emission factor	Range
Arsenic	0.085	0.04-0.16	0.77	0.18-1.4
Cadmium	0.002	0.001-0.004	0.07	0.02-0.09
Copper	0.11	0.06-0.15	0.46	0.18-1.4
Chromium	0.045	0.02-0.085	0.41	0.14-0.7
Mercury	0.25	0.15-0.4	0.18	0.13-0.3
Nickel	0.11	0.02-0.22	0.85	0.35-1.25
Lead	0.20	0.10-0.40	2.0	0.5-5
Selenium	0.5	0.02-0.9	0.04	0.02-0.08
Zinc	0.45	0.2-0.7	3.4	0.9-7.2

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Combustion of brown coal

It is not recommended to use the methodology proposed for coal also for brown coal. The only emission factors available have been presented by Germany [59]. These emission factors are given in table 2.4.2.

Table 2.4.2 Examples of emission factors for heavy metals from brown coal combustion in g.Mg⁻¹ coal

Substance	Emission factor	Range
Arsenic	0.04	0.025-0.05
Cadmium	0.004	0.003-0.005
Copper	0.02	0.006-0.03
Chromium	0.03	0.004-0.1
Mercury	0.06	0.05-0.07
Nickel	0.04	0.005-0.1
Lead	0.04	0.015-0.07
Zinc	0.1	0.015-0.3

Combustion of fuel oil

Emissions of heavy metals from liquid fossil fuels traditionally did not catch attention as did emissions from solid fuels. Probably the difference in dust generation is due to this. Generally, soot from the combustion of liquid (and gaseous) fuels is not filtered out of the flue gas. Heavy metals present in oils are assumed to be emitted completely. Soot adhering to walls of flue gas ducts may reduce emission [51b].

If it is assumed that all metals in fuels are emitted, then emission factors only depend on composition data which, similarly to coal, should be collected.

For the situation in the Netherlands such a survey has been made, resulting in the emission factors given in table 2.4.3. These factors can only be applied in situations where the mean fuel composition is comparable to the situation in the Netherlands [56].

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Table 2.4.3 Emission factors for heavy metals from combustion of fuel oil in g.Mg^{-1} fuel

Substance	Diesel fuel	Heavy oil	Range
Arsenic	0.05	1.0	0.05-2
Cadmium	0.05	1.0	0.01-2
Copper	0.05	1.0	0.2-2
Chromium	0.02	2.5	0.1-5
Nickel	0.05	35	20-50
Lead	0.2	1.3	0.5-2
Selenium ¹⁾	0.001	0.05	n.a.
Zinc	0.1	1.0	0.2-2

1) Estimation [32]

The information about emissions of the listed organic compounds from combustion of fossil fuels is scarce. Therefore only a few remarks from literature are mentioned:

Pentachlorophenol seems to be emitted only in negligible amounts from fossil fuel combustion [8].

Dioxin emission from coal-fired power plants might be $0.03 - 0.3 \mu\text{g.Mg}^{-1}$ according to partially confidential sources, but residential coal combustion could contribute $50 \mu\text{g.Mg}^{-1}$ [9]. Residential wood combustion has comparable emissions, but residential oil combustion is one to two orders of magnitude lower [9]. From Danish investigations an emission factor of $130 \mu\text{g.Mg}^{-1}$ for residential wood combustion was estimated; for wood-waste briquettes, paper, etc. emissions might be twice as high [14].

Automotive fuels

Based on few literature sources [24 - 28] an indication of emissions of heavy metals in exhaust particles can be given.

Table 2.4.4 Emission factors for heavy metals from automotive fuels in mg.Kg^{-1} fuel

Substance	Gasoline	Diesel
Cadmium	0.5 - 1	0.05
Copper	0.5 - 3	1 - 10
Chromium	< 0.5	n.a.
Nickel	0.5	1 - 10
Lead	*	20
Selenium	0.05	n.a.
Zinc	5	5 - 10

n.a.: not available

*: Lead emissions from leaded gasoline are directly related to fuel lead content. About 75% of all lead leaves the tail pipe but the airborne fraction is estimated to be only about one third.

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Emissions from diesel fuel cannot be directly compared with emissions from distillate oils, used in stationary combustion sources.

Lead scavengers in gasoline are a possible source of dioxin emissions. No information is available.

Combustion of natural gas

Natural gas from the Netherlands (Slochteren) contains after cleaning $5 \mu\text{g}$ mercury M_0^{-3} or 0.15 g.TJ^{-1} . On combustion, it is assumed to be completely emitted. No information is available for other gas fields.

Combustion of waste oil

The emissions from combustion of waste oil are determined by the composition of the fuel and the burner type used [10].

The following emission factors only give a rough indication for the situation in the Netherlands. Besides the emission factor for lead is declining, due to the decrease of the lead content in the fuel.

Table 2.4.5 Emission factors for combustion of waste oil in the Netherlands in g.Mg^{-1}

Substance	Gasoline
Arsenic	1
Cadmium	3
Chromium	13
Copper	25
Mercury	n.a.
Nickel	n.a.
Lead	800
Selenium	n.a.
Zinc	600

n.a.: not available

Combustion of wood

Information about emissions of heavy metals from wood combustion is extremely scarce. Figures mentioned in literature [11, 12, 13] are given in table 2.4.6.

Dioxin emissions from wood combustion have already been mentioned in this chapter. The order of magnitude is $100 \mu\text{g.Mg}^{-1}$ [14].

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Table 2.4.6 Emission factors for wood combustion in g.Mg⁻¹

Substance	Emission factor
Arsenic	n.a.
Cadmium	<0.1
Chromium	n.a.
Copper	<0.1
Mercury	0-0.2
Nickel	n.a.
Lead	<0.05
Selenium	n.a.
Zinc	2

n.a. not available

2.5 Waste incineration

2.5.1 Municipal waste (snap code 9.2.1)

2.5.1.1 Emission of heavy metals

The information about heavy metal emissions from waste incineration as available in literature provides no sound basis for a general emission factor. Differences generally can be attributed to different results of off-gas cleaning. Effects of lime injection and dechlorination should also be considered.

Assuming that the mean composition of municipal waste does not show many variation between most countries a mean emission factor can be calculated from the dust concentration in the off-gases.

A study by CITEPA [5] provides the necessary information.

In this study, a large number of installations were included, in as well as outside Europe. Cleaning equipment used can be described as follows:

17 installations with electrofilters	:	65 (12 - 130) mg dust.m ₀ ⁻³
4 installations with electrofilters	:	515 (200 - 800) mg dust.m ₀ ⁻³
9 installations with multicyclones	:	990 (200 - 1800) mg dust.m ₀ ⁻³
7 installations with scrubbers	:	85 (15 - 250) mg dust.m ₀ ⁻³

Values as low as 5 mg.m₀⁻³ have been reached in special cases.

Off-gas volume rates were:

19 installations with 5000 ± 2000 m₀³.Mg⁻¹¹)

6 installations with 24000 ± 14000 m₀³.Mg⁻¹

Taking 5000 m₀³.Mg⁻¹ as a representative off-gas rate and combining this value with the metal content in the dust from table 2.5.1, as reported by [5], it is possible to calculate emission factors at a chosen dust concentration it was possible to calculate the emission factors presented in table 2.5.2. For the dust concentration 100 mg.m₀⁻³ is chosen. This is arbitrarily because the best available technology makes 10 mg.m₀⁻³ possible [54b].

The CEC adopted a limit of 30 mg.m₀⁻³ as well as limits for combinations of heavy metal emissions [54b]. These limits, as well as reported data, suggest that the calculated emission factors are low by a factor of 2-3, except for nickel, lead and mercury. The first two show only a small deviation, whereas mercury may be a factor of three too high.

On the other hand, the majority of the factors in table 2.5.2 is comparable with those derived from German measurements [59]. These are based on 6000 m₀³.Mg⁻¹ and 75 mg.m₀⁻³. Of these, cadmium is twice higher indeed, but chromium is markedly lower and nickel is much higher.

¹⁾ For twelve installations in The Netherlands: 5300 ± 1400 m₀.Mg⁻¹ was found.

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Table 2.5.1 Percentage of heavy metals in dust from waste incineration [5]

Substance	Percentage in dust	Range	Number of installations
Arsenic	0.01	0.005-0.02	7
Cadmium (low)	0.04	0.01-0.1	24
Cadmium (high)	0.2	0.1-0.3	6
Chromium	0.15	0.02-0.5	22
Copper	0.2	0.05-0.4	19
Mercury	0.6	0.1-1.4	7
Nickel (low)	0.04	0.02-0.07	19
Nickel (high)	0.25	0.15-0.45	4
Lead	2	0.5-4	29
Selenium	0.0025	0.0005-0.005	4
Zinc	3.3	1-7	21

Table 2.5.2 Emission factors for heavy metals from waste incineration in g.Mg⁻¹ waste

Substance	Emission factor	Range
Arsenic	0.05	0.015-0.15
Cadmium	0.2	0.03-0.7
Chromium	0.75	0.05-3.5
Copper	1	0.15-3
Mercury	3	0.3-10
Nickel	0.2	0.05-5
Lead	10	1.5-30
Selenium	0.013	0.0015-0.04
Zinc	17	3-50

2.5.1.2 Emission of organic substances

Emission factors for pentachlorophenol and hexachlorobenzene are found in literature (in g.Kg⁻¹ waste)

Substance	Emission factor	Range	References
Pentachlorophenol	0.15	0.03-0.3	[8]
Hexachlorobenzene	2	1-5	[4, 54d, 56]

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— Dioxins

Municipal waste incineration has been recognized as an important source of PCDD/F. Dioxin formation may, however, be not significantly influenced by the chlorine content of waste. Start-up and shutdown leading to furnace temperatures below design value can increase emissions by more than an order of magnitude [29].

Much effort is being put presently into reduction of dioxin emissions and levels of $1 \mu\text{g.Mg}^{-1}$ can be reached [9]. The guideline is at the moment a concentration of 0.1 ng/m_0^{-3} in the flue gas.

2.5.2 Industrial waste (snap code 9.2.2)

This source definition is too vague to allow development of emission factors. For the incineration of wastes, other than municipal waste and sewage sludge emission factors are given by Germany [59]. The applicability of these factors in other countries is not known.

Table 2.5.3 Emission factors for heavy metals from the incineration of wastes other than municipal waste and sewage sludge in g.Mg^{-1} [59]

Substance	Emission factor
Arsenic	0.12
Cadmium	0.36
Chromium	0.48
Copper	1.2
Mercury	0.96
Nickel	1.2
Lead	9
Selenium	0.06
Zinc	12.6

2.5.3 Sewage sludge incineration (snap code 9.2.5)

Emission factors for heavy metals from sewage sludge incineration have been established for the situation in Germany [59] and in the Netherlands [19]. Emissions, and consequently emission factors, mainly depend on sludge composition and applied technology. These factors are presented in table 2.5.4.

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Table 2.5.4 Emission factors for heavy metals from sewage sludge incineration in g.Mg⁻¹ sludge

Substance	Ref. [19]	Ref. [59]	Ref. [16]	Ref. [1]	Emission factor
Arsenic	1.4	0.08	-	-	0.5
Cadmium	1.4	0.4	1	12	1
Chromium	9.0	0.4	-	-	5
Copper	24.6	0.5	-	-	10
Mercury	1.0	1.6	-	-	1
Nickel	0.4	0.5	-	-	0.5
Lead	32.2	3.2	-	140	15
Zinc	6.9	16.8	-	104	10

Sewage sludge incineration was recently found to be a source of PCDD/F. Emission factors might be developed from input data [62].

2.5.4 Incineration of automobile tyres

Automobile tyres contain 1.2 - 2.7% zincoxide [20], or 1 - 2% zinc. Old tyres are used as a waste fuel, therefore slags and flue dust have been subjects of investigation.

According to [20] fly ash production is 4.5%. Assuming an efficiency of cleaning equipment of 99%, the emission is 450 g.Mg⁻¹ tyres.

Using composition of flyash figures from ref. [21] the following emission factors can be derived:

Table 2.5.5 Emission factors for burning tyres in g.Mg⁻¹ tyres burned

Substance	Emission factor	Range
Arsenic	0.1	-
Cadmium	0.2	-
Chromium	0.1	-
Copper	2.0	-
Nickel	0.1	-
Lead	0.9	-
Zinc	200	100-500

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2.6 Inorganic Chemical Industry

2.6.1 Phosphate fertilizer (snap code 4.4.6)

Experience from the first round of the Emission Inventory in the Netherlands [34] (1974-1980) indicated emission factors for cadmium of 0.5 g.Mg⁻¹ ore for the thermal process, and 0.06 g.Mg⁻¹ for the wet process. The latter be somewhat high [51b]. No more recent information is available.

Substance	Process	Emission factor
Cadmium	thermal	0.5 g.Mg ⁻¹ ore
Cadmium	wet	0.06 g.Mg ⁻¹ ore

2.6.2 Nitrogen fertilizer(snap code 4.4.7)

Emission factors for ammonia from nitrogen fertilizer production are available from Sweden [51b] and The Netherlands [38]. A proposed (uncontrolled emissions) emission factor is 800 g.Mg⁻¹ nitrogen.

Substance	Emission factor	Range
Ammonia	800 g.Mg ⁻¹ nitrogen	500-1000

2.6.3 Chloralkali industry

The chloralkali industry can be a source of mercury emissions depending on the process used. An inventory for the 1989 situation in ten countries in Western Europe gives the emission factor in the table below (if the mercury process is used).

Substance	Emission factor	Range
Mercury	3.1 g.Mg ⁻¹ chlorine ¹⁾	1.2-7.6

¹⁾ According to PARCOM decision 90/3, all existing mercury plants should, at latest 1996, meet a limit of 2 g.Mg⁻¹ chlorine to the atmosphere. Emissions can be reduced to <0.5 g.Mg⁻¹ [2d]. The membrane process is considered to be the best available technology, because this process has no mercury emissions.

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2.6.4 Pigment production

The emission factors found in literature are presented in table 2.6.1. For chromium pigments only an emission factor per inhabitant could be established.

Table 2.6.1 Emission factors for pigment production g.Mg⁻¹ product

Substance	Emission factor	Reference
Cadmium pigments	210	1
Lead pigments	310	50
Zinc oxide	600	34
Chromium pigments	6 mg/inhabitant.year	34

2.7 Organic Chemical Industry

2.7.1 Halogenated hydrocarbons (snap codes 4.5.3 - 4.5.5)

For the production of halogenated hydrocarbons, the following emissions factors have been established [37, 38]

Table 2.7.1 Emission factors for halogenated hydrocarbons in g.Mg^{-1} product

Production of	Substance emitted	Emission factor
Pentachlorophenol	pentachlorophenol	9
Sodiumpentachlorophenol	pentachlorophenol	33
Tetrachloroethylene	tetrachloroethylene	350
Tetrachloroethylene	hexachlorobenzene	6
Tetrachloromethane	tetrachloromethane	10 (controlled)
Tetrachloromethane	tetrachloromethane	2800 (uncontrolled) ¹⁾
Tetrachloromethane	hexachlorobenzene	8
Trichloroethylene	hexachlorobenzene	3
Freon 11/12	tetrachloromethane	50 (controlled)
Freon 11/12	tetrachloromethane	500 (uncontrolled) ¹⁾
Pentachlorothiophenol	hexachlorobenzene	-

¹⁾ abatement unknown
 - unknown

Apart from these substances, dioxins might be emitted.

2.7.2 Production of glycerol

For the production of glycerol no emission data or emission factors for the listed substances have been found.

2.7.3 Pesticides production and formulation

The production and formulation of pesticides releases only minor emissions into the atmosphere, due to the extensive abatement measures. Anyhow, emissions are negligible as compared with emissions from pesticide use.

2.7.4 Paint production (snap code 6.3.7)

In the Netherlands no listed substances are emitted by paint production. In other countries the situation might be different. The amount probably will be small.

2.7.5 Ink production (snap code 6.3.8)

In the production of ink no listed substances are emitted.

2.7.6 Pharmaceutical industry (snap code 6.3.6)

The pharmaceutical industry produces a wide range of products, using different technologies and various solvents. Therefore a general applicable emission factor cannot be given. A common aspect of the pharmaceutical industry is solvent use.

The only method for establishing the emissions is making an inventory of solvent use assuming that all solvents are emitted to air. For the situation in the Netherlands from the listed substances trichloroethylene and tetrachloromethane are used. They come from rather specific processes that may or may not be used in other countries.

2.7.7 Refineries

Residues, fueled in refineries, need not be representative for heavy fuel oils as a product. Composition data of residues are needed to estimate heavy metal emissions.

2.7.8 Handling and Storage

2.7.8.1 Solid materials

For the handling of ores some emission factors are available [34]. However, much depends on the moisture content and the wind velocity. A mean emission factor is 100 g.Mg⁻¹ ore (range 40 - 200). The emissions from storage are negligible as compared to handling emissions. Heavy metal contents of ores are needed to estimate their emissions.

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2.7.8.2 Liquid materials

Storage and handling of solvents produce emissions to the air. The amount is largely dependent on factors depending on the construction of the tank and the loading technology [34]. Therefore a calculation must be based on local information and a general applicable emission factor cannot be given.

In the Netherlands where storage and handling is an important activity in the harbour area the contribution of halogenated hydrocarbons to the total emission is only 0.3-5%. Therefore it is assumed that the contribution will be small in most countries.

2.7.8.3 Other activities

Fossil fuels and solvents are of course used in many sectors of industry. If the activities are known emission factors as described in other chapters can be used.

A general enquiry about solvent use is the only effective instrument.

2.8 Building Materials Industry

2.8.1 Cement production (snap code 3.3.11)

The dust emissions from cement production may contain a small amount of heavy metals. The amount is determined by the composition of basic material and the type of fuels used for firing.

The emission factors in table 2.8.1 only give an order of magnitude of the emissions that might occur in certain circumstances [3, 33]

Table 2.8.1 Emission factors for cement production in g.Mg^{-1} cement

Substance	Coal and oil fired [51b]	Larger proportion of waste oil [51b]	Fuel unknown [1]	Ref. [59]	Ref. [60]
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 - .2	1.1	0.216	≤ 0.033
Mercury	-	-	-	0.275	-
Nickel	-	-	-	0.111	-
Selenium	-	-	-	0.002	-
Zinc	-	-	11	0.293	0.003-0.47

- not available

2.8.2 Glass production (snap codes 3.3.14, 3.3.15)

The emissions from glass production are largely determined by the composition of the basic materials and the product. For some products information is available:

- For the production of lead crystal glass an emission factor of 60 gram lead per Mg^{-1} product is mentioned. This emission factor applies to the situation after abatement (bag filter). Without abatement the emission factor is estimated to be 1% of the lead content of the glass [51b].
- French literature mentions factors for cadmium emissions of $0.11\text{-}0.15\text{ g.Mg}^{-1}$ for crude glass and 100 g.Mg^{-1} for coloured glass [50].
- For the situation in The Netherlands an emission factor of 30 g lead Mg^{-1} glass is used (due to the use of recycled glass) [50].

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- In Germany [59] reported emission factors (mg.kg^{-1}) for arsenic and lead are:
lead crystal glass ($> 24\% \text{ PbO}$): 140 (22-310) and 2700 (2200-3200) resp.;
crystal glass: 96 and 480 resp.; other glass: 0.12 (0.1-0.24) and 12 (2-24) resp..
Other factors are – generalized for the glass industry in Germany –:
Cadmium : 0.15 (0.06-0.24)
Chromium : 2.4 (0.5-5)
Copper : 0.6 (0.4-1.1)
Mercury : 0.05 (0.036-0.072)
Nickel : 1.9 (1.2-2.6)
Selenium : 18 (2.4-24)
Zinc : 11 (4.8-24)

Lead emissions from recycled glass are in Germany reported to be smaller than 1 g.Mg^{-1} [60].

2.8.3 Ceramics and enamels production (snap codes 3.3.19, 3.3.20)

Production of ceramics and enamels produces a small amount of dust. Minor quantities of arsenic, cadmium, lead and selenium might be present in negligible amounts. No emission factors are available.

2.8.4 Other activities

Many activities in this area may produce small amounts of metal containing dusts. No relevant factor can be given and contributions will be minor.

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2.9 Other industry

2.9.1 Mining of ores and oil

Ores Mining

Mining of ore produces dust that contains some heavy metals. It will be clear that general applicable emission factors cannot be given. However, the examples given below give at least an idea of the order of magnitude that might be expected.

Crushing and milling, prior to beneficiation, generates dust. Reduction of dust emissions should preferably be done with fabric filters, concentrations of $< 10 \text{ mg.m}_0^{-3}$ being attainable [2e].

Dewatering of ore concentrate also causes dust emissions. These can largely be reduced with pressure filters. Pressure filters should be considered the best available technology.

Abatement

Table 2.9.1 Emission factors for heavy metals from sulphide ore treatment and dewatering of concentrates (g.Mg^{-1} ore) [51b]

Substance	Oil fired driers	Air pressure filters
Copper from copper ore	80	1
Lead from lead ore	170	2.5
Zinc from zinc ore	200	3

a. Emission factors for heavy metals from lead mining [1]:

- Lead: 900 g.Mg^{-1} processed
- Zinc: 80 g.Mg^{-1} (zinc, copper and lead) mined.

Substance	Emission factor
Lead	900 g.Mg^{-1} processed
Zinc	80 g.Mg^{-1} mined (zinc, copper, or lead ore)

Off-shore activities

Offshore exploration activities produce some non-usable products that must be flared. Emission factors for flaring are not easy to apply. If the amount flared is known emission factors for burning of fossil fuels might be used as a first approximation.

2.9.2 Metal products industry (including electric and electronic appliances)

In these industries halogenated hydrocarbons are used for degreasing. The only good method for establishing emissions is making an inventory of solvent use.

In recent years there has been a shift from trichloroethylene to 1,1,1 trichloroethane. The amount used is of course largely dependent on the very wide range of products that have to be degreased. As a first approximation the number of employees in this branch can be used. As the total amount used for degreasing in The Netherlands is known, and the number of people employed in that branch is about 380,000 emission factors can be calculated (assuming that the total amount used is emitted). These are given in table 2.9.2.

Table 2.9.2 Emission factors for the metalelectro industry in g.empl⁻¹.year⁻¹

Substance	Emission factor
Tetrachloroethylene	2000
Trichloroethane	9400
Trichloroethylene	1600 ¹⁾

¹⁾ In Germany 233 g trichloroethylene.empl.⁻¹ was emitted in 1990. Emissions are decreasing rapidly [60]

Of course these figures can only be used as a first approximation.

2.9.3 Electroplating

The larger part of the emissions from electroplating are emissions into water. There are, however, a few processes that might give some emissions to air. These employ baths with a relatively low current efficiency. Emission factors for chromium are reported:

- 14 g.hr⁻¹.m⁻² surface for hard chromium
- 8.5 g.hr⁻¹.m⁻² surface for ornamental chromium

The emissions can be easily abated by using wet scrubbers (efficiency 99%) [38]. Also some solvent emissions may occur. These are included in the factors for the metalproducts industry.

2.9.4 Paper and pulp industry (snap code 4.6.2, 4.6.3)

In measurements of air emissions from recovery boilers, bark-fired boilers and lime kilns a small amount of dioxin has been found. The total amount is negligible compared to other sources [51b].

2.9.5 Textile industry

Emissions of halogenated hydrocarbons are produced in the textile finishing industry. An inventory of solvent use is necessary. The emissions mainly consist of trichloroethylene [35]. From the situation in The Netherlands an emission factor of 80 kg/employee can be estimated based on 2300 employees. A shift to trichloroethane may be possible in several countries. The emission factor can only be used as a first approximation.

2.9.6 Production of batteries

The following emission factors have been found.

Substance	Product	Emission factor	Reference
Lead	Lead batteries	5 g.Mg ⁻¹ lead used	[51b]
Cadmium	Nickel-cadmium batteries	860 g.Mg ⁻¹ cadmium used	[1]
		30 g.Mg ⁻¹ cadmium used ¹⁾	[60]

¹⁾ recycling of cadmium from Ni/Cd scrap takes place exclusively in closed systems

2.9.7 Printing industry (snap code 6.4.3)

In the printing industry a small amount of tetrachloroethylene is used in a specific moulding process. The degree to which this process is used in other countries is not known. Therefore a general emission factor cannot be given.

2.9.8 Industrial coating

In industrial coating some halogenated hydrocarbons may be used. Because of present restrictive policies which will be different in other countries no relevant emission factor can be given.

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2.10 Surface treatment and wear

2.10.1 Shipyards

The application of blasting agents in shipyards results in metal emissions into the air.

For copper containing blasting agents the following emission factor is established [34].

Substance	Emission factor
Copper	200 g/kg abrasive used

The emissions are mainly of local importance, because probably only a small part of the emissions will become airborne.

2.10.2 Overhead wires

Emission of copper occurs by corrosion, spark erosion and wear. From measurements of the weight loss of the electric wires an emission factor of 40 g copper train km⁻¹ can be calculated. Probably, emissions from spark erosion are airborne. The airborne fractions of corrosion and wear, however, are unknown.

2.10.3 Automobile tyre and brake wear

Emission factors for heavy metals from tyre and brake wear have been established for the situation in the Netherlands [36].

The results are presented in tables 2.10.1 and 2.10.2.

Table 2.10.1 Emission factors for tyre wear in microgram/km

Substance	Light duty vehicle	Heavy duty vehicle
Cadmium	5	50
Chromium	20	180
Copper	30	250
Nickel	20	170
Zinc	2500	20000

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*Table 2.10.2 Emission factors for brake wear
in microgram/km*

Substance	Emission factor
Copper	260
Zinc	160

Debris from tyre and brake wear is for the largest part deposited near road systems. No information is available on airborne fractions.

2.10.4 Maintenance of bridges

Blasting of bridges prior to painting results in metal emissions, in most cases lead. The amount of the emission largely depends on the blasting agent. No emission factor can be given. Besides only a small part of the emission will become airborne.

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2.11 Agriculture

2.11.1 Pesticides

The greater part of the substances from the PARCOM-ATMOS program that are used as pesticides are either forbidden or being phased out in most countries. This applies to arsenic containing pesticides, hexachloro-phenol and mercury compounds. For the other compounds, general applicable emission factors cannot be given as the policy, allowing certain substances for certain applications is very different from country to country. Some examples of substances that have still some applications in the Netherlands are given below.

An inventory should consist of:

- an inventory of substances admitted;
- an inventory of the amount used;
- an inventory of the application mode (for instance airplane spraying or soil injection).

Substance	Application
copper	apples
copperoxychloride	trees in nurseries
hexachlorocyclohexane	soil disinfection (phased out)
zineb (contains zinc)	bulbs, asparagus and some vegetables
quintozene (contains HCB)	bulbs

2.11.2 Fertilizer use (snap code 10.1)

Emission factors for the use of the different nitrogen containing fertilizers are given by Asman [57]. These figures are given in table 2.11.1, together with an addition by Richter [65c].

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Table 2.11.1 Emission factors for nitrogen containing fertilizers, expressed as percentage loss of nitrogen content

Fertilizer	% loss of N	Ref. [65c]
Ammonium sulphate	8	15
Urea	15	10
Ammonium nitrate	2	-
Calcium ammonium nitrate	2	-
Ammonia, direct application	1	-
Nitrogen solutions	2.5	-
Other straight nitrogen	2.5	-
Total straight nitrogen	4	-
Ammonium phosphate	4	-
Other NP N	3	-
NK N	2	-
NPK N	4	-
Compound N	4	-

2.11.3 Manure production (snap code 10.5)

Manure of domestic animals is the main source of emissions of ammonia to the air. A recent study by Asman [57] gives very detailed information about the emissions in the different situations.

This information is presented in table 2.11.2. If less information is available the mean emission factors from table 2.11.3 can be used.

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Table 2.11.2 Emission factors for ammonia emissions for livestock categories
 (kg NH₃.animal⁻¹ yr⁻¹)

Category	Stable + storage	Spreading	Grazing	Total
Young cattle	3.870	6.340	2.830	13
Dairy and calf cows	12.870	21.090	5.760	40
Breeding bulls > 2 yr.	10.580	17.330		28
Fattening calves	1.600	3.630		5.2
Young cattle for fattening	5.760	9.430		15
Fattening/grazing cattle > 2 yr.			8.220	8.2
Piglets < 20 kg				
Fattening pigs	3.180	3.800		7.0
Breeding sows 20-50 kg	2.420	2.800		5.2
Breeding sows > 50 kg	8.090	8.040		16
Other sows	8.090	8.040		16
Boars > 50 kg	3.180	3.800		7.0
Mature boars	5.520	5.480		11
Horses and ponies	3.900	3.600	4.700	12
Ewes	0.700	1.280	1.390	3.4
Broilers	0.065	0.102		0.17
Mother animals < 6 months	0.141	0.128		2.7
Mother animals > 6 months	0.315	0.283		0.60
Laying hens < 18 weeks	0.050	0.120		0.17
Laying hens > 18 weeks	0.100	0.205		0.31
Milch goats	2.300	4.100		6.4
Ducks	0.117			0.12
Turkeys for slaughter	0.429	0.429		0.86
Turkeys < 7 months	0.445	0.445		0.89
Turkeys > 7 months	0.639	0.639		1.3

Table 2.11.3 Averaged emission factors for livestock categories in Europe
 (kg NH₃.animal⁻¹ yr⁻¹)

Category	Stable + storage	Spreading	Grazing	Total
Cattle	7.396	12.244	3.403	23.043
Pigs	2.521	2.836	-	5.357
Poultry	0.095	0.154	-	0.248
Horses	3.900	3.600	4.700	12.200
Sheep	0.381	0.639	0.623	1.697

It must be emphasized that these emission factors apply to a situation without abatement measures. Injection into the soil for instance can greatly reduce the emissions.

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The emission factors in tables 2.11.2 and 2.11.3 are derived for the situation in the Netherlands. Differences in nitrogen content of the cattle feed may lead to different factors in other countries. Also some differences in definitions may play a role, especially for pigs [69]. As an example the factors found by ApSimon [67] and Möller [68] are presented in table 2.11.4.

Table 2.11.4 Emission factors for ammonia from livestock as found by ApSimon and Möller

Category	ApSimon	Möller
Cattle	19.3	26.8
Pigs	2.9	6.3
Poultry	0.23	0.27
Horses	31.6	18.2
Sheep	2.68	3.6

2.12 Natural sources

2.12.1 Heavy metals

A compilation of surveys of worldwide emissions of heavy metals has been made by Pacyna [23]. The main natural sources are windblown dust, vulcanogenic particles, forest wildfires, biological mobilization from vegetation and seaspray. If these emissions are compared with a worldwide inventory of emissions from anthropogenic sources from 1975, natural sources of nickel are half of anthropogenic sources, those of arsenic, copper and selenium are one-third and those of cadmium, lead and zinc are 5-15% of anthropogenic sources. Vulcanogenic particulate matter and windblown dust are the main sources. Zinc is an exception, biological mobilization being 20% of natural zinc emissions.

These figures only give an indication of possible contributions from natural sources. For a calculation of the contribution to the pollution for Western Europe information about residence times and geographical distribution would be needed.

2.12.2 Other substances

Anaerobic conditions in natural soils can produce ammonia emissions. An emission factor of 88 kg ammonia/km²/year⁻¹ has been mentioned (48). There is however much uncertainty. The factor might be used for situations in wetlands.

2.13 Miscellaneous

2.13.1 Cremation

Table 2.13.1 gives some measured and estimated data for mercury emissions from dental fillings. They are a poor basis for emission factor development. Nonetheless a default figure of 0.5 g of mercury per corpse is proposed.

Table 2.13.1 Mercury emissions form cremation

Country	mg.m ⁻³ measured [60]	g.corpse ⁻¹ estimated
United Kingdom		< 0.77 [61, 64, 65a]
Switzerland	0.1	1 [63] or 0.12 ¹⁾
Germany	0.08	0.1 ¹⁾
Austria	< 0.001	0.001 ¹⁾

¹⁾ Estimated with 4000 m³.h⁻¹ [60] and 0.3 h.corpse⁻¹

2.13.2 Wastewater treatment (snap code 9.1)

Analysis of wastewater from domestic sources gives from time to time rather high values for halogenated hydrocarbons. These substances probably will be emitted at the wastewater treatment plants. However, the main source is probably illegal dumping of solvent containing products in the sink. A general applicable emission factor cannot be given.

2.13.3 Dry cleaning (snap code 6.2.2)

The use of trichloroethylene for dry cleaning has declined very much in the Netherlands. As this situation might be different in other countries no general applicable emission factor can be given. For tetrachloroethylene, having a more stable application, an emission factor, based on the use in the Netherlands of 150 g/cap./year can be given. An inventory of solvent use is of course the best method.

For the UK an emission factor of 150 g trichloroethylene.Kg⁻¹ textiles is mentioned. Emissions are dependent on the machine type (closed or open).

2.13.4 Household products (snap code 6.4.8)

Halogenated hydrocarbons are present in several consumer products. In the Netherlands the emissions from the substances from the PARCOM-ATMOS program are mercury from broken thermometers, cadmium from cigarette smoking, and mercury from switches. No general applicable factors can be given. An inventory of solvent use is the only practical method.

2.13.5 Wood preservation (snap code 6.4.6)

Pentachlorophenol

Pentachlorophenol is used in a number of countries as an efficient preservation agent for timber. It is released into the atmosphere by evaporation. General emission factors cannot be given. Besides, the loss rate will be the determining factor. Some examples of the situation in different countries are:

1. Great Britain [8]: 290 Mg.y⁻¹ used. Estimated loss is 30% in one year [30]. Imported timber may contain 1000 Mg pentachlorophenol. Estimated loss is 5%.y⁻¹ (conservative rate). Emissions 87, respectively 40 Mg.y⁻¹.
2. Germany [51a]: Estimated loss is 90% in first year after application.
3. The Netherlands [4]: Use in 1980: 45 Mg; 1985: 4 Mg; ban per 1 January 1989. Present emissions are therefore from wood, preserved in the past. Estimated loss is 3.3%.y⁻¹ or 50% in 15 years. Emission in 1987: 35 Mg; in 1995: 23 Mg.
Emission from imported wood: 13 Mg.y⁻¹. This will remain constant for the time being.

On a per capita basis emissions in the UK are twice those in the Netherlands which, in view of the uncertainties involved makes a satisfying comparison. The loss rate reported by Germany may be too high.

Losses from imported wood are for the UK 0.7 g.cap⁻¹.y⁻¹. An emission factor of 1 g.cap⁻¹.y⁻¹ is proposed.

Hexachlorocyclohexane:

In [31] a study from 1979 was quoted, where consumption figures for six Western European countries were reported. On a per capita basis 0.1 - 1.5 g.y⁻¹ was used. Emissions were assumed to be half of consumption [31]. As the use of this substance is phased out in most countries relevant emission factors cannot be given.

2.13.6 Traffic emissions (snap code 7)

Emissions of heavy metals from traffic can be calculated by using the emission factors from chapter 2.4.

As far as lead scavengers are used, emission of dioxins is possible.

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3 Substance-activity matrix

Heavy metals

List of abbreviations and indications

blocks	=	emission factor available		
brackets	=	possible source – no information available		
void	=	no emissions of this substance		
As	=	arsenic	Ni	= nickel
Cd	=	cadmium	Pb	= lead
Cr	=	chromium	Se	= selenium
Cu	=	copper	Zn	= zinc
Hg	=	mercury		
HCH	=	hexachlorocyclohexane		
PCP	=	pentachlorophenol		
HCB	=	hexachlorobenzene		
TCM	=	tetrachloromethane		
TRI	=	trichloroethylene		
PER	=	tetrachloroethylene		
TCB	=	trichlorobenzene		
TCE	=	trichloroethane		
Diox	=	dioxins		
NH ₃	=	ammonia		

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3.1 Heavy metals

Table 4.1 Heavy metals

Nr.	Substance Activity	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
1	Iron and steel production									
1.1	Sinter plants	■	■	■	■	■	■	■	■	■
1.2	Pellet plants	■		■	■	■	■			
1.3	Blast furnace	■	■	■	■	■	■	■	■	■
1.4	Oxygen furnace	■	■	■	■	■	■	■	■	■
1.5	Open hearth furnace	()	()	()	()	()	()	()	()	()
1.6	Electric arc furnace	■	■	■	■	■	■	■	■	■
1.7	Coke production	■	■	■	■	■	■	■	()	■
1.8	Foundries	■	■	■			■	■		■
2	Primary non ferrous m. pr.									
2.1	Primary copper production	■	■		■			■		■
2.2	Primary lead production	■	■		■	■		■		■
2.3	Primary zinc production		■			■		■		■
2.4	Primary aluminium prod.		■				■		■	
3	Secondary non ferro metals		■					■		■
4	Combustion of fossil fuels									
	coal	■	■	■	■		■	■	■	■
	brown coal	■	■	■	■	■	■	■	()	■
	oil		■	■	■		■	■	■	■
	natural gas					■				
5	Waste incineration									
5.1	Municipal waste	■	■	■	■	■	■	■	■	■
5.2	Industrial waste	()	()	()	()	()	()	()	()	()
5.3	Sewage sludge	■	■	■	■	■	■	■		■
5.4	Automobile tyres	■	■	■	■		■	■		■
6	Inorganic chemical industry									
6.1	Phosphate fertilizer		■							
6.2	Nitrogen fertilizer									
6.3	Chloralcali industry					■				
6.4	Pigments		■	■				■		■
7	Organic chemical industry									
7.1	Halogenated hydrocarbons									
7.2	Glycerol									
7.3	Pesticides production/form									
7.4	Paint									■
7.5	Ink									
7.6	Pharmaceutical industry									
7.7	Refineries	()	()	()	()	()	()	()	()	()
7.8	Handling and storage			■	■		■	■		■
7.9	Other activities									

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Table 4.1 (Continued)

Nr.	Substance Activity	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
8	Building materials industry									
8.1	Cement		■	■				■		■
8.2	Glass		■					■		
8.3	Ceramics and enamels	()	()					()	()	
8.4	Other activities									
9	Other industry									
9.1	Mining of ores and oil		()	()	■	()	()	■		■
9.2	Metal products industry			■	■		■	■		■
9.3	Electroplating			■			()			
9.4	Paper and pulp industry									
9.5	Textile industry									
9.6	Battery production		■					■		
9.7	Printing industry									
9.8	Industrial coating									
10	Surface treatment and wear									
10.1	Shipyards				■					
10.2	Corrosion of railway wires				■					
10.3	Automobile tyre and brake wear		■	■	■		■			■
10.4	Maintenance of bridges									
11	Agriculture									
11.1	Pesticide use									()
11.2	Fertilizer use									
11.3	Manure production									
12	Natural sources	()	()	()	()	()	()	()	()	
13	Miscellaneous									
13.1	Cremation					■				
13.2	Wastewater treatment									
13.3	Dry cleaning									
13.4	Household products									
13.5	Wood preservation									
13.6	Traffic emissions		■	■	■		■	■	■	■

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3.2 Halogenated hydrocarbons and ammonia

Table 4.2 Heavy metals

Nr.	Substance Activity	HCH	PCP	HCB	TCM	TRI	PER	TCB	TCE	Diox	NH ₃
1	Iron and steel production										
1.1	Sinter plants									■	
1.2	Pellet plants										
1.3	Blast furnace										
1.4	Oxygen furnace										
1.5	Open hearth furnace										
1.6	Electric arc furnace		■	■							
1.7	Miscellaneous										
2	Primary non ferrous m. production										
2.1	Primary copper production										
2.2	Primary lead production										
2.3	Primary zinc production										
2.4	Primary aluminium production										
3	Secondary non ferro metal production			■						■	
4	Combustion of fossil fuels										
	coal									■	
	oil									■	
	natural gas										
5	Waste incineration										
5.1	Municipal waste		■	■						■	
5.2	Industrial waste		()	()	()	()	()	()	()	()	
5.3	Sewage sludge										
5.4	Automobile tyres										
6	Inorganic chemical industry										
6.1	Phosphate fertilizer										
6.2	Nitrogen fertilizer										■
6.3	Chloralcali industry										
6.4	Pigments										
7	Organic chemical industry										
7.1	Halogenated hydrocarbons		■	■	■	■	■	■	■		
7.2	Glycerol										
7.3	Pesticides production/formulation	()									
7.4	Paint										
7.5	Ink										
7.6	Pharmaceutical industry										
7.7	Refineries					()	()				
7.8	Handling and storage										
7.9	Other activities				()	()	()	()	()		

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Table 4.2 (Continued)

Nr.	Substance Activity	HCH	PCP	HCB	TCM	TRI	PER	TCB	TCE	Diox	NH ₃
8	Building materials industry										
8.1	Cement										
8.2	Glass										
8.3	Ceramics and enamels										
8.4	Other activities										
9	Other industry										
9.1	Mining of ores and oil										
9.2	Metalproducts industry					■	■		■		
9.3	Electroplating										
9.4	Paper and pulp industry									()	
9.5	Textile industry					()	■	()	()		
9.6	Battery production										
9.7	Printing industry						()				
9.8	Industrial coating					()	()				
10	Surface treatment and wear										
10.1	Shipyards										
10.2	Corrosion of railway wires										
10.3	Automobile tyre and brake wear										
10.4	Maintenance of bridges		■								
11	Agriculture										
11.1	Pesticide use	()									
11.2	Fertilizer use										■
11.3	Manure production										■
12	Natural sources										
13	Miscellaneous										
13.1	Cremation										
13.2	Wastewater treatment	()			()	()					
13.3	Dry cleaning					()	■				
13.4	Household products					()	()				
13.5	Woodpreservation		■								
13.6	Traffic emissions										

4 Discussion and recommendations

4.1 General remarks

- The emission factors in this manual are based on the best information available from widely different sources. Some emission factors are more reliable than others. The cause of this is either limited information from the measurements on which the emission factors are based, or uncertainties about the processes used for the different activities
- In making an emission inventory emission factors are used in combination with other information about the activities.
The uncertainty in the result is determined by the uncertainty both in the emission factor and in the basic data. Examples of uncertainties in basic data are:
 - metal content of fuels and ores
 - shape of dust particles
 - the part of the emissions that is airborne
 - the amount of solvent used for a given application

4.2 Heavy metals

Pollution of the air with heavy metals largely is in the shape of particulate matter, the exception being those metals that because of their volatility are released as vapours (mercury and - partially - arsenic, cadmium and selenium). For a reliable estimation of emissions therefore dust concentrations in off-gases need to be known together with the composition of the particles. For a reliable methodology as a basis for an emission inventory unabated dust concentrations and metal contents together with the efficiency of cleaning equipment should be known.

Considering the number of source types, the variation in processes, the variation in metal contents of raw materials and fuels and the variation in efficiencies in cleaning devices (type, maintenance) it is clear that many measurements would be needed to provide a sound basis for an inventory. It is not to be expected that such a level of knowledge will be in the near future throughout Europe and therefore default average data will be needed. Every opportunity to improve this situation should be seized.

For the analysis of priorities for improvement the following exercise is useful.

To give an impression of the relative importance of different activities for heavy metal emissions some calculations have been carried out using the emission factors from this report and statistical material from miscellaneous sources, representative for the mid-eighties in Western Europe.

High emission rates are a result of a high activity rate, or a large emission factor or both.

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Table 4.1 Possible emissions of heavy metals from main sources in W.Europe

Activity	Production/ consumption (Tg.y ⁻¹)	Emissions Mg.y ⁻¹							Gg.y ⁻¹	
		As	Cd	Cu	Cr	Hg	Ni	Se	Pb	Zn
Sinter	90	5	9	14	27	4	90	1	0.5	<0.1
Pig iron	80	8	40	4	16	8	24	4	1.2	2
Prim. steel	110	2	3	17	6	<1	6	<1	0.2	0.4
Sec. steel	50 ¹⁾	5	12	40	120	8	36	3	0.6	2.3
Prim. + sec. Cu	1.3	50-100	5-20	300					0.3	0.3-0.8
Prim. + sec. Pb	1.6	<5	<5	10					0.2-0.5	<0.5
Prim. + sec. Zn	2.2		20			4			0.8	13
Hard coal	249	25	<10	60	25	10	50	10	0.1	<0.1
Brown coal ²⁾	218	<20	<10	<40	<15	<5	<30	<5	<0.1	<0.1
Resid. oil	106	10	10	100	100	0.5-200	3200	10-100	0.2	0.1
Dist. oil, stat.	115	3	3	8	2	0.5-5	6	<1	0.02	0.01
Dist. oil, mob.	73		4	70-700			70-700		1.5	0.3-0.7
Gasoline	104		50-100	50-300	<50		50		17	0.5
Mun. waste ³⁾	25	3	13	60	45	25	5	1	0.25	1.1
Cement	220		9		3-60				<0.2	2.4
Chlorine						21 ⁴⁾				

¹⁾ ca. 10% stainless steel

²⁾ Insufficient concentration data available. They generally are lower than concentrations in hard coal

³⁾ Comments on factors (par. 2.5.1.1) taken into account

⁴⁾ [52a]

Table 4.2 Possible emissions of heavy metals from main sources in W. Europe in percentages

Activity	Production/ consumption	Relative emissions (in %)								
		As	Cd	Cu	Cr	Hg	Ni	Se	Pb	Zn
Sinter		3	4	1	6	2	2	1	2	-
Pig iron		5	17	-	4	4	1	5	5	8
Prim. steel		1	1	1	1	1	-	1	1	2
Sec. steel		3	5	3	27	4	1	4	2	10
Prim. + sec. Cu		47	5	25	-	-	-	-	1	2
Prim. + sec. Pb		3	2	1	-	-	-	-	13	2
Prim. + sec. Zn		-	8	-	-	2	-	-	3	55
Hard coal		16	4	5	6	5	1	12	-	-
Brown coal		12	4	3	3	3	1	6	-	-
Resid. oil		6	4	8	23	53	82	68	1	-
Dist. oil, stat.		2	1	1	-	2	-	1	-	2
Dist. oil, mob.		-	2	33	-	-	10	-	6	2
Gasoline		-	2	14	11	-	1	-	64	5
Mun. waste		2	31	5	10	13	-	1	1	10
Cement		-	5	-	7	-	-	-	1	-
Chlorine		-	4	-	-	11	-	-	-	-
Total		100	100	100	100	100	100	100	100	100

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Although these calculations have only a tentative character some conclusions and recommendations with respect to the priority areas for the *improvement* of emission factors and basic data about the activities are:

- Compared to what basic data are available at present, it would be a real improvement if all countries would systematically record heavy metal contents of some fuels and raw materials and abatement practices. A combined effort at analysis of imported and produced coal and fuel oil - as an example - will be relatively inexpensive (cluster analysis).
- Liquid fuel use - both stationary and mobile - is a very important anthropogenic source of heavy metals. Since this never has been recognized (apart from nickel from residual oil and lead from gasoline) this source of heavy metals seems to be neglected so far. It is recommended that heavy metal contents of fuels, especially residual oil should be assessed. The same applies to the heavy metal contents of coal.
- In addition to producing heavy metals from fuel use, mobile sources also can be a source of heavy metals from wear of mechanical parts. There is uncertainty about the part of the emissions that becomes airborne. (Copper from overhead wires, and zinc from tyre wear). Measurements should improve this situation.
- As can be expected production of metals is a very important source category. The wide diversity of process technology makes the establishment of emission factors from measured data rather difficult. It is recommended to establish a well defined inquiry about available measured data, if necessary supplemented by a measuring campaign. Examples of such campaigns have been carried out for the secondary steel and chlorine production. In Western Europe 60 integrated iron and steel mills, about 200 sites with electric arc furnaces and at least 100 non-ferrous metal plants are present. According to table 4.2.1. the first attention should be directed at emissions of arsenic, cadmium and chromium from iron and steel production, arsenic and copper from copper production and zinc from zinc production.
- It is recommended that attention should be paid to zinc emissions from cement production, and emissions of chromium and mercury from municipal waste incineration. Only scarce data are available so far.

4.3 Organic compounds

Emission factors for the organic compounds listed are usually based on the assumption that the emissions are equal to the consumption, taking into account the distribution over the environmental compartments and decomposition losses. Information about solvent use and pesticide use should be collected on a regular basis.

The incomplete knowledge on dioxines is caused by the complexity of the problem, and the lack of knowledge about the frequency by which the circumstances that might result in dioxin emissions occur, especially in thermal processes.

Current research programmes might improve this situation.

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