Category		Title
NFR	2.C.7.a	Copper production
SNAP	040309a	Copper production
ISIC	2720	Manufacture of basic precious and non-ferrous metals
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Contents

1 Overview

This chapter presents information on atmospheric emissions during the production of copper (Cu), which includes primary and secondary copper. This chapter only addresses the process emissions of copper production, whereas emissions originating from combustion are discussed in source category 1.A.2.b.

There is an overall trend in copper production towards integrated/multi metallic smelters, where primary smelters are using increasingly secondary material feeds and secondary smelters are using also sulphur-containing feeds. Generally speaking, there are three steps in the pyrometallurgical primary copper production process: roasting of ores to remove sulphur; smelting of roaster product to remove a part of the gangue for production of the copper matte; and converting the copper matte to blister copper. Atmospheric emissions of sulphur dioxide and heavy metals on fine particles occur during all the above mentioned processes.

Various trace elements from impurities are present in the copper ores, which are emitted during the production process. The process is a major source of atmospheric arsenic and copper (50% of the global emissions of these elements), indium (almost 90%), antimony, cadmium and selenium (approximately 30%) and nickel and tin (approximately 10%) (Nriagu and Pacyna, 1998).

In secondary copper smelting, 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 production of copper.

2 Description of sources

2.1 Process description

2.1.1 Primary copper production

The pyrometallurgical copper production route entails a number of steps, depending on the concentrate used. The majority of concentrates are sulphidic and the stages involved are roasting, smelting, converting, refining and electro-refining. Roasting and smelting are usually carried out simultaneously in a single furnace at high temperatures to produce a melt that can be separated into a matte (copper sulphide with some iron sulphide) and some slag rich in iron and silica (European Commission, 2014).

In the traditional pyrometallurgical copper smelting process, 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 fluidised bed dryers and then converting and refining the dried product in the same manner as the traditionally used process (US 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 20–50% 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 35–65% 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 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 (US 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. Electric arc furnaces do not produce fuel combustion gases, so flow rates are lower and so are the sulphur dioxide concentrations.

The final step in the production of blister copper is converting. The remaining iron and sulphur in the matter 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.

2.1.2 Secondary copper production

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 or products from cable processing;
- alloy scrap, such as brass, gunmetal, bronze, in the form of radiators, fittings, machine parts, turnings or shredder metals;
- copper-iron scrap like electric motors or parts thereof, plated scrap, circuit elements and switchboard units, telephone scrap, transformers and shredder 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 1% to nearly 100% (EIPPCB, 2014). The associated metals that 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% Cu in the average charge);
- mini smelter;
- top blown rotary furnace (TBRC);
- ISA Smelt;
- converters (about 75% Cu);
- electric arc furnaces (about 95% Cu);
- Contimelt (>99% 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 that 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 Mini Smelter is used for secondary copper production, using scrap that contains iron and tin. In this application, the iron acts as the reducing agent in the first stage to produce metallic copper and then oxygen is blown into the melt to oxidise iron and the other metals (lead and tin) present which are recovered in the slag. The oxidation of the iron content provides the heat to drive the process and excess heat is recovered (European Commission, 2014).

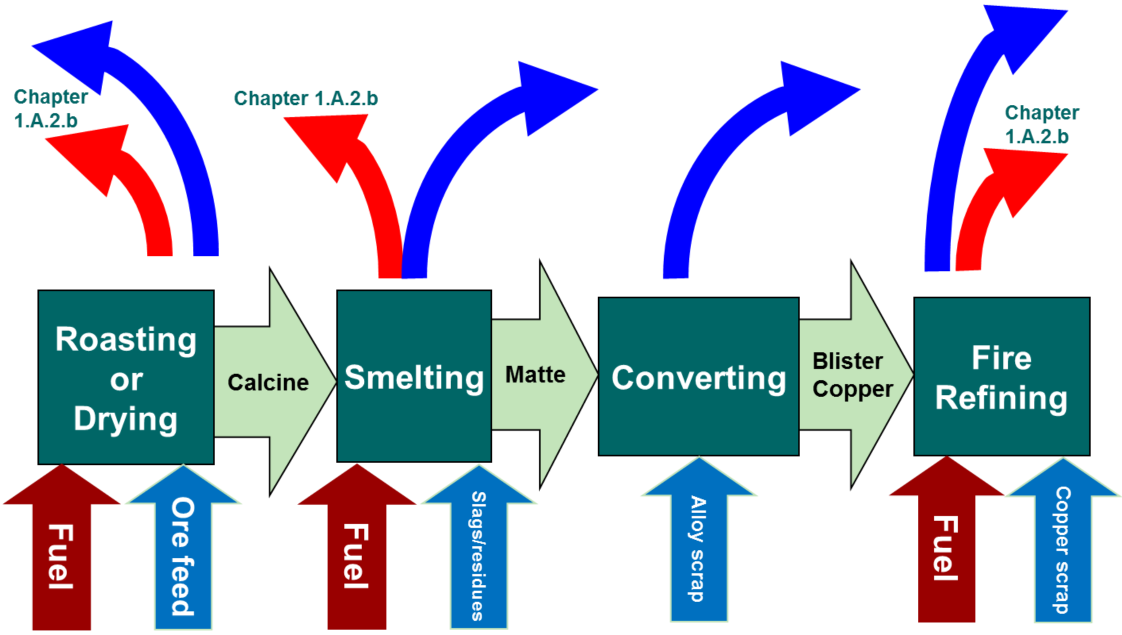
The converters used in primary copper smelting, working on mattes containing iron sulfide, generate surplus heat and additions of scrap copper are often used to control temperature. The converter provides a convenient and cheap form of scrap treatment but often with only moderately efficient gas cleaning. Alternatively, hydrometallurgical treatment of scrap, using ammonia leaching, yields to solutions which can be reduced by hydrogen to obtain copper powder (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 an 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% lead, are widely used in various applications and recycling of their scrap waste is an important activity. Such scrap usually contains 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 pretreatment to remove these non-metallics. The smaller sizes of scrap can be pretreated thermally in a rotary kiln provided with an after-burner to consume smoke and oil vapors (the so-called Intal process). There are also various techniques available to remove rubber and plastic insulations of cables (Barbour *et al.*, 1978; UN ECE, 1994).

The production of copper from either primary or secondary material streams is illustrated in **Error! Reference source not found.**.

Figure 2-1 Schematic description of a combined primary/secondary copper production process, using ore concentrate with silica fluxes, slags, alloy scrap and copper scrap as inputs, and anode copper as output from the fire refining process.



2.2 Techniques

The descriptions of the different processes used in the process of producing primary and secondary copper are given in section 2.1. In the converting process during primary copper production, two techniques can be distinguished:

- batch converting: blowing an air/oxygen mixture through the matte recovered from the smelting operation;
- continuous converting, of which three types exist. the Mitsubishi and Noranda converters receive molten feed for conversion, while in the Kennecott/Outokumpu process the matte from the smelting furnace is first granulated in water, crushed and dried.

More information about these techniques can be found in the section on copper production in the Reference Document on Best Available Techniques (BREF) for the Non-Ferrous Metal Industries (European Commission, 2014) with expected adaptation in 2016 (1).

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(1) The BREF document for non-ferrous metals industries is presently in final draft stage. A finalised version is expected to be adopted in 2016. Information concerning the status of BREF documents is available at http://eippcb.jrc.es/reference/. The previous version of the BREF was published in 2001 (European Commission, 2001).

2.3 Emissions

Pollutants released during copper production are particulate matter (PM), 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 POPs are mostly dioxins and furans, which are emitted from shaft furnaces, converters, and flame furnaces.

More information on emissions and control techniques used in copper production can be found in the revised BREF on non-ferrous metal industries (European Commission, 2014).

Note that PM emission factors in the Guidebook represent primary emissions from the activities and not formation of secondary aerosol from chemical reaction in the atmosphere after release.

A number of factors influence the measurement and determination of primary PM emissions from activities and, the quantity of PM determined in an emission measurement depends to a large extent on the measurement conditions. This is particularly true of activities involving high temperature and semi-volatile emission components – in such instances the PM emission may be partitioned between a solid/aerosol phase and material which is gaseous at the sampling point but which can condense in the atmosphere. The proportion of filterable and condensable material will vary depending on the temperature of the flue gases and in sampling equipment.

A range of filterable PM measurement methods are applied around the world typically with filter temperatures of 70-160°C (the temperature is set by the test method). Condensable fractions can be determined directly by recovering condensed material from chilled impinger systems downstream of a filter – note that this is condensation without dilution and can require additional processing to remove sampling artefacts. A common approach for total PM includes dilution where sampled flue or exhaust gases are mixed with ambient air (either using a dilution tunnel or dilution sampling systems) which collect the filterable and condensable components on a filter at lower temperatures (but depending on the method this can be 15-52°C).

Copper smelters are a source of sulphur oxides (SO_x). Emissions are generated from the roasters, smelting furnaces and converters. Fugitive emissions are generated during material handling operations. Remaining smelter operations use material containing very little sulphur, resulting in insignificant SO_2 emissions (US EPA, 1995). Here only emissions from combustion processes with contact are relevant.

Energy demand

Copper production requires energy in most stages, the energy use of the electrolytic process is most significant. The production energy (net) requirement for a number of processes using copper concentrate is in the range 14 – 20 GJ/t of copper cathode. The exact figure depends mainly on the concentrate (% S and Fe), but also on the smelting unit used, the degree of oxygen enrichment and the collection and use of process heat. Comparative data based solely on the type of smelter are therefore liable to inaccuracies. The utilisation of the energy content of the concentrate is more important and smelters that achieve autogenic operation have lower energy use (European Commission, 2014).

The energy consumed by the electro-refining stage of copper production is reported to be 300 - 400 kWh per tonne of copper, but the energy use is considerably higher when high impurity anodes are electro-refined. The type of blank cathode used (stainless steel or copper) mainly influences the efficiency of tank house and this can range from 92% to 97% in terms of current efficiency (European Commission, 2014).

2.4 Controls

2.4.1 Primary copper production

Emission controls on primary 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 96% to 99.1% conversion of SO_2 from plant effluent gas. Double-contact acid plants collect from 99.2% to more than 99.9% of the SO_2 (European Commission, 2014). Absorption of the SO_2 in dimethylaniline solution has also been used in US-American smelters to produce liquid SO_2 (US EPA, 1995).

Electrostatic precipitators (ESPs) are the common particulate matter control devices employed at copper smeltering facilities. The control efficiency of wet ESPs can reach about 99.9 %. It should be added that most of the trace elements are condensed on very fine particles, e.g. <1.0 µm diameter, and the control efficiency for these particles is lower (US EPA, 2003).

A detailed description of control techniques and Best Available Techniques for the copper production is available in the revised BREF (European Commission, 2014).

2.4.2 Secondary copper production

Controls in secondary copper production should include effective emission collecting arrangements such as hooding, enclosure and boosted suction systems for both primary exhaust gases and fugitive emissions. Reducing dust and metal emissions can be done using a bag filter and/or a scrubber in combination with an ESP. The use of an afterburner, quench, injection of lime and/or active coal before the bag filter may further reduce emission levels, including emissions of dioxin and other organic compounds (European Commission, 2014).

3 Methods

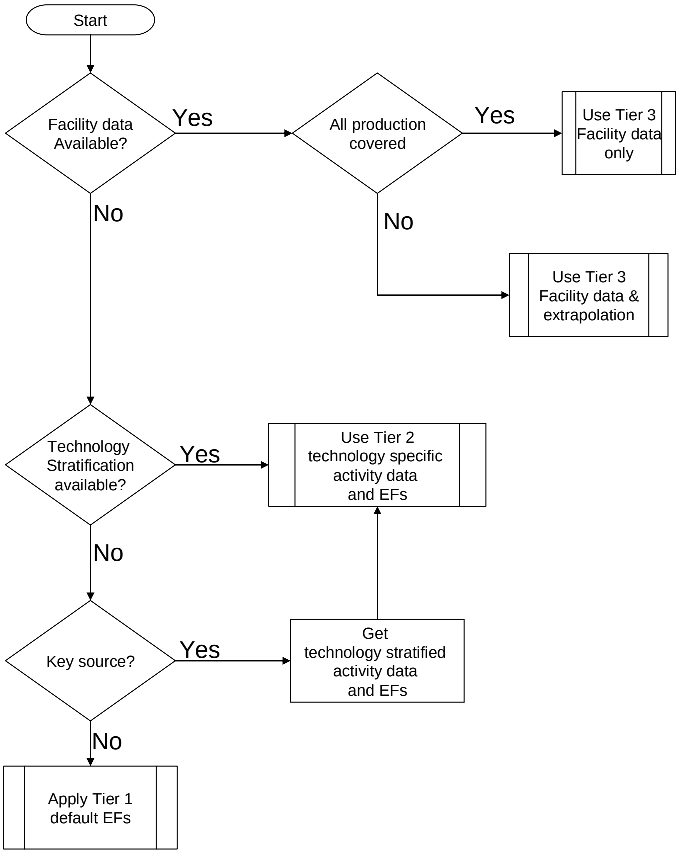
3.1 Choice of method

Figure 3-1 presents the procedure to select methods for estimating process emissions from copper production. The basic idea is as follows.

- If detailed information is available: use it.
- If the source category is a key category, a Tier 2 or better method must be applied and detailed input data must be collected. The decision tree in Figure 3.1 directs the user in such cases to the Tier 2 method, since it is expected that it is more easy to obtain the necessary input data for this approach than to collect facility level data needed for a Tier 3 estimate;

- The alternative of applying a Tier 3 method using detailed process modelling is not explicitly included in this decision tree. However, detailed modelling will always be done at facility level and results of such modelling could be seen as 'facility data' in the decision tree.

Figure 3-1 Decision tree for source category 2.C.7.a Copper production



3.2 Tier 1 default approach

3.2.1 Algorithm

The Tier 1 approach for process emissions from copper production uses the general equation:

$$E_{pollutant} = AR_{production} \times EF_{pollutant} \tag{1}$$

Where:

$E_{pollutant}$ = the emission of the specified pollutant

$AR_{production}$ = the activity rate for the copper production

$EF_{pollutant}$ = the emission factor for the pollutant

This equation is applied at the national level, using annual national total copper production. Information on the production of copper, suitable for estimating emissions using the simpler estimation methodology (Tier 1 and 2), is widely available from United Nations statistical yearbooks or national statistics.

The Tier 1 emission factors assume an 'averaged' or typical technology and abatement implementation in the country and integrate all different sub-processes in the production of copper, from the treatment of the ore concentrate until after the fire refining, producing anode copper.

In cases where specific abatement options are to be taken into account a Tier 1 method is not applicable and a Tier 2 or Tier 3 approach must be used.

3.2.2 Default emission factors

The Tier 1 approach needs emission factors for all relevant pollutants. These default emission factors as given in **Error! Reference source not found.** have been derived from various references. The emission factors for total suspended particulate matter (TSP), SO_x, Pb, As and Cu are from the BREF document for the non-ferrous metal industry (European Commission, 2014), while PM_{10} and $PM_{2.5}$ are interpreted from the profile used in the Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP) study (Visschedijk *et al*., 2004) for a conventional plant. Other values are taken from the 'Estimation of willingness-to-pay to reduce risks of exposure to heavy metals and cost-benefit analysis for reducing heavy metals occurrence in Europe' (Espreme) project (Theloke *et al*., 2008) for plants with limited control. To estimate Tier 1 emission factors, it is assumed that about 75% of the copper production is primary copper and 25% is secondary copper (Althaus, 2003).

Emission factors in the BREF documents are mostly given in ranges. Where these emission factors are used in the table below, the range is interpreted as the 95% confidence interval, while the geometric mean of this range is chosen as the value for the emission factor.

Emissions of NO_x and CO are assumed to originate mainly from combustion and are discussed in chapter 1.A.2.b. All other emissions are assumed to originate primarily from the process and are therefore discussed in the present chapter.

Table 3-1 Tier 1 emission factors for source category 2.C.7.a Copper production.

Tier 1 default emission factors					
	Code	Name			
NFR source category	2.C.7.a	Copper production			
Fuel	NA				
Not applicable	HCH				
Not estimated	NO_x, CO, NMVOC, NH_3, Se, Zn, Benzo(a)pyrene, Benzo(a)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB,				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
TSP	320	g/Mg copper	100	1 000	European Commission (2014)
PM_{10}	250	g/Mg copper	80	800	Visschedijk et al. (2004) applied on TSP
$PM_{2.5}$	190	g/Mg copper	60	600	Visschedijk et al. (2004) applied on TSP
BC[2]	0.1	% of $PM_{2.5}$	0.05	0.2	US EPA (2011, file no.: 91158)
SO_x	3000	g/Mg copper	500	18 000	European Commission (2014)
Pb	19	g/Mg copper	6	60	European Commission (2014)

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(2) For the purposes of this guidance, BC emission factors are assumed to equal those for elemental carbon (EC). For further information, please refer to Chapter 1.A.1 Energy Industries.

Cd	11	g/Mg copper	9	19	Theloke et al. (2008)
Hg	0.023	g/Mg copper	0.016	0.039	Theloke et al. (2008)
As	4	g/Mg copper	0.5	27	European Commission (2014)
Cr	16	g/Mg copper	11	22	Theloke et al. (2008)
Cu	32	g/Mg copper	8	130	European Commission (2014)
Ni	14	g/Mg copper	8.7	22	Theloke et al. (2008)
PCBs	0.9	μg/Mg copper	0.6	1.5	Note
PCDD/F	5	μg I-TEQ/Mg copper	0.01	800	UNEP (2005)

Note: The EF for PCB may be revised in the future based on new information from UNEP: *Toolkit for Identification and Quantification of Releases of Dioxins and Furans and Other Unintentional POPs*: http://chm.pops.int/Implementation/UnintentionalPOPs/ToolkitforUPOPs/Overview/tabid/372/Default.aspx

3.2.3 Activity data

Information on the production of copper in primary smelters, suitable for estimating emissions when using Tier 1 or Tier 2 is widely available from the United Nations statistical yearbooks or national statistics.

3.3 Tier 2 technology-specific approach

3.3.1 Algorithm

The Tier 2 approach is similar to the Tier 1 approach. To apply the Tier 2 approach, both the activity data and the emission factors need to be stratified according to the different techniques that may occur in the country.

The Tier 2 approach is as follows:

Stratify the copper production in the country to model the different product and process types occurring in the national copper industry into the inventory by:

- defining the production using each of the separate product and/or process types (together called ‘technologies’ in the formulae below) separately; and
- applying technology specific emission factors for each process type:

$$E_{pollutant} = \sum_{technologies} AR_{production,technology} \times EF_{technology,pollutant} \qquad (2)$$

where:

$AR_{production,technology}$ = the production rate within the source category, using this specific technology

$EF_{technology,pollutant}$ = the emission factor for this technology and this pollutant

A country where only one technology is implemented will result in a penetration factor of 100 % and the algorithm reduces to:

$$E_{pollutant} = AR_{production} \times EF_{technology,pollutant} \qquad (3)$$

where:

$E_{pollutant}$ = the emission of the specified pollutant

$AR_{production}$ = the activity rate for the copper production

$EF_{pollutant}$ = the emission factor for this pollutant

The emission factors in this approach will still include all sub-processes within the industry from the feeding of raw materials until the produced copper is shipped to the customers.

3.3.2 Technology-specific emission factors

This subsection provides specific emission factors for primary and secondary copper production.

For the Tier 2 approach, emissions of NO_x and CO are assumed to originate mainly from combustion and are discussed in chapter 1.A.2.b. All other emissions are assumed to originate primarily from the process and are therefore discussed in this chapter.

Emission factors in the BREF documents are mostly given in ranges. The range is interpreted as the 95% confidence interval, while the geometric mean of this range is chosen as the value for the emission factor in the tables below.

Table 3-2 Tier 2 emission factors for source category 2.C.7.a Copper production, primary copper.

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.C.7.a	Copper production			
Fuel	NA				
SNAP (if applicable)	040309a Copper production				
Technologies/Practices	Primary copper production				
Region or regional conditions					
Abatement technologies					
Not applicable	HCH				
Not estimated	NO_x, CO, NMVOC, NH_3, Se, Zn, PCBs, Benzo(a)pyrene, Benzo(a)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
TSP	320	g/Mg copper	130	800	European Commission (2014)
PM_{10}	260	g/Mg copper	105	640	Visschedijk et al. (2004) applied on TSP
$PM_{2.5}$	200	g/Mg copper	80	480	Visschedijk et al. (2004) applied on TSP
BC	0.1	% of $PM_{2.5}$	0.05	0.2	US EPA (2011, file no.: 91158)
SO_x	10400	g/Mg copper	6 000	18 000	European Commission (2014)
Pb	16	g/Mg copper	6	45	European Commission (2014)
Cd	15	g/Mg copper	12	23	Theloke et al. (2008)
Hg	0.031	g/Mg copper	0.021	0.052	Theloke et al. (2008)
As	7	g/Mg copper	2	27	European Commission (2014)
Cr	21	g/Mg copper	15	29	Theloke et al. (2008)
Cu	57	g/Mg copper	25	130	European Commission (2014)
Ni	19	g/Mg copper	12	29	Theloke et al. (2008)
PCDD/F	0.01	µg I-TEQ/Mg copper	0.003	0.03	UNEP (2005)

Table 3-3 Tier 2 emission factors for source category 2.C.7.a Copper production, secondary copper.

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.C.7.a	Copper production			
Fuel	NA				
SNAP (if applicable)	040309a Copper production				
Technologies/Practices	Secondary copper production				
Region or regional conditions					
Abatement technologies					
Not applicable	HCH				
Not estimated	NO_x, CO, NMVOC, NH_3, Hg, Cr, Se, Zn, Benzo(a)pyrene, Benzo(a)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB,				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
TSP	320	g/Mg copper	100	1 000	European Commission (2014)
PM_{10}	250	g/Mg copper	80	800	Visschedijk et al. (2004) applied on TSP
$PM_{2.5}$	190	g/Mg copper	60	600	Visschedijk et al. (2004) applied on TSP
BC	0.1	% of $PM_{2.5}$	0.05	0.2	US EPA (2011, file no.: 91158)
SO_x	1320	g/Mg copper	500	3 500	European Commission (2014)
Pb	24	g/Mg copper	10	60	European Commission (2014)
Cd	2.3	g/Mg copper	1.1	4.6	Theloke et al. (2008)
As	2	g/Mg copper	0.5	5	European Commission (2014)
Cu	28	g/Mg copper	8	100	European Commission (2014)
Ni	0.13	g/Mg copper	0.057	0.17	Theloke et al. (2008)
PCBs	3.7	μg/Mg copper	2.4	6	Note
PCDD/F	50	μg I-TEQ/Mg copper	0.03	800	UNEP (2005)

Notes: The EF for PCB may be revised in the future based on new information from UNEP: *Toolkit for Identification and Quantification of Releases of Dioxins and Furans and Other Unintentional POPs*: http://chm.pops.int/Implementation/UnintentionalPOPs/ToolkitforUPOPs/Overview/tabid/372/Default.aspx

The BC EF for secondary cupper production is assumed to be the same as for primary production.

These PM factors represent filterable PM emissions only (excluding any condensable fraction).

3.3.3 Abatement

A number of add-on technologies exist that are aimed at reducing the emissions of specific pollutants. The resulting emission can be calculated by replacing the technology specific emission factor with an abated emission factor as given in the formula:

$$EF_{technology,abated} = (1-\eta_{abatement}) \times EF_{technology,unabated} \tag{4}$$

where:

$EF_{technology,\ abated}$ = the emission factor after implementation of the abatement

$\eta_{abatement}$ = the abatement efficiency

$EF_{technology,\ unabated}$ = the emission factor before implementation of the abatement

Typical abatement efficiencies and pollutant flue gas concentrations related to a specific abatement technique can be found in the revised BREF document on the non-ferrous metal industries (European Commission, 2014).

Table 3-4, Table 3-5 and Table 3-6 present default abatement efficiencies for particulate matter, SO_x and heavy metal emissions. The particulate matter (PM) efficiencies for older abatement equipment are based on AP 42 (US EPA, 1998), while efficiencies for modern equipment are based on the draft BREF document for the large combustion plants sector (European Commission, 2013). It should be noted that the efficiencies from the LCP BREF are primarily based on observations made for fly ash from coal-fired power plants. For other types of dust efficiencies may be lower. The abatement efficiencies for heavy metals are based on Theloke et al. (2008) and the SO_x abatement efficiency for sulphuric acid plants is taken from the BREF (European Commission, 2014). Final abatement efficiency is dependent on the maintenance and state of the abatement equipment installed.

Table 3-4 Dust abatement efficiencies ($\eta_{abatement}$) for source category 2.C.7.a Copper production

Tier 2 Abatement efficiencies					
	Code	Name			
NFR Source Category	2.C.7.a	Copper production			
Fuel	NA	not applicable			
SNAP (if applicable)	040309a	Copper production			
Abatement technology	**Pollutant**	**Efficiency**	**95% confidence interval**		**Reference**
		Default Value	**Lower**	**Upper**	
Multicyclone	particle > 10 µm	78.7%	36.2%	92.9%	US EPA (1998)
	10 µm > particle > 2.5 µm	75.8%	27.5%	91.9%	
	2.5 µm > particle	75.0%	25.0%	91.7%	
Spray tower	particle > 10 µm	77.6%	32.7%	92.5%	US EPA (1998)
	10 µm > particle > 2.5 µm	74.4%	23.2%	91.5%	
	2.5 µm > particle	72.5%	17.5%	90.8%	
ESP + spray tower	particle > 10 µm	95.1%	85.3%	98.4%	US EPA (1998)
	10 µm > particle > 2.5 µm	94.6%	83.8%	98.2%	
	2.5 µm > particle	96.3%	88.8%	98.8%	
Wet ESP	particle > 10 µm	98.2%	94.5%	99.4%	US EPA (1998)
	10 µm > particle > 2.5 µm	96.4%	89.2%	98.8%	
	2.5 µm > particle	94.4%	83.1%	98.1%	
Modern ESP	particle > 10 µm	>99.95%			European Commission (2013)
	10 µm > particle > 2.5 µm	>99.95%			
	2.5 µm > particle	97.4%	>96.5%	>98.3%	
Crossflow packed bed scrubber	particle > 10 µm	71.9%	15.7%	90.6%	US EPA (1998)
	10 µm > particle > 2.5 µm	67.9%	3.8%	89.3%	
	2.5 µm > particle	76.9%	30.6%	92.3%	

Floating bed scrubber	particle > 10 µm	79.6%	38.8%	93.2%	US EPA (1998)
	10 µm > particle > 2.5 µm	76.8%	30.4%	92.3%	
	2.5 µm > particle	75.0%	25.0%	91.7%	
Venturi Scrubber	particle > 10 µm	96.7%	90.0%	98.9%	US EPA (1998)
	10 µm > particle > 2.5 µm	96.2%	88.6%	98.7%	
	2.5 µm > particle	92.3%	77.0%	97.4%	
Modern Venturi scrubber	particle > 10 µm	>99.9%			European Commission (2013)
	10 µm > particle > 2.5 µm	99.9%			
	2.5 µm > particle	99.0%	98.5%	99.5%	
Dry + secondary scrubber	particle > 10 µm	99.1%	97.4%	99.7%	US EPA (1998)
	10 µm > particle > 2.5 µm	98.3%	95.0%	99.4%	
	2.5 µm > particle	97.5%	92.5%	99.2%	
Coated fabric filter	particle > 10 µm	98.1%	94.3%	99.4%	US EPA (1998)
	10 µm > particle > 2.5 µm	96.3%	88.8%	98.8%	
	2.5 µm > particle	94.4%	83.1%	98.1%	
Modern fabric filter	particle > 10 µm	>99.95%			European Commission (2013)
	10 µm > particle > 2.5 µm	>99.9%			
	2.5 µm > particle	>99.6%			

Table 3-5 SOx abatement efficiencies (ηabatement) for source category 2.C.7.a Copper production

Tier 2 Abatement efficiencies					
	Code	Name			
NFR Source Category	2.C.7.a	Copper production			
Fuel	NA	not applicable			
SNAP (if applicable)	040309a	Copper production			
Abatement technology	**Pollutant**	**Efficiency**	**95% confidence interval**		**Reference**
		Default Value	**Lower**	**Upper**	
Single contact sulphuric acid plants	SO_x	97.6%	96%	99.10%	European Commission (2014)
Double contact sulphuric acid plants	SO_x	99.6%	99.20%	99.97%	European Commission (2014)

Table 3-6 Metal abatement efficiencies ($\eta_{abatement}$) for source category 2.C.7.a Copper production

Tier 2 Abatement efficiencies					
	Code	Name			
NFR Source Category	2.C.7.a	Copper production			
Fuel	NA	not applicable			
SNAP (if applicable)	040309a	Copper production			
Abatement technology	**Pollutant**	**Efficiency**	**95% confidence interval**		**Reference**
		Default Value	**Lower**	**Upper**	
Dry ESP	Hg	5%	0%	68%	Theloke et al. (2008)
	Cd	84.7%	54%	95%	Theloke et al. (2008)
	Ni	84.7%	54%	95%	Theloke et al. (2008)
	As	84.7%	54%	95%	Theloke et al. (2008)
	Pb	84.7%	54%	95%	Theloke et al. (2008)
State of the art fabric filter	Hg	10%	0%	70%	Theloke et al. (2008)
	Cd	99.99%	99.97%	99.997%	Theloke et al. (2008)
	Ni	99.99%	99.97%	99.997%	Theloke et al. (2008)
	As	99.99%	99.97%	99.997%	Theloke et al. (2008)
	Pb	99.99%	99.97%	99.997%	Theloke et al. (2008)
	PCDD/F	10%	0%	70%	Theloke et al. (2008)

3.3.4 Activity data

Information on the production of copper, suitable for estimating emissions using the simpler estimation methodology (Tier 1 and 2), is widely available from United Nations statistical yearbooks or national statistics.

For a Tier 2 approach these data need to be stratified according to technologies applied. Typical sources for these data might be industrial branch organisations within the country or from specific questionnaires to the individual copper production sites.

3.4 Tier 3 emission modelling and use of facility data

3.4.1 Algorithm

Two different emission estimation go beyond the technology-specific approach described above:

- detailed modelling of the copper production process;
- facility-level emission reports.

Detailed process modelling

A Tier 3 emission estimate using process details will make separate estimates for the consecutive steps in the production process of copper:

- roasting/drying;
- smelting;
- converting;
- fire refining.

Facility-level data

Where facility-level emissions data of sufficient quality (see the guidance chapter on QA/QC in Part A of the Guidebook) are available, it is good practice to indeed use these data. There are two possibilities:

- facility reports cover all copper production in the country;
- facility-level emission reports are not available for all copper plants in the country.

If facility level data cover all copper production in the country, it is good practice to compare the implied emission factors (reported emissions divided by the national copper production) with the default emission factor values or technology-specific emission factors. If the implied emission factors are outside the 95 % confidence intervals for the values given below, it is good practice to explain the reasons for this in the inventory report

If the total annual copper production in the country is not included in the total of the facility reports, it is good practice to estimate the missing part of the national total emissions from the source category, using extrapolation by applying:

$$E_{Total,pollutant} = \sum_{Facilities} E_{Facility,pollutant} + \left(National\ Production - \sum_{Facilities} Production_{Facility} \right) \times EF \tag{5}$$

Where:

$E_{total,pollutant}$	=	the total emission of a pollutant for all facilities within the source category
$E_{facility,pollutant}$	=	the emission of the pollutant as reported by a facility
$Production_{total}$	=	the production rate in the source category
$Production_{facility}$	=	the production rate in a facility
$EF_{pollutant}$	=	the emission factor for the pollutant

Depending on the specific national circumstances and the coverage of the facility-level reports as compared to the total national copper production, it is good practice to choose the emission factor (EF) in this equation from the following possibilities, in decreasing order of preference:

- technology-specific emission factors, based on knowledge of the types of technologies implemented at the facilities where facility level emission reports are not available;
- the implied emission factor derived from the available emission reports:

$$EF = \sum_{Facilities} E_{Facility,pollutant} \Big/ \sum_{Facilities} Production_{Facility} \tag{6}$$

- the default Tier 1 emission factor: this option should only be chosen if the facility level emission reports cover more than 90 % of the total national production.

3.4.2 Tier 3 emission modelling and use of facility data

Copper plants are major industrial facilities and emission data for individual plants might be available through a pollutant release and transfer registry (PRTR) or another emission reporting scheme. When the quality of such data is assured by a well-developed quality assurance/quality control (QA/QC) system and the emission reports have been verified by an independent auditing scheme, it is good practice to use such data. If extrapolation is needed to cover all copper production in the country either the implied emission factors for the facilities that did report, or the emission factors as provided above could be used.

No generally accepted emission models are available for the copper industry. Such models could be developed, however, and used in national inventories. If this happens, it is good practice to compare the results of the model with a Tier 1 or Tier 2 estimate to assess the credibility of the model. If the model provides implied emission factors that lie outside the 95 % confidence intervals indicated in the tables above, it is good practice to include an explanation for this in the documentation with the inventory and preferably reflected in the Informative Inventory Report.

3.4.3 Activity data

Since PRTRs generally do not report activity data, such data in relation to the reported facility level emissions are sometimes difficult to find. A possible source of facility level-activity might be the registries of emission trading systems.

In many countries national statistics offices collect production data on facility level but these are in many cases confidential. However, in several countries, national statistics offices are part of the national emission inventory systems and the extrapolation, if needed, could be performed at the statistics office, ensuring that confidentiality of production data is maintained.

4 Data quality

4.1 Completeness

Care must be taken to include all emissions, from combustion and processes. It is good practice to check, whether the emissions, reported as ‘included elsewhere’ (IE) under chapter 2.C.7.a are indeed included in the emission reported under combustion in chapter 1.A.2.b.

4.2 Avoiding double counting with other sectors

Care must be taken that the emissions are not double counted in processes and combustion. It is good practice to check that the emissions reported under chapter 2.C.7.a are not included in the emission reported under combustion in chapter 1.A.2.b.

4.3 Verification

4.3.1 Best Available Technique emission factors

Table 4-1 provides some typical dust concentrations for processes in best available technique (BAT)-associated facilities.

Table 4-2 provides some typical concentrations for SO_x, dioxins and TVOC in best available technique (BAT)-associated facilities. More information is provided in the revised BREF document for the non-ferrous metal industry (European Commission, 2014).

Table 4-1 BAT-associated dust emission factors for source category 2.C.7.a Copper production

BAT compliant emission factors				
	Code	Name		
NFR Source Category	2.C.5.a	Copper production		
Fuel	N/A	not applicable		
Pollutant		Dust		
Process	**Value**	**Unit**	**95% confidence interval**	
			Lower	**Upper**
Storage, handling and transport of raw materials	2 - 5	mg/Nm3		
Concentrate drying	3 - 5	mg/Nm3		
Primary copper smelter and converter	2 - 5	mg/Nm3		
Secondary copper smelter and converter	2 - 4	mg/Nm3		
Anode furnace	2 - 5	mg/Nm3		
Anode casting	<5 - 15	mg/Nm3		

Table 4-2 BAT-associated emission factors for source category 2.C.7.a Copper production, primary fire refining and melting processes

BAT compliant emission factors				
	Code	Name		
NFR Source Category	2.C.5.a	Copper production		
Fuel	N/A	not applicable		
Pollutant	**Value**	**Unit**	**95% confidence interval**	
			Lower	**Upper**
SOx	<50-500	mg/Nm3		
Dioxins	≤0.1	ng TEQ/Nm3		
TVOC	3 - 30	mg/Nm3		

4.4 Developing a consistent time series and recalculation

No specific issues.

4.5 Uncertainty assessment

In relation to Section 3.3.3, the abatement efficiency is highly dependent on factors such as filter maintenance and operating conditions, absorption agents and filter materials.

4.5.1 Emission factor uncertainties

No specific issues.

4.5.2 Activity data uncertainties

No specific issues.

4.6 Inventory quality assurance/quality control (QA/QC)

No specific issues.

4.7 Gridding

National emission estimates can be disaggregated on the basis of production, population or employment statistics.

4.8 Reporting and documentation

No specific issues.

5 Glossary

$AR_{production, technology}$	The production rate within the source category, using s specific technology
$AR_{production, technology}$	The production rate within the source category, using s specific technology
$AR_{production}$	The activity rate for the copper production
Combustion process with contact	Is a process in which the hot flue gases from a combustion process are directly injected into the reactor where the chemistry and physics take place converting the raw materials into the product. Examples are • Primary iron and steel • Cement • …
$E_{facility, pollutant}$	The emission of the pollutant as reported by a facility
$E_{pollutant}$	The emission of the specified pollutant
$E_{total, pollutant}$	The total emission of a pollutant for all facilities within the source category

$EF_{\text{country, pollutant}}$	A country specific emission factor
$EF_{\text{pollutant}}$	The emission factor for the pollutant
$EF_{\text{technology, abated}}$	The emission factor after implementation of the abatement
$EF_{\text{technology, pollutant}}$	The emission factor for this technology and this pollutant
$EF_{\text{technology, unabated}}$	The emission factor before implementation of the abatement
ESP	Electrostatic precipitator: dust emissions abatement equipment
FF	Fabric filters: dust emissions abatement equipment
$\text{Penetration}_{\text{technology}}$	The fraction of production using a specific technology
$\text{Production}_{\text{facility}}$	The production rate in a facility
$\text{Production}_{\text{total}}$	The production rate in the source category
$\eta_{\text{abatement}}$	The abatement efficiency

6 References

Althaus, H.-J., 2003. *Life Cycle Inventories of Metals*. Ecoinvent database, (www.ecoinvent.ch) accessed 23 July 2019.

Barbour A.K., Castle J.F. and Woods S.E. 1978. *Production of non-ferrous metals. In: Industrial Air Pollution Handbook*. Parker, A. (ed.), Mc Graw-Hill Book Comp. Ltd., London.

European Commission, 2001. *Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques (BREF) in the Non-Ferrous Metal Industries*, (https://eippcb.jrc.ec.europa.eu/reference/) accessed 23 July 2019.

European Commission, 2013. *Integrated Pollution Prevention and Control (IPPC). Draft Reference Document on Best Available Techniques for the Large Combustion Plants*. Draft 1, June 2013, (https://eippcb.jrc.ec.europa.eu/reference/) accessed 23 July 2019.

European Commission, 2014. *Integrated Pollution Prevention and Control (IPPC). Final Draft Reference Document on Best Available Techniques for the Non-Ferrous Metals Industries*. Draft October 2014, (https://eippcb.jrc.ec.europa.eu/reference/) accessed 23 July 2019.

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., Van der Most, P., Hobson, M., Wieser, M., Müller, B., Duval, L., Spezzano, P., Lotz, T., Kakareka, S., 2002. *Combustion and Industry Expert Panel workshop*. European Joint Research Centre (JRC), Ispra.

Theloke, J., Kummer, U., Nitter, S., Geftler, T. and Friedrich, R., 2008. *Überarbeitung der Schwermetallkapitel im CORINAIR Guidebook zur Verbesserung der Emissionsinventare und der Berichterstattung im Rahmen der Genfer Luftreinhaltekonvention*. Report for Umweltbundesamt, April 2008.

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, Czech Republic.

UNEP, 2005. *PCDD/PCDF Toolkit 2005*. United Nations Environmental Programme, Nairobi.

US EPA, 1993. *Locating and estimating air emission from sources of mercury and mercury compounds*. US Environmental Protection Agency, EPA-454/R-93-023, Research Triangle Park, NC.

US EPA, 1995. *AP-42 CD-ROM*. U.S. Environmental Protection Agency, Research Triangle Park, NC.

US EPA, 1998. *AP 42 (5th edition), October 1998, Chapter 12*. US Environmental Protection Agency. Available at: www.epa.gov/ttn/chief/ap42/ch12/index.html. [Accessed 9 July 2009].

US EPA, 2011. SPECIATE database version 4.3, U.S. Environmental Protection Agency's (EPA). Available at: http://cfpub.epa.gov/si/speciate/. (accessed 5 June 2013).

Visschedijk, A.J.H., Pacyna, J., Pulles, T., Zandveld, P. and Denier van der Gon, H., 2004. 'Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP)', In: Dilara, P. *et al.* (eds.), *Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004*. EUR 21302 EN, JRC, pp 163–174.

7 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on Combustion and Industry. Please refer to the TFEIP website (www.tfeip-secretariat.org) for the contact details of the current expert panel leaders.