Category		Title
NFR	2.C.3	Aluminium production
SNAP	040301 030310	Aluminium production (electrolysis) Secondary aluminium production
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Coordinator

Jeroen Kuenen

Contributing authors (including to earlier versions of this chapter)

Jan Berdowski, Pieter van der Most, W. Mulder, Jan Pieter Bloos, Jozef M. Pacyna, Otto Rentz, Dagmar Oertel, Mike Woodfield, Tinus Pulles, Wilfred Appelman and Stijn Dellaert

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1 Overview

Primary aluminium is produced by means of electrolytic reduction of alumina. This chapter covers the complete process of primary aluminium production, from the production of alumina from bauxite until the shipment of the aluminium off the facilities. For secondary aluminium production, it covers the whole process starting from the melting of scrap.

This chapter only covers process emissions from primary and secondary aluminium production. In secondary aluminium production, combustion activities also cause emissions. These emissions are addressed in section 1.A.2.b.

The most important pollutants emitted from the primary aluminium electrolysis process are sulphur dioxide (SO_2), carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAHs) and the greenhouse gas carbon dioxide (CO_2). Polyfluorinated hydrocarbons and fluorides are also produced during the electrolysis process. Dust is emitted mainly during the electrolysis stage in the primary production of aluminium.

2 Description of sources

2.1 Process description

2.1.1 Primary aluminium production

Production of alumina

The production of primary aluminium starts with the production of alumina from bauxite, the so-called “Bayer process”. This is a standard process using caustic soda to extract alumina from bauxite at elevated temperatures and pressures in digesters. The slurry that is produced in this process contains dissolved sodium aluminate and a mixture of metal oxides: bauxite residue (also called red mud) that is removed in the thickeners. The aluminate solution is cooled and seeded with alumina to crystallise hydrated alumina. The crystals are washed and then calcined in rotary kilns or fluid bed/fluid flash calciners before use or shipping. Although this process is standard across the industry, a variety of different equipment is used, in particular with respect to the digesters and calciners.

Electrolytic reduction

Primary aluminium is produced by electrolytic reduction of alumina (Al_2O_3) dissolved in a molten bath of mainly sodium aluminium fluoride (cryolite) at a temperature of approximately 960 °C. The electrolytic process occurs in steel cells lined with carbon. Carbon electrodes extend into the cell and serve as anodes whereas the carbon lining of the cell is the cathode. Liquid aluminium is produced at the cathode, while at the anode oxygen combines with carbon from the anode to form carbon dioxide. The net electrolytic reduction reaction can be written as:

$$2\ Al_2O_3 + 3\ C \rightarrow 4\ Al + 3\ CO_2$$

The alumina is added to the cells, to maintain an alumina content of 2–6 % in the molten bath. A modern plant uses computer controlled additions. Fluoride components are added to lower the bath melting point, making it possible to operate the cells at a lower temperature. Aluminium fluoride

(AlF_3) is also added to neutralise the sodium oxide present as an impurity in the alumina feed. The AlF_3 content of the bath is significantly in excess of the cryolite in modern plants. Consequently, fluoride emissions increase as the excess AlF_3 in the bath is increased.

Refining

After the electrolysis, the metal is refined to remove impurities such as sodium, calcium oxide particles and hydrogen. This refining stage is performed by the injection of a gas into the molten metal usually in an in-line reactor. The treatment gas used varies depending on the impurities. More information can be found in the revised BREF on Non-Ferrous Metals Industries (European Commission, 2014) ([1]).

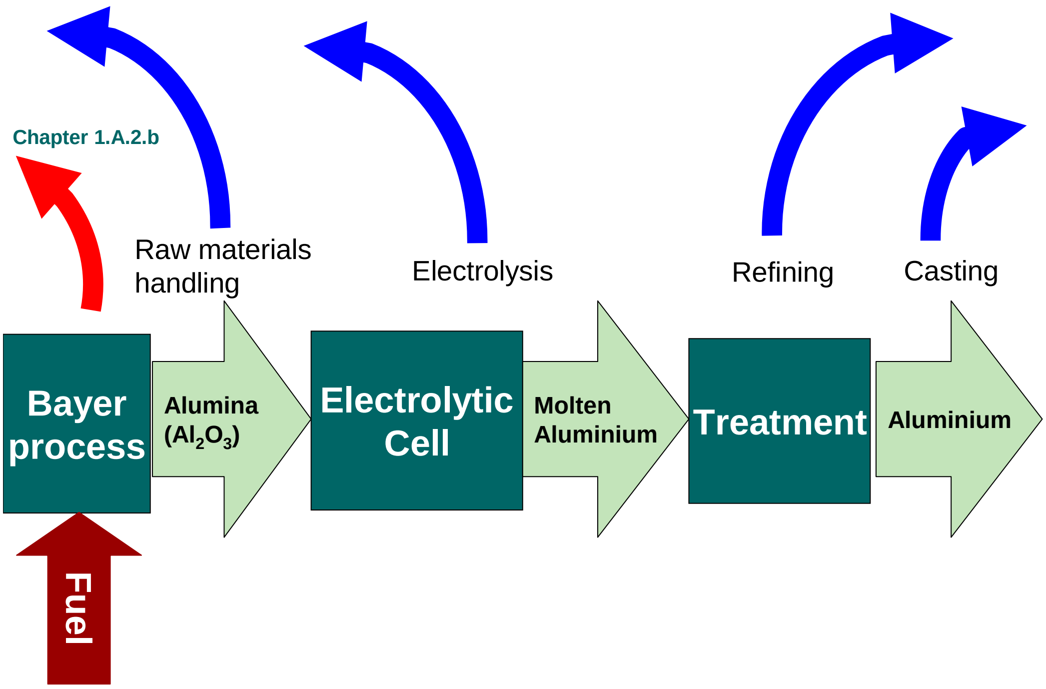
Skimmings are produced at this stage and removed from the surface of the molten metal. They are recycled by the secondary aluminium industry.

Casting

Slabs, T-bars or billets are cast in vertical direct chill casting machines that use water-cooled metal moulds and a holding table at the bottom part of the moulds. The table is lowered as the ingot is formed. Other casting methods include the use of metal moulds (static or continuously moving), continuous casting of thin sheets and continuous casting of wire rod. Additional small quantities of skimmings are also produced at this stage and are removed from the surface of the molten metal.

The process is schematically shown in Figure 2.1.

Figure 2.1 Process scheme for primary aluminium production



([1]) The BREF document for non-ferrous metals industries is presently in the final drafting 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 BREF version was released in 2001 (European Commission, 2001).

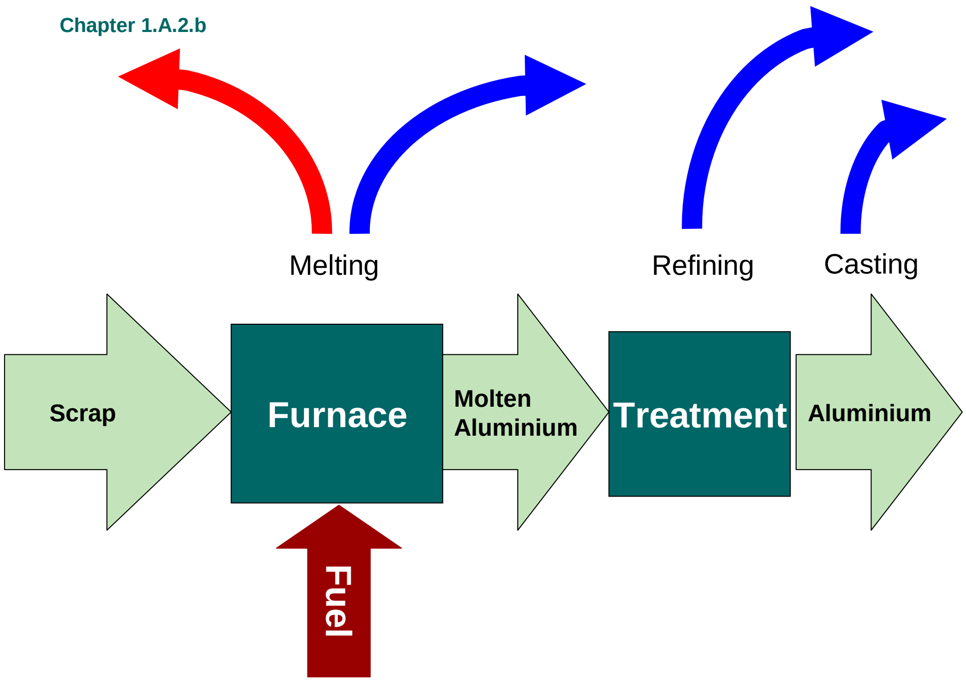
2.1.2 Secondary aluminium production

A secondary aluminium smelter is defined as any plant or factory in which aluminium-bearing scrap or aluminium-bearing materials, other than aluminium-bearing concentrates (ores) derived from a mining operation, are processed into aluminium alloys for industrial castings and ingots. Energy consumption for secondary refining is only about 5 % of that required for primary aluminium production.

The furnace used for melting aluminium scrap depends on the type of scrap and there is a wide variety of scraps and furnaces used. In general, for fabrication scrap and cleaner materials, reverbatory and induction furnaces are used. For more contaminated grades of scrap, rotary furnaces, tilting or horizontal furnaces are used. The scrap may also be pre-treated, depending on type of scrap and contamination. Coated scrap, like used beverage cans, is de-coated as an integrated part of the pre-treatment and melting process. The metal is refined either in the holding furnace or in an inline reactor to remove gases and other metals generally in the same way as for primary aluminium. If magnesium needs to be removed, this is done by treatment with chlorine gas mixtures.

The process is schematically shown in Figure 2.2.

Figure 2.2 Process scheme for secondary aluminium production; there may be some pre-treatment to the raw materials before these are fed to the furnace.



2.2 Techniques

Two techniques are used in the electrolysis process of primary aluminium production. Modern aluminium plants use pre-baked anodes, while in older plants the Søderberg process is used.

- Søderberg anodes are made in situ from a paste of calcined petroleum coke and coal tar pitch, which is baked by the heat arising from the molten bath. The current is fed into the Søderberg anode through studs that have to be withdrawn and re-sited higher in the anode as the anode is consumed. As the anode is consumed, more paste descends through the anode shell, thus providing a process that does not require changing of anodes. Alumina is added periodically to Søderberg cells through holes made by breaking the crust of alumina and frozen electrolyte which covers the molten bath. Automatic point feeding systems are used in upgraded plants, eliminating the need for regular breaking of the crust. A gas skirt is attached to the lower part of the anode casing for gas collection. Fumes are collected and combusted in burners to reduce the emission of tars and PAHs. Pot room ventilation gases may also be collected and treated.

- Pre-baked anodes are manufactured from a mixture of calcined petroleum coke, coal tar pitch, and anode butts which is formed into a block and baked in a separate anode plant. The anode production plant is often an integrated part of the primary aluminium plant and should be included in the definition of installation for such facilities; the contribution of anode production to the total emissions should also be included. The anodes are suspended in the cells by hanger rods attached to anode beams, which also serve as the electrical conductor. The anodes are gradually lowered as they are consumed and are replaced before the rods are attacked by the molten bath. The remnants of the anodes, which are known as anode butts, are cleaned of bath material and recycled through the anode plant.

  Pre-bake cells normally have 12–40 individual anodes, which are changed at regular intervals. In a large pot room, anode changing is a frequent occurrence and involves the removal of the cell cover shields. Although there is usually little leakage from the cell being maintained (depending on the rating of the extraction system), the overall extraction rate from other cells is reduced. This results in an increase in fugitive emissions if several covers are removed at the same time. However, some modern plants also have extra suction on pots when hoods are opened (EAA, 2012).

  Pre-bake cells can be one of two types depending on how alumina is added:

  - Side-worked pre-baked anode cells (SWPB); alumina is fed into the cells after the crust is broken around the circumference. The gas collection hoods over the length of the cells have to be opened during this operation. SWPB plants are any longer operational in Europe (EAA, 2012).
  - Centre-worked pre-baked anode cells (CWPB) are fed with alumina after the crust is broken, along the centreline or at selected points on the centreline of the cell (point feeder or PFPB). These feeding methods are automated and do not require opening the gas collection hoods.

The gas collection system extracts the process gases to an abatement system that uses dry alumina scrubbers to remove and reclaim hydrogen fluoride (HF) and fluorides. The scrubber also removes residual tars but does not remove sulphur dioxide. The alumina leaving the scrubbers is removed in bag filters and is usually fed directly to the cells. Pot-room ventilation gases may also be collected and treated in a wet scrubber system. Due to the efficient collection systems, the treatment of pot-room ventilation air in a wet scrubbing unit is no longer needed and remains in only one case in Europe, for a Søderberg line (EAA, 2012).

The cathode is not consumed in the process but the cathodes deteriorate with time. Carbon blocks absorb electrolyte and after five to eight years have to be replaced due to swelling and cracking which results in penetration of molten electrolyte and aluminium to the cathode conductor bar and steel shell. Small amounts of cyanides are formed through a reaction between nitrogen and carbon. The cathode residue is known as spent pot lining. Several disposal and recycling routes for this material are used and are described later in subsection 4.2.1.4 of the present chapter.

Molten aluminium is periodically withdrawn from the cells by vacuum siphon into crucibles. The crucibles are transported to the casting plant and the aluminium emptied into heated holding furnaces. Alloying additions are made in these furnaces and the temperature is controlled.

Skimmings formed by the oxidation of molten aluminium on the surface of the melt are skimmed off, sealed containers can be used to minimise further oxidation of the skimmings, and nitrogen or argon blanketing is also used.

2.3 Emissions

Emissions may occur during the different stages of the aluminium production process. Significant fuel-related emissions of SO_2 may occur during alumina production due to the use of high sulphur fuels, however, these combustion emissions should be included in NFR category 1.A.2.b. Other processes that yield high emissions are the electrolysis and melting stages, discussed below.

2.3.1 Electrolysis

The main emission during the electrolysis process in primary aluminium production is CO_2, which is an integral part of the process. More information with regard to the CO_2 emissions can be found in the 2006 IPCC Guidelines (IPCC, 2006). Other emissions are as follows.

- The main fluoride pollutants are gaseous HF, aluminium fluoride and cryolite. HF accounts for 50–80 % of the fluoride emissions and is formed by the reaction of aluminium fluoride and cryolite with hydrogen during the electrolysis process. Since the excess of AlF_3 in the process has increased over the years, this emission has become more important.
- Perfluorocarbons (PFCs) are formed as a result of anode effects. Tetra-fluoro methane (CF_4) and hexa-fluoro ethane (C_2F_6) are emitted in the ratio 10:1 and cannot be removed from the gas stream with existing technology once they are formed.
- PAHs are emitted during the anode production. Emissions of PAHs during the electrolysis process are negligible for pre-bake plants but for Søderberg plants in which the anode is self-baked in situ, emissions do occur.
- SO_2 or carbonyl sulphide (COS) is emitted due to the reaction of oxygen with the sulphur that is present in the anodes.
- Dust is emitted during electrolysis as alumina and cryolite. Casting may also be a source of dust emissions. PAHs emission are partly in solid form at ambient temperature.

2.3.2 Melting

There are potential emissions to air of dust, metal compounds, chlorides, hydrogen chloride (HCl) and products of poor combustion such as dioxins and other organic compounds from the melting of primary and secondary aluminium, as well as from treatment furnaces. The formation of dioxins in the combustion zone and in the cooling part of the off-gas treatment system (de-novo synthesis) may be possible. The emissions can escape the process either as stack emissions or as fugitive emissions depending on the age of the plant and the technology used. Stack emissions are normally monitored continuously or periodically and reported by on-site staff or off-site consultants to the competent authorities.

The potential releases to air are:

- Dust (particulate matter) and smoke;
- metal compounds;
- organic materials (volatile organic compounds (VOCs) and dioxins) and CO;
- nitrogen oxides (NO_x) and sulphur dioxide (SO_2);
- chlorides, HCl and HF.

A significant proportion of the emission of these substances is produced by the fuel used and by contamination of the feed material. Some dust is produced by fine dusty scrap and by salt fume.

For more information about the emissions for each process, see the revised BREF document 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).

Energy demand

The production of alumina requires energy for digestion and calcination. The energy use is influenced mainly by the origin and chemical composition of the bauxite, the type of digesters used and the type of calciners used. The range of energy used in European plants is 7.6–11.7 GJ per tonne (European Commission, 2014). The quantities of NaOH and CaO used are also linked to the composition of the bauxite.

The reduction of energy demand is mainly influenced by the use of tube digesters, which are able to operate at higher temperatures using a fused salt heat transfer medium. These plants have an energy consumption of less than 10 GJ per tonne. However, tube digesters are only used in one refinery in Europe and are cannot be retrofitted to an existing configuration (EAA, 2012).

The electrolysis stage has a high energy use ranging from 13 MWh per tonne for the best operated centre work pre-bake (CWPB) cells (including anode production) to 17 MWh per tonne for some traditional Søderberg cells.

The specific energy consumption of secondary aluminium products ranges from 2 GJ/tonne to 9 GJ/tonne. Although the recycling of the lower quality scraps usually requires more energy, secondary aluminium production typically consumes only 5% of the energy needed for the production of primary aluminium (European Commission, 2014).

2.4 Controls

2.4.1 Primary aluminium production

Emission controls include dry scrubbing using alumina as an absorbent for HF removal, followed by fabric filters. The alumina absorbent is later used in the pots. Fugitive emissions from the pot room, particularly at older plants, can be significant. A few older smelters have ventilation air scrubbing systems with seawater for the ventilation air, capturing the fugitive emissions (today only 1 smelter (Søderberg) has ventilation air scrubbing (EAA, 2012)). Modern plants rely on better hooding of the pots to reduce fugitive emissions. Some smelters also have water-scrubbing systems after the dry scrubbing for SO_2 removal.

2.4.2 Secondary aluminium production

Controls in secondary aluminium production should include effective dust collecting arrangements for dust from both primary exhaust gases and fugitive dust emissions. Fabric filters can be used reducing the dust emissions to below 10 mg/m^3.

Fume extraction is an important element in secondary aluminium production as dust and smoke can be formed from contaminants on the feed as well as from the combustion and melting stages (Mantle, 1988). The presence of several possible emission points on a furnace is also significant, and the collection of the emissions from such points needs to be addressed. In addition, various systems may be employed to reduce fugitive emissions during the charging phase of the process. For example, docking cars that seal against the charging door can be used to prevent emissions during charging.

The other important factor is the combustion of organic coatings in the pre-treatment or melting furnace and the extraction and abatement systems can all be designed to cope with the treatment of these emissions. Fugitive emissions can be significant unless the fume collection systems are well designed. Afterburners are used generally to convert unburned VOC to CO_2 and H_2O.

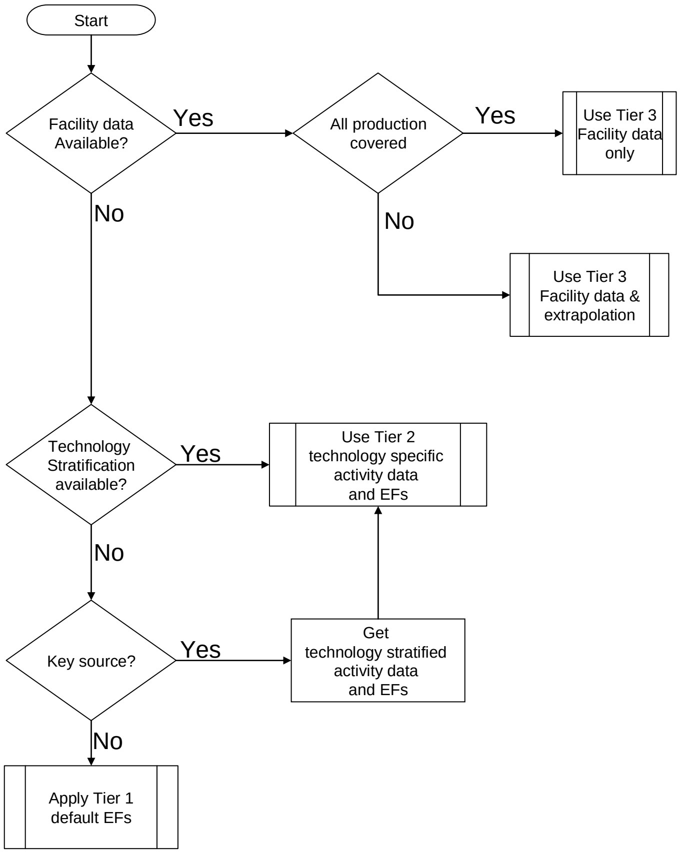
3 Methods

3.1 Choice of method

Figure 3.1 presents the procedure to select the methods for estimating process emissions from the aluminium industry. 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.3 Aluminium production.



3.2 Tier 1 default approach

3.2.1 Algorithm

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

$$E_{pollutant} = AR_{production} \times EF_{pollutant} \quad (1)$$

Where:

$E_{pollutant}$	=	the emission of the specified pollutant
$AR_{production}$	=	the activity rate for the aluminium production
$EF_{pollutant}$	=	the emission factor for the pollutant

This equation is applied at the national level, using annual national total aluminium production.

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 aluminium primary or secondary production.

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 requires emission factors for all relevant pollutants for the production process of primary aluminium. Default emission factors are given in Table 3.1 and have been derived from the revised BREF document for non-ferrous metal production, taking into account the results of an assessment of emission factors included in the earlier versions of the Guidebook. Please bear in mind that these values provide a typical average for primary aluminium production and will depend heavily on the process type (see Tier 2). For secondary aluminium production it is advised to use the Tier 2 methodology. The emission factor for BC (2) is obtained from US EPA, SPECIATE database version 4.3 (US EPA, 2011). The aluminium industry is also a major emitter of fluorides and PFCs but these pollutants are not covered by this Guidebook.

Emissions of NO_x, SO_x and non-methane volatile organic compounds (NMVOCs) are included in this chapter in the Tier 1 approach.

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 table below.

Table 3.1 Tier 1 emission factors for source category 2.C.3 Aluminium production, primary aluminium production

Tier 1 default emission factors					
	Code	Name			
NFR source category	2.C.3	Aluminium production			
Fuel	NA				
Not applicable	PCBs				
Not estimated	NMVOC, NH_3, Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, HCB, PCDD/F				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NO_x	1	kg/Mg aluminium	0.5	2	European Commission (2014)
CO	120	kg/Mg aluminium	100	150	European Commission (2014)
SO_x	4.5	kg/Mg aluminium	0,8	25	European Commission (2014)
TSP	0.9	kg/Mg aluminium	0.2	4	European Commission (2014)
PM_{10}	0.7	kg/Mg aluminium	0.17	3.2	Visschedijk et al. (2004) applied on TSP
$PM_{2.5}$	0.6	kg/Mg aluminium	0.13	2.4	Visschedijk et al. (2004) applied on TSP
BC	2.3	% of $PM_{2.5}$	1.2	4.6	US EPA (2011, file no.: 91137).
Benzo(a)pyrene	9	g/Mg aluminium	5	15	European Commission (2014)
Benzo(b)fluoranthene	9	g/Mg aluminium	5	15	Ratio from Berdowski et al. (1995) applied on BaP
Benzo(k)fluoranthene	9	g/Mg aluminium	5	15	Ratio from Berdowski et al. (1995) applied on BaP
Indeno(1,2,3-cd)pyrene	1.1	g/Mg aluminium	0.6	1.9	Ratio from Berdowski et al. (1995) applied on BaP

(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.

Notes:

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

PAH emissions occur mainly at Søderberg cell facilities. For other types of facilities, PAH emissions are substantially lower (see Tier 2 emission factors);

PCDD/F emissions occurs mainly in secondary aluminium production. For primary production, PCDD/F emissions are not relevant (see Tier 2 emission factors).

3.2.3 Activity data

For the relevant activity statistics, it is good practice to use standard national or international production statistics.

Information on the production of aluminium, suitable for estimating emissions using Tier 1 or Tier 2, is widely available from United Nations statistical yearbooks or national statistics. This information is satisfactory to estimate emissions with the use of the simpler estimation methodology.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), volume 3 on Industrial Processes and Product Use (IPPU), chapter 4.4.2.5, 'Choice of activity data'.

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 approach followed to apply a Tier 2 approach is as follows.

Stratify the aluminium production in the country to model the different product and process types occurring in the national aluminium 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:

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

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:

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

where:

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

$AR_{production}$ = the activity rate for the aluminium 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 aluminium is shipped to the customers.

3.3.2 Technology-specific emission factors

Applying a Tier 2 approach for the process emissions from aluminium production, technology specific emission factors are needed. These are provided in this section. A so-called BREF document for this industry is available at http://eippcb.jrc.es/reference/. In section 4.3.1 emission factors derived from the emission limit values (ELVs) as defined in the BREF document are provided for comparison.

This section provides two technology-specific process emission factors for primary aluminium production, for the electrolysis process using the pre-baked anodes or the Søderberg anodes, as well as typical emission factors applicable to secondary aluminium production.

For primary aluminium, the emissions of NO_x, SO_x and CO are mainly from the process. For secondary aluminium production, however, these originate mainly from combustion and are therefore reported as 'not estimated' in the emission factor table. Guidance on estimating these emissions from secondary aluminium production can be found in chapter 1.A.2.b. 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.

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.

Primary aluminium production — pre-bake cell

Table 3.2 Tier 2 emission factors for source category 2.C.3 Aluminium production, primary aluminium production, pre-baked cell.

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.C.3	Aluminium production			
Fuel	NA				
SNAP (if applicable)	040301 Aluminium production (electrolysis)				
Technologies/Practices	Pre-baked anodes				
Region or regional conditions					
Abatement technologies					
Not applicable	PCBs				
Not estimated	NMVOC, NH_3, Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NO_x	1	kg/Mg aluminium	0.5	2	European Commission (2014)
CO	120	kg/Mg aluminium	100	150	European Commission (2014)
SO_x	5	kg/Mg aluminium	1	25	European Commission (2014)

TSP	0.6	kg/Mg aluminium	0.2	1.7	European Commission (2014)
PM_{10}	0.5	kg/Mg aluminium	0.17	1.4	Visschedijk et al. (2004) applied on TSP
$PM_{2.5}$	0.4	kg/Mg aluminium	0.13	1.0	Visschedijk et al. (2004) applied on TSP
BC	2.3	% of $PM_{2.5}$	1.2	4.6	US EPA (2011, file no.: 91137).
Benzo(a)pyrene	0.07	g/Mg aluminium	0.0015	3	European Commission (2014)
Benzo(b)fluoranthene	0.02	g/Mg aluminium	0.0005	1	Ratio from Berdowski et al. (1995) applied on BaP
Benzo(k)fluoranthene	0.02	g/Mg aluminium	0.0005	1	Ratio from Berdowski et al. (1995) applied on BaP
Indeno(1,2,3-cd)pyrene	0.01	g/Mg aluminium	0.001	0.1	Ratio from Berdowski et al. (1995) applied on BaP

Notes:

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

The PAH emissions arise from the anode production. These emission factors are only applicable when anode production occurs within the same facility/country as the primary aluminium production.

Primary aluminium production – Søderberg cell

Table 3.3 Tier 2 emission factors for source category 2.C.3 Aluminium production, primary aluminium production, Søderberg cell.

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.C.3	Aluminium production			
Fuel	NA				
SNAP (if applicable)	040301 Aluminium production (electrolysis)				
Technologies/Practices	Søderberg anodes				
Region or regional conditions					
Abatement technologies					
Not applicable	PCBs				
Not estimated	NMVOC, NH_3, Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
NO_x	1	kg/Mg aluminium	0.5	2	European Commission (2014)
CO	120	kg/Mg aluminium	100	150	European Commission (2014)
SO_x	4.5	kg/Mg aluminium	0.8	25	European Commission (2014)
TSP	1.8	kg/Mg aluminium	0.8	4	European Commission (2014)
PM_{10}	1.5	kg/Mg aluminium	0.7	3.2	Visschedijk et al. (2004) applied on TSP
$PM_{2.5}$	1.1	kg/Mg aluminium	0.5	2.4	Visschedijk et al. (2004) applied on TSP
BC	2.3	% of $PM_{2.5}$	1.2	4.6	US EPA (2011, file no.: 91137).

Benzo(a)pyrene	9	g/Mg aluminium	5	15	European Commission (2014)
Benzo(b)fluoranthene	9	g/Mg aluminium	5	15	Ratio from Berdowski et al. (1995) applied on BaP
Benzo(k)fluoranthene	9	g/Mg aluminium	5	15	Ratio from Berdowski et al. (1995) applied on BaP
Indeno(1,2,3-cd)pyrene	1.1	g/Mg aluminium	0.6	1.9	Ratio from Berdowski et al. (1995) applied on BaP

Note:

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

Secondary aluminium production

For secondary aluminium production, pollutant emission factors are given in Table 3.4. It is assumed that the NO_x, SO_x and CO emitted from secondary aluminium production is mostly a result of combustion in the production process. Guidance on estimating these emissions is given in chapter 1.A.2.b.

Table 3.4 Tier 2 emission factors for source category 2.C.3 Aluminium production, secondary aluminium production.

Tier 2 default emission factors					
	Code	Name			
NFR source category	2.C.3	Aluminium production			
Fuel	NA				
SNAP (if applicable)	030310 Secondary aluminium production				
Technologies/Practices					
Region or regional conditions					
Abatement technologies					
Not applicable	PCBs				
Not estimated	NO_x, CO, NMVOC, SO_x, NH_3, Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3--cd)pyrene, HCB				
Pollutant	Value	Unit	95 % confidence interval		Reference
			Lower	Upper	
TSP	2	kg/Mg aluminium	1.3	3	Visschedijk et al. (2004)
PM_{10}	1.4	kg/Mg aluminium	0.9	2	Visschedijk et al. (2004)
$PM_{2.5}$	0.55	kg/Mg aluminium	0.4	0.8	Visschedijk et al. (2004)
BC	2.3	% of $PM_{2.5}$	1.2	4.6	US EPA (2011, file no.: 91137).
PCDD/F	35	µg-I-TEQ/Mg aluminium	0.5	150	UNEP (2005)
HCB	5	g/Mg aluminium	0.5	50	PARCOM (1992)

Note:

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:

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

Where

EF technology, abated	=	the emission factor after implementation of the abatement
η 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 3.5presents default abatement efficiencies for a number of abatement options, applicable in the aluminium industry. Abatement efficiencies are available only for particulate emission factors. Abatement efficiencies for older dust abatement equipment in the aluminium production 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, particularly for ESPs.

Table 3.5 Abatement efficiencies ($\eta_{abatement}$) for source category 2.C.3 Aluminium production

Tier 2 Abatement efficiencies					
	Code	Name			
NFR Source Category	2.C.3	Aluminium production			
Fuel	NA	not applicable			
SNAP (if applicable)	040301	Aluminium production (electrolysis)			
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%			

3.3.4 Activity data

Information on the production of aluminium, suitable for estimating emissions using the simpler estimation methodology (Tier 1 and 2), is widely available from United Nations statistical yearbooks or national statistics. This information is satisfactory to estimate emissions with the use of the simpler estimation methodology.

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

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), volume 3 on Industrial Processes and Product Use (IPPU), chapter 4.4.2.5, 'Choice of activity statistics'.

3.4 Tier 3 emission modelling and use of facility data

3.4.1 Algorithm

There are two different methods to apply emission estimation methods that go beyond the technology specific approach described above:

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

Detailed process modelling

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

- production of alumina and pre-treatment;
- electrolysis;
- post-treatment (refining and casting).

For secondary aluminium production, these steps would be:

- pre-treatment of the scrap;
- melting of the scrap;

- post-treatment (refining and casting).

Facility-level data

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

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

If facility level data cover all aluminium production in the country, it is good practice to compare the implied emission factors (reported emissions divided by the national aluminium 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 aluminium 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:

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

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 aluminium 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:

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

- 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

Aluminium production sites 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 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 aluminium 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 (see section 3.3 of the present chapter).

No generally accepted emission models are available for the aluminium 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 at the 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 as well as from processes. It is good practice to check whether the emissions reported as 'included elsewhere' (IE) under chapter 2.C.3 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, whether the emissions, reported under chapter 2.C.3 are not included in the emission reported under combustion in source category 1.A.2.b.

4.3 Verification

4.3.1 Best Available Technique emission factors

This section provides some typical concentrations for 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 emission factors for source category 2.C.3 Aluminium production, electrolysis process in primary aluminium production

BAT compliant emission factors				
	Code	Name		
NFR Source Category	2.C.3	Aluminium production		
Fuel	N/A			
Other		Primary aluminium, electrolysis		
			95% confidence interval	
Pollutant	**Value**	**Unit**	**Lower**	**Upper**
Dust	2 - 5	mg/Nm3		
Polyfluorinated hydrocarbons	< 0.1	kg/Mg aluminium		
Hydrogen Fluoride (HF)	≤ 1	mg/Nm3		
Total Fluoride	≤ 1.5	mg/Nm3		

Table 4.2 BAT-associated emission factors for source category 2.C.3 Aluminium production, melting, molten metal treatment and casting of primary aluminium

BAT compliant emission factors				
	Code	Name		
NFR Source Category	2.C.3	Aluminium production		
Fuel	N/A			
Other		Primary aluminium, melting, molten metal treatment and casting		
			95% confidence interval	
Pollutant	**Value**	**Unit**	**Lower**	**Upper**
Dust	2 - 25	mg/Nm3		

Table 4.3 BAT-associated emission factors for source category 2.C.3 Aluminium production, secondary aluminium production

BAT compliant emission factors				
	Code	Name		
NFR Source Category	2.C.3	Aluminium production		
Fuel	N/A			
Other		Secondary aluminium, furnace processes, re-melting		
			95% confidence interval	
Pollutant	**Value**	**Unit**	**Lower**	**Upper**
Dust	2 - 5	mg/Nm3		
SOx	< 100	mg/Nm3		
Chloride	≤ 0.1	mg/Nm3		
Dioxins	≤ 0.1	ng TEQ/Nm3		
HCl	≤ 5 - 10	mg/Nm3		
VOC	10 - 30	mg/Nm3		
HF	≤ 0.1	mg/Nm3		

4.4 Developing a consistent time series and recalculation

No specific issues.

4.5 Uncertainty assessment

No specific issues.

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

No specific issues.

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 lime production
$E_{facility, pollutant}$	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
$EF_{country, pollutant}$	A country-specific emission factor
$EF_{pollutant}$	The emission factor for the pollutant
$EF_{technology, abated}$	The emission factor after implementation of the abatement
$EF_{technology, pollutant}$	The emission factor for the technology and the pollutant
$EF_{technology, unabated}$	The emission factor before implementation of the abatement
$Penetration_{technology}$	The fraction of production using a specific technology
$Production_{facility}$	The production rate in a facility

Production total	The production rate in the source category
$\eta_{abatement}$	The abatement efficiency

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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.