INTERNATIONAL STANDARD

ISO 19694-4

First edition
2023-03

Stationary source emissions — Determination of greenhouse gas emissions in energy-intensive industries —

Part 4: Aluminium industry

Emissions de sources fixes — Détermination des émissions de gaz à effet de serre dans les industries énergo-intensives —

Partie 4: Industrie de l'aluminium

Reference number
ISO 19694-4:2023(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 1, *Stationary source emissions.*

A list of all parts in the ISO 19694 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document serves the following purposes:

— to measure, test and quantify GHG emissions from the aluminium industry;

— to assess the level of GHG emissions performance of production processes over time at production sites;

— to establish and provide reliable, accurate and quality information for reporting and verification purposes.

This document can be used to measure, report and compare the GHG emissions of an aluminium production facility. Data for individual facilities, sites or works can be combined to measure, report and compare GHG emissions for a company, corporation or group.

Direct fuel-based emissions are not included; for calculation of this part of the GHG emissions, see ISO 19694-1.

This document deals with sector-specific aspects for the determination of greenhouse gas (GHG) emissions from aluminium production and is based on documents mentioned under tier 3 of Section 4.4.2.4 of the 2006 IPCC guidelines[6].

Stationary source emissions — Determination of greenhouse gas emissions in energy-intensive industries —

Part 4: Aluminium industry

1 Scope

This document specifies a harmonized method for calculating the emissions of greenhouse gases from the electrolysis section of primary aluminium smelters and aluminium anode baking plants. This document also specifies key performance indicators for the purpose of benchmarking of aluminium and boundaries.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19694-1, *Stationary source emissions — Determination of greenhouse gas emissions in energy-intensive industries — Part 1: General aspects*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19694-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
aluminium electrolysis
section of an aluminium primary smelter where aluminium is converted from aluminium oxide to aluminium metal in electrolysis cells

3.2
anode baking plant
production of carbon anodes for use in aluminium prebake electrolysis cells

3.3
PFC gas
gas emitted from *aluminium electrolysis* (3.1) consisting of CF_4 and C_2F_6

3.4
grid specific CO_2 factor
CO_2 factor (t CO_2/MWh) associated with the electricity delivered to a specific aluminium smelter from their supplier

Note 1 to entry: The unit for grid specific CO_2 factor is t CO_2/MWh.

4 Symbols and abbreviated terms

4.1 Abbreviated terms

AE	Anode effect
CWPB	Centre-worked prebake
DAE	Direct anode emissions
DEE	Direct electrolysis emissions
GHG	Green house gas
HSS	Horizontal stud Søderberg
IPCC	Intergovernmental Panel on Climate Change
PFC	Perfluorocarbon
PFPB	Point feeder prebake
SWPB	Side-worked prebake
TIE	Electrolysis electricity consumption
VSS	Vertical stud Søderberg
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

4.2 Symbols and chemical formulae

4.2.1 Symbols

A_{EM}	Anode effect minutes per cell-day (equals to frequency multiplied by average duration)
A_{EO}	Anode effect overvoltage
A_{NC}	Net anode consumption
A_{sha}	Ash content in baked anodes
A_{shp}	Ash content in pitch, % mass fraction
A_{shpc}	Ash content in packing coke, % mass fraction
B_A	Baked anode production
B_{AW}	Baked anode mass
B_C	typical binder content in paste, % mass fraction
C_{BA}	Carbon content of baked anodes
C_{Butt}	Carbon content of anode butts
C_E	Current efficiency for aluminium production

C_D Carbon in skimmed dust from anode from Søderberg cells, tonnes carbon per tonne aluminium

C_{SM} Emissions of cyclohexane soluble matter, kilograms per tonnes aluminium

E_{CF_4} Emissions of tetrafluoromethane, kg CF_4 per year

$E_{C_2F_6}$ Emissions of hexafluoroethane, kg C_2F_6 per year

E_{CO_2} CO_2 emissions, tonnes per year

E_{FPC} Emission factor of packing coke, tCO_2/t of packing coke

$F_{\frac{C_2F_6}{CF_4}}$ Mass fraction of $\frac{C_2F_6}{CF_4}$

G_A Mass of loaded green anodes, $G_A = \left(\frac{G_{AW}}{B_{AW}}\right)B_A$

G_{AW} Green anode mass

G_{WP} Global warming potential; use latest G_{WP} data from IPCC

H_w Hydrogen content in green anode

H_p Hydrogen content in pitch, % mass fraction

M_{BA} Total mass of baked anodes

M_{Butt} Total mass of anode butts

M_P Total metal production, tonnes aluminium per year

N_{AC} Net anode consumption, tonnes per tonnes aluminium

O_{FPC} Oxidation factor of packing coke (typically 1 for this stream)

O_{VC} Overvoltage coefficient for CF_4

P_C Paste consumption, tonnes per tonnes aluminium

P_{CC} Packing coke consumed per tonnes of baked anode

P_{CW} Packing coke mass

R_{CF_4} Emission rates of CF_4, kg per tonne of aluminium produced

$R_{C_2F_6}$ Emission rates of C_2F_6, kg per tonne of aluminium produced

S_a Sulfur content in baked anodes

S_c Sulfur content in calcined coke, % mass fraction

S_p Sulfur content in pitch, % mass fraction

S_{pc} Sulfur content in packing coke, % mass fraction

S_{CF_4} Slope coefficient for CF_4, kg CF_4 per tonne aluminium per anode effect minute per cell day

W_T Waste tar collected

4.2.2 Chemical formulae

Al	Aluminium
Al_2O_3	Aluminium oxide (alumina)
C	Carbon
CF_4	Tetrafluoromethane
C_2F_6	Hexafluoroethane
CO	Carbon monoxide
CO_2	Carbon dioxide
$NaAlF_6$	Sodium aluminium hexafluoride (cryolite)
NaF	Sodium fluoride

5 Calculation methods — General remarks

5.1 General

This document shall be used in conjunction with ISO 19694-1 which contains generic, overall requirements, definitions and rules applicable to the determination of GHG emissions for all energy-intensive sectors, provides common methodological issues and specifies the details for applying the rules. The application of this document to the sector-specific standards ensures accuracy, precision and reproducibility of the results.

5.2 Calculation methods for process GHG emissions from primary aluminium production

Figure 1 gives sources of process emissions and references to where in the standard calculation methods are specified.

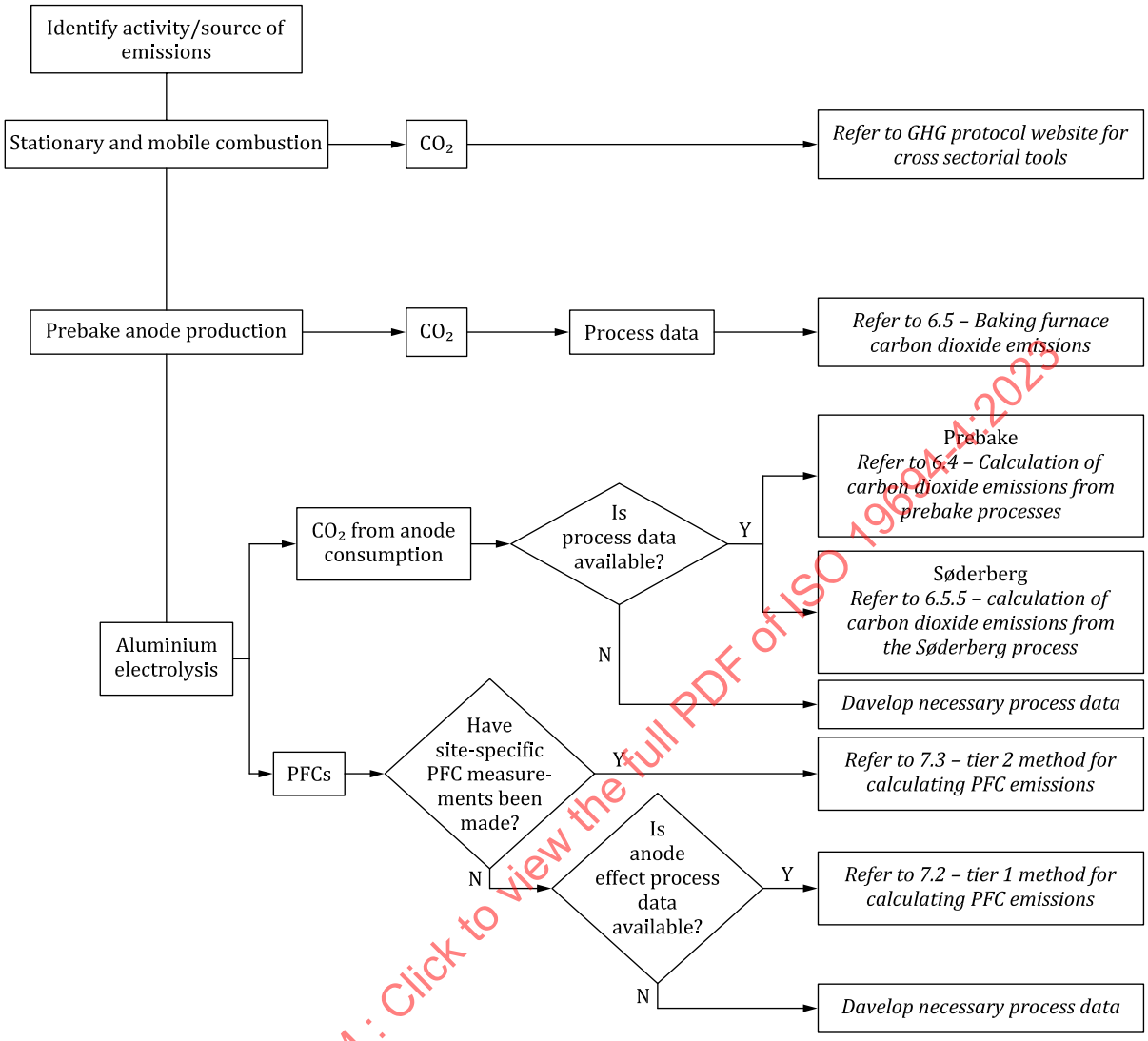

Figure 1 — Decision tree for process carbon dioxide and perfluorocarbon emissions from primary aluminium production

Process CO_2 emissions in state-of-the-art aluminium smelters comprise around 90 % of total direct CO_2 equivalent emissions, with the balance of emissions consisting of CO_2 from fossil fuel combustion and PFC emissions. Guidance on CO_2 emissions from fuel combustion is not included in this document. Methodology for calculating CO_2 emissions from the combustion of fuel in anode baking furnaces is described elsewhere[6],[7], while methodology for calculating process CO_2 emissions is given in Clause 7.

5.3 Sources of greenhouse gases

5.3.1 Electrolysis

Most of the CO_2 emissions result from the electrolytic reaction of the carbon anode with alumina as given in Formula (1):

$$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2 \quad (1)$$

Carbon dioxide is also emitted during the electrolysis reaction as the carbon anode reacts with other sources of oxygen, primarily from the air. Carbon dioxide is also formed as a result of the Boudouard reaction where CO_2 reacts with the carbon anode forming carbon monoxide, which is then oxidized to

form CO_2. Each unit of CO_2 participating in the Boudouard reaction produces two units of CO_2 after air oxidation [see Formulae (2) and (3)]:

$$CO_2 + C \rightarrow 2CO \quad (2)$$

$$2CO + O_2 \rightarrow 2CO_2 \quad (3)$$

All carbon monoxide formed is assumed to be converted to CO_2. By industry convention, no correction is made for the minute amount of carbon consumed as PFCs rather than CO_2 emissions. No CO_2 is produced from cathode consumption unless there is on-site incineration and no recommendation is included here. For such operations, CO_2 emission from addition of sodium carbonate to electrolyses cells is not included as this is added at infrequent intervals and is an insignificant source.

5.3.2 Anode baking

Another source of CO_2 emissions, specific to prebake technologies, is the baking of green anodes, wherein CO_2 is emitted from the combustion of volatile components from the pitch binder and, for baking furnaces fired with carbon based fuels, from the combustion of the fuel source. Some of the packing coke used to cover the anodes is also oxidized, releasing CO_2 during anode baking.

Carbon dioxide is emitted from the fuel used in the paste plant and the fuel used for firing the anode baking furnace.

5.3.3 Aluminium smelting supporting processes

A further source of carbon dioxide emissions is fuel used in the cast house for heating of the metal during treatment processes before casting, and some fuel can also be used in rodding operations.

5.3.4 Alumina refining

Carbon dioxide is not produced as process emission in the Bayer Process, the process through which alumina is refined from bauxite ore. Most of the emissions associated with alumina refining are from the combustion of fossil fuels, which are covered in the WRI/WBCSD[10] calculation tools for GHG emissions from energy and electricity.

5.3.5 Sources of PFC

Two perfluorocarbon gases (PFCs), tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6), can be produced during primary aluminium production [see Formulae (4) and (5)].

$$4Na_3AlF_6 + 3C \rightarrow 4Al + 12NaF + 3CF_4 \quad (4)$$

$$4Na_3AlF_6 + 4C \rightarrow 4Al + 12NaF + 2C_2F_6 \quad (5)$$

NOTE The following recommendations for calculating PFC emissions are consistent with the inventory guidance of the Intergovernmental Panel on Climate Change (IPCC)[6],[15].

6 Methods for calculation of process greenhouse gas emissions

6.1 General

Direct CO_2 emissions from aluminium production shall be calculated by using one of the following two tiers:

— tier 1: process specific formulae with industry typical parameters;

— tier 2: process specific formulae with site or company specific parameters.

NOTE Tier 1 and tier 2 in this document correspond to what is listed as tier 2 and tier 3 in the IPCC technical guidance[6].

Reference should be made to Figure 1 as an overall guide on how to proceed when calculating direct CO_2 emissions. For calculation of key performance indicator, tier 2 shall be used.

6.2 Tier 1 — Method using process specific formulae with technology typical parameters for carbon dioxide emissions

Tier 1 method for the calculation of total direct CO_2 emissions shall be based on the calculation of CO_2 emissions from each individual process step which are then summed to calculate total emissions. Formulae in 6.4 specify the calculation of CO_2 for prebake technologies, while 6.5.5 contains the formulae for Søderberg technologies.

6.3 Tier 2 — Method using process specific formulae with facility specific parameters for carbon dioxide emissions

The most accurate inventories of CO_2 are obtained by using site or company specific data in the formulae for calculating emissions (tier 2 method). This data can come from measurements made on site or from data from suppliers. The formulae are identical to those used in the tier 1 method specified above. However, facility specific or company specific data, rather than technology typical data, shall be used.

6.4 Calculation of carbon dioxide emissions from prebake processes

6.4.1 General

Carbon dioxide emissions resulting from CWPB and SWPB reduction technologies have as their sources electrolysis and anode baking.

6.4.2 Greenhouse gas emissions from prebake anode consumption during electrolysis

The following formula should be used for calculation of CO_2 emissions from prebake anode consumption during electrolysis:

$$E_{CO_2} = \left[M_P \times N_{AC} \left(\frac{100 - S_a - A_{sha}}{100} \right) \right] \times 3{,}664 \quad (6)$$

where

E_{CO_2} is the CO_2 emissions in tonnes per year;

M_P is the total metal production, tonnes aluminium per year;

N_{AC} is the net anode consumption, tonnes per tonne aluminium;

S_a is the sulfur content in baked anodes, % mass fraction;

A_{sha} is the ash content in baked anodes, % mass fraction;

3,664 is the CO_2 molecular mass: carbon atomic mass ratio, t CO_2/t C.

Parameters used in Formula (6) are specified in Table 2 together with technology typical values for calculating CO_2 emissions from prebake anode consumption during electrolysis.

Alternatively, the following formula may also be used:

$$E_{CO_2} = (M_{BA} \times C_{BA} - M_{Butt} \times C_{Butt}) \times 3{,}664 \quad (7)$$

where

E_{CO_2} is the CO_2 emissions, tonnes per year;

M_{BA} is the total mass of baked anodes, tonnes anodes per year;

C_{BA} is the carbon content of baked anodes, % mass fraction;

M_{Butt} is the total mass of anode butts, tonnes anodes per year;

C_{Butt} is the carbon content of anode butts, % mass fraction.

Parameters used in Formula (7) are defined in Table 1 together with technology typical values for calculating CO_2 emissions from prebake anode consumption during electrolysis.

Table 1 — Typical uncertainty for individual parameters and analyses used in tier 1 or tier 2 method for carbon dioxide emissions from prebake cells

Parameter	Tier 1 method		Tier 2 method	
	Data source	Data uncertainty ±%	Data source	Data uncertainty ±%
M_P, tonnes aluminium per year	Individual facility records	2	Individual facility records	2
N_{AC}, tonnes per tonne aluminium	Individual facility records	5	Individual facility records	5
S_a, % mass fraction	Use industry typical value, 2	3	Individual facility records	3
A_{sha}, % mass fraction	Use industry typical value, 0,4	3	Individual facility records	3
M_{BA}, tonnes anodes per year	Individual facility records	2	Individual facility records	2
C_{BA}, % mass fraction	Use industry typical value, 98	5	Individual facility records	2
M_{Butt}, tonnes anodes per year	Individual facility records	2	Individual facility records	2
C_{Butt}, % mass fraction	Use industry typical value, 98	5	Individual facility records	2

6.5 Baking furnace greenhouse gas emissions

6.5.1 General

Baking furnace emissions result from three sources:

— combustion of the fuel for firing the furnace;

— combustion of volatile matter released during the baking operation;

— combustion of baking furnace packing material.

6.5.2 Fuel

Carbon dioxide emissions resulting from the fuel consumed during baking furnace firing can be calculated using the WRI/WBCSD[10] calculation tools for GHG emissions from energy and electricity.

6.5.3 Combustion of volatile matter

Calculation of carbon dioxide emissions from pitch volatiles combustion should be calculated according to:

$$E_{CO_2} = \left[G_A - \left(\frac{H_W \times G_A}{100} \right) - B_A - W_T \right] \times 3{,}664 \quad (8)$$

where

E_{CO_2} is the CO_2 emissions, tonnes per year;

G_A is the mass of loaded green anodes, $G_A = \left(\frac{G_{AW}}{B_{AW}} \right) B_A$;

G_{AW} is the green anode mass, tonnes;

B_{AW} is the baked anode mass, tonnes;

B_A is the baked anode production, tonnes baked anode per year;

H_W is the hydrogen content in green anodes, % mass fraction;

W_T is the waste tar collected, tonnes;

3,664 is the CO_2 molecular mass: carbon atomic mass ratio, dimensionless.

Parameters included in Formula (8) are specified and industry typical values noted in Table 2.

Alternatively, Formula (9) may also be used:

$$E_{CO_2} = (G_{AW} \times C_{GA} - B_{AW} \times C_{BA}) \times 3{,}664 \quad (9)$$

where

E_{CO_2} is the CO_2 emissions, tonnes per year;

G_{AW} is the green anodes mass, tonnes;

C_{GA} is the carbon content of green anodes, % mass fraction;

B_{AW} is the baked anodes mass, tonnes;

C_{BA} is the carbon content of baked anodes, % mass fraction.

Table 2 — Typical uncertainty for individual parameters and analyses used in tier 1 or tier 2 method for CO_2 emissions from bake furnace pitch volatiles combustion

Parameter	Tier 1 method		Tier 2 method	
	Data source	Data uncertainty ±%	Data source	Data uncertainty ±%
G_{AW}, in tonnes	Individual facility records	2	Individual facility records	2
B_{AW}, in tonnes	Individual facility records	2	Individual facility records	2
H_W, in % mass fraction	Use industry typical value, 0,5	5	Individual facility records	5
B_A, in tonnes per year	Individual facility records	2	Individual facility records	2
W_T, in tonnes a) Riedhammer furnaces b) All other furnaces	Use industry typical value: a) 0,005 × G_A b) Insignificant	20	Individual facility records	20
C_{GA}, in % mass fraction	Use industry typical value, 98	5	Individual facility records	2
C_{BA}, in % mass fraction	Use industry typical value, 98	5	Individual facility records	2

6.5.4 Baking furnace packing material

Carbon dioxide emissions from packing coke should be calculated according to:

$$E_{CO_2} = \left[P_{CC} \times B_A \left(\frac{100 - S_{pc} - A_{shpc}}{100} \right) \right] \times 3{,}664 \quad (10)$$

where

E_{CO_2} is the CO_2 emissions, tonnes per year;

P_{CC} is the packing coke consumed, tonnes per tonne of baked anode;

B_A is the baked anode production, tonnes baked anode per year;

S_{pc} is the sulfur content in packing coke, % mass fraction;

A_{shpc} is the ash content in packing coke, % mass fraction;

3,664 is the CO_2 molecular mass: carbon atomic mass ratio, dimensionless.

Parameters included in Formula (10) are specified and industry typical values noted in Table 3.

Alternatively, by considering packing coke as a fuel, Formula (11) may be used:

$$E_{CO_2} = P_{CW} \times E_{FPC} \times O_{FPC} \quad (11)$$

where

E_{CO_2} are the CO_2 emissions, tonnes per year;

P_{CW} is the packing coke mass, tonnes;

E_{FPC} is the emission factor of packing coke, tCO_2/t of packing coke;

O_{FPC} is the oxidation factor of packing coke (typically 1 for this stream).

Table 3 — Typical uncertainty for individual paramters and analyses used in tier 1 or tier 2 method for carbon dioxide emissions from oxidation of bake furnace packing material

Parameter	Tier 1 method		Tier 2 method	
	Data source	Data uncertainty ±%	Data source	Data uncertainty ±%
P_{CC}, in tonnes per tonne BA	Use industry typical value, 0,015	7,5	Individual facility records	2
B_A, in tonnes per year	Individual facility records	2	Individual facility records	2
S_{pc}, in % mass fraction	Use industry typical value, 2	5	Individual facility records	6
A_{shpc}, in % mass fraction	Use industry typical value, 2,5	5	Individual facility records	6
P_{CW}, in tonnes	Individual facility records	2	Individual facility records	2
E_{FPC}, in t CO_2/t of packing coke	3,19[4]	Not relevant	3,19[4]	Not relevant
O_{FPC}	1	Not relevant	1	Not relevant

6.5.5 Calculation of greenhouse gas emissions from the Søderberg process

Carbon dioxide process emissions for Søderberg technologies shall be calculated according to:

$$E_{CO_2} = \left[\begin{array}{l} (M_P \times P_C) - \left(C_{SM} \times {M_P}/{1\,000} \right) - \left[\left({B_C}/{100} \right) P_C \times M_P \left(\dfrac{S_p + A_{shp} + H_p}{100} \right) \right] \\ - \left[\left(\dfrac{100 - B_C}{100} \right) P_C \times M_P \left(\dfrac{S_c + A_{shc}}{100} \right) \right] - (M_P \times C_D) \end{array} \right] \times 3{,}664 \quad (12)$$

NOTE An acceptable alternative method is to use the parameter of 'pitch coking' in lieu of deducting measured or default values for S_p, H_p, A_{shp} and C_{SM} from Formula (4). The pitch coking value is a commonly determined parameter for many facilities with Søderberg cells.

where

E_{CO_2} is the CO_2 emissions, tonnes per year;

M_P is the total metal production, tonnes aluminium per year;

P_C is the paste consumption, tonnes per tonne aluminium;

C_{SM} is the emission of cyclohexane soluble matter, kg per tonne aluminium;

B_C is the typical binder content in paste, % mass fraction;

S_p is the sulfur content in pitch, % mass fraction;

A_{shp} is the ash content in pitch, % mass fraction;

H_p is the hydrogen content in pitch, % mass fraction;

S_c is the sulfur content in calcined coke, % mass fraction;

A_{shc} is the ash content in calcined coke, % mass fraction;

C_D is the carbon in skimmed dust from Søderberg cells, tonnes carbon per tonne aluminium;

3,664 is the CO_2 molecular mass: carbon atomic mass ratio, dimensionless.

Parameters used in Formula (12) are specified in Table 4 together with industry typical values for calculating CO_2 emissions for Søderberg technologies.

Table 4 — Typical uncertainty for individual parameters and analyses used in tier 1 or tier 2 method for carbon dioxide emissions from Søderberg cells

Parameter[a]	Tier 1 Method		Tier 2 Method	
	Data source	Data uncertainty ±%	Data source	Data uncertainty ±%
M_P, in tonnes per year	Individual facility records	2	Individual facility records	2
P_C, in tonnes per tonne aluminium	Individual facility records	2–5	Individual facility records	2–5
C_{SM}, in kg per tonne aluminium	Use industry typical value, HSS – 4,0 VSS – 0,5	30	Individual facility records	15
B_C, in % mass fraction	Use industry typical value, dry paste – 24 wet paste – 27	25	Individual facility records	5
S_p, in % mass fraction	Use industry typical value, 0,6	20	Individual facility records	10
A_{shp}, in % mass fraction	Use industry typical value, 0,2	20	Individual facility records	10
H_p, in % mass fraction	Use industry typical value, 3,3	20	Individual facility records	10
S_c, in % mass fraction	Use industry typical value, 1,9	20	Individual facility records	10
A_{shc}, in % mass fraction	Use industry typical value, 0,2	20	Individual facility records	10
C_D, in tonnes per tonne aluminium	Use industry typical value, 0,01	99	Individual facility records	30

[a] The influence of some parameters with high uncertainty is very low on the total GHG emissions.

Referring to Formula (12), the overall uncertainty is approximately 5 %.

7 Methods for calculation of PFC emissions

7.1 General

Three sequential steps specified below shall be used to calculate the carbon dioxide equivalent emissions represented by PFC emissions from primary aluminium production.

— Emissions of each of the two PFC gases are first calculated per tonne of primary aluminium produced.

— These emission rates per tonne of aluminium are multiplied by the total production of aluminium during the time period for which the inventory is being developed.

— The equivalent CO_2 emissions are calculated by multiplying the PFC emissions by appropriate global warming potential (G_{WP}) factors.

Two separate approaches are specified below for calculating PFC emissions per tonne of aluminium with relative uncertainty varying from low to high.

Tier 1 is a method using a combination of plant specific process data and technology specific slope factor.

Tier 2 is a method using plant specific process data and plant specific slope factor.

Plant specific process data and plant specific slope factors should be measured by using the Tier 2 method with an uncertainty of less than 15 %. Tier 1 is only suitable for the calculation of PFC emissions in case Tier 2 is not feasible for economic or technical reasons.

7.2 Tier 1 method for calculating PFC emissions

This method is based on calculations using site specific anode effect or overvoltage process data but industry average coefficients in place of coefficients calculated from site specific measurements of PFC gases. PFC emission rates and CO_2 equivalent emissions should be calculated as in the Tier 2

method using Formulae (17) and (18) in 7.4.2. The current recommended average slope and overvoltage coefficients are listed in Table 5.

Table 5 — Technology-specific slope and overvoltage coefficients for the calculation of PFC emissions per tonne aluminium from AE process data

Technology	Slope coefficient [a, b] (kg_{PFC}/t_{Al}) / (AE-mins/cell-day)		Overvoltage coefficient [a, b, c, d] (kg_{CF4}/t_{Al}) / (mV)		Mass fraction C_2F_6/CF_4 %	
	S_{CF_4}	Uncertainty ±%	O_{VC}	Uncertainty ±%	$F_{C_2F_6/CF_4}$	Uncertainty ±%
CWPB	0,143	6	1,16	24	0,121	11
SWPB	0,272	15	3,65	43	0,252	23
VSS	0,092	17	NR	NR	0,053	15
HSS	0,099	44	NR	NR	0,085	48

Key

NR : not relevant

[a] This data has been taken from Reference [11] through sponsored measurements and at multiple site measurements.

[b] Embedded in each slope and overvoltage coefficient is an assumed emissions collection efficiency as follows: CWPB 98 %, SWPB 90 %, VSS 85 %, HSS 90 %. These collection efficiencies have been assumed based on measured PFC collection fractions, measured fluoride collection efficiencies and expert opinion.

[c] The noted coefficients reflect measurements made at some facilities recording positive overvoltage and others recording algebraic overvoltage. No robust relationship has yet been established between positive and algebraic overvoltage. Positive overvoltage should provide a better correlation with PFC emissions than algebraic overvoltage.

[d] Overvoltage coefficients are not relevant to VSS and HSS technologies.

The latest revision of the EPA/IAI GHG Protocol[11] should be considered and thereof updated values applied.

The uncertainties indicated in Table 5 refer to the determination of the industry average of the technology-specific coefficients. The plant-specific uncertainties of the PFC calculation using the tier 1 approach, applying these coefficients, can be significantly higher than those reached through the tier 2 approach. Data regarding the variation of these values are found in Reference [8].

7.3 Tier 2 method for calculating PFC emissions

This method is based on calculations using site-specific anode effect process data, aluminium production data and coefficients based on direct local facility measurements of PFCs. The measurements on which the coefficients are based on should be made according to Reference [11] – if FTIR is applied, ISO 20264 should be considered.

7.4 Calculation of PFC emissions from aluminium reduction processes

7.4.1 Step 1 — Calculation of the emissions of each PFC gas per tonne of aluminium

7.4.1.1 General

PFC emissions per tonne aluminium shall be calculated by either the slope method or the overvoltage method depending on the type of anode effect process data recorded at the facility.

7.4.1.2 Calculation of the emission rate of CF_4 and C_2F_6 per tonne aluminium using anode effect minutes per cell day — Slope method

The slope coefficient is the kg of CF_4 per tonne of aluminium produced, divided by anode effect minutes per cell-day. Since PFC emissions are measured per tonne of aluminium produced, the slope coefficient includes the effects of pot amperage and current efficiency, the two main factors determining the amount of aluminium produced in the pot.