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

固定源排放—能源密集型工业中温室气体排放的测定

Part 4: Aluminium industry

第4部分：铝工业

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内容

Foreword

前言

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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).

ISO/IEC 指令第1部分描述了用于编制本文件和用于进一步维护的程序。特别是，应注意不同类型的 ISO 文件所需的不同批准标准。本文件根据 ISO/IEC 指令第2部分的编辑规则起草(见 www.iso.org/directives)。

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

本文件由技术委员会ISO/TC146、空气质量、小组委员会SC1、固定源排放编制。

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

ISO19694系列中所有部件的列表可以在ISO网站上找到。

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Introduction

This document serves the following purposes:
本文件的目的如下:

— to measure, test and quantify GHG emissions from the aluminium industry;
-计量、检测和量化铝工业的碳排放量;

— to assess the level of GHG emissions performance of production processes over time at production sites;
-评估生产工序在一段时间内的温室气体排放情况;

— to establish and provide reliable, accurate and quality information for reporting and verification purposes.
-建立和提供可靠、准确和高质量的信息以供报告和核查之用。

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.
该文件可用于核算、报告和比较铝生产设施的温室气体排放。单个设施、场地或工程的数据可以结合起来衡量、报告和比较一个公司、法人（团体）或集团的温室气体排放。

Direct fuel-based emissions are not included; for calculation of this part of the GHG emissions, see ISO 19694-1.
燃料的直接排放不包括在内;关于这部分温室气体排放量的计算，见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].
本文件涉及确定铝生产温室气体(GHG)排放的特定行业方面，并基于2006年IPCC指南第4.4.2.4节第3级提到的文件。

Stationary source emissions — Determination of greenhouse gas emissions in energy-intensive industries —
固定源 —排放能源密集型工业中温室气体排放的测定 —

Part 4:
Aluminium industry
铝工业

1 Scope
1 范围

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.

本文件规定了计算原铝电解工厂和铝用预焙阳极工厂温室气体排放量的统一方法。该文件还规定了铝的关键绩效指标和边界基准。

2 Normative references

2 规范性引用文件

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.

在本文中提及以下文件时，其部分或全部内容构成本文件的要求。对于注明日期的参考文件，只适用所引用的版本。对于未注明日期的参考文件，适用参考文件的最新版本 (包括任何修订) 。

ISO 19694-1, *Stationary source emissions — Determination ofgreenhouse gas emissions in energy-intensive industries — Part 1: General aspects*
ISO 19694-1，固定源排放能源密集型工业中温室气体排放的测定第1部分：通用要求

3 Terms and definitions

3 术语和定义

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

本文件适用ISO 19694-1中给出的术语和定义。

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/

ISO和IEC在以下地址维护用于标准化的术语数据库:
—ISO在线浏览平台:https://www.iso.org/obp
- IEC电子百科:可从https://www.electropedia.org/获得

3.1
aluminium electrolysis

3.1
电解铝

section of an aluminium primary smelter where aluminium is converted from aluminium oxide to aluminium metal in electrolysis cells
原铝冶炼厂的一部分，铝在电解槽中由氧化铝转化为铝金属。

3.2
anode baking plant

3.2
焙烧阳极车间

production of carbon anodes for use in aluminium prebake electrolysis cells
用于预焙电解槽的碳阳极生产

3.3
PFC gas

3.3
PFC气体

gas emitted from *aluminium electrolysis* (3.1) consisting of CF_4 and C_2F_6
铝电解过程排放的由CF_4和C_2F_6组成的气体

3.4
grid specific CO_2 factor

3.4
电网特定的CO_2因子

CO_2 factor (t CO_2/MWh) associated with the electricity delivered to a specific aluminium smelter from their supplier
二氧化碳因子(t CO_2/MWh)与从供应商输送到特定铝冶炼厂的电力相关

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

注1:电网比CO_2因子单位为tCO_2/MWh。

4 Symbols and abbreviated terms
4 符号和缩写术语

4.1 Abbreviated terms
4.1 缩写术语

AE	Anode effect 阳极效应
CWPB	Centre-worked prebake 中间下料的预焙槽
DAE	Direct anode emissions 直接阳极排放
DEE	Direct electrolysis emissions 直接电解排放
GHG	Green house gas 温室气体
HSS	Horizontal stud Søderberg 水平螺柱Søderberg
IPCC	Intergovernmental Panel on Climate Change 政府间气候变化专门委员会
PFC	Perfluorocarbon 全氟化碳
PFPB	Point feeder prebake 点料机预焙
SWPB	Side-worked prebake 侧边下料的预焙槽
TIE	Electrolysis electricity consumption 电解耗电量
VSS	Vertical stud Søderberg 垂直螺柱Søderberg

WBCSD World Business Council for Sustainable Development 世界可持续发展工商理事会

WRI World Resources Institute 世界资源研究所

4.2 Symbols and chemical formulae

4.2 符号和化学式

4.2.1 Symbols

4.2.1 符号

A_{EM} Anode effect minutes per cell-day (equals to frequency multiplied by average duration)
平均每天每台槽阳极效应持续时间，（等于频率乘以平均持续时间）单位为分钟。

A_{EO} Anode effect overvoltage 阳极效应过电压

A_{NC} Net anode consumption 阳极净消耗量

A_{sha} Ash content in baked anodes 阳极焙烧中的灰分含量

A_{shp} Ash content in pitch, % mass fraction 沥青中的灰分含量，%

A_{shpc} Ash content in packing coke, % mass fraction 填充料中的灰分含量，%

B_A Baked anode production 预焙阳极的年产量

B_{AW} Baked anode mass 焙烧阳极块

B_C typical binder content in paste, % mass fraction 糊料中典型粘结剂含量，%

C_{BA} Carbon content of baked anodes 阳极焙烧的含碳量

C_{Butt} Carbon content of anode butts 残极含碳量

C_E Current efficiency for aluminium production 铝生产的电流效率

C_D	Carbon in skimmed dust from anode from Søderberg cells, tonnes carbon per tonne aluminium 从自焙阳极槽中去除的粉尘中的碳，每吨铝中的碳吨（碳吨/每吨铝）
C_{SM}	Emissions of cyclohexane soluble matter, kilograms per tonnes aluminium 环己烷可溶性物质排放量，公斤数/每吨铝
E_{CF_4}	Emissions of tetrafluoromethane, kg CF_4 per year 四氟化碳排放量，千克CF_4/每年
$E_{C_2F_6}$	Emissions of hexafluoroethane, kg C_2F_6 per year 六氟化二碳的排放，千克C_2F_6/年
E_{CO_2}	CO_2 emissions, tonnes per year 二氧化碳排放量，吨/年
E_{FPC}	Emission factor of packing coke, tCO_2/t of packing coke 填充料排放因子， tCO_2/吨
$F_{\frac{C_2F_6}{CF_4}}$	Mass fraction of $\frac{C_2F_6}{CF_4}$ $\frac{C_2F_6}{CF_4}$ 的质量分数
G_A	Mass fraction of $\frac{C_2F_6}{CF_4}$ $G_A = \left(\frac{G_{AW}}{B_{AW}}\right) B_A$ 负载生阳极块，G_A =如上…

G_{AW}	Green anode mass 生阳极块
G_{WP}	Global warming potential; use latest G_{WP} data from IPCC 全球变暖潜势，从IPCC中使用最新的全球变暖潜势
H_w	Hydrogen content in green anode 生阳极中的氢含量
H_p	Hydrogen content in pitch, % mass fraction 沥青中氢的含量，%
M_{BA}	Total mass of baked anodes 阳极焙烧的总量
M_{Butt}	Total mass of anodes butts 残极的总量
M_P	Total metal production, tonnes aluminium per year 年度内的电解铝产量，吨铝/年
N_{AC}	Net anode consumption, tonnes per tonnes aluminium 净阳极消耗量，吨/吨铝
O_{FPC}	Oxidation factor of packing coke (typically 1 for this stream) 填充料的氧化系数(通常为1)
O_{VC}	Overvoltage coefficient for CF_4 CF_4过电压系数
P_C	Paste consumption, tonnes per tonnes aluminium 糊料消耗量，吨/吨铝
P_{CC}	Packing coke consumed per tonnes of baked anode 每吨预焙阳极消耗的填充料重量
P_{CW}	Packing coke mass 填充料块
R_{CF_4}	Emission rates of CF_4, kg per tonne of aluminium produced CF_4的排放率，每生产一吨铝的公斤数
$R_{C_2F_6}$	Emission rates of C_2F_6, kg per tonne of aluminium produced C_2F_6的排放率，每生产一吨铝的公斤数
S_a	Sulfur content in baked anodes 阳极焙烧中的硫含量
S_c	Sulfur content in calcined coke, % mass fraction 煅烧焦炭中硫含量，%
S_p	Sulfur content in pitch, % mass fraction 沥青中硫含量，%
S_{pc}	Sulfur content in packing coke, % mass fraction 填充料中硫含量，%
S_{CF4}	Slope coefficient for CF_4, kg CF_4 per tonne aluminium per anode effect minute per cell day CF_4的斜率系数
W_T	Waste tar collected 收集的废焦油

4.2.2 Chemical formulae
4.2.2 化学式

Al	Aluminium 铝
Al_2O_3	Aluminium oxide (alumina) 氧化铝
C	Carbon 碳
CF_4	Tetrafluoromethane 四氟化碳
C_2F_6	Hexafluoroethane 六氟化二碳
CO	Carbon monoxide 一氧化碳
CO_2	Carbon dioxide 二氧化碳
$NaAlF_6$	Sodium aluminium hexafluoride (cryolite)六氟化铝钠(冰晶石)
NaF	Sodium fluoride 氟化钠

5 Calculation methods — General remarks
5 计算方法— 总论

5.1 General
5.1 概述

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.

本文件应与ISO 19694-1结合使用，ISO 19694-1包含适用于所有能源密集型部门温室气体排放量测定的通用、总体要求、定义和规则，提供了共同的方法问题，并规定了应用规则的细节。本文件适用于特定行业标准，可确保结果的准确性、精密度和可重复性。

5.2 Calculation methods for process GHG emissions from primary aluminium Production
5.2 原铝生产过程温室气体排放量的计算方法

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

图1给出了过程排放的来源和标准计算方法的参考。

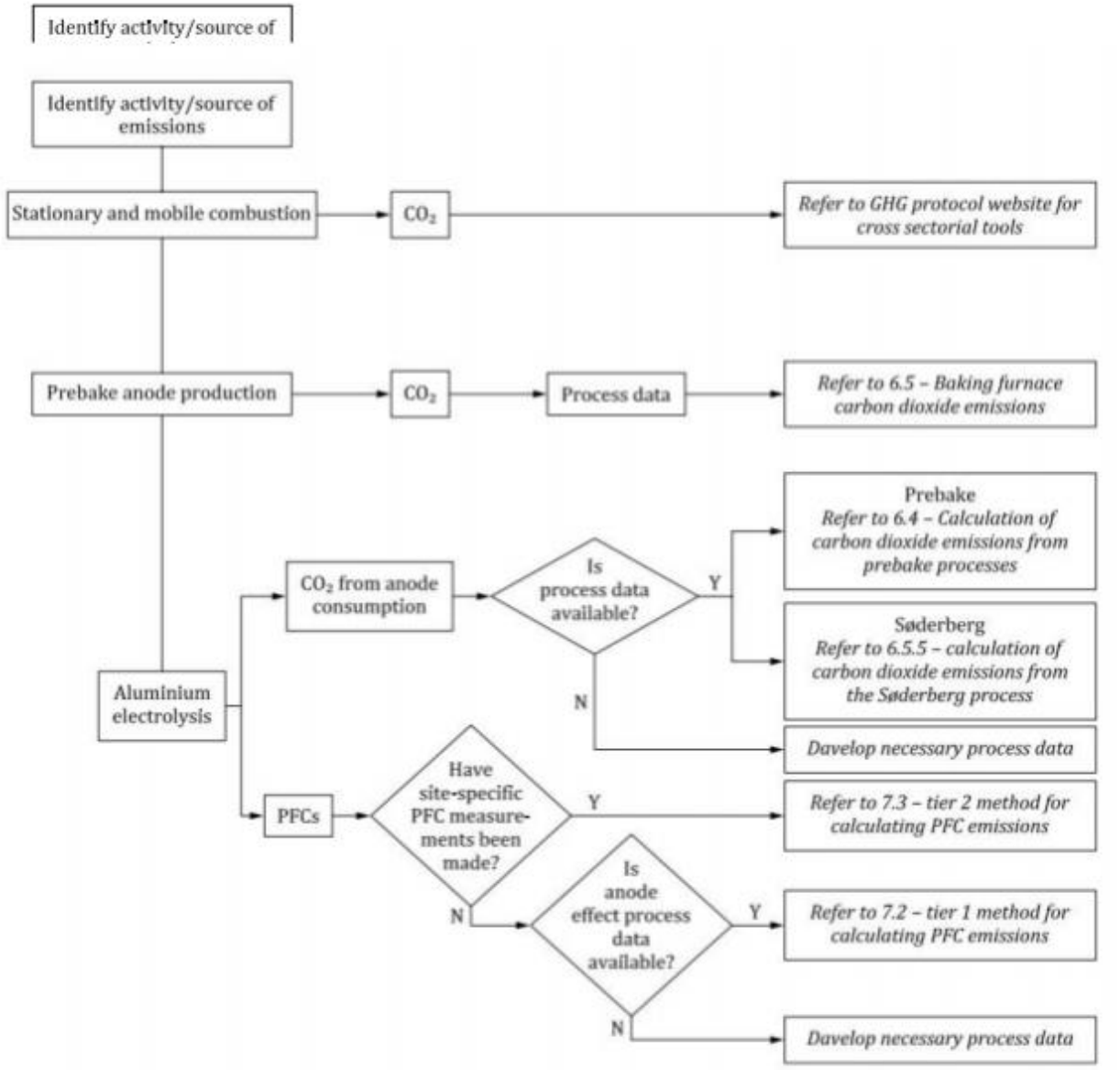

Figure 1 — Decision tree for process carbon dioxide and perfluorocarbon emissions from primary aluminium production

图1 — 原铝生产过程中二氧化碳和全氟碳排放的决策树

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.

最先进的铝冶炼厂的预焙阳极消耗产生的碳排放约占直接排放总量的90%，其余排放量由燃料燃烧和PFC排放产生的二氧化碳组成。关于燃料燃烧产生的二氧化碳排放的指南不包括在本文件中。计算阳极焙烧炉中燃料燃烧产生的二氧化碳排放量的方法在其他地方描述[6]，[7]，而计算过程二氧化碳排放量的方法在第7条中给出。

5.3 Sources of greenhouse gases

5.3 温室气体的来源

5.3.1 Electrolysis

5.3.1 电解

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

大部分CO2排放来自碳阳极与氧化铝的电解反应，如式(1)所示:

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

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)]:

在电解反应过程中，当碳阳极与其他氧气源(主要来自空气)发生反应时，也会排放二氧化碳。二氧化碳也会在Boudouard反应中形成，其中二氧化碳与碳阳极反应形成一氧化碳，然后一氧化碳被氧化形成二氧化碳。参与Boudouard反应的每一单位的CO_2在空气氧化后产生两个单位的CO_2[见式(2)、(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.

所有形成的一氧化碳都被认为转化为二氧化碳。根据行业惯例，排放全氟化碳和二氧化碳所需的碳微量的差值不进行校正。除非有现场焚烧，否则阴极消耗不会产生二氧化碳，这里不包括任何建议。对于此类操作，不包括向电解槽中添加碳酸钠所产生的二氧化碳排放，因为这是以不频繁的时间间隔添加的，是一个无关紧要的来源。

5.3.2 Anode baking

5.3.2 阳极焙烧

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.

二氧化碳排放的另一个来源，具体到预焙技术，是生阳极的焙烧，其中二氧化碳是由沥青粘合剂的挥发性成分燃烧产生的，对于使用碳基燃料的焙烧炉，是由燃料源的燃烧产生的。一些用于覆盖阳极的填充料也被氧化，在阳极焙烧过程中释放出二氧化碳。

糊料厂使用的燃料和阳极焙烧炉使用的燃料燃烧产生碳排放。

5.3.3 Aluminium smelting supporting processes

5.3.3 铝冶炼配套过程

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.

二氧化碳排放的另一个来源是铸造车间在浇铸前的处理过程中用于加热金属的燃料，一些燃料也可以用于圆棒浇铸。

5.3.4 Alumina refining

5.3.4 氧化铝精炼

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.

在使用拜耳法从铝土矿矿石中生产氧化铝时，不产生二氧化碳过程排放。与氧化铝精炼相关的大部分碳排放来自化石燃料的燃烧，这在WRI/WBCSD[10]能源和电力温室气体排放的计算工具中都有涵盖。

5.3.5 Sources of PFC

5.3.5 PFC的来源

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

在原铝生产过程中可生产两种全氟碳气体，即CF_4和C_2F_6[见式(4)和(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].
请注意 以下计算PFC排放量的建议与政府间气候变化专门委员会(IPCC)的清单指南一致[6]，[15]。

6 Methods for calculation of process greenhouse gas emissions

6 过程温室气体排放的计算方法

6.1 General

6.1 概述

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

铝生产产生的直接二氧化碳排放量应采用以下两种级别之一进行计算:

— tier 1: process specific formulae with industry typical parameters;
— 第1级：行业典型参数的特定公式;
— tier 2: process specific formulae with site or company specific parameters.
— 第2级：厂地或公司具体参数的特定公式;

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].
本文中的第1级和第2级与IPCC技术指南中所列的第2级和第3级相对应[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.

在计算二氧化碳直接排放量时，应参考图1作为总体指南。关键绩效指标的计算应采用第2级。

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

第1级— 二氧化碳排放中使用过程特定公式和技术典型参数的方法

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.

第1级方法计算二氧化碳总直接排放量时，需要计算每个工序的二氧化碳排放量，然后将其累加得到总排放量。6.4中的公式说明了预焙技术的CO_2计算，而6.5.5中包含了Søderberg技术的公式。

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

第2级 — 二氧化碳排放量的过程特定公式和设施特定参数的方法

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.

在计算排放的公式中使用厂地或公司的特定数据（第2级方法）可以获得最准确的二氧化碳排放清单。这些数据可以来自现场测算，也可以来自供应商。这些公式与上述第1级方法中使用的公式相同。但是，应该使用设施特定数据或公司特定数据，而不是技术典型数据。

6.4 Calculation of carbon dioxide emissions from prebake processes

6.4 预焙过程中二氧化碳排放量的计算

6.4.1 General

6.4.1 概述

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

电解和阳极焙烧是CWPB和SWPB还原技术产生二氧化碳的主要来源。

6.4.2 Greenhouse gas emissions from prebake anode consumption during electrolysis

6.4.2 电解过程中预焙阳极消耗产生的温室气体排放

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

电解过程中预焙阳极消耗的CO_2排放量应采用下式计算:

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

E_{CO_2}	is the CO_2 emissions in tonnes per year; 为CO_2 年排放量，单位是吨/年
M_P	is the total metal production, tonnes aluminium per year;

	为原铝年产量，单位是吨铝/年
N_{AC}	is the net anode consumption, tonnes per tonne aluminium; 为净阳极消耗量，单位是吨/吨铝;
S_a	is the sulfur content in baked anodes, % mass fraction; 为预焙阳极产品中的硫含量，%;
A_{sha}	is the ash content in baked anodes, % mass fraction; 为预焙阳极产品中的灰分含量，%;
3.664	is the CO_2 molecular mass: carbon atomic mass ratio, t CO_2/t C. 为CO_2分子质量:碳原子质量比，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.

公式(6)中使用的参数及电解过程中预焙阳极消耗CO2排放计算的技术典型值见表2。

Alternatively, the following formula may also be used:
或者，也可以使用以下公式:

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

where

E_{CO_2}	is the CO_2 emissions, tonnes per year; 为CO_2 排放量，单位是吨/年;
M_{BA}	is the total mass of baked anodes, tonnes anodes per year; 为预焙阳极的总量，单位吨/年;
C_{BA}	is the carbon content of baked anodes, % mass fraction; 为预焙阳极的含碳量，%;
M_{Butt}	is the total mass of anode butts, tonnes anodes per year; 为残极的总量，单位为吨;
C_{Butt}	is the carbon content of anode butts, % mass fraction. 为残极的含碳量，%质量分数。

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.

公式(7)中使用的参数定义见表1，以及计算电解过程中预焙阳极消耗产生的CO_2排放量的技术典型值。

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

表1 — 预焙槽产生的二氧化碳排放量第1级或第2级方法中使用的单个参数的不确定性和分析

Parameter 参数	Tier 1 method第1级方法		Tier 2 method第2级方法	
	Data source 数据来源	Data uncertainty ±% 数据不确定性	Data source 数据来源	Data uncertainty ±% 数据不确定性
M_P, tonnes aluminium per year 原铝总产量，吨铝/年	Individual facility records 单个设施记录	2	Individual facility records 单个设施记录	2
N_{AC}, tonnes per tonne aluminium 阳极净耗量，吨/吨铝	Individual facility records 单个设施记录	5	Individual facility records 单个设施记录	5
S_a, % mass fraction 预焙阳极硫含量，%质量分数	Use industry typical value, 2 使用行业典型值，2	3	Individual facility records 单个设施记录	3
A_{sha}, % mass fraction 预焙阳极灰分含量，%质量分数	Use industry typical value, 0,4 使用行业典型值， 0,4	3	Individual facility records 单个设施记录	3
M_{BA}, tonnes anodes per year 预焙阳极的总量，吨/年	Individual facility records 单个设施记录	2	Individual facility records 单个设施记录	2
C_{BA}, % mass fraction 预焙阳极的含碳量，%质量分数	Use industry typical value, 98 使用行业典型值，98	5	Individual facility records 单个设施记录	2
M_{Butt}, tonnes anodes per year 残极的总量，吨	Individual facility records 单个设施记录	2	Individual facility records 单个设施记录	2
C_{Butt}, % mass fraction 残极的含碳量，%质量分数	Use industry typical value, 98 使用行业典型值，98	5	Individual facility records 单个设施记录	2

6.5 Baking furnace greenhouse gas emissions

6.5 焙烧炉温室气体排放

6.5.1 General

6.5.1 概述

Baking furnace emissions result from three sources:

焙烧炉排放有三个来源:

— combustion of the fuel for firing the furnace;
— 燃烧燃料的排放（锅炉、窑炉等设备）
— combustion of volatile matter released during the baking operation;

— 生阳极焙烧过程中煤沥等青挥发物燃烧产生的二氧化碳排放;
— combustion of baking furnace packing material.
— 生阳极焙烧过程中填充料燃烧产生的二氧化碳排放。

6.5.2 Fuel

6.5.2 燃料

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.

使用WRI/WBCSD[10]能源和电力温室气体排放计算工具，可以计算焙烧炉燃烧过程中消耗的燃料所产生的二氧化碳排放量。

6.5.3 Combustion of volatile matter

6.5.3 挥发性物质燃烧

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

沥青挥发物燃烧产生的二氧化碳排放量计算:

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

where

E_{CO_2}	is the CO_2 emissions, tonnes per year; 为CO_2 排放量，单位是吨/年；
G_A	Is mass of loaded green anodes, $G_A = \left(\frac{G_{AW}}{B_{AW}} \right) B_A$ 生阳极的年装炉重量
G_{AW}	is the green anode mass, tonnes; 单块生阳极重量，吨
B_{AW}	is the baked anode mass, tonnes; 单块熟阳极的重量，吨
B_A	is the baked anode production, tonnes baked anode per year; 预焙阳极的年产量，吨/年
H_W	is the hydrogen content in green anodes, % mass fraction; 生阳极中的氢含量，%质量分数
W_T	is the waste tar collected, tonnes; 全年收集的废焦油，吨
3.664	is the CO_2 molecular mass: carbon atomic mass ratio, dimensionless. 为CO2分子质量:碳原子质量比，无量纲量

Parameters included in Formula (8) are specified and industry typical values noted in Table 2. Alternatively, Formula (9) may also be used:

公式(8)中所包含的参数，以及行业典型值见表2。也可采用公式(9):

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

where

E_{CO_2}	is the CO_2 emissions, tonnes per year; 为CO_2排放量，单位是吨/年；
G_{AW}	is the green anodes mass, tonnes; 单块生阳极的重量，吨
C_{GA}	is the carbon content of green anodes, % mass fraction; 生阳极中的碳含量，%质量分数
B_{AW}	is the baked anodes mass, tonnes; 单块熟阳极的重量，吨
C_{BA}	is the carbon content of baked anodes, % mass fraction. 熟阳极的含碳量，%质量分数

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

表2 — 焙烧炉沥青挥发物燃烧产生的CO2排放第1级或第2级方法中使用的单个参数的不确定性和分析

Parameter 参数	Tier 1 method 第1级方法		Tier 2 method第2级方法	
	Data source 数据来源	Data uncertainty ±% 数据不确定性	Data source 数据来源	Data uncertainty ±% 数据不确定性
G_{AW}, in tonnes、 生阳极块，吨	Individual facility records 单个设施记录	2	Individual facility records 单个设施记录	2
B_{AW}, in tonnes 熟阳极块，吨	Individual facility records 单个设施记录	2	Individual facility records 单个设施记录	2
H_W, in % mass fraction 生阳极中的氢含量，%质量分数	Use industry typical value, 0,5 使用行业典型值，0,5	5	Individual facility records 单个设施记录	5
B_A, in tonnes per year 预焙阳极的年产量，吨	Individual facility records 单个设施记录	2	Individual facility records 单个设施记录	2
W_T, in tonnes 全年收集的废焦油，吨 a) Riedhammer furnaces Riedhammer炉 b) All other furnaces 所有其他炉子	Use industry typical value: 使用行业典型值 a) 0,005 × G_A b) Insignificant 微量的，不重要的	20	Individual facility records 单个设施记录	20
C_{GA}, in % mass fraction 生阳极中的碳含量，%质量分数	Use industry typical value, 98 使用行业典型值，98	5	Individual facility records 单个设施记录	2
C_{BA}, in % mass fraction 熟阳极的含碳量，%质量分数	Use industry typical value, 98 使用行业典型值， 98	5	Individual facility records 单个设施记录	2

6.5.4 Baking furnace packing material

6.5.4 挥发性物资燃烧

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

填充料产生的二氧化碳排放量应按以下方式计算:

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

E_{CO_2}	is the CO_2 emissions, tonnes per year; 为CO_2 排放量，单位是吨/年；
P_{CC}	is the packing coke consumed, tonnes per tonne of baked anode; 每吨阳极焙烧消耗的填充料
B_A	is the baked anode production, tonnes baked anode per year; 预焙阳极产量，吨/年
S_{pc}	is the sulfur content in packing coke, % mass fraction; 填充料中硫含量，%质量分数
A_{shpc}	is the ash content in packing coke, % mass fraction; 填充料中的灰分含量，%质量分数
3,664	is the CO_2 molecular mass: carbon atomic mass ratio, dimensionless. 为CO2分子质量:碳原子质量比，无量纲量

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:

指定式(10)中所包含的参数，行业典型值见表3。或者考虑将填充料作为燃料，则可采用式(11):

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

where

E_{CO_2}	are the CO_2 emissions, tonnes per year; 为CO_2 排放量，单位是吨/年；
P_{CW}	is the packing coke mass, tonnes; 填充料，吨；
E_{FPC}	is the emission factor of packing coke, tCO_2/t of packing coke; 填充料排放因子， tCO2/吨；
O_{FPC}	is the oxidation factor of packing coke (typically 1 for this stream). 填充料的氧化系数(通常为1)。

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

表3—焙烧炉填料氧化产生的CO_2排放量第1级或第2级方法中使用的单个参数的不确定性和分析

Parameter 参数	Tier 1 method第1级方法		Tier 2 method第2级方法	
	Data source 数据来源	Data uncertainty ±% 数据不确定性	Data source 数据来源	Data uncertainty ±% 数据不确定性
P_{CC}, in tonnes per tonne BA 每吨阳极焙烧消耗的填充料	Use industry typical value, 0,015 使用行业典型值， 0,015	7,5	Individual facility records 单个设施记录	2
B_A, in tonnes per year 阳极焙烧产量，吨/年	Individual facility records 单个设施记录	2	Individual facility records 单个设施记录	2
S_{pc}, in % mass fraction 填充料中硫含量，%质量分数	Use industry typical value, 2 使用行业典型值， 2	5	Individual facility records 单个设施记录	6
A_{shpc}, in % mass fraction 填充料中的灰分含量，%质量分数	Use industry typical value, 2,5 使用行业典型值， 2,5	5	Individual facility records 单个设施记录	6
P_{CW}, in tonnes 填充料，吨	Individual facility records 单个设施记录	2	Individual facility records 单个设施记录	2
E_{FPC}, in t CO_2/t of packing coke 填充料排放因子， tCO2/吨	3,19[4]	Not relevant	3,19[4]	Not relevant 不相关
O_{FPC} 填充料的氧化系数(通常为1)	1	Not relevant	1	Not relevant 不相关

6.5.5 Calculation of greenhouse gas emissions from the Søderberg process

6.5.5 Søderberg过程中温室气体排放量的计算

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

Søderberg技术的二氧化碳过程排放量应按以下方式计算:

$$E_{CO_2} = \left[(M_P \times P_C) - \left(C_{SM} \times \frac{M_P}{1\,000} \right) - \left[\left(\frac{B_C}{100} \right) PC \times M_P \left(\frac{S_p + A_{shp} + H_p}{100} \right) \right] - \left[\left(\frac{100 - B_C}{100} \right) P_C \times M_P \left(\frac{S_c + A_{shc}}{100} \right) - (M_P \times C_D) \right] \right] \times 3{,}664 \qquad (12)$$

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.

注： 一个可行的替代方法是使用"沥青焦化"参数，而不是从公式(4)中扣除Sp、Hp、Ashp和CSM的测量值或默认值。沥青焦化值是许多采用Søderberg槽的设施确定的参数。

where

E_{CO_2}	is the CO_2 emissions, tonnes per year; 每年CO_2 排放量（吨）；
M_P	is the total metal production, tonnes aluminium per year; 金属总产量，吨铝/年
P_C	is the paste consumption, tonnes per tonne aluminium; 每吨铝的糊料消耗量（吨）
C_{SM}	is the emission of cyclohexane soluble matter, kg per tonne aluminium; 每吨铝中环己烷可溶性物质排放量（kg）
B_C	is the typical binder content in paste, % mass fraction; 糊料中典型粘结剂含量（%）
S_p	is the sulfur content in pitch, % mass fraction; 沥青中硫含量（%）
A_{shp}	is the ash content in pitch, % mass fraction; 沥青中的灰分含量（%）
H_p	is the hydrogen content in pitch, % mass fraction; 沥青中的氢含量（%）
S_c	is the sulfur content in calcined coke, % mass fraction; 煅烧焦炭的硫含量（%）
A_{shc}	is the ash content in calcined coke, % mass fraction; 煅烧焦炭的灰分含量（%）
C_D	is the carbon in skimmed dust from Søderberg cells, tonnes carbon per tonne aluminium; 每吨铝中从Søderberg槽阳极中去除的粉尘中的碳（吨）；
3,664	is the CO_2 molecular mass: carbon atomic mass ratio, dimensionless. 为CO_2分子质量:碳原子质量比，无量纲

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

表4给出了公式(12)中使用的参数以及Søderberg技术计算CO_2排放量的行业典型值。

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

表4 —Søderberg槽产生的二氧化碳排放量第1级或第2级方法中使用的单个参数的不确定性和分析

Parameter[a] 参数	Tier 1 Method第1级方法		Tier 2 Method第2级方法	
	Data source 数据来源	Data uncertainty ±% 数据不确定性	Data source 数据来源	Data uncertainty ±% 数据不确定性
M_P, in tonnes per year 金属总产量，吨铝/年	Individual facility records 单个设施记录	2	Individual facility records 单个设施记录	2
P_C, in tonnes per tonne aluminium 每吨铝的糊料消耗量（吨）	Individual facility records 单个设施记录	2–5	Individual facility records 单个设施记录	2–5
C_{SM}, in kg per tonne Aluminium 每吨铝中环己烷可溶性物质排放量（kg）	Use industry typical value, 使用行业典型值 HSS – 4,0 VSS – 0,5	30	Individual facility records 单个设施记录	15
B_C, in % mass fraction糊料中典型粘结剂含量（%）	Use industry typical value, 使用行业典型值 dry paste – 24 wet paste – 27	25	Individual facility records 单个设施记录	5
S_p, in % mass fraction 沥青中硫含量（%）	Use industry typical value, 0,6 使用行业典型值， 0,6	20	Individual facility records 单个设施记录	10
A_{shp}, in % mass fraction 沥青中的灰分含量（%）	Use industry typical value, 0,2 使用行业典型值， 0,2	20	Individual facility records 单个设施记录	10
H_p, in % mass fraction 沥青中的氢含量（%）	Use industry typical value, 3,3 使用行业典型值， 3,3	20	Individual facility records 单个设施记录	10
S_c, in % mass fraction 煅烧焦炭的硫含量（%）	Use industry typical value, 1,9 使用行业典型值， 1,9	20	Individual facility records 单个设施记录	10
A_{shc}, in % mass fraction 煅烧焦炭的灰分含量（%）	Use industry typical value, 0,2 使用行业典型值， 0,2	20	Individual facility records 单个设施记录	10
C_D, in tonnes per tonne aluminium 每吨铝中从Søderberg槽阳极中去除的粉尘中的碳（吨）	Use industry typical value, 0,01 使用行业典型值， 0,01	99	Individual facility records 单个设施记录	30

[a] The influence of some parameters with high uncertainty is very low on the total GHG emissions .
一些不确定度较高的参数对温室气体排放总量的影响很小。

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

由式(12)可知，总体不确定性约为5%。

7 Methods for calculation of PFC emissions

7 PFC排放的计算方法

7.1 General

7.1 概述

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

以下指定的三个连续步骤应用于计算原铝生产中以PFC排放为代表的二氧化碳当量排放量。

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

— 首先计算每生产一吨原铝时两种PFC气体的排放量。

— 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.
— 这些每吨铝的排放率乘以在报告期内的铝总产量。

— The equivalent CO_2 emissions are calculated by multiplying the PFC emissions by appropriate global warming potential (GWP) factors.
— 通过将PFC排放量乘以合理的全球变暖潜势(GWP)因子来计算CO2当量排放量。

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

下面指定了两种不同的方法来计算每吨铝的PFC排放量，其相对不确定性从低到高不等。

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

Tier 1是一种结合使用工厂特定过程数据和技术特定斜率因子的方法。

Tier 2 is a method using plant specific process data and plant specific slope factor.
Tier 2是一种使用工厂特定过程数据和工厂特定斜率因子的方法。

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.

工厂特定过程数据和工厂特定斜率因子应使用不确定度小于15%的Tier 2方法进行测量。Tier 1仅适用于在Tier 2因经济或技术原因不可行的情况下计算PFC排放量。

7.2 Tier 1 method for calculating PFC emissions

7.2 计算PFC排放量的第1级方法

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.

该方法基于工厂特定阳极效应或过电压过程数据的计算，但行业平均系数代替了根据工厂测量的PFC气体计算出的系数。PFC排放率和CO2当量排放率应按第2级方法计算，使用7.4.2中的公式(17)和(18)。当前推荐的平均斜率和过电压系数如表5所示。

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

表5 — 根据AE过程数据计算每吨铝PFC排放量的特定技术斜率和过电压系数

Technology **技术**	**Slope coefficient** [a, b] **斜率** (kg_{PFC}/t_{Al}) / (AE-mins/cell-day)		**Overvoltage coefficient** [a, b, c, d] **过电压系数** (kg_{CF4}/t_{Al}) / (mV)		**Mass fraction C_2F_6/CF_4** %	
	S_{CF4}	**Uncertainty** ±% 不确定性	o_{VC}	**Uncertainty** ±% 不确定性	$F_{C2F6/CF4}$	**Uncertainty** ±% 不确定性

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 NR：不相关

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

该数据来自文献[11]，通过赞助测量和多地点测量。

[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.

在每个斜率和过电压系数中嵌入假设的排放收集效率如下:CWPB 98%， SWPB 90%， VSS 85%， HSS 90%。这些收集效率是根据测量的PFC收集分数、测量的氟化物收集效率和专家意见来假设的。

[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.

注记的系数反映了在一些记录正过电压的设施和其他记录代数过电压的设施所作的测量。正过电压和代数过电压之间还没有可靠的关系。正过电压比代数过电压与PFC排放有更好的相关性。

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

过电压系数与VSS和HSS技术无关。

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

应考虑最新修订的EPA/IAI温室气体议定书[11]，并应用其更新值。

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].

表5所示的不确定性指的是特定技术系数的行业平均值的确定。采用第1级方法并应用这些系数进行PFC计算的具体工厂不确定性可能大大高于通过第2级方法得出的不确定性。有关这些值变化的数据见参考文献[8].

7.3 Tier 2 method for calculating PFC emissions

7.3 计算PFC排放量的第2级方法

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.

该方法是基于工厂特定阳极效应过程数据、铝产量数据和直接当地设施测量的PFCs系数的计算。这些系数所依据的测量应参照参考文献[11]进行--如果采用红外光谱，应考虑采用ISO20264。

7.4 Calculation of PFC emissions from aluminium reduction processes

7.4 铝还原过程中PFC排放的计算

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

7.4.1 步骤1 -计算每吨铝的每种PFC气体的排放量

7.4.1.1 General

7.4.1.1 概述

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.

每吨铝的PFC排放量应根据设施中记录的阳极效应过程数据的类型，采用斜率法或过电压法计算。

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

7.4.1.2 利用每天每台槽阳极效应的分钟数计算每吨铝的CF4和C2F6排放率-斜率法

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.

斜率系数是每吨铝生产的CF_4千克数除以平均每天每台槽的阳极效应分钟数。由于PFC排放量是按每吨生产的铝进行测量的，因此斜率系数包括槽内安培数和电流效率的影响，这是决定槽内铝产量的两个主要因素。

Formulae (13) and (14) shall be used when anode effect minutes per cell day is the anode effect process data correlated with emission rate. The formulae shall be applied for each operating potline in the facility to obtain the specific emissions per tonne aluminium produced for each potline.
当每天每台槽阳极效应分钟数为与排放率相关的阳极效应过程数据时，应使用公式（13）和（14）。该公式应适用于设施中的每条运行的槽线，以获得每条槽线生产的每吨铝的具体排放量

$$R_{CF_4} = A_{EM} \times S_{CF_4} \quad (13)$$

$$R_{C_2F_6} = R_{CF_4} \times F_{\frac{C_2F_6}{CF_4}} \quad (14)$$

where

R_{CF_4}	is the emission rate for CF4 kg, CF_4 tonne aluminium; CF4的排放率，每生产一吨铝的公斤数
A_{EM}	is the anode effects minutes per cell day (equals to frequency multiplied by average duration); 平均每天每台槽阳极效应持续时间，（等于频率乘以平均持续时间）单位为分钟。
S_{CF_4}	is the slope coefficient for CF4, kg CF4per tonne aluminium per anode effect minute per cell day; CF4的斜率系数，每槽每日每吨铝阳极效应每分钟产生的CF4量
$R_{C_2F_6}$	is the emission rate for C2F6, kg C_2F_6 per tonne aluminium; C2F6的排放率，每吨铝阳极效应产生的C2F6量
$F_{\frac{C_2F_6}{CF_4}}$	is the mass fraction of $\frac{C_2F_6}{CF_4}$. $\frac{C_2F_6}{CF_4}$ 的质量分数

7.4.1.3 Calculation of the emission rate of CF_4 and C_2F_6 per tonne aluminium using anode effect overvoltage — Overvoltage method

7.4.1.3 采用阳极效应过电压-过电压法计算每吨铝中CF4和C2F6的排放率

Some process control systems characterize anode effects by calculating an anode effect overvoltage (A_{EO}) statistic. A_{EO} is specified as the extra cell voltage above the target operating voltage. This shall be calculated by summing the product of time and voltage above the target operating voltage and dividing this figure by the time over which data were collected.

一些过程控制系统通过计算阳极效应过电压(AEO)统计来表征阳极效应。AEO被指定为高于目标工作电压的额外槽子电压。其计算方法是将时间和高于目标工作电压的电压的乘积相加，然后将该数值除以收集数据的时间。

Formulae (15) and (16) shall be used when anode effect overvoltage is the process data correlated with the emission rate. As with the slope method noted above the following formulae shall be applied for each individual potline operating at the facility:

当阳极效应过电压为与排放率相关的过程数据时，应使用公式（15）和（16）。与上述斜率法一样，以下公式应适用于在设施中运行的每个单独的槽线：

$$R_{CF_4} = O_{VC} \times \frac{A_{EO}}{C_E} \quad (15)$$

$$R_{C_2F_6} = R_{CF_4} \times F_{\frac{C_2F_6}{CF_4}} \quad (16)$$

where

R_{CF_4}	is the emission rate for CF4 kg, CF_4 tonne aluminium; CF4的排放率，每生产一吨铝的公斤数
O_{VC}	is the overvoltage coefficient for CF_4 as calculated from facility specific measurements according to guidance given in Reference [11]; 为CF4的过电压系数，根据参考文献[11]中给出的指导，由设施具体测量计算得到;
A_{EO}	is the anode effect overvoltage, millivolts; 是阳极效应过电压，毫伏;
C_E	is the current efficiency for aluminium production, %; 电流效率，%;
$R_{C_2F_6}$	is the emission rate for C2F6, kg C_2F_6 per tonne aluminium; C2F6的排放率
$F_{\frac{C_2F_6}{CF_4}}$	is the mass fraction of $\frac{C_2F_6}{CF_4}$. $\frac{C_2F_6}{CF_4}$ 的质量分数

7.4.2 Step 2 — Calculation of the total kilogram emissions of each PFC gas

7.4.2 第二步——计算每一种PFC气体的总千克排放量

Total PFC emissions shall be calculated from Formulae (17) and (18). For each operating potline, the emission rate (from Step 1) of each PFC gas per tonne of primary aluminium produced shall be multiplied by the tonnes of aluminium produced on that potline to calculate total PFC emissions for the line. Total PFC emissions are calculated by summing the emissions overall operating potlines at the facility[7].

PFC排放总量由式(17)和式(18)计算。对于每条正在运行的电解槽，每生产一吨原铝的每一PFC气体的排放率(从步骤1开始)应乘以该电解槽上生产的铝的吨数，以计算该电解槽的PFC排放总量。PFC排放总量通过对[7]设施整体运行的电解槽排放量进行求和来计算。

$$E_{CF_4} = R_{CF_4} \times M_P \quad (17)$$

$$E_{C_2F_6} = R_{C_2F_6} \times M_P \quad (18)$$

where

E_{CF_4}	is the emission of tetrafluoromethane, kg CF_4 per year; 四氟化碳的排放量，千克/每年
$E_{C_2F_6}$	is the emission of hexafluoroethane, kg C_2F_6 per year; 六氟化二碳的排放量，千克/每年
R_{CF_4}	is the emission rate of CF_4, kg per tonne of aluminium produced; CF4的排放率，每生产一吨铝的公斤数
$R_{C_2F_6}$	is the emission rate of C_2F_6, kg per tonne of aluminium produced; C2F6的排放率
M_P	is the metal production, tonnes aluminium per year. 原铝总产量，吨铝/年

7.4.3 Step 3 — Calculation of the total tonnes of carbon dioxide emissions equivalent to the PFC Emissions

.4.3步骤3 -计算二氧化碳排放量的总吨数，相当于PFC排放量

The CO_2 equivalent emissions for PFC emissions shall be calculated by summing the product of each PFC emission and its respective global warming potential, G_{WP}. The G_{WP} used for this calculation are those given in Reference [7].

PFC排放的CO2当量排放量应通过将每种PFC排放量与其各自的全球变暖潜势GWP相加来计算。本计算使用的GWP为参考文献[7]中给出的GWP。

$$E_{CO2\text{-}eq} = \frac{\left(G_{WP_{CF_4}} \times E_{CF_4}\right) + \left(G_{WP_{C_2F_6}} \times E_{C_2F_6}\right)}{1\,000} \quad (19)$$

where

$E_{CO2\text{-}eq}$	is the carbon dioxide equivalent emissions in tonnes per year; 为二氧化碳当量排放量，单位为每年吨数;
E_{CF_4}	is the emission of tetrafluoromethane, kg CF_4 per year; 四氟化碳的排放量，千克/每年
$E_{C_2F_6}$	is the emission of hexafluoroethane, kg C_2F_6 per year; 六氟化二碳的排放量，千克/每年
G_{WP}	is the global warming potential. 全球变暖潜势

7.5 Verification of the GHG calculation

7.5 温室气体计算的验证

7.5.1 Validation of the CO_2 emission calculation

7.5.1 CO2排放计算的验证

The measurements were performed by using a mobile FTIR-system. After checking the homogeneity of the sampling plane (see EN 15259[1]) a heated probe was installed and all relevant components were analysed by the heated FTIR-system (CO_2, CO and moisture). Only oxygen was analysed by means of a paramagnetic measuring system in the exhaust of the FTIR-system. For the measurement of the mass flow, the volume flow was measured continuously according to ISO 16911-1 and ISO 16911-2. Measurements were performed for one month at each sampling site. Quality assurance was done prior to the measurements (i.e. linearity) and during the measurements (check gas, zero gas).

通过使用移动FTIR系统进行测量。在检查取样平面的均匀性之后（见EN 15259[1]）安装加热的探针，并通过加热的FTIR系统分析所有相关组分（CO2、CO和水分）。利用顺磁测量系统对ftir系统排气中的氧气进行了分析。对于质量流量的测量，按照ISO 16911-1和ISO 16911-2连续测量体积流量。在每个采样点进行了一个月的测量。在测量之前(即线性)和测量期间(检查气体，零气体)进行质量保证。

7.5.2 Validation of the PFC emission calculation

7.5.2 PFC排放计算的验证

An analysis of the data from PFC measurements at 38 primary aluminium production facilities made after publication of the 2006 updated tier 1 formula coefficients confirms and validates the IPCC Tier 1 methodology for calculation of anode effect related CF_4 and C_2F_6 emissions from primary aluminium production based on plant anode effect process data. The data analysed covered all the major primary aluminium technology types including point feed prebake, side work prebake, vertical stud Søderberg and horizontal stud Søderberg cell types. The analysis of the measurement data also confirmed that the IPCC Tier 1 formula slope and overvoltage parameters for calculation of PFC emission factors from plant anode effect process data conforms to statistical expectations. For the most widely used PFPB technology the expanded measurement data set confirms the uncertainty of measurement of the 2006 IPCC Tier 1 formula parameter is better than ± 6 %. Similarly, the post 2006 measurement data confirm the documented Tier 1 factors for the other technology types used to produce primary aluminium.

在2006年更新的第1级公式系数公布后，对38个原铝生产设施的PFC测量数据进行了分析，确认并验证了IPCC基于工厂阳极效应过程数据计算原铝生产中与CF4和C2F6相关的阳极效应的1级方法。分析的数据涵盖了所有主要的原铝技术类型，包括点料机预焙、侧边下料预焙、垂直螺柱Søderberg和水平螺柱Søderberg槽子类型。对测量数据的分析也证实了从工厂阳极效应过程数据中计算PFC排放因子的IPCC Tier 1公式斜率和过电压参数符合统计预期。对于应用最广泛的PFPB技术，扩展的测量数据集证实了2006年IPCC第1级公式参数的测量不确定度优于±6%。同样，2006年后的测量数据也证实了用于生产原铝的其他技术类型所记录的1级因素。

8 Key performance indicators

8 关键绩效指标

For calculation of key performance, indicator values obtained from tier 2 methods shall be used, except the case of PFCs for which the values obtained from tier 1 methods based on technology specific factors have a better accuracy.

对于关键绩效的计算，应使用第2级方法得出的指标值，但PFCs除外，因为就PFCs而言，基于特定技术因素的第1级方法得出的数值具有较高的准确性。

The methods to be used to compare similar plants are shown in Tables 6, 7 and 8.

要用于同类工厂比较的方法见表6、表7和表8。

Table 6 — Calculation of the total direct emissions from electrolysis

表6 — 电解直接排放总量的计算

Calculation result 计算结果	Calculation contribution	Description 描述
$DEE =$		total DEE, expressed as tCO_{2eq}/t of aluminium 总DEE，用tCO2eq/t表示
	$+ \Sigma CO_{2,\ \text{anode consumption}}$	sum of CO_2 emissions from anode consumption 阳极消耗产生的二氧化碳排放量总和
	$+ \Sigma CO_{2,\ PFC}$	PFC emissions expressed as CO_2 equivalent/t electrolysis metal PFC排放量以CO2e/t Al表示

Table 7 — Calculation of the total direct emissions from anode baking

表7 —预焙阳极直接排放总量的计算

Calculation result 计算结果	Calculation contribution	Description 描述
$DAE =$		total DAE (tCO_{2eq}/t of anode) 总DAE (tCO_{2eq}/t of anode)
	$+ \Sigma CO_{2,\ process}$	sum of CO_2 emissions from process 过程中的二氧化碳排放总量
	$+ \Sigma CO_{2,\ fuel\ emissions}$	fuel emissions/t baked anodes 燃料燃烧排放/t 预焙阳极

Table 8 — Calculation of the total indirect emissions from electrolysis

表8 —电解间接排放总量的计算

Calculation result 计算结果	Calculation contribution	Description 描述
$TIE =$		total indirect emissions from electrolysis (TIE), ($tCO_{2\ eq}$/t of aluminium) 电解产生的间接排放总量 ($tCO_{2\ eq}$/t of aluminium)
	$P_{electricity,\ \ consumption}$	electrolysis electricity consumption (MWh/t) 电解耗电量
	$\bullet\ E_{CO2\ ,\ \ grid\ \ specific}$	grid specific CO_2 factor (tCO_2/MWh) 电网比CO2因子

It is generally of interest to know how the electricity is generated, i.e. hydro power, gas, coal, nuclear, combination. The GHG emission of hydropower is far lower than, for example, gas generated electricity.

人们通常感兴趣的是知道电力是如何产生的，即水力发电、天然气发电、煤炭发电、核能发电、综合发电。水力发电的温室气体排放量远低于天然气发电等。

Bibliography

[1] EN 15259, *Air quality — Measurement of stationary source emissions — Requirements for measurement sections and sites andfor the measurement objective, plan and report*

[2] ISO 16911-1, *Stationary source emissions — Manual and automatic determination of velocity and volume flow rate in ducts — Part 1: Manual reference method*

[3] ISO 16911-2, *Stationary source emissions — Manual and automatic determination of velocity and volume flow rate in ducts — Part 2: Automated measuring systems*

[4] Commission Implementing Regulation (EU) 2020/2085 of 14 December 2020 amending and correcting Implementing Regulation (EU) 2018/2066 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council (Monitoring and reporting regulation, MRR)

[5] Directive 2010/75/EC on industrial emissions (integrated pollution prevention and control)

[6] IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3 Industrial Processes and Product Use, 2006

[7] The Aluminium Sector Greenhouse Gas Protocol (Addendum to the WRI/WBCSD Greenhouse Gas protocol), International Aluminium Institute, October 2006

[8] Protocol for Measurement of Tetrafluoromethane (CF4), U. S. Environmental Protection Agency and the International Aluminium Institute, April 2008

[9] Life Cycle Assessment of Aluminium: Inventory Data for the Worldwide Primary Aluminium Industry, International Aluminium Institute, London, UK: https://international-aluminium.org/resource/environmental-metrics-report-2010-data/

[10] WBCSD/WRI protocol: The Aluminium Sector Greenhouse Gas Protocol. 2006

[11] US EPA, Protocol for Measurement of Tetrafluoromethane (CF4) and Hexafluoroethane (C2F6) Emissions from Primary Aluminum Production.

[12] Inventory guidance of the Intergovernmental Panel on Climate Change (IPCC)

[13] WRI/WBCSD. Calculation Tool for Direct Emissions from Stationary Combustion (Version 3.0), World Resources Institute/World Business Council for Sustainable Development (2005), Washington, DC: https://www.ghgprotocol.org/files/ghgp/tools/Stationary_Combustion_Guidance_final.pdf

[14] Life Cycle Assessment of Aluminium: Inventory Data for the Worldwide Primary Aluminium Industry, International Aluminium Institute, London, UK: https://www.world-aluminium.org/publications/

[15] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3: Industrial Processes and Product Use

[16] ISO 20264, *Stationary source emissions — Determination of the mass concentration of individual volatile organic compounds (VOCs) in waste gases from non-combustion processes*

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