

International Aluminium Institute

The Aluminium Sector Greenhouse Gas Protocol
(Addendum to the WBCSD/WRI Greenhouse Gas Protocol)

Greenhouse Gas Emissions Monitoring and Reporting
by the Aluminium Industry

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Introduction

The Aluminium Sector Addendum to the WBCSD/WRI Greenhouse Gas Protocol Initiative

This International Aluminium Institute (IAI) *Aluminium Sector Addendum to the WBCSD/WRI Greenhouse Gas Protocol* maintains as an underlying premise that the international aluminium industry generally accepts and endorses “The Greenhouse Gas Protocol: a corporate accounting and reporting standard” (October 2001) developed by the World Business Council for Sustainable Development (WBCSD) and the World Resource Institute (WRI). This Addendum was developed by IAI to supplement the WBCSD/WRI standard by providing additional interpretation, guidance, and examples tailored to the international aluminium industry. This standard is recommended.

The **WBCSD/WRI** protocol is available for review at the WBCSD/WRI-*GHG Protocol* website: www.ghgprotocol.org

The WBCSD/WRI standard addresses the following topics related to GHG accounting and reporting:

- GHG accounting and reporting principles
- Business goals and inventory design
- Setting organizational boundaries
- Setting operational boundaries
- Accounting for GHG reductions
- Setting a historic performance datum
- Identifying and calculating GHG emissions
- Managing inventory quality
- Reporting GHG emissions
- Verification of GHG emissions

The goal of this Aluminium Sector Addendum is to provide focus within the international aluminium industry on the following areas:

- emissions sources
- definitions
- methodologies of measuring and calculating GHG emissions
- inventory boundaries
- best practices

It is hoped that this focus will help to achieve a reliable, consistent and transparent calculation and reporting of Greenhouse Gases throughout the Aluminium Sector for internal company use and for reporting to the public and to specific audiences such as governments and special interest groups. The methodologies outlined

herein constitute a standard for the aluminium industry. When reporting against this standard, any deviations should be clearly noted.

The document provides aluminium industry specific examples of emissions calculations to support clarity and consistency in preparing and maintaining GHG inventories and reports.

The document has been prepared with the support and approval of the IAI board of directors acting on behalf of its member companies. A number of groups have been given the opportunity to comment and contribute to the enclosed document including the WBCSD and WRI.

This Addendum will be reviewed at least annually by the IAI and will be updated, as necessary, with a goal of consistency with any changes made by WBCSD and WRI to its Greenhouse Gas Protocol. Issues being considered by IAI for future revisions of this Addendum include: (See Section 4)

- Process for securing data for Scope 2 emissions; and
- Inventory and reporting of Scope 3 emissions.

The work was initiated during an IAI GHG Protocol Workshop in March 2002 and a Final Draft Addendum was presented and approved by the Board of Directors during October 2002

Section 1

GHG Accounting and Reporting Principles

This Addendum accepts and endorses that GHG accounting and reporting by the aluminium industry should be based on the following principles as outlined by the WBCSD and WRI:

- **Relevance** Define boundaries that appropriately reflect GHG emissions of the business and the decision-making needs of users.
- **Completeness** Account for all GHG emissions sources and activities within the chosen organizational and operational boundaries. Any specific exclusions should be stated and justified.
- **Consistency** Allow meaningful comparison of emissions performance over time. Any changes to the basis of reporting should be clearly stated to enable continued valid comparison.
- **Transparency** Address all relevant issues in a factual and coherent manner, based on a clear audit trail. Important assumptions should be disclosed and appropriate references made to the calculation methodologies used.
- **Accuracy** Exercise due diligence to ensure that GHG calculations have the precision needed for their intended use, and provide reasonable assurance on the integrity of reported GHG information.

Section 2

Business Goals and Inventory Design

The aluminium industry agrees with WBCSD and WRI that improving understanding of individual company's GHG emissions by compiling a GHG inventory makes good business sense. As articulated in WBCSD/WRI protocol, the four categories of business goals most frequently listed by companies as reasons for compiling a GHG inventory are the following:

- GHG risk management
- Public reporting/participation in voluntary initiatives
- GHG markets
- Regulatory/government requirements

Establishing a GHG target

Some IAI member companies have established specific greenhouse gas reduction targets by entering formal voluntary agreements with government jurisdictions. For instance, Aluminium companies located in Quebec province of Canada have agreed to reduce greenhouse gas emissions by up to 200,000 metric tonnes during the period 2002 – 2007.

IAI and this Addendum support this approach for establishing voluntary agreements including specific targets for reducing greenhouse gas emissions.

Section 3

Setting Organizational Boundaries

As stipulated in the WBCSD/WRI protocol, when accounting for GHG emissions from partially-owned entities/facilities, it is important to draw clear organizational boundaries. Such boundaries should be consistent with the organizational boundaries drawn up for financial reporting purposes.

GHG emissions information should be collected and reported in a transparent manner on the basis of control/influence and equity share. Equity share is defined as the percentage of economic interest in or benefit derived from an operation. This approach increases the usability of GHG information for different users and aims, as far as possible, to mirror the approach adopted by financial accounting and reporting standards.

If there is a contractual arrangement that covers GHG emissions, the company should defer to this for the purposes of emissions allocation and include an appropriate explanation as an appendix to the inventory and report.

Section 4

Setting Operational Boundaries

As recommended in the WBCSD/WRI protocol operational boundaries must also be defined. This involves accounting for certain direct and indirect GHG emissions.

Direct GHG emissions are emissions from sources that are owned or controlled by the reporting company, e.g. emissions from factory stacks, manufacturing processes and vents, and from company-owned/controlled vehicles.

Indirect GHG emissions are emissions that are a consequence of the activities of the reporting company, but occur from sources owned or controlled by another company, e.g. emissions from the production of purchased electricity, contract manufacturing, employee travel on scheduled flights, and emissions occurring during down stream product use.

The WBCSD/WRI protocol introduces and explains the concept of “scope”. (See WBCSD/WRI protocol Chapter 4). Consistent with the WBCSD/WRI protocol, this Addendum recommends that aluminium companies account for and report as a minimum scopes 1 and 2.

Scope 1 accounts for direct GHG emissions from sources that are owned or controlled by the reporting company. Examples of Scope 1 emissions include:

- Emissions from electricity, heat, or steam production through fuel combustion
- Emissions from physical or chemical processing, e.g. coke calcining, aluminium smelting, anode baking
- Emissions from transportation of materials, products, waste, and employees in company owned/controlled vehicles, e.g. use of mobile combustion sources, such as: trucks, trains, ships, airplanes, buses, and cars
- Fugitive emissions, e.g. intentional or unintentional releases such as equipment leaks from joints, seals; methane emissions from coal mines; HFC emissions during the use of air conditioning equipment; and CH₄ leaks from gas transport

Scope 2 accounts for indirect emissions associated with the generation of imported/purchased electricity, heat, or steam.

Emissions attributable to the generation of exported/sold electricity, heat, or steam should be reported separately under supporting information. These emissions must also be included in scope 1. To increase data transparency, emissions data associated with imported and exported electricity, heat, or steam should not be netted.

Scope 3 allows for the treatment of other indirect emissions that are a consequence of the activities of the reporting company, but occur from sources owned or controlled by another company. Companies should consider reporting emissions

from scope 3 activities that are important to their business and goals and for which they have reliable information. Examples of Scope 3 emissions include:

- Emissions from employee business travel
- Emissions from transportation of products, materials, and waste
- Emissions from outsourced activities, contract manufacturing, and franchises
- Emissions from waste generated by the reporting company when the point of GHG emissions occurs at sources or sites that are owned or controlled by another company, e.g. methane emissions from landfilled waste
- Emissions from the use and end-of-life phases of products and services produced by the reporting company
- Emissions from employees commuting to and from work
- Emissions from production of imported materials

The international aluminium industry through the IAI supports the use of the GHG protocol methodology for reporting of corporate emissions. It is hoped that, where appropriate, individual governments will establish reporting requirements that mirror protocol methodology.

Section 5

Accounting for GHG Reductions

The aluminium industry accepts and endorses WBCSD/WRI protocol recommendations related to accounting for GHG reductions (See WBCSD/WRI protocol Chapter 5).

The recommended approach for calculating GHG emissions is a bottom-up approach. This involves calculating emissions at the level of an individual source and then rolling this up via facilities to the corporate level.

Emissions savings from the use and end-of-life phases of products and services produced by the reporting company should be considered and clearly documented as part of the accounting process (e.g. use of aluminium in vehicles reduces greenhouse gas emissions by an average of 20% during the life of the vehicle).

Section 6

Setting a Historic Performance Datum

This Addendum recommends setting a historic performance datum for comparison over time based on 1990 as the base year if verifiable emissions data is available to support such base year emissions. If verifiable emissions data is not available to support 1990 as base year emissions, then companies should establish the earliest verifiable emissions after 1990 to represent base year.

The following rules, as stipulated by WBCSD/WRI protocol should be observed for any base year emissions adjustments:

- The base year emissions should be adjusted to maintain comparability if significant structural changes occur in the organization. What defines a significant structural change usually depends on the size of the organization. Examples include mergers, major acquisitions, and divestitures.
- The base year emissions should be adjusted to account for the transfer of ownership/control of emissions sources.
- The base year emissions should not be adjusted for organic growth or decline of the organization. Organic growth/decline refers to increase/decrease in production output, changes in product mix, plant closures and the opening of new plants. The rationale for this is that organic growth results in new or additional emissions to the atmosphere, whereas an acquisition only transfers existing GHG emissions from one company's balance sheet to another.
- The base year emissions should not be adjusted for any changes in outsourcing activities if the company is reporting its indirect emissions from such activities under scopes 2 or 3. The same rule applies to in sourcing.
- If significant structural changes occur during the middle of a year, the base year emissions should be adjusted on a pro-rata basis.
- The base year emissions should be adjusted for changes in calculation methodologies that result in significant changes in your calculated GHG emissions data. Discovery of errors, or a number of cumulative errors, that significantly affect base year emissions should result in an adjustment of base year emissions.

Examples:

Base year emissions adjustment for an acquisition

Aluminium Company Gamma consists of two business units (A and B). In its base year (year one) the company emits 100,000 tonnes CO₂. In year two, the company undergoes organic growth, leading to an increase in emissions to 60,000 tonnes CO₂ per business unit, (i.e. 120,000 tonnes CO₂ in total). The base year emissions are not adjusted in this case. In the beginning of year three, Gamma acquires a production facility C from another company. The annual emissions of facility C in year one were 15,000 tonnes CO₂, and 20,000 tonnes CO₂ in year two. The total emissions of company Gamma in year three, including facility C are therefore

140,000 tonnes CO₂ (i.e., 120,000 + 20,000). To maintain consistency over time, the company recalibrates its base year emissions to take into account the acquisition of facility C. The base year emissions increase by 15,000 tonnes CO₂ – the quantity of emissions produced by facility C during Gamma's base year. The adjusted base year emissions are 115,000 tonnes CO₂ (i.e., 100,000 + 15,000).

Base year emissions adjustment for a divestment

Aluminium Company Beta consists of three business units (A, B, and C). Each business unit emits 25,000 tonnes CO₂ and the total emissions for the company are 75,000 tonnes CO₂ in the base year (year one). In year two, the output of the company grows, leading to an increase in emissions to 30,000 tonnes CO₂ per business unit, i.e. 90,000 tonnes CO₂ in total. In year three, Beta divests business unit C, and its annual emissions are now 60,000 tonnes, representing an apparent reduction of 15,000 tonnes relative to the base year emissions. However, to maintain consistency over time, the company recalibrates its base year emissions to take into account the divestment of business unit C. 25,000 tonnes CO₂ – the quantity of emissions produced by the business unit C in the base year, lowers the base year emissions. The adjusted base year emissions are 50,000 tonnes CO₂, and the emissions of company Beta are seen to have risen by 10,000 tonnes CO₂ over the three years.

Acquisition of a facility that came into existence after the base year was set

Aluminum Company Theta consists of two business units (A and B). In its base year (year one) the company emits 50,000 tonnes CO₂. In year two, the company undergoes organic growth, leading to an increase in emissions to 30,000 tonnes CO₂ per business unit, i.e. 60,000 tonnes CO₂ in total. The base year emissions are not adjusted in this case. In the beginning of year three, Theta acquires a production facility C from another company. Facility C came into existence in year two, its emissions being 15,000 tonnes CO₂ in year two and 20,000 tonnes CO₂ in year three. The total emissions of company Theta in year three, including facility C are therefore 80,000 tonnes CO₂. In this acquisition case, the base year emissions of company Theta do not change because the acquired facility C did not exist in year one when the base year of Theta was set. The base year emissions datum of Theta therefore remains at 50,000 tonnes CO₂.

Organic Growth, Plant Closure and Opening of a New Plant

Aluminum Company Omega initially operates smelter A which emits 150,000 tonnes of CO₂e and smelter B which emits 100,000 tonnes of CO₂e. Therefore, Omega's base year (year one) emissions are 250,000 tonnes of CO₂e. In year three, smelter A emits 160,000 tonnes of CO₂e (10,000 tonnes increase due to organic growth), smelter B is closed due to technical obsolescence, and a new smelter C is commissioned which emits 200,000 tonnes of CO₂e. The base year emissions (year one) of Aluminum Company Omega remains unchanged at 250,000 tonnes of CO₂e because the new plant C did not exist in year one when the base year was set, and Omega should be allowed credit for not emitting GHG from plant B any longer.

Section 7

Identifying and Calculating GHG Emissions

This Addendum generally accepts and endorses recommended practices stipulated in WBCSD/WRI protocol Chapter 7 for identifying and calculating GHG emissions. Such practices include the following steps:

- Identify GHG emissions sources
- Select an emissions calculation approach
- Collect activity data and choose emissions factors
- Apply calculation tools to estimate GHG emissions
- Roll-up GHG data to corporate level

Appendix A of this Addendum includes guidance and examples representing current best practices for calculating CO₂ and PFC emissions from various operations associated with primary aluminium production.

Appendix B contains a spreadsheet tool that can be used to assist in the calculation of these emissions.

Examples of direct and indirect emissions from the aluminium production include:

Direct CO₂e Emissions from Aluminium Production

- CO₂e from Coke Calcination
- CO₂e from Anode Production
- CO₂e from Anode Consumption
- CO₂e from PFCs
- CO₂e from Lime Production
- CO₂e from CH₄ and N₂O
- CO₂e from SF₆
- CO₂e from Electrical Generation and Reservoirs

Indirect CO₂e Emissions

- External Electricity Production
- External heat or Steam Production
- Transportation
- Raw Material Imports

There are two basic approaches for gathering data on GHG emissions from a corporation's sites:

- Individual sites directly calculate their GHG emissions and report this data to the corporate level
- Individual sites report activity/fuel use data (such as quantity of fuel used) to the corporate level, where GHG emissions are calculated

Reports should include all relevant information as specified in WBCSD/WRI protocol Chapter 9 including:

- A brief description of the emissions sources
- A list and justification of specific exclusion or inclusion of sources
- Comparative information from previous years
- The reporting period covered
- Any trends seen in data
- Progress toward any business targets
- An estimation of accuracy of activity/fuel use data reported
- A description of events and changes that have an impact on reported data (acquisitions, divestitures, closures, technology upgrades, changes of reporting boundaries or calculation methodologies applied, etc.)

Section 8

Managing Inventory Quality

This Addendum generally accepts and endorses recommended practices stipulated in WBCSD/WRI protocol Chapter 8 for managing GHG inventory quality. Appendix A serves as a replacement for the information provided by the WBCSD/WRI in the Aluminium section of the supporting materials to the GHG protocol. These can be found at the GHG protocol website, noted below.

Ensuring inventory quality by minimizing systemic and inherent uncertainty is important for maintaining accurate inventories and reports.

The following steps should be included to improve inventory quality:

- Adopt and apply GHG accounting and reporting principles
- Use a standardized system for calculation and internal reporting of GHGs across multiple business units/facilities
- Select an appropriate calculation methodology
- Set up a robust data collection system
- Establish appropriate information technology controls
- Undertake regular accuracy checks for technical errors
- Conduct periodic internal audits and technical reviews
- Ensure management review of the GHG information
- Organize regular training sessions for inventory development team members
- Perform uncertainty analysis
- Obtain independent external verification

These methods are explained in detail in the guidelines on quantification of uncertainty available at the WBCSD/WRI *GHG Protocol* website: www.ghgprotocol.org

Section 9

Reporting GHG Emissions

This Addendum generally accepts and endorses recommended practices stipulated in WBCSD/WRI protocol Chapter 9 for reporting GHG emissions.

Reported information should be relevant, complete, consistent, transparent and accurate. GHG reports should be based on the best data available at the time of publication. Any limitations should be fully documented and disclosed. Any discrepancies identified should be corrected and communicated in subsequent years.

The following should be considered as minimum content of a public GHG emissions report

- **Description of the reporting organization and its boundaries**
- **Information on emissions and performance**
- **Supporting information**

Section 10

Verification of GHG Emissions

This Addendum generally accepts and endorses recommended practices stipulated in WBCSD/WRI protocol Chapter 10 for verification of GHG emissions.

Verification is the objective and independent assessment of whether the reported GHG inventory properly reflects the GHG impact of the company in conformance with the pre-established GHG accounting and reporting standards. Verification involves testing certain assertions of the GHG inventory, such as accuracy and completeness. Verification also requires evaluating and testing the 'supporting' evidence (in the form of an audit trail) of how the GHG inventory was generated, compiled/aggregated and reported. The practice of verifying corporate GHG inventories is not fully developed, and the absence of generally accepted GHG accounting and reporting standards means that reporting standards against which verifications have taken place may vary from company to company.

Objectives

Before commissioning and planning an independent verification, the reporting company should clearly define its objectives (more information in Section 2: *Business goals and inventory design*) and decide whether an external verification is appropriate. Reasons for undertaking an external verification include:

- To add credibility to publicly reported information and reduction goals, and to enhance stakeholder trust in the reporting organization
- To increase management and board confidence in reported information
- To improve internal GHG accounting and reporting practices (data calculation, recording and internal reporting systems, application of GHG accounting principles, e.g. checks for completeness, consistency, accuracy), and to facilitate learning and knowledge transfer within the organization
- To meet or anticipate the requirements of future trading programs
- To comply with government regulatory requirements

The highest level verification might involve a team of third-party reviewers made up of representatives from knowledgeable consulting, verification and financial auditing firms, independent experts from government, NGOs, or academia. There are other ways to improve the quality, reliability, and usefulness of GHG information, such as those described in Section 9: Managing Inventory Quality.

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Appendix B

Excel Spreadsheet Tools and guidance for calculating total Carbon Dioxide Equivalent Emissions from Primary Aluminium Production.

Appendix C

Acknowledgements

Appendix A

Calculation Methods for PFC Emissions and Direct Carbon Dioxide Emissions Resulting From Aluminium Reduction and Supporting Processes.

1 PFC Emissions

The following recommendations are consistent with the three tier framework of the Intergovernmental Panel on Climate Change (IPCC) Good Practices Guidance for inventory of greenhouse gases from industrial processes¹ with necessary modifications to achieve the highest accuracy for inventorying of the two PFC gases, tetrafluoromethane (CF₄) and hexafluoroethane (C₂F₆), produced during primary aluminium production.

Three sequential steps described below lead to calculation of 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 for each operating potline.
- These emission rates per tonne aluminium are multiplied by the total production of aluminium on each operating potline during the time period for which the inventory is being developed. The total emissions from each facility is calculated by summing the results obtained for each potline.
- The equivalent amount of emissions of carbon dioxide is calculated by multiplying the PFC emissions by standard Global Warming Potential (GWP) factors.

Three separate approaches are described below for calculating PFC emissions per tonne of aluminium with relative uncertainty varying from lowest to highest. This Addendum strongly recommends the use of the Tier 3 highest accuracy method for producing the best quality inventories of PFC gases from primary aluminium production.

1.1 Tier 3b Highest Accuracy Method

This method is based on calculations using anode effect process data, aluminium production data and equation coefficients based on direct local facility measurements of PFCs. The measurements on which the equation coefficients are based should be made according to the PFC Measurement Protocol describing good measurement practices² and attached here.

¹ IPCC, Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Section 3.3, PFC Emissions from Aluminium Production, http://www.ipcc-nggip.iges.or.jp/public/gp/pdf/3_Industry.pdf.

² PFC Good Measurements Practices are described in the joint USEPA/IAI Measurement Protocol: Measurement of Tetrafluoromethane (CF₄) and Hexafluoroethane (C₂F₆) Emissions from Primary Aluminum Production, http://www.world-aluminium.org/environment/climate/pfc_measurement.pdf

1.1.1 Step 1 – Calculate the emissions of each PFC gas per tonne of aluminium

Equation 1a and 1b should be used when anode effect minutes per cell day is the anode effect process data correlated with emission rate. The equations should be applied for each operating pot line in the facility to obtain the specific emissions for each potline.

Equation 1 – Calculation of Emission Rate of CF₄ and C₂F₆ per Tonne Aluminium using the Slope Method

$$\text{Equation 1a.} \quad R_{CF_4} = AE \text{ min/ cell day} \times f_{CF_4}$$

and

$$\text{Equation 1b.} \quad R_{C_2F_6} = AE \text{ min/ cell day} \times f_{C_2F_6}$$

where:

R_{CF_4} = Specific emission rate for CF₄ in kg CF₄ per tonne aluminium as calculated from local facility specific measurements according to guidance in the PFC Measurement Protocol

$R_{C_2F_6}$ = Specific emission rate for C₂F₆ in kg C₂F₆ per tonne aluminium as calculated from local facility specific measurements according to guidance in the PFC Measurement Protocol

f_{CF_4} = Slope factor for CF₄ in kg CF₄/tonne aluminium per anode effect minute/cell day

$f_{C_2F_6}$ = Slope factor for C₂F₆ in kg C₂F₆/tonne aluminium per anode effect minute/cell day

Equations 2a and 2b should be used when anode effect over voltage is the process data correlated with emission rate. As noted above the equations should be applied for each individual potline operating at the facility.

Equation 2 – Calculation of Emission Rate of CF₄ and C₂F₆ per Tonne Aluminium using the Over Voltage Method

$$2a. \quad R_{CF_4} = fP_{CF_4} \times \frac{AEO}{CE}$$

and

$$2b. \quad R_{C_2F_6} = fP_{C_2F_6} \times \frac{AEO}{CE}$$

where:

R_{CF_4} = Specific emission rate for CF_4 in kg CF_4 per tonne aluminium

$R_{C_2F_6}$ = Specific emission rate for C_2F_6 in kg C_2F_6 per tonne aluminium

fP_{CF_4} and $fP_{R_{C_2F_6}}$ = Over voltage factors for CF_4 and C_2F_6 as calculated from facility specific measurements according to guidance in the PFC Measurement Protocol

AEO = Anode effect over voltage in millivolts

CE = Current efficiency for aluminium production in percent

1.1.2 Step 2 – Calculate the total kilograms emissions of each PFC gas

Total PFC emissions should be calculated from Equation 3 below. For each operating potline the specific emission rate of each PFC gas, tetrafluoromethane, CF_4 , and hexafluoroethane, C_2F_6 , as kilograms of CF_4 or kilograms C_2F_6 per tonne of primary aluminium produced from step 2 above is multiplied by the weight of aluminium produced on that potline to calculate total PFC emissions for the line. Total PFC emissions are calculated by summing the emissions over all operating potlines at the facility.

Equation 3 – Calculation of Total Emissions of CF_4 and C_2F_6

Equation 3a.
$$E_{CF_4} = R_{CF_4} \times W$$

Equation 3b.
$$E_{C_2F_6} = R_{C_2F_6} \times W$$

where:

E_{CF_4} and $E_{C_2F_6}$ = Emissions of CF_4 and C_2F_6 in kilograms

R_{CF_4} and $R_{C_2F_6}$ = Specific emission rates of CF_4 and C_2F_6 in kg per tonne aluminium produced (kg CF_4 /tonne Al or kg C_2F_6 /tonne Al)

W = Weight of primary aluminium produced in tonnes

1.1.3 Step 3 – Calculate the total tonnes of carbon dioxide emissions equivalent to the PFC emissions

The carbon dioxide equivalent emissions for PFC emissions is calculated by multiplying the mass of PFC emissions by the Global Warming Potential (GWP) for each PFC compound and summing the equivalent effects of the two PFC gases. The GWP values that should be used for this calculation are those noted in the IPCC Second Assessment Report³

³ While the IPCC Third Assessment Report published newly revised global warming potential values for a number of gases including revisions for tetrafluoromethane and hexafluoroethane, Kyoto Protocol Decision 2/CP.3, Methodological issues related to the Kyoto Protocol, paragraph 3, reaffirms that global warming potentials used by Parties should be those provided by the Intergovernmental Panel on Climate Change in its Second Assessment Report (“1995 IPCC GWP values”) based on the effects of the greenhouse gases over a 100-year time horizon, taking into account the inherent and complicated uncertainties involved in global warming potential estimates.

Equation 4 – Calculation of Carbon Dioxide Equivalent Emissions from Total Emissions of CF₄ and C₂F₆

$$E_{CO2-eq} = \frac{(6500 \times E_{CF_4}) + (9200 \times E_{C_2F_6})}{1000}$$

where:

E_{CO2-eq} = Carbon dioxide equivalent emissions in tonnes

E_{CF_4} = Emissions of tetrafluoromethane in kilograms

$E_{C_2F_6}$ = Emissions of hexafluoroethane in kilograms

1.2 Tier 2 Intermediate Accuracy Method

This method is based on calculations where anode effect process data is available. Average slope factors or average over voltage factors have been used in place of facility specific factors calculated from direct measurements of PFC gases. The current IPCC recommended values⁴ for these average slope and over voltage factors are listed below in Table 1. Carbon dioxide equivalent emissions should be calculated as in the highest accuracy case except that the average slope and over voltage factors for each reduction technology category are substituted for the facility specific values in equations 3a and 3b for the calculation of emissions of CF₄ and C₂F₆ per tonne of aluminium.

Table 1 – Average Slope and Over Voltage Factors for Calculation of PFC Emissions Per Tonne Aluminium From Anode Effect Process Data

Technology	Slope factor		Over voltage factor	
	f_{CF_4}	$f_{C_2F_6}$	fP_{CF_4}	$fP_{R_{C_2F_6}}$
Center Work Prebake	0.14	0.018	1.9	Note 1
Side Work Prebake	0.29	0.029	1.9	Note 1
Vertical Stud Søderberg	0.067	0.003	Note 2	Note 2
Horizontal Stud Søderberg	0.18	0.018	Note 2	Note 2

Note 1: No over voltage coefficient was recommended for calculation of C₂F₆. Until such a recommendation is made C₂F₆ should be estimated by taking one-tenth of the specific emission value calculated for CF₄.

Note 2: No data has been reported correlating anode effect over voltage with PFC emissions for Vertical Stud or Horizontal Stud Søderberg technology.

⁴ IAII staff members are currently engaged with IPCC in the process for updating and revising the average factors.

1.3 Tier 1 Lowest Accuracy Default Factor Method⁵

It is expected that all primary aluminium production facilities operating today will collect and archive anode effect process data needed to calculate PFC emissions by one of the two methods above. However, in cases where historical process data may not be available and aluminium production data is available IAI suggests using the default specific CF₄ emissions values tabulated in Table 2. Total PFC emissions are calculated as for Tier 2 and Tier 3 calculations by multiplying the specific emissions of each PFC gas by the primary aluminium production. Also, as before, carbon dioxide equivalent emissions are calculated by multiplying the total PFC emissions by the Global Warming Potential values and summing for the two PFC gases.

Table 2 – Historical Default CF₄ Emission Values by Reduction Technology Type

Technology	Specific emissions (kg CF₄/t Al)		
	1990 - 1993	1994 - 1997	1998 - 2000
Center Work Prebake	0.4	0.3	0.2
Point Fed Prebake	0.3	0.1	0.08
Side Word Prebake	1.4	1.4	1.4
Vertical Stud Søderberg	0.6	0.5	0.4
Horizontal Stud Søderberg	0.7	0.6	0.6

The corresponding specific emission values for C₂F₆ should be calculated by multiplying the specific CF₄ emission value by the technology specific multiplier factor from Table 3 as shown in Equation 5.

Table 3 – Multiplier Factors for Calculation of Hexafluoroethane by Technology Type

Technology	Multiplier Factor⁶
Center Work Prebake	0.17
Point Fed Prebake	0.17
Side Word Prebake	0.24
Vertical Stud Søderberg	0.06
Horizontal Stud Søderberg	0.09

⁵ It should be noted that the IAI proposed lowest accuracy default method departs from the IPCC default method. In the IPCC default method a single specific emission value is offered for each of four reduction technology categories - Centerwork prebake, Sidework prebake, Vertical stud Søderberg and Horizontal Stud Søderberg. The IPCC expert working panel for the most part based these default factors on 1990 average IAI anode effect data and the average technology specific slope factors. IAI survey data collected since the publication of the original IPCC default values shows substantial reductions over the period 1990 to 2000 in specific emissions in all technology categories. In addition it has been shown that among the overall category of centerwork prebake cells that the more modern point fed prebake cells have made progress at a faster rate than for the older bar broken centerwork prebake cells. Thus the original category has been broken into two separate categories here.

⁶ Multiplier factors in Table 3 are derived from a consolidation of measured ratios of C₂F₆ to CF₄ by technology from direct measurement data reported through 2001. As noted in footnote 4 above IAI is working with IPCC to update Tier 2 emission factors to reflect recent measurement data that filled gaps in knowledge when Tier 2 technology specific emission factors were first developed.

Equation 5 – Lowest Accuracy Calculation of C₂F₆ Emissions per Tonne Aluminium

$\text{Kg C}_2\text{F}_6/\text{t Al} = \text{Technology specific kg CF}_4/\text{t Al from Table 2} \times \text{Multiplier Factor from Table 3}$

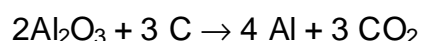
2 Direct Carbon Dioxide Process Emissions

The following recommendations are consistent with the basic three tier framework of the Intergovernmental Panel on Climate Change (IPCC) Good Practices Guidance for inventory of greenhouse gases from industrial processes⁷. Process carbon dioxide emissions make up about half of total direct carbon dioxide equivalent emissions from aluminium production with the remainder greenhouse gases emitted being perfluorinated carbon (PFC) gases. Guidance on CO₂ emissions from fuel combustion for electrical power production, and for alumina production, is not included in this documents. Methodology for calculating CO₂ emissions from the combustion of fuel in anode baking furnaces is described elsewhere⁸ while equations for calculating the emissions associated with the oxidation of volatile compounds are given in this document (2.6.2).

2.1 Sources of Carbon Dioxide

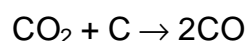
Most of the carbon dioxide emissions result from the electrolysis reaction of the carbon anode (following Reaction 1) with alumina.

Reaction 1:



Carbon dioxide is also emitted during the electrolysis reaction as the carbon anode reacts with other sources of oxygen, primarily from air. Carbon dioxide is also formed as a result of the Boudouard reaction where carbon dioxide reacts with the carbon anode forming carbon monoxide, which then is oxidized to form carbon dioxide. Each unit of carbon dioxide participating in the Boudouard reaction (Reaction 2) produces two units of carbon dioxide (Reaction 3) after air oxidation.

Reaction 2:



Reaction 3:



All carbon monoxide formed is assumed to be converted to carbon dioxide. By industry convention no correction is made for the minute amount of carbon consumed as PFCs rather than carbon dioxide emissions. No carbon dioxide is produced from cathode consumption unless there is on-site incineration and no recommendation is included here for such operations. Another source of carbon dioxide emissions specific to prebake technologies is the baking of green anodes where carbon dioxide is emitted from combustion of volatile components from the

⁷ IPCC, Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Section 3.3, PFC Emissions from Aluminium Production, http://www.ipcc-nggip.iges.or.jp/public/gp/pdf/3_Industry.pdf.

⁸ World Resources Institute, Calculating CO₂ emissions from stationary combustion, <http://www.ghgprotocol.org/standard/tools.htm>

pitch binder and, for baking furnaces fired with carbon based fuels, carbon dioxide from the combustion of the fuel source. Also, during anode baking some of the

packing coke used to cover the anodes during baking is oxidized to release carbon dioxide.

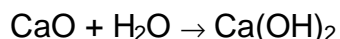
Another source of carbon dioxide is coke calcination used in anodes and cathodes. Many operating facilities purchase coke materials in the calcined state, however formulas for calculating carbon dioxide from calcining are included here because some facilities operate calcining furnaces. Also, carbon dioxide is released during the calcination of calcium carbonate, CaCO_3 , performed for quick lime (CaO) or slaked lime, Ca(OH)_2 , production. Alumina refineries, as part of the refining operations, sometimes perform this operation. The chemical reactions are described below.

Reaction 4:



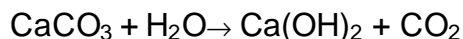
Potentially followed by hydrolysis as shown in reaction 5.

Reaction 5:



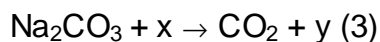
The overall combined reaction can be written as follows.

Reaction 6:



Another potential source of CO_2 is the use of soda ash (Na_2CO_3) when used in the process (e.g. for flue gas scrubbing).

Reaction 7:



Where x and y are acidic flue gas components and the sodium salt reaction product of the acidic gas component respectively.

Guidance is given here on inventory of direct carbon dioxide emissions from aluminium production in three tiers from highest to lowest accuracy:

Tier 3: Process specific formula with site or company specific factors.

Tier 2: Process specific formula with industry typical factors.

Tier 1: Industry wide process factors by reduction technology. Because this gives the lowest accuracy it should not to be used by aluminium companies.

2.2 Tier 3 – Highest Accuracy Method Using Process Specific Formulas with Facility Specific Parameters for Carbon Dioxide Emissions

The most accurate inventories of carbon dioxide are obtained by using site or company specific data in the equations for calculating emissions. This data might come from measurements made on site or from data from suppliers. The equations

for calculating Tier 3 carbon dioxide emissions are identical to those used in the Tier 2 method described below, however, facility specific or company specific data are used rather than industry typical data. The equations for calculating carbon dioxide emissions from facility or company specific data are embedded in the Excel spreadsheet tools included in Appendix B.

2.3 Tier 2 – Intermediate Accuracy Process Specific Formulas with Industry Typical Parameters for Carbon Dioxide Emissions

Tier 2 calculation of carbon dioxide emissions is based on calculation of carbon dioxide emissions from each individual process step and then summing the emissions from each step to calculate total emissions. Equations in 2.5 describe the calculation of carbon dioxide for Söderberg technologies while 2.6 contains equations for Prebake technologies.

2.4 Tier 1 - Lowest Accuracy Default Factor Method for Carbon Dioxide Emissions

The lowest accuracy default method should only be used for estimating carbon dioxide process emissions when no specific process data is available other than reduction technology type and aluminium production levels. Default emission factors from the table are multiplied by aluminium production levels to obtain total emissions of carbon dioxide. Because it gives the lowest accuracy, and because the aluminum facilities typically track parameters enabling them to calculate emissions as per the Tier 2 specific formula at a minimum, Tier 1 should not to be used by aluminium companies.

Table 1 – Tier 1 Default Factors for Carbon Dioxide Emissions

<i>Technology</i>	<i>CO₂ Emissions (tonnes CO₂/tonne Al)</i>
Prebake	1.6 ⁹
Söderberg	1.7

⁹ This value includes contributions from baking anodes, including the carbon dioxide from fuel combustion, and from electrolysis process emissions.

2.5 Calculations for Söderberg Technologies

Equation 1.

$$\text{CO}_2 \text{ emissions (t)} = [(\text{PC} \times \text{MP}) - (\text{BSM} \times \text{MP}/1000) - [\% \text{BC}/100 \times \text{PC} \times \text{MP} \times (\% \text{S}_p + \% \text{Ash}_p + \% \text{H}_p)/100] - [(100 - \% \text{BC})/100] \times \text{PC} \times \text{MP} \times (\% \text{S}_c + \% \text{Ash}_c)/100] \times 44/12$$

where:

Parameters used in Equation 1 are defined in the Table 2 together with industry typical values for use calculating carbon dioxide emissions for Söderberg technologies.

Table 2 – Industry Typical Parameters for Calculating Tier 2 Söderberg Process Carbon Dioxide Emissions

<i>Parameter</i>	<i>Industry Typical Value</i>
MP: metal production (t)	Not applicable
PC: paste consumption (t paste/t Al)	0.51
BSM: emissions of benzene soluble matter (kg/t Al)	HSS – 4.0 VSS – 0.5
BC: typical binder content in paste (wt %)	25 - 30
S _p : sulphur content in pitch (wt %)	0.0.55
Ash _p : ash content in pitch (wt %)	0.15
H _p : hydrogen content in pitch (wt %)	4.5
S _c : sulphur content in calcinated coke (wt %)	1.8
Ash _c : ash content in calcinated coke (wt %)	0.1

2.6 Calculations for Prebake Technologies

Carbon dioxide emissions resulting from CWPB and SWPB reduction technologies are from electrolysis and from anode baking.

2.6.1 Carbon Dioxide Emissions from Prebake Anode Consumption During Electrolysis

Equation 2.

$$\text{CO}_2 \text{ emissions (t)} = [\text{NCC} \times \text{MP} \times (100 - \% \text{Sa} - \% \text{Ash}_a - \% \text{Imp}_a)/100] \times 44/12$$

Table 3 – Industry Typical Parameters for Calculating Tier 2 Prebake Process Carbon Dioxide Emissions from Anode Consumption

Parameter	Industry Typical Value
MP: total aluminium production (t)	Not applicable
NCC: net anode consumption per tonne of aluminum (t C/t Al)	0.4
S _a : sulphur content in baked anodes (wt %)	1.6
Ash _a : ash content in baked anodes (wt %)	0.8
Imp _a : fluorine and other impurities in baked anodes (wt %)	0.4

2.6.2 Baking Furnace Emissions

Baking furnace emissions result from three sources, the combustion of volatile matter released during the baking operation, the combustion of the fuel for firing the furnace and combustion of bake furnace packing material.

2.6.2.1 Pitch volatile matter oxidation from pitch coking

Equation 3. CO_2 from pitch coking (t) = (GAW – BAP – HW – RT/1000) x 44/12
and

Equation 4. $\text{HW (t)} = \%H_p/100 \times \text{PC}/100 \times \text{GAW}$

The above equations assume 100% of the weight loss is burnt or waste hydrocarbons, where:

Table 4 – Industry Typical Parameters for Calculating Tier 2 Prebake Process Carbon Dioxide Emissions from Bake Furnace Pitch Volatiles Coking

Parameter	Industry Typical Value
GAW: loaded green anode tonnage (t)	Not applicable ¹⁰
BAP: unloaded baked anode tonnage (t)	Not applicable
HW : weight of hydrogen from pitch (t)	Not applicable
H _p : hydrogen content in pitch (wt %)	4.45
PC: pitch content (wt %) in green anode	15
RT: waste tar (kg/ t BAP)	5 (Riedheimer furnace) 0 (All other furnaces)

¹⁰ If Loaded green anode tonnage is not directly available it can be estimated with only small error by multiplying the baked anode tonnage by the factor 1.055 which accounts for baking losses.

2.6.2.2 Fuel for Bake Furnace Firing

Carbon dioxide emissions resulting from the fuel consumed during bake furnace firing can be calculated using cross sector tools available at the World Resources Institute website¹¹.

2.6.2.3 Bake Furnace Packing Material

Equation 6.

$$\text{CO}_2 \text{ from packing coke (t)} = [\text{PCC} \times \text{BAP} \times (100 - \% \text{Ash}_{\text{pc}} - \% \text{S}_{\text{pc}} - \text{Imp}) / 100] \times 44 / 12$$

Parameters included in equation 6 are defined and industry typical values noted in Table 6 below.

Table 6 – Industry Typical Parameters for Calculating Tier 2 Prebake Process Carbon Dioxide Emissions from Oxidation of Bake Furnace Packing Material

Parameter	Industry Typical Value
PCC: packing coke consumption per tonne of baked anode (t coke / t anodes)	0.010
BAP: Baked anode production (t)	Not applicable
Ash _{pc} : ash content in metallurgical (coal coke) packing coke (wt %)	5
Ash _{pc} : ash content in petroleum packing coke (wt %)	0.2
S _{pc} : sulphur content in packing coke (wt %) Metallurgical (coal coke)	3
S _{pc} : sulphur content in petroleum packing coke (wt %)	3
Imp: other impurities	0.1

2.7 Alternative Method for Carbon Dioxide Inventory Based on Raw Materials Purchases

This alternative approach for carbon dioxide emissions is applied to the aluminum production processes within the process boundaries shown in Figure 1 below. Carbon dioxide emissions are calculated from the carbon content of carbon containing materials consumed for the period of the inventory.

¹¹ World Resources Institute, Calculating CO₂ emissions from stationary combustion, <http://www.ghgprotocol.org/standard/tools.htm>

¹² Source: IAI survey data.

Show purchased anode as an input and sold anodes as an output in Figure 1.

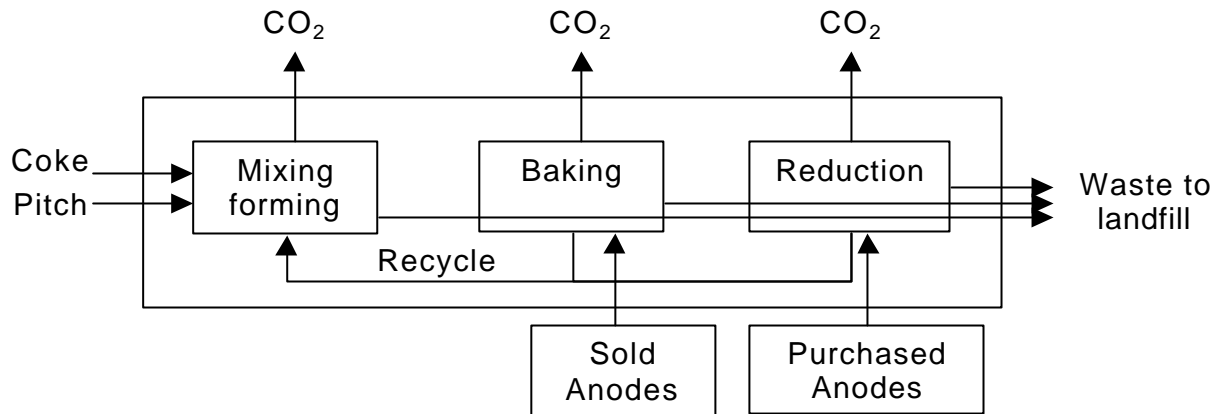


Figure 1 – Process Boundaries for Carbon Content of Consumed Materials Method for Carbon Dioxide Emissions Inventory

Equation 7 calculates total carbon dioxide emissions for the period considered. Inputs into the anode process system boundary are pitch, coke, purchased anodes and packing coke. Fuel and electricity are not included. Outputs from the anode process system boundary are CO₂ resulting from mixing and forming, baking and the reduction of the anode in the cell. Carbon wastes including fines or sludge disposed of to landfill and sold anodes are also a system output. The sum of the carbon inputs from pitch, coke and packing coke and can only leave the system boundary as CO₂ or as scrap carbon, fines and residues that are disposed of to landfill. The carbon mass balance shall be maintained. It is assumed that all carbon except verifiable carbon sent to landfill, is converted to CO₂ during the process. This assumes that any CO produced is further oxidized in the atmosphere to CO₂. Corrections are made for non-carbon constituents of pitch and coke including sulphur, ash and hydrogen that do not contribute to the greenhouse effect and are therefore not included in the calculation. Finally, fuels and electrical energy used in mixing, forming, baking, rodding and transportation of anodes are not included in the anode calculation. Greenhouse gas emissions from these inputs are calculated and reported separately.

$$\text{Equation 7. } \text{TCC} = \text{TPC} \times \text{PC}\%/100 + \text{Coke} \times \text{CC}\%/100 + \text{TPCC} \times \text{PCC}\%/100 - \text{TWC} + \text{PA} \times \text{PAC}/100 - \text{SA} \times \text{SAC}\%/100$$

$$\text{Equation 8. } \text{CO}_2\text{t} = \text{TCC} \times 44/12$$

where:

TCC	Total carbon consumed (t)
TPC	Total Pitch consumed (t)
PC%	Carbon content of pitch (wt %)
PCC%	Carbon content of packing coke (wt %)
Coke	Total coke consumed (t)
TPCC	Total packing coke consumed (t)
TWC	Total waste carbon to landfill (t)
CC%	Carbon content of coke (wt %)
PA	Total mass of purchased anodes (t)
PAC	Carbon content of purchased anodes (wt %)
SA	Total mass of sold anodes (t)
SAC%	Carbon content of sold anodes (wt %)
CO ₂ t	CO ₂ produced (t)

2.8 Additional Sources of Carbon Dioxide- Coke Calcination

For those production facilities that have coke calcining operations the following equation calculates carbon dioxide emissions resulting from calcining.

$$\text{Equation 9. } \text{CO}_2 \text{ emissions (t)} = [[\text{GC} \times (100 - \% \text{H}_2\text{O}_{\text{gc}} - \% \text{V}_{\text{gc}} - \% \text{S}_{\text{gc}}) / 100] + (\text{CC} + \text{UCC} + \text{DE}) \times (100 - \% \text{S}_{\text{cc}}) / 100] \times 44 / 12] + [\text{GC} \times 0.035 \times 44 / 16]$$

where; GC : green coke feed (t), and industry typical values for use in the above equation follow in Table 7.

Table 7 – Industry Typical Parameters for Calculating Tier 2 Process Carbon Dioxide Emissions from Calcining Operations

Parameter	Industry Typical Value
H ₂ O _{gc} : humidity in green coke (wt %)	10
V _{gc} : volatiles in green coke ¹³ (wt %)	10
S _{gc} : sulphur content in green coke (wt %)	3
S _{cc} : sulphur content in calcinated coke (wt %)	2.5
CC : calcinated coke produced (t)	0.8 x GC
UCC : under calcinated coke collected (t)	0
DE : coke dust emissions (t)	0.075 x GC ¹⁴

Note:

- 44/12: conversion factor from carbon to CO₂
- 44/16 : conversion factor from CH₄ to CO₂

¹³ Based on past research work, it is assumed that volatiles content in coke is about 3.2% CH₄, 0.3% tars and 7.1% H₂. The contribution of CH₄ and tars (3.5%) to CO₂ emissions is included in the equation. (Ref.: Jean Perron, *Modélisation mathématique d'un four de calcination du coke de pétrole* (mathematical model of a petroleum coke calcination furnace), doctorate thesis, Université de Montréal, École polytechnique, 1991.)

¹⁴ Ref: email from R. Cahill to J. Marks, Industry Average Values, Sept. 4, 2002.

Comments:

Any fuel consumption for coke calcination is included in the overall plant fuel consumption thus excluded from the above calculation.

2.9 Additional Sources of Carbon Dioxide– Lime Production

The following formula shall be used for calculation of carbon dioxide emissions from the production of lime associated with aluminium production.

$$\text{Equation 10. Emission of CO}_2 \text{ (t)} = Q_i \text{ (t)} \times 44/56 \times P_i + Q_s \text{ (t)} \times 44/74 \times P_s$$

Where parameters in Equation 10 are described in Table 8 along with industry typical values.

Table 8 – Industry Typical Parameters for Calculating Tier 2 Process Carbon Dioxide Emissions from Lime Production

Parameter	Industry Typical Value
Q _i : Quantity quick lime produced (t)	Not applicable
P _i : Purity of quick lime (decimal fraction)	0.95 ¹⁵
Q _s : Quantity of slaked lime produced (t)	Not applicable
P _s : Purity slaked lime (decimal fraction)	0.95 ¹⁶

2.10 Additional Sources of Carbon Dioxide– Emission of CO₂ from Soda Ash used in Aluminium Production Processes

The following formula shall be used for calculation of carbon dioxide emissions from the use of soda ash associated with aluminium production.

$$\text{Equation 11. Emission of CO}_2 \text{ (t)} = Q_{\text{soda ash}} \times 44/106 \times P_{\text{soda ash}}$$

Where parameters in Equation 11 are described in Table 9 along with industry typical values.

Table 9 – Industry Typical Parameters for Calculating Tier 2 Process Carbon Dioxide Emissions from Soda Ash used in Aluminium Production Processes

Parameter	Industry Typical Value
Q _{soda ash} : Quantity of soda ash (Na ₂ CO ₃) consumed (t)	Not applicable
P _{soda ash} : Purity of soda ash consumed (decimal fraction)	0.95

¹⁵ Source: Ref [2], table 3-4, page 3.22

¹⁶ Source: Ref[2], table 3-4, page 3.22

Appendix B

Excel Spreadsheet tool and guidance for calculating total Carbon Dioxide Equivalent Emissions from Primary Aluminium Production



AluminumGuidance_06-03.doc



aluminum_Tool_06-03.xls

Appendix C

Acknowledgements:

Within the International Aluminium Institute the work on this document was organized in 3 Working Groups:

WG 1: WBCSD/WRI protocol review and integration (corporate boundary issues and reporting)

Lead:	Patrick Grover	Alcoa
Participants:	Fraser Thomson	Alcan
	Lawrence Leung	BHP Billiton
	Brian Glazebrook	PricewaterhouseCoopers
	Willy Bjerke	IAI
	Robert P. Strieter	AA

WG 2: Best practice for process related CO₂ calculation methodologies

Lead:	Guy Bouchard	Alcan
	and Michel Labarre	Pechiney
Participants:	John Bryson Aitchison	Alcan
	Bernard P. Leber	Kaiser
	Hendrik Louw	BHP Billiton
	Kenneth J. Martchek	Alcoa

WG 3: Good Practice Guidance on Inventorying Perfluorocarbon Compounds (PFC) Emissions

Lead:	Jerry Marks	IAI
Participants:	Patrick R. Atkins	Alcoa
	Michel Lalonde	Alcan
	Edgar Sagen	Hydro Aluminium
	Pieter de Waal	IAI