ENERGY. TRANSFORMED.

Aluminum GHG Emissions Reporting Guidance

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1 BACKGROUND

1.1 Introduction

Aluminum is the second most used metal. It is utilized in various sectors such as construction, electric transmission, transport, and consumer goods. Aluminum also plays a critical role in accelerating the transition to a low-carbon economy given its prominence in clean technologies such as power transmission, solar panels, electric cars, and others.

The aluminum sector is a significant emitter of greenhouse gases (GHGs). It was responsible for more than 1.1 gigatons (Gt) of CO_2 equivalent (CO_2e) in 2018, which is around 2% of global anthropogenic emissions.[1] Current aluminum production heavily relies on fossil fuels for power supply and making anode materials used in aluminum smelting. As a result, the transition to renewable energy sources and low-carbon manufacturing technologies is needed to fundamentally decarbonize the sector.

As environmental, social, and governance considerations become a core strategy for companies worldwide, end-users of aluminum that seek to cut carbon emissions from their supply chains, such as electric vehicle, electronic device, and beverage can manufacturers, will drive the demand for low-carbon aluminum.[i] To fulfill this demand, it is necessary for various players in the aluminum supply chain to provide emissions information at the product level using a consistent and transparent method to ensure accuracy and comparability. This allows end-users to confidently purchase aluminum with low embodied emissions and ensure that the purchasing decisions drive sectoral decarbonization in the aluminum industry.

This guidance details the methods for emissions calculation and reporting that aluminum companies can use to provide emissions information in a consistent and transparent manner, and in so doing, meet the demand for low-carbon aluminum.

1.2 Purpose

This guidance serves as a useful reference for aluminum companies to report emissions in a way that drives industry-wide actions on decarbonization and accelerates the development of a differentiated market for low-carbon aluminum.[ii]

The broad intent of the implementation of this guidance is to ensure the following:

1. Increase transparency of aluminum product-level GHG emissions with a globally consistent methodology.
2. Credibly recognize aluminum producers leading the market in terms of climate performance.
3. Accelerate the development of essential technologies for net-zero aluminum by ensuring sufficient information is available to link demand with supply.
4. Enable end-users to compare climate performance across supplied aluminum products (of various specifications) to better inform procurement decisions.

[i] The industry has not formally defined low-carbon aluminum. Commonly, it is referred as 4 tons CO_2e/ton primary aluminum ingot for Scope 1 and Scope 2 emissions at the smelter.
[ii] Emissions here and throughout the document refers to the GHG emissions.

5. Aid end-users in purchasing aluminum with credible and transparent climate data so they can demonstrate evidence of climate performance to their customers.[iii]

1.3 Principles

This guidance is developed based on the carbon accounting principles of RMI's Horizon Zero project.[2] The overarching principle is the need for companies to report emissions at the product level from a specific asset (see section 2 for definition of an "asset"). This is required because purchasing decisions for a material are made at the product level. This guidance seeks to inform such purchasing decisions by providing carbon accounting principles designed to drive industry decarbonization actions.

To enable useful product-level GHG emissions disclosures, three key principles are applied:

1. Primary data: As much as possible, emissions calculations should be based on first-hand information from various supply chain partners.

2. Consistent boundary for comparison: Companies shall report emissions against a fixed boundary (i.e., a consistent set of processes) to enable comparability and consistency between disclosures.

3. Measurement made for market: Calculation and reporting decisions should enable the development of a market for low-carbon products, resulting in low-carbon production for the aluminum sector as a whole.

This guidance provides details specific to the aluminum sector to implement these broad accounting principles.

1.4 Scope

This guidance is intended to be used by any organization that owns and operates aluminum production facilities for primary and recycled aluminum production, as shown in Exhibit 1 (page 10). For this guidance, aluminum producers refer to companies producing aluminum, including liquid aluminum metal, aluminum cast-house products (primary and recycled) in all forms (e.g., ingots, slabs, bars), and aluminum semifinished products (semis) in all forms (e.g., foil, sheet, profiles). These aluminum producers shall report their emissions against the fixed boundaries (this could be the benchmarking boundary or the full boundary or both depending on the producer) shown in Exhibit 1. This includes emissions from bauxite mining facilities, alumina refiners, anode manufacturers, and other processes even if they are not vertically integrated with aluminum smelters and cast-houses. Other actors in the supply chain (such as downstream aluminum purchasers) may use this guidance to request emissions intensity data to better understand supply chain emissions.

The bauxite mines, stand-alone alumina refineries, stand-alone anode manufacturers, and stand-alone semi-fabrication facilities that are not part of any vertically integrated aluminum producers should provide relevant emissions data to their respective buyers but need not report their emissions, as per the whole fixed boundaries given in Exhibit 1.

[iii] Climate performance refers to the product-level climate data enabled by this tool. It includes emissions intensity for aluminum ingot, emissions intensity for aluminum semifinished product (if relevant), mine-to-smelter emissions intensity for ore-based aluminum, share of scrap-based aluminum, postconsumer scrap share, and share of primary data in carbon accounting.

The discussion of emissions in this guidance includes all relevant GHGs with the 100-year time frame for global warming potential (GWP) consideration. For the aluminum industry, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and perfluorocarbons (PFCs), including tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6), are particularly relevant.

1.5 Terminology

This guidance applies different terms to differentiate requirements, recommendations, and permissible options in line with the Pathfinder Framework.[3]

Term	Definition
Shall	The rules to be followed by companies applying RMI's Aluminum GHG Emissions Reporting Guidance
Should	The rules that are recommendations
May	A permissible option

2 EMISSIONS REPORTING

The key requirements for reporting in this Aluminum GHG Emissions Reporting Guidance are as follows:

1. Product level: Emissions shall be reported at the product level for an individual site.[iv]
2. Fixed system boundary: All emissions from a set of processes shall be reported irrespective of whether the company has ownership or control of these processes.
3. Supply chain transparency: Emissions related to primary metal and scrap input shall be additionally reported. This provides some context for the overall emissions footprint. Additional reporting on the type of scrap used provides more context related to recycled content.
4. Primary data source: Emissions disclosures shall include the share of the emissions footprint based on primary data.

Following these key requirements, the metrics reported for each product are given below. This data shall be reported on an annual basis at the asset level.

- **Benchmarking footprint:** The overall emissions footprint for the aluminum product as per the benchmarking boundary, in tons of CO_2e per ton of aluminum ingot (refer to Sections 3.1 and 3.3). This may also be referred to as mine-to-final cast-house emissions intensity for primary aluminum products without scrap inputs.

[iv] An "individual site," also called an asset in this guidance, refers to a single production facility with a given geographical address. In some cases, an asset can refer to multiple production facilities when there is constant movement of raw materials or shared use of intermediate products among them. The definition of a product depends on whether the emissions footprint is calculated for the benchmarking boundary or the full boundary. See section 2.2 for the boundary definitions.

- **Full footprint** (if relevant): The overall emissions footprint for the aluminum product as per the full reporting boundary, in tons of CO_2e per ton of aluminum semis (refer to Sections 3.1 and 3.3). This includes emissions from the mine to the last process in the full boundary. Thus, it includes benchmarking emissions as well.
- **Mine-to-smelter emissions intensity** (if relevant): The overall emissions intensity for primary aluminum, in tons of CO_2e per ton of primary aluminum (refer to Section 3.3.2).
- **Share of scrap-based content:** The share of scrap-based input used to generate the product as per the benchmarking boundary and further disclosure of the share of postconsumer scrap separately (refer to Section 3.2).
- **Share of primary data:** The share of primary data used to calculate the overall emissions footprint for the full reporting boundary (refer to Section 3.6.5).

The reporting responsibility for the metrics of benchmarking footprint, mine-to-smelter emissions intensity, share of scrap-based content, and share of postconsumer scrap lies with the facility that produces final cast-house products (i.e., value-added products such as slabs, billets, foundry alloys, wire rods, and other specialty products) used in semi-fabrication processes (such as rolling, extrusion, and foundry casting). The facility with the final cast house shall collect the necessary emissions information from its suppliers, metal traders, and other supply chain partners. If the final cast house is not integrated with semi-fabrication facilities, it shall report the metrics to the semi-fabrication facility, which then reports the full list of metrics to its downstream buyers. If the final cast house is integrated with semi-fabrication units, this integrated facility shall report all the required metrics to its buyers. In addition, all supply chain partners should provide relevant emissions information to their downstream buyers (refer to Section 1.4).

2.1 Product Level

The reporting in this guidance enables the emissions information to flow alongside the product and accumulate as products are moved (and transformed) along a supply chain. This enables each actor in the supply chain to accurately understand the embodied emissions of both purchased and sold products. This can help companies set informed net-zero-carbon targets and take effective decarbonization actions.

To achieve this, companies shall report emissions of aluminum on the product level for each asset. This reporting shall be done against the benchmarking boundary for aluminum final cast-house products and against both the benchmarking and full boundaries for aluminum semifinished products. The emissions intensity calculations shall be based on details given in Section 3 and in line with the other reporting requirements outlined in this section.

2.2 Fixed System Boundary

The fixed boundary defines all the process steps to report emissions irrespective of an aluminum producer's ownership structure. This approach solves two key problems:

1. **Corporate-level emissions disclosure varies depending on the degree of vertical integration.** In the aluminum industry, vertical integration can extend to emissions-intensive processes such as lime calcination or anode production. For aluminum producers that own and operate these processes, emissions would be included in Scope 1

(according to the GHG Protocol[4]). For nonintegrated producers, the same emissions would count as Scope 3, which may not be reported, presenting challenges in comparing GHG emissions at the corporate level across the sector.

2. **Changes in the sector required by the energy transition may result in emissions shifting between Scopes 1 and 2.** For example, as the need for decarbonizing power generation increases, smelters operating or owning fossil-based captive power plants may consider procuring green electricity or relocating to renewable-rich regions and connecting to grids. In these cases, emissions may shift from Scope 1 (self-generated electricity) to Scope 2 (grid-purchased electricity).

Exhibit 1 shows the fixed boundaries against which reporting is to be done in this guidance. These reporting boundaries are designed in accordance with aluminum sectoral 1.5°C decarbonization pathways to help track sectoral decarbonization progress.[5] To enable comparison among products, the benchmarking boundary is defined to include processes from mining to the final cast house. The last casting process yields the final cast-house products, including slabs, billets, wire rods, foundry alloys, and other specialty products ready for further semi-fabrication processes. All final cast-house products require emissions reporting against the benchmarking boundary for comparability.

If the aluminum products also require further processing (e.g., rolling, extrusion, foundry casting), emissions from these processes shall be added to report the overall emissions intensity for the full boundary.

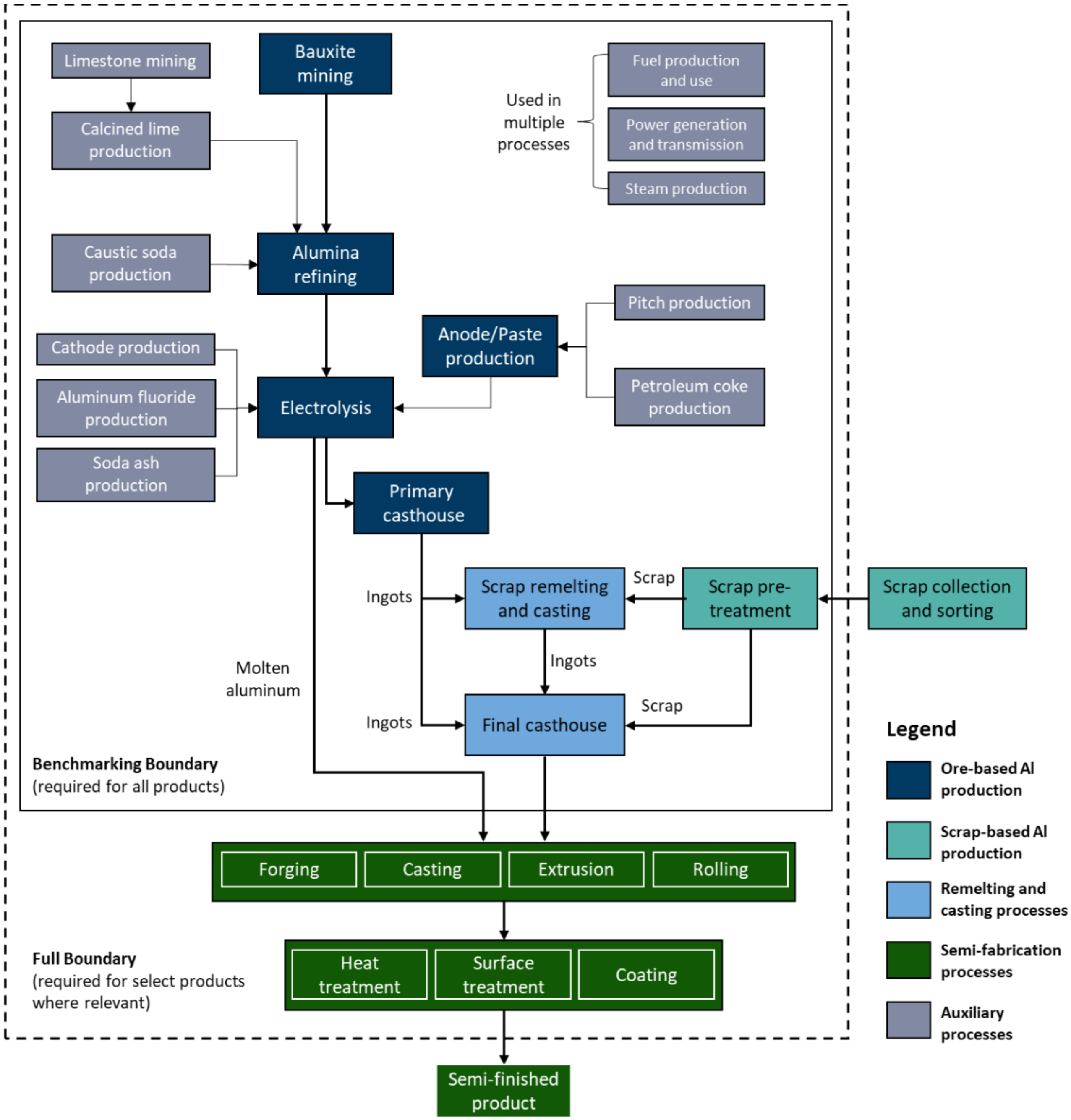
Alloying emissions (i.e., emissions from alloying process and embodied emissions of alloy metals), if relevant, shall be included in the calculation for both boundaries considering the materiality of these emissions. The specific guidelines for alloying emissions are in Section 3.3.4.

Emissions related to transport activities are excluded from both boundaries because this guidance is focused on decarbonization of the aluminum sector. Aluminum producers are encouraged to refer to transportation sector guidance, such as the Global Logistics Emissions Council framework, to account for these emissions.[6]

In summary, this guidance sets two boundaries for distinct purposes:

- **The benchmarking boundary,** which includes all relevant processes from bauxite mining to final cast house, ensuring comparability between aluminum products with different specifications. This does not include semi-fabrication processes and processes that occur after the final cast house.
- **The full boundary** includes all relevant processes in the benchmarking boundary, semi-fabrication processes, and further downstream processes to capture cradle-to-gate emissions. Accounting for emissions from the semi-fabrication processes emphasizes the increasingly important role of material efficiency in determining the overall emissions intensity. The full boundary is also designed to be a flexible boundary depending on the producer, with the cradle-to-gate emissions reported until the last step of emissions of a sold product.

Exhibit 1: Fixed System Boundaries for Aluminum GHG Emissions Reporting



Note:

- **Fuel** includes all the solid, gas, liquid fuels used in the production.
- **Input production** (e.g., Soda ash production) refers to the cradle-to-gate emissions of inputs.
- **Final casthouse** is the same as semi-fabrication ingot casthouse. It is the last casting process producing billets, slabs, sows, ready for semi-fabrication.

RMI Graphic.

2.3 Supply Chain Transparency

Aluminum is currently produced in two ways: ore based (primary) and scrap based (recycled). Primary aluminum is produced mainly from the bauxite obtained from bauxite mines and refined to alumina through the Bayer process. This alumina is then converted to liquid aluminum by the Hall-Héroult electrolysis process, which uses electricity to break the strong chemical bonds between aluminum and oxygen. Recycled aluminum is produced by remelting and refining end-of-life scrap; scrap from aluminum rolling, forming, and other semi-fabrication processes; scrap from downstream fabrication; and aluminum recovered from dross or other aluminum-containing waste. Primary aluminum ingot may be added in the remelting process to produce recycled aluminum. There is no functional difference between primary and recycled aluminum in final products, except that primary aluminum provides more flexibility for making alloys.

GHG emissions intensity significantly differs between primary aluminum and recycled aluminum. Emissions from recycled aluminum production processes are around 6% of those from primary aluminum production process.[v] Such variability makes recycled aluminum the fastest effective way to reduce emissions across the sector in the near term. However, its overall potential of emissions reduction is constrained by scrap availability. The International Aluminium Institute's (IAI's) 1.5°C pathway maintains that recycled aluminum is anticipated to meet only 50%–60% of the total demand by 2050 under several scenarios.[7] It is impossible to completely decarbonize the aluminum sector using only recycled aluminum due to constrained supply of aluminum scrap. The limited supply of aluminum scrap indicates that producing more aluminum from scrap alone may not result in the required reduction of the sector's emissions. Thus, it will also be necessary to invest in and deploy decarbonization technologies in the primary production route.

To showcase efforts to decarbonize primary aluminum, aluminum producers shall disclose the emissions intensity of primary aluminum used in the final cast-house products. Primary metal ingots and scrap are usually mixed in the ingot casting processes. This makes it difficult for end-users to compare climate performance across products, especially if they are made with different shares of primary aluminum and scrap. Therefore, aluminum producers shall calculate and report the mine-to-smelter emissions intensity value for the primary aluminum input to improve the emissions transparency. This helps differentiate low-carbon aluminum produced using low-emissions technologies (e.g., renewable energy, inert anode) and prevents aluminum producers from competing for scrap to reduce the emissions intensity of their products.

Decarbonization of the aluminum industry also requires the minimization of pre-consumer scrap and improved recycling of postconsumer scrap. Pre- and postconsumer scrap are usually mixed in the remelting process and not disclosed separately. This hampers the ability of end-users to drive change in aluminum recycling. Therefore, aluminum producers shall disclose the share of scrap-based inputs using a consistent method, along with a separate disclosure of postconsumer scrap. The specific calculation procedure and definition of scrap-based content are provided in Section 3.2.

2.4 Primary Data Source

To ensure that purchasing decisions based on emissions performance of different aluminum products drive investments in low-emissions technologies, it is necessary to use primary data to quantify the various reported metrics. Primary data refers to data provided directly by the entity responsible for those emissions (i.e., Scope 1 or 2 emissions of these entities).

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[v] Emissions from recycled aluminum production refers to the emissions related to scrap pretreatment, remelting, and casting.

Aluminum companies shall report the share of emissions calculated using primary data. This may require the companies to request the share of primary data used in emissions estimates from upstream suppliers. The method for companies to calculate the share of primary data is provided in Section 3.6.5.

3 EMISSIONS CALCULATION REQUIREMENTS

3.1 Emissions Calculation Procedure

The calculation procedure for process-level emissions is adapted from the reporting documents from IAI, which are the guidance commonly used by the aluminum industry. Specifically, this guidance incorporates the following:

- The Aluminum Sector Greenhouse Gas Protocol[8]
- Aluminum Carbon Footprint Technical Support Document[9]
- Good Practice Guidance for Calculation of Primary Aluminium and Precursor Product Carbon Footprints v2[10]
- Good Practice Guidance: Measuring Perfluorocarbons[11]
- Reference Document on Carbon Footprint Calculations of Aluminium Scrap[12]

In general, the overall emissions shall be divided by the mass of aluminum produced to calculate the emissions intensity value. The overall emissions shall be calculated as follows:

$$E_{\mathrm{CO2}} = \sum_{t=1}^{N} EF_{t,d,\mathrm{CO2e}} \times Q_{t,d} + \sum_{t=1}^{N} EF_{t,i,\mathrm{CO2e}} \times Q_{t,i} - \sum_{t=1}^{N} EF_{t,s,\mathrm{CO2e}} \times Q_{t,s}$$

where

- t, from 1 to N, refers to each emissions source (e.g., fuel, energy, or other input).
- EF refers to emission factors.
- Q refers to quantity of an emissions source used at an asset.
- d, i, and s refer to direct, indirect, and subtracted emissions, respectively, which are defined as follows:
    - Direct: This refers to carbon emissions from production process reactions (for example, reaction at carbon anode) and use of fuel sources and on-site electricity generation where the emissions factor is defined based on the carbon intensity of that fuel source/electricity generation. This also includes PFC emissions from aluminum production processes.
    - Indirect: This refers to emissions outside of the corporate boundary of an aluminum producer, such as embodied emissions of anode materials, ancillary process emissions outside of the aluminum producer boundary, generation emissions for purchased power, and upstream emissions for fuels and electricity used during aluminum production. Despite being outside an aluminum producer's boundary, these emissions need to be included as part of the fixed boundary (refer to Section 2.2). These emissions should be determined by the relevant supply chain partner and the data should be transferred to the aluminum

producer. Where this is impossible, average emissions factors can be used. However, the use of average emissions factors affects the share of primary data, weakening data reliability. For efficient facilities and processes, the use of average emissions factors could lead to overestimation of emissions (refer to Section 3.6.4).

  - Subtracted: This refers to emissions that should be subtracted from the emissions estimate and applies only to emissions not relevant to the production of aluminum at that site (e.g., sold intermediate products). Refer to Section 3.5 for details.

The required emissions sources and associated emissions factors for direct and indirect are provided in Section 3.6, details on calculating electricity-related emissions in Section 3.4, and categories and emissions factors for exported products in Section 3.5.

3.2 Reporting of Scrap-Based Content

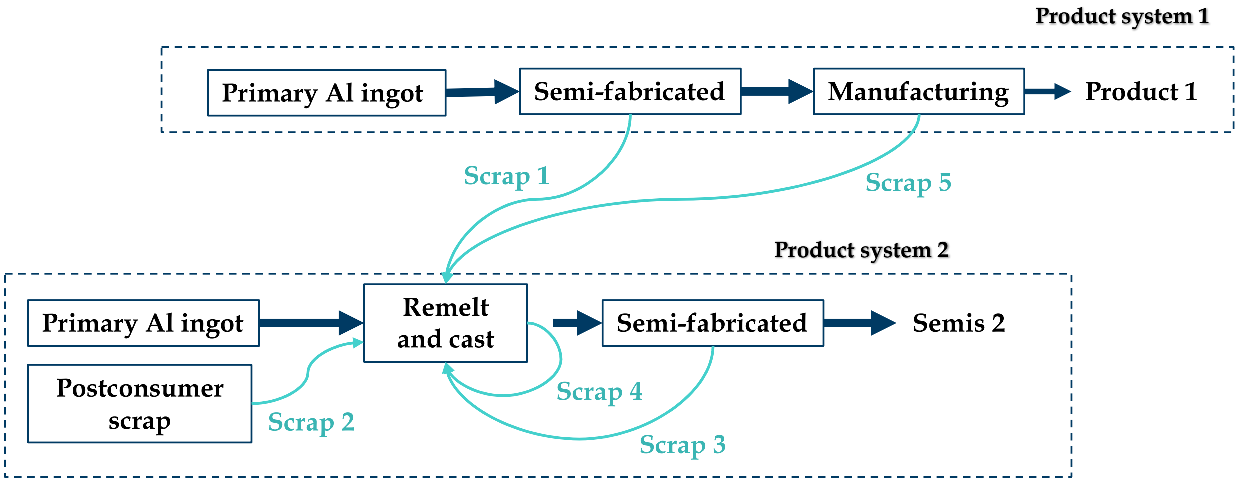
Definition of scrap-based content

The metallic input of aluminum products is sourced from either bauxite ore or scrap. Scrap can be further categorized into pre-consumer and postconsumer scrap. Different industry associations categorize scrap differently. In this guidance, scrap is defined based on IAI's draft document on how to treat scrap flow in carbon footprint calculations for aluminum products and shown in Exhibit 2.[13] The various definitions related to scrap in this guidance are as follows:

- Internal scrap: Also called runaround scrap or home scrap, this is generated at the casting step of the remelting process and reintroduced to the same remelting process.
- Pre-consumer scrap: This is material containing aluminum that is diverted from the waste stream from a manufacturing or similar process. This pre-consumer material is unfit for end use and cannot be reclaimed within the same process step that generated it. This includes both the scrap generated at the same site that produces aluminum and the fabrication scrap produced outside of the aluminum producer through downstream manufacturing processes at a different site.
- Postconsumer scrap: This is recovered from aluminum-containing products that have reached their end of life (e.g., recycling of aluminum from used beverage cans).

In addition to these three scrap types, there is also aluminum recycled from dross or other aluminum-containing waste that is used in the aluminum production process. The definitions of pre-consumer scrap are unclear in International Organization for Standardization (ISO) standards, leaving room for interpretation.[14] A major discrepancy is related to whether the scrap generated at the semi-fabrication process and reintroduced to the co-located remelting process (i.e., scrap 3 in Exhibit 2, also defined as inside scrap in the IAI reference document on scrap flow) should be defined as pre-consumer scrap. In this case, the definition of pre-consumer scrap is tied to the integration level of the semi-fabrication process (i.e., whether the remelting/casting and semi-fabrication processes are part of the same company). This inconsistency has created confusion and compromised comparability across aluminum products. For the purposes of this guidance, when the remelting/casting and semi-fabrication processes are part of the same company, the scrap generated from the semi-fabrication process and used in the remelting/casting is considered to be part of the scrap-based input. Harmonizing the definition of scrap flow is beyond the scope of this guidance, but it aims to improve cross-product comparability by decoupling the definition of pre-consumer scrap from the facility integration level.

Exhibit 2: Example of Different Scrap Flows



Scrap Flows	ISO Recycled Content Definition	IAI Aluminum LCA Definition	Horizon Zero Al Guidance Definition
Scrap 1	Pre-consumer scrap	Process scrap	Pre-consumer scrap
Scrap 2	Postconsumer scrap	Postconsumer scrap	Postconsumer scrap
Scrap 3	Pre-consumer scrap (*depending on the definition of a process*)	Inside scrap	Pre-consumer scrap
Scrap 4	Not pre-consumer	Inside scrap	Not pre-consumer (internal scrap)
Scrap 5	Pre-consumer scrap	Process scrap	Pre-consumer scrap

RMI Graphic. Source: Adapted from IAI, https://international-aluminium.org/wp-content/uploads/2023/01/Carbon-footprint-of-recycled-aluminium-IAI-Document-Public-Review-Final.pdf

Share of scrap-based content

The calculation of the share of scrap-based content in this guidance specifically applies to the benchmarking boundary and its product (i.e., final cast-house products). To simplify the calculation, this guidance defines any pre- or postconsumer scrap input to the aluminum production process as scrap-based input. This includes any aluminum recovered from dross (or other aluminum-containing waste) used in aluminum production. Any permanent melt loss, scrap sold by the site, or aluminum content in dross leaving the site shall be subtracted from the total scrap-based input to ensure that scrap leaving the site is not counted. The share of scrap input shall be calculated at every process step in which pre- or postconsumer scrap is added (i.e., every melting step, if there are multiple melting steps involved in the manufacture of the final cast-house product). Specifically, the share of scrap-based input shall be calculated as follows:

$$\text{Share of scrap} - \text{based content} = \frac{M_{\text{Scrap}}}{M_{\text{Scrap}} + M_{\text{Primary}}}$$

where M_{Scrap} is the net mass of scrap (defined as mass of pre- and postconsumer scrap including recovered aluminum from dross minus the mass of sold scrap); and M_{Primary} is the mass of primary aluminum in either solid or molten form with minimum 99.7% aluminum purity.

The scrap-based content in this guidance is not intended to replace existing definitions of recycled content used by the aluminum industry. But defining the scrap-based content against the fixed benchmarking boundary gives consistent results for facilities with different integration levels. It is also consistent with the scrap-based content definition in the RMI Steel GHG Emissions Reporting Guidance.[15]

Share of postconsumer scrap

Recycling and using postconsumer scrap reduces the need for extracting bauxite ore for aluminum production. This can result in significant environmental benefits. Recycling and resource efficiency is identified as one of the pathways toward achieving a 1.5°C-aligned aluminum sector.[16] It requires the increase of postconsumer scrap recycling along with the usage and minimization of pre-consumer scrap. In some end-uses, like in buildings, postconsumer scrap has high collection rates. In other cases, postconsumer has low collection rates and low quality as it is mixed with other scrap.

To improve the recycling and use of postconsumer scrap, this guidance requires the disclosure of postconsumer scrap share as a key product metric. Along with disclosing the share of total scrap-based content, aluminum producers shall report the share of aluminum input from postconsumer scrap, calculated as follows:

$$\text{Share of postconsumer scrap} = \frac{M_{\text{Postconsumer}}}{M_{\text{Primary}} + M_{\text{Scrap}}}$$

Defining the share of postconsumer scrap may be challenging considering pre- and postconsumer scrap can be mixed during the collection and distribution of scrap. Producers should first make efforts to improve recycling transparency by requesting primary information from scrap traders or suppliers. If a data gap still exists, producers may refer to the IAI regional default conversion factors to estimate the postconsumer scrap share of their scrap input based on the location from which their scrap is sourced.[17]

The share of scrap-based content and the share of postconsumer scrap in this guidance are defined for the final cast-house products. However, as long as there is no change of input materials between the final cast-house products and the semi-fabricated products (like rolled sheet, extrusion profiles), the semi-fabricated products will maintain the same scrap-based content and postconsumer content values as the final cast-house products from which they are made.

Allocation of recycled content based on mass balance

This guidance does not recommend using the mass balance approach for allocation of recycled content as this practice is not generally allowed within the industry. Calculation for emissions associated with recycled content should be consistent with recommendations within the guidance.

3.3 Transparent Reporting of Product Emissions Intensity

General calculation principles

In general, companies shall use the following principles to determine emissions associated with producing aluminum products. These principles broadly align with the guidelines in the IAI documents listed in Section 3.1.

- The product-level metrics shall be calculated and reported for a given asset (a production site). If a company has multiple assets, the relevant product metrics shall be separately calculated and reported for each asset. In some cases, an asset can refer to multiple production facilities when there is constant movement of raw materials or shared use of intermediate products among the facilities, and it is hard to separate raw material and intermediate product usage at these facilities. Or, if multiple facilities have the same energy source, and a single environmental product declaration is created for these facilities combined, then these facilities together may be considered an "asset".
- Product emissions shall comprise all GHG emissions for all processes included in the fixed boundaries in Exhibit 1. This encompasses process direct emissions, upstream and combustion emissions of thermal fuels, life-cycle emissions of electricity, and cradle-to-gate emissions of ancillary materials.
- Product emissions intensity shall be calculated based on the final output for each fixed boundary and reported as tons of CO_2e per ton of output. For example, the benchmarking footprint of the final cast-house slabs shall be calculated as total emissions divided by total output of slabs. Similarly, the full footprint for semifinished products shall be calculated as total emissions divided by total output of semifinished products.
- For product systems involving the use of primary ingots (or molten primary aluminum) in the remelting or refining process (e.g., in the manufacture of slabs), companies shall also report the emissions intensity of primary aluminum covering mine-to-smelter emissions. More details are provided in Section 3.3.2.
- For product systems involving scrap (pre- or postconsumer), the benchmarking footprint (i.e., mine-to-final cast house) shall be calculated using the cutoff approach. The co-product allocation approach shall also be used if reliable data on scrap embodied emissions is available and transferred across the aluminum value chain. Refer to Section 3.3.3 for more details.
- Alloying emissions shall be included in the emissions intensity calculations for the benchmarking and full boundaries. Relevant guidelines are provided in Section 3.3.4.
- The GHG emissions associated with intermediate products within the aluminum supply chain and exported energy shall be subtracted from the emissions calculation to reflect the actual emissions of the final product. More instructions are listed in Section 3.5.1 for intermediate products and Section 3.5.3 for exported energy.
- By-products and waste cannot be credited in the emissions calculation. Refer to Section 3.5.2.

- Emissions benefits from sourcing renewable energy shall not be allocated across a specific product portfolio to reduce greenwashing risks. For more details, refer to Section 3.4.
- If market instruments of sourcing renewable energy need to be involved in aluminum production, companies shall first check the criteria for high-quality market instruments to get a broad idea of whether the involved instrument is credible. Next, companies can follow the decision-making hierarchy to decide which renewable energy mechanism suits them best. More details are given in Section 3.4.
- This guidance recommends reporting electricity impact using both location- and market-based methods. If only one method is used, the reporting entity shall specify the method selected.

Emissions transparency of primary production

Primary aluminum production requires a substantial amount of energy. Many primary smelters still rely on fossil fuels and fossil-powered electricity, contributing to a major portion of the sector's emissions. Although shifting to recycling has considerable decarbonization opportunities, the supply of scrap is constrained and would only meet approximately 54% of the global demand for aluminum in 2050.[18] As a result, achieving the sector's decarbonization goals will inevitably require a focus on reducing emissions in primary production. This can be achieved through low-carbon power and deployment of zero-emissions technologies.

Improving emissions transparency of primary aluminum production plays a critical role in driving sectoral decarbonization actions. This guidance contributes by requiring additional reporting of mine-to-smelter emissions intensity for products with primary metal as input. It would help climate-leading producers better demonstrate their efforts of decarbonizing primary production. It also provides investors and end-users with transparent and credible metrics to understand an individual aluminum supplier's progress on sectoral decarbonization.[vi]

For mine-to-smelter emissions, producers shall calculate all the direct and indirect emissions related to mining, alumina refining, anode production, smelting, and primary casting (if relevant), including emissions from ancillary processes and materials. Aligned with benchmarking footprint and full footprint calculations, transport emissions are excluded. If scrap is added in the primary cast house and requires additional fuels for remelting, emissions related to additional fuels may be estimated by the energy demand for remelting the amount of additional solid scrap and can be deducted from mine-to-smelter emissions. Also, the reported mine-to-smelter emissions intensity would be the total mine-to-smelter emissions associated with making the primary metal divided by the total primary metal output (i.e., excluding any scrap metal added). The extra emissions for the scrap remelting (if any) shall be added back to product emissions intensity calculations for both benchmarking and full boundaries.

Product-level calculation

The calculation of the product-level emissions footprint shall follow the principles in Section 3.3.1 for both the benchmarking system and full system boundary (if relevant). Typically, pre- and postconsumer scrap is considered burden free in cradle-to-gate product carbon footprint (PCF) calculations. More recently, there has been a debate on whether to assign an embodied burden to pre-consumer scrap to further differentiate pre- and postconsumer scrap. However, for pre-consumer scrap flow, there is no broad agreement on whether emissions should be assigned. This affects comparability and consistency between

[vi] This refers to 1.5°C-aligned pathways developed by the Mission Possible Partnership and IAI for primary aluminum production.

disclosures. IAI has taken efforts to improve transparency in scrap emissions by publishing a draft reference document to enhance and align industry-wide understanding of common methods for scrap embodied emissions.[19] Aluminum producers are recommended to refer to that document for more details.

In general, cutoff, co-product allocation, and substitution are mainly used to incorporate pre-consumer scrap emissions in PCF calculations. These methods are considered valid in ISO standards and are fundamentally different in the assumptions about the function of pre-consumer scrap flow (i.e., as waste, co-product, or secondary material).

The widely used cutoff approach of treating pre-consumer scrap as burden-free(i.e., having zero embodied emissions) requires the lowest calculation effort. This is convenient especially when scrap used in aluminum production comes from multiple sources and it is hard to trace the scrap back to its origin. The cutoff approach promotes reduced scrap generation in the aluminum production process, resulting in overall efficiency, and drives the use of scrap from an emissions perspective because it is burden free. However, some argue that the use of pre-consumer scrap has enough economic incentives. The concern is that, in some cases, the cutoff approach creates limited incentives for postconsumer scrap recycling because the cutoff approach does not distinguish the use of pre-consumer and postconsumer scrap. It may risk creating circumvention opportunities or an unintended competitive advantage for pre-consumer scrap produced from high-carbon primary aluminum made using fossil fuels.

Co-production allocation and substitution methods assign some emissions to pre-consumer scrap. They require a more complex calculation procedure that often necessitates a certain level of traceability of the origin and destination of scrap flow. Lack of traceability can result in emissions leakage or double counting. Use of either of these methods creates limited incentives for recycling pre-consumer scrap into alloys of similar composition, before the scrap is mixed with scrap of another alloy composition. Therefore, some argue that these methods may result in increased scrap generation. Nevertheless, both methods offer emissions incentives to differentiate pre- and postconsumer scrap types. This further drives industry actions on improving postconsumer scrap recycling and low-carbon primary production, which are essential for sectoral decarbonization.

The following considerations explain some nuances regarding scrap embodied emissions:

- Existing policies may require how process scrap should be modeled for cradle-to-grave life-cycle assessments, but they do not have explicit requirements and implications for cradle-to-gate analysis.
- Co-product allocation has low uncertainty in emissions leakage (because the scrap generator allocates their actual process emissions to scrap). It is relatively easier for scrap users to trace their scrap back to their suppliers (as is required for co-product allocation) than for scrap generators to trace the scrap down to their buyers (as is required for the substitution approach).
- The co-product allocation approach provides more differentiation among pre-consumer scrap types generated from aluminum with various emissions intensities (high-carbon prime versus low-carbon prime).
- Across the world, many aluminum producers still use the cutoff method. To report under a new method, producers need time to transition and set new data collection systems in place.

Given these considerations, this guidance requires reporting of benchmarking PCF using the cutoff approach. In addition, if reliable data on embodied emissions of pre-consumer scrap is available, benchmarking PCF using the co-product allocation approach shall also be reported. Otherwise, IAI regional default factors can be applied to fill the data gap for co-product allocation approach. Practitioners should refer to the guidelines in the next two sections regarding PCF calculations for cutoff and co-product allocation methods to ensure consistency and no carbon leakage.

Cutoff method

This approach requires companies generating pre-consumer scrap to attribute all production emissions to their main end products in PCF calculations. Zero emissions are assigned to the generated process scrap. When reused, scrap users also treat such scrap as zero emissions in their subsequent PCF calculation. Companies can refer to the example in the *Appendix* for a sample calculation. In practice, scrap users shall confirm with their scrap suppliers to ensure that no emissions burden is placed on their scrap to avoid carbon leakage and ensure consistency.

Co-product allocation method

This approach specifically refers to the mass-based allocation of material production impact.[vii] It requires allocating the impact of primary material production between the main product and scrap on the basis of the mass of each material generated during production. For example, consider the simplified product system 1 in Exhibit 2. Emissions for semi-fabrication scrap (scrap flow 1) should be determined by allocating emissions from primary aluminum ingot production based on the mass of semis product and scrap flow 1. Specific calculation examples can be found in the *Appendix*.

When implementing this method, practitioners (especially scrap users) often face challenges in tracing scrap flow and understanding the actual impact of primary material production, especially if multiple scrap flows are involved. To alleviate the calculation complexity and ensure integrity, this guidance recommends the following decision hierarchy:

- Scrap generators should prioritize using primary data for material flow and primary aluminum production emissions. If scrap generators purchase primary ingots (or molten metal) through third-party suppliers, the emissions intensity data should be collected from those suppliers. The scrap embodied emissions can be estimated following the reporting tool provided along with this guidance. The IAI reference document and tool for the CP0 approach can also be used.[20] Scrap users should prioritize requesting relevant information from their scrap suppliers and traders. An example of the CP0 approach is available in the *Appendix*.

- If the suggested primary data is unknown, scrap users should make efforts to trace the input composition and usage of primary metal involved in the scrap generation process. The goal is to trace the primary metal into the process that originally generated the scrap.[viii]

    - When the process generating scrap has more than 50% primary aluminum as input materials, scrap users may use the corresponding emissions intensity value of primary metal as a proxy for scrap embodied emissions.

[vii] There are different variations in co-product allocation method, and the specific requirements recommended here are aligned with the CP0 approach in the IAI reference document (https://international-aluminium.org/resource/public-review-guidelines-on-transparency-aluminium-scrap/). In the CP0 approach, emissions for semi-fabrication scrap should be determined by allocating emissions from primary aluminum ingot production based on the mass of semis product and scrap flow.

[viii] This may extend to multiple sources of primary metal, where a weighted average of the emissions intensity values of the primary metal involved should be applied to reflect scrap embodied emissions.

- When the process generating scrap has more than 50% external purchased pre-consumer scrap as input materials, scrap users are recommended to trace the associated intensity value of the primary metal when scrap was originally produced.

- If the primary data from scrap suppliers is unavailable, scrap users shall use the default emissions factors provided by IAI based on the sourcing region of scrap to fill the data gap.

- Scrap generators shall confirm with their scrap buyers and users and ensure that the associated emissions burden is correctly added to their product PCFs to avoid carbon leakage and ensure consistency.

Recognizing the challenges of these calculations, this guidance encourages both scrap generators and users to start such data collection exercises soon. This incentivizes the development of traceability systems and technology. Overall, this guidance recommends reporting of cutoff PCFs and co-product allocation PCF to drive more industry actions urgently needed to decarbonize primary aluminum production and improve end-of-life collection and recycling. If co-product allocation PCF is calculated using regional average data for scrap embodied emissions, then it should be communicated to the aluminum buyer accordingly. This will be useful when the buyer is interpreting the co-product allocation PCF value.

Alloy emissions

This guidance recognizes that alloying emissions can be material to the cradle-to-gate PCF of an aluminum product, especially if emissions-intensive elements such as silicon, magnesium, manganese, and copper are used. Aluminum producers shall calculate emissions associated with alloying, including process emissions and embodied emissions of alloy metals. For the embodied emissions of alloy elements, this guidance recommends using the prime substitution method, which replaces all newly added alloy elements with the same amount of primary aluminum, to maintain comparability between products. This method is commonly applied in the aluminum industry to treat alloy emissions, especially considering the great variety of alloys, the proportion of emissions, proprietary information of alloy specifications, and the higher emissions intensity of primary aluminum than most of the alloy elements.

3.4 Energy Impact

The calculations of energy impact required by this framework are aligned with IAI's Aluminium Carbon Footprint Good Practice Guidance as well as guidance for other sectors under the Horizon Zero project.[21] For the different fuels used by aluminum producers in various processes, they shall report emissions tied to both upstream production (i.e., cradle-to-gate emissions) and consumption of those fuels.

For fuels (solid, liquid, gas) used on-site in the production of aluminum, producers should determine a site-specific emissions factor (for emissions from fuel consumption) based on the carbon content of specific fuels used. Where this is impossible, the standard emissions factors for various fuel types are provided in Section 3.6.2. For upstream production emissions of fuels, aluminum producers are encouraged to request site-specific emissions factors that shall include all GHG emissions associated with fuel extraction and production (including fugitive methane emissions) from their fuel provider. Other data sources and methods for determining upstream production emissions and fugitive methane emissions can be found in Section 3.6.4.

For electricity impact, this guidance requires reporting life-cycle emissions of electricity consumption for both purchased and self-generated electricity. This includes emissions from the extraction and production of fuels, the combustion of fuels for electricity generation, and transmission and distribution (T&D) losses. Aluminum producers shall prioritize using site-specific emissions factors associated with the electricity used at the facility. They can also calculate site-specific estimates of the emissions factors following IAI's Good Practice Guidance.[22] If site-specific emissions factors are impossible to calculate or obtain, regional or national emissions factors are provided in Section 3.6.3 of this guidance.

Purchased electricity and heat

Emissions reporting for purchased electricity and heat

The GHG Protocol Scope 2 Guidance provides two methods (location based and market based) for determining an electricity emissions factor.[23] It encourages companies to report purchased electricity emissions using both methods because each provides different information.

For reporting using this guidance, reporting entities are recommended to calculate PCFs using both methods. If only one method is used, the selected method shall be disclosed in a clear and transparent way. Aluminum producers shall obtain the relevant emissions factor (life-cycle emissions factor) from the electricity supplier. Otherwise, life-cycle emissions factors at the regional or national level can be used (see Section 3.6.2).

Sourcing renewable energy

Power decarbonization is the most critical decarbonization pathway for the aluminum industry. Considering the significant amount of electricity demand by the electrolysis process, aluminum smelters shall follow this hierarchy when deciding power purchase or transition options to best drive decarbonization:

- Physical transition is prioritized for assets with self-generation facilities (on- or off-site) to shift from fossil fuel to renewable energy.

- If market-based mechanisms are needed, producers shall prioritize these options:

    - Purchase from on-site installations owned by a supplier and directly delivered to the reporting company (through or not through the local grid).
    - Direct sourcing from an off-site generator with no grid transfers.
    - Direct procurement from off-site grid-connected generators (e.g., power purchase agreements) that are in the same grid as the purchaser.
    - In the above options, the renewable generation project shall not participate in other Energy Attribute Certificate (EAC) programs.

- When other options are unavailable, producers may use unbundled EACs. In this case, producers shall have an internal policy to ensure that industry best practices are followed for the purchase of EACs.[ix] These best practices are in line with guidelines from ISO 14067[24] and other documents.

If market instruments must be used, aluminum producers are encouraged to use high-quality ones in sourcing renewable energy for emissions reduction. When determining whether a market instrument option is of high quality, aluminum producers shall refer to the following criteria:

- Additionality: The procurement directly adds new renewable energy capacity to the grid.

- Regional support: The procurement is physically linked to the electricity generated in the same grid as the purchaser.

- Long-term commitment: The procurement belongs to a long-term contract or has measures to ensure long-term financial support to specific renewable energy projects.

Producers beyond smelters are also encouraged to follow the same criteria and decision hierarchy in sourcing renewables. With the principle of transparency and avoidance of double counting, any EACs issued by the above cases shall be retained or retired by the reporting producer or on the producer's behalf. Aluminum producers shall acquire the emissions factors for the contractual amount of energy from the specific generation facility and the associated energy mix. If aluminum producers claim to use renewable energy for their electricity needs, their power supply contracts, EACs (e.g., Renewable Energy Certificates, Guarantees of Origins, and other such certificates), or meter readings shall constitute enough proof of the renewable energy claim. In addition, a residual emissions factor (i.e., the average of all generation sources connected to the grid, except for those that separately sold the emissions attributed through a market mechanism) shall be used to avoid potential double-counting incidents associated with using both market- and location-based reporting methods.

Self-generated electricity and heat

Aluminum producers that own and operate an on-site electricity generation plant shall possess the relevant emissions factor for self-generated energy. If not, they can estimate custom emissions factors following the methodology of IAI's Good Practice Guidance.[25] Emissions from upstream production of fuels used for power generation shall follow the same method used for calculating upstream emissions of on-site fuels.

In many cases, some share of self-generated electricity (and steam) is sold to other users or power companies (steam may be sold for district heating). The emissions associated with the sold electricity and steam shall be accounted for based on the method described in Section 3.5.3 of this guidance.

[ix] Industry best practices here refer to actions or plans to ensure the purchase of unbundled EACs meet the three criteria of high-quality market instruments.

Allocation of renewable energy credits

This guidance does not recommend using the mass balance approach to allocate emissions reduction of renewable energy across a product portfolio to drive long-term decarbonization actions and full asset transition to renewable power. Emissions benefits from sourcing renewable energy shall be calculated at the site level and distributed equally across products.

3.5 Exported Products

Intermediate products used in the aluminum supply chain

A few intermediate products within the aluminum supply chain are not used in the production of aluminum. The GHG emissions associated with such intermediate products within the aluminum supply chain shall be subtracted from the emissions calculation to ensure the reported emissions are only from the processes responsible for the production of aluminum.

The most common intermediate products not used in the production of aluminum are non-calcined hydrates from alumina refineries and surplus anodes from anode manufacturing facilities. The calcined alumina from alumina refineries is sold to aluminum smelters. The non-calcined hydrates from alumina refineries are sold to end-users other than smelters. The surplus anodes from anode manufacturing facilities can be sold to other aluminum smelters or end-users. The emissions tied to producing non-calcined hydrates and exported anodes shall be subtracted from the total emissions calculation.

In the case of alumina refineries, the refineries should determine the actual emissions intensity of aluminum hydroxide (also called aluminum trihydrate) to be used in the subtraction calculations. The calculation of emissions intensity of aluminum hydroxide involves determining the total emissions in the refinery, emissions tied to calcination, mass of aluminum hydroxide for exports, and mass of aluminum hydroxide for producing metallurgical-grade alumina before calcination. The emissions intensity of aluminum hydroxide is calculated by the total emissions in the refinery before calcination divided by the total amount of intermediate products (both for exports and smelters). An example of this calculation is provided in Exhibit 3. If the mass of aluminum hydroxide for calcination cannot be acquired, refineries can use the mass conversion factor, 1.53 tons (t) aluminum hydroxide per ton alumina,[x] to get the estimate.

Exhibit 3: Example Subtraction Calculation for Intermediate Product

Parameters	Aluminum hydroxide for calcination	Aluminum hydroxide for export
Hydroxide production emissions (Mt CO_2)	12.0	
Aluminum hydroxide production (Mt)	15	5
Emissions intensity of aluminum hydroxide (t CO_2e/t)	0.6 = 12.0 / (5 + 15)	
Alumina calcination emissions (Mt CO_2)	5.0	
Total site emissions after subtraction (Mt CO_2)	14.0 = 0.6 x 15 + 5.0	

[x] This conversion factor is based on the mass balance of aluminum hydroxide ($Al(OH)_3$) and alumina (Al_2O_3) in the aluminum calcination process (i.e., $2Al(OH)_3 \rightarrow Al_2O_3 + 3H_2O$).

When estimating GHG emissions from anode manufacturing facilities, any emissions associated with surplus anodes that are sold to other end-users shall be excluded. The emissions of the exported surplus anodes would instead be included in the emissions calculation of the end-users that purchased those anodes. Notably, while calculating the process GHG emissions from anode manufacturing, not all the carbon content of the input materials (pitch and coke) is converted to carbon anode and CO_2. Some of the input material carbon content is also converted to carbon waste. This carbon waste is in a chemically stable form that will not convert to GHG emissions under proper waste management at the anode manufacturing facility.

Where a site does not have sufficient information to calculate the emissions intensity of the aforementioned exported products, the default emissions factor in Exhibit 4 can be used. If these factors are used in the emissions calculation, it will reduce the share of primary data (refer to Section 3.6.5).

Exhibit 4: Default Emissions Factors for Exported Products

CO_2 emissions source	Unit	Emissions factor (t CO_2 e/unit)*	Source
Bauxite	t	0.0084	IAI Scope 3 guidance (2023)[26]
Aluminum hydroxide	t	1.42	
Alumina	t	1.26	
Anode	t	1.75	
Liquid primary aluminum	t	13.01	
Primary cast ingot	t	16.48	

Note: *This refers to the cradle-to-gate emissions factor with transportation excluded.

By-products used in other supply chains

The aluminum production process can produce several by-products or waste such as red mud, spent-pot liner, salt slag, sludge, and other carbon or noncarbon products. Some of these by-products may be recycled or used in other industries. Their use is regulated differently by every country. For example, red mud is not approved for use in the United States but is allowed in building materials in some countries in the European Union. These applications are also not significant. Based on these considerations, GHG emissions associated with the use of the aforementioned by-products currently produced by the aluminum industry shall not be credited in the emissions calculation.

Energy exports

Many aluminum producers, especially for an alumina refinery owning on-site power generation, sell back a significant share of the produced electricity (and steam) to the wholesale energy market, large industrial consumers, distribution companies, and others. In this case, the sold energy and corresponding emissions shall be subtracted from the total energy emissions calculation. This can be done by determining the site-specific emissions factors and multiplying them by the quantity of the energy outputs sold.

Emissions allocation for a combined heat and power plant

Some alumina refineries and aluminum smelters use combined heat and power (CHP) plants to generate electricity and steam (heat) on-site. Emissions for the electricity and steam outputs in a CHP plant shall be determined following the efficiency method for allocation in the GHG Protocol.[27, xi]

$$E_H = \frac{H/e_H}{H/e_H + P/e_P} \times E_T \quad \text{and} \quad E_P = E_T - E_H$$

where

- E_P and E_H are the emissions allocated to electricity and steam production, respectively.
- E_T is the total emissions of the CHP plant.
- *H* is the steam output (kilowatt-hours).
- *P* is the generated electricity output (kilowatt-hours).
- e_P and e_H are the assumed efficiency values of typical power production and steam, respectively. The standard values for e_H= 0.8 and $e_P = 0.35$ are taken from the US Environmental Protection Agency's (EPA's) GHG Protocol guidance document.[28]

Emissions factors for electricity and steam output shall then be obtained by dividing the emissions related to electricity and steam from the CHP plant by the electricity and steam output from the plant (i.e., E_P/P and E_H/H, respectively). These emissions factors shall be used to calculate corresponding emissions tied to sold energy from the CHP plant. Aluminum producers are encouraged to estimate site-specific efficiency values (e_H and e_P) for their CHP plants rather than using the standard assumed values. This can be done using the method described in Section 6.4.2.2 of IAI's Aluminium Carbon Footprint Good Practice Guidance.[29]

Emissions allocation for sold power

Aluminum producers often source electricity from multiple power suppliers (or have multiple on-site power generation facilities). They may resell the purchased or self-generated electricity through various means. If electricity is sold from a specific generation facility or through a specific contract defining the source, aluminum producers shall use the emissions factors specific to the generation facility or contractual agreement to calculate emissions tied to sold electricity. When surplus electricity is sold, producers shall calculate the weighted average emissions factors reflecting the actual emissions of sold energy.

A case example is provided in Exhibit 5 to show the emissions calculation for different power resale options. As the example illustrates, direct sale of self-generated electricity from plant 1 shall use its specific emissions factor to calculate emissions tied

[xi] This method is based on the assumption that the conversion of fuel energy to steam energy is more efficient than converting fuel to electricity.

to sold electricity. The same applies to resale via contract for purchased source 3. If purchased energy is surplus and sold, the emissions shall be calculated based on the actual use of different purchased sources (e.g., 50 megawatt-hours [MWh] from source 1, 100 MWh from source 2, and 50 MWh left from source 3) to calculate the weighted average emissions factor.

Exhibit 5: Calculation Example of Emissions Factors for Different Energy Resale Options

Electricity sources	Electricity generated/ purchased (MWh)	Emissions factor (t CO_2e/MWh)	Self-used electricity (MWh)	Sold electricity (MWh)	Emissions factor for sold energy (t CO_2e/MWh)
Self-generation plant 1	100	1.5	80	20 (direct sales)	1.5
Self-generation plant 2	60	1	60	Not sold	—
Self-generation plant 3	20	0.5	20	Not sold	—
Purchased source 1	50	0.8	50	50 (sold surplus electricity)	0.5 = (50 x 0.8 + 100 x 0 + 50 x 1.2) / (50 + 100 + 50)
Purchased source 2	100	0	100		
Purchased source 3	150	1.2	50	100 (resold via contract)	1.2

Note: This example only represents some power resale options. In practice, aluminum producers can decide their own resale options, but they should calculate the corresponding emissions factors for sold power following the method in this example.

3.6 Data Sources

Data quality

Although providing a specific data quality requirement is beyond the scope of this guidance, reporting entities are encouraged to calculate a Data Quality Rating (DQR) metric. This communicates the relevance and reliability of the data sources that were used to calculate product emissions. Aluminum producers may refer to specific DQR metrics in other initiatives, such as the World Business Council for Sustainable Development Pathfinder framework and the EU Product Environmental Footprint rules.[30]

Direct emissions factors

Direct emissions sources refer to fuel (solid, liquid, or gas) used on-site in the production of aluminum. Where possible, aluminum producers should determine the emissions factor of the specific fuel used on-site (this includes CH_4 and N_2O

emissions released due to incomplete combustion as well as any other non-CO_2 GHG emissions). Where this is impossible, the standard emissions factors for various fuel types provided in Exhibits 6 and 7 can be used. The emissions factors provided in the exhibits below include CO_2, CH_4, and N_2O emissions converted to CO_2e using the Intergovernmental Panel on Climate Change's (IPCC's) Fifth Assessment Report (AR5)[xii] 100-year GWP values. These emissions factors refer to the emissions from fuel combustion. The emissions tied to the upstream of fuel combustion are discussed in the Indirect emissions from fuels section below.

Exhibit 6: Direct Emissions Factors for Solid Fuel Sources

GHG emissions source	Unit	Emissions factor (t CO_2e/unit)	Source
Anthracite	t	2.64	IPCC, 2006[31]
Coking coal	t	2.69	IPCC, 2019[32]
Other bituminous coal	t	2.46	IPCC, 2006
Sub-bituminous coal	t	1.83	IPCC, 2006
Lignite	t	1.21	IPCC, 2006

Exhibit 7: Direct Emissions Factors for Liquid and Gas Fuel Sources

GHG emissions source	Unit	Emissions factor (kg CO_2e/unit)	Source
Heavy oil (residual fuel oil)	Liters	2.95	IPCC, 2006
Diesel	Liters	2.69	IPCC, 2006
Liquefied petroleum gas	Liters	1.62	IPCC, 2006
Natural gas	Gigajoules	58.47	IPCC, 2006

Other direct inputs with carbon content are used in the aluminum smelting process. Two types of aluminum smelting techniques are used in the industry. The prebake smelting technique employed to make almost 95% of the aluminum manufactured each year uses prebaked blocks (made using petrol coke and pitch) as anodes. Furthermore, the Søderberg technique uses carbon briquettes (also made using petrol coke and pitch) in the anode. As with fuels, wherever possible, the carbon content of these inputs (like petrol coke and pitch) should be measured to determine a site-specific GHG emissions factor. Aluminum producers are encouraged to estimate the site-specific emissions factor using the method in the Aluminium Sector Greenhouse Gas Protocol.[33]

Where this is impossible, the emissions factors in Exhibit 8 can be used. The emissions factors in Exhibit 8 for the prebake and Søderberg smelting techniques represent the process CO_2 emissions from the anode and paste used. The emissions factor for petrol coke, anode baking, lime, and soda ash represents the process CO_2 emissions from the use of these inputs in aluminum production.

[xii] The AR5 emissions factors were used to make the exhibits 6 and 7 consistent with the electricity life-cycle emission factors (see Section 3.6.3) referenced elsewhere in the document.

Exhibit 8: Direct Emissions Factors for Other Inputs

GHG emissions source	Unit	Emissions factor (t CO_2e/unit)	Source
Petrol coke calcination	t green coke	0.22	IAI-GHG Protocol Al sector tool, 2015[34]
Anode baking	t baked anode	0.23	
Prebake process anode consumption	t anode consumed	3.61	
Søderberg process paste consumption	t paste consumed	3.52	
Soda ash consumption	t soda ash	0.39	
Lime calcination	t lime	0.78	

Note: CO_2 emissions from fuel combustion are excluded. These should be added following the calculation method for fuel use.

In addition to process CO_2 emissions, the aluminum smelting process also releases PFC emissions — another class of GHGs. These PFCs are emitted during a phenomenon called anode effect when the alumina ore content in the smelting process is below the optimal level required to produce aluminum. During this anode effect stage, CF_4 and C_2F_6 are the two PFCs generated.[35] Wherever possible, the PFC emissions from the smelting process shall be determined using site-specific parameters (see IAI-GHG Protocol Al sector tool).[36] The PFC emissions shall be multiplied with their respective GWP values to obtain a site-specific GHG emissions factor. For reference, over 100 years, CF_4 has a GWP of 6,630 times that of CO_2, and C_2F_6 has a GWP value of 11,100 times that of CO_2.[37] Where this is impossible, the emissions factors in Exhibit 9 can be used. PFC emissions factors for the following technologies are listed in Exhibit 9:

- Horizontal stud Søderberg technology: electrical connections (or studs) placed horizontally into the anode along its length
- Vertical stud Søderberg technology: electrical connections (or studs) placed vertically into the top of the anode
- Side-worked prebake technology: alumina feeding and other activities occur along longitudinal sides of the cell
- Center-worked prebake technology: alumina feeding and other cell activities performed along longitudinal center line of the cell

Exhibit 9: Emissions Factors for PFCs

Process	Unit	PFC type		Emissions factor	Source
		CF_4 (kg/unit)	C_2F_6 (kg/unit)	(tCO_2e/unit)	
Center-worked prebake	t Al	0.4	0.04	3.1	IAI-GHG Protocol Al sector tool, 2015[38]
Side-worked prebake	t Al	1.6	0.4	15.05	
Vertical stud Søderberg	t Al	0.8	0.04	5.75	
Horizontal stud Søderberg	t Al	0.4	0.03	2.98	

Electricity emissions factors

Whenever possible, aluminum producers shall obtain the relevant life-cycle GHG emissions factors for electricity used at the production facility. These emissions factors shall be obtained from electricity suppliers. This life-cycle GHG emissions factor includes emissions from the extraction, production, and transportation of the fuels used in electricity generation. It includes the emissions associated with construction and the raw materials used for constructing the electricity generation facility. It also includes emissions associated with T&D loss occurring between the electricity generation facility and the aluminum production facility (see Section 6.4 of IAI's Aluminium Carbon Footprint Good Practice Guidance[39]).

If the electricity used at an aluminum production facility is self-generated, the life-cycle GHG emissions factor associated with the self-generation facility shall be used. When this is impossible, default emissions factors in Exhibit 10 can be used depending on the fuel mix of the electricity at the self-generation facility. The emissions factors in Exhibit 10 include life-cycle emissions from the individual fuel sources.

Exhibit 10: Life-cycle GHG Emissions Factors from Electricity Sources

Fuel source	Unit	Emissions factor (t CO_2e/unit)	Source
Coal	MWh	0.82	IPCC AR5 WG 3, 2014[40]
Gas	MWh	0.50	IPCC AR5 WG 3, 2014
Other fossil	MWh	0.66	IPCC AR5 WG 3, 2014
Nuclear	MWh	0.01	IPCC AR5 WG 3, 2014
Hydro	MWh	0.02	IPCC AR5 WG 3, 2014
Wind	MWh	0.01	IPCC AR5 WG 3, 2014
Solar	MWh	0.05	IPCC AR5 WG 3, 2014
Bioenergy	MWh	0.23	IPCC AR5 WG 3, 2014
Other renewables	MWh	0.06	IPCC AR5 WG 3, 2014

If purchased electricity was used, to the extent possible, aluminum producers shall obtain the fuel mix and life-cycle GHG emissions factors (including T&D loss) for the regional grid from which their electricity was purchased. If this is unavailable, they shall rely on fuel mix and life-cycle emissions data of the national grid in which they operate. They shall obtain such data from country-specific data sources. If the fuel mix of the electricity used by aluminum producers is unknown, aluminum producers can use national-level electricity fuel mix data from credible data providers. This fuel mix data can then be used along with the IPCC life-cycle GHG emissions factors and the estimated T&D loss for individual sources to obtain the GHG emissions factor for the grid electricity purchased by an aluminum producer.

Indirect emissions factors

Indirect emissions factors refer to the GHG emissions that occur during the production of input material as opposed to the GHG emissions that come from the carbon content of a fuel or other inputs that are combusted. These factors can be used to estimate the emissions for processes not operated by the aluminum producer but required as part of the fixed boundary.

Wherever possible, aluminum producers should request actual emissions from the supplier or customer that operates these processes instead of using the standard emissions factors. Where the emissions factors listed in this section are used, the primary data share will be reduced (see Section 3.6.5). Using data directly from suppliers avoids this issue.

Emissions from purchased goods and off-site processing

Processes that may not be directly operated by the aluminum producer include those required to make the inputs used in aluminum manufacturing. These processes include mining for bauxite and limestone, and production of calcined lime and caustic soda. Calcined lime, caustic soda, and bauxite are used in alumina refining from which alumina is made. This alumina is an important input in the aluminum manufacturing process along with aluminum fluoride and soda ash. Carbon anodes, which are another important input in the aluminum manufacturing process, are made using calcined petroleum coke and coal tar pitch. If the aluminum producer does not operate these processes, data for the embodied emissions of these materials should be obtained from suppliers. Where this is impossible, the default emissions factors for purchased goods in Exhibit 11 and emissions factors for potential off-site processing in Exhibit 12 can be used. However, the actual emissions factor for these materials will vary depending on the specific processing technologies, fuels, and electricity source used.

Exhibit 11: Cradle-to-Gate Emissions Factors for Purchased Goods

Embodied emissions of purchased materials	Unit	Emissions factor (t CO_2e/unit)	Source
Bauxite	t bauxite	0.0084	IAI Scope 3 Calculation Tool[41]
Caustic soda	t NaOH	1.12	
Calcined lime	t CaO	0.79	
Sulfuric acid	t sulfuric acid	0.14	
Calcined petrol coke	t petrol coke	1.88	
Coal tar pitch	t coal tar pitch	2.62	
Anode	t anode	1.75	
Alumina	t alumina	1.26	
Sodium carbonate	t Na_2CO_3	0.41	
Steel (cathodes)	t steel	1.89	
Liquid aluminum	t Al	13.01	
Aluminum fluoride	t AlF_3 produced	1.02	Peng et al., 2019[42]

Exhibit 12: Gate-to-gate Indirect Emissions Factors for Potential Off-site Processing

Process	Unit	Emissions factor (t CO_2e/unit)	Source
Limestone mining	t limestone	0.003*	US DOE, 2003[43]
Ingot casting	t ingot	0.139	IAI Scope 3 Calculation Tool[44]
Rolling	t semis	0.43	IAI Scope 3 Calculation Tool[45]
Extrusion	t semis	0.68	IAI Scope 3 Calculation Tool[46]
Scrap remelting/refining	t recovered aluminum	0.53	Aluminum Association, 2022[47]

Note: *The non-CO_2 GHG emissions for this process are not provided in the source document. Hence, these values represent just the CO_2 emissions. The non-CO_2 GHG emissions could be minimal and can be estimated from the amount and type of fuel used in the process.

Indirect emissions from fuels

The production process for each fuel also involves emissions, including those from the production, processing, and transport of fuels. Among these emissions, fugitive methane is the most notable, particularly for coal and natural gas production. Given that the fuel production processes are covered in the fixed boundary, these emissions must also be reported. Where possible, the fuel provider should determine upstream emissions for fuel and provide this information to the aluminum producer. Where this is impossible, the aluminum producer may use the standard emissions factor provided in Exhibit 13. For fugitive methane emissions, aluminum producers may request their fuel producers use an existing standard (such as the MiQ standard for natural gas or the EPA subpart FF methodology for coal[48]) to determine the methane emissions. More details are described in the next section.

Exhibit 13: Upstream Emissions Factors for Fuel Sources

GHG emissions source	Emissions factor (t CO_2e/terajoule)	Source
Natural gas	8.7	IAI Scope 3 Calculation Tool[49]
Coal	14.7	
Heavy fuel oil	11.2	
Light fuel oil	11.2	
Liquefied petroleum gas	7.03	
Diesel	16.36	
Gasoline	17.29	
Propane	6.95	

Note: To convert the emissions factors from a unit energy basis to a unit mass or volume basis, use energy density values from standard sources like the GHG Protocol's "Emission Factors from Cross-Sector Tools" spreadsheet.

To convert natural gas from mass units to energy units, it can be assumed that a metric ton of natural gas is equivalent to 55.58 gigajoules of energy and 1,470.3 m^3.

Fugitive methane

Fugitive methane refers to the methane gas released into the atmosphere during coal mining and along the natural gas supply chain. The fugitive methane emissions from coal mining come from the methane that is trapped in the coal seams and escapes during the mining process. The amount of methane released during the coal mining process depends on various factors such as the type of coal being mined, mine depth, and method of mining. Typical values of emissions factors for fugitive methane emissions from coal mines are given in Exhibit 14. These values are only estimates, and the actual values can vary as much as ±15%.

Fugitive methane emissions can also come from different stages in the natural gas supply chain, such as production, processing, transmission, and distribution. About 1.3%–2.2% of the natural gas supplied to end consumers escapes into the atmosphere as fugitive methane. The emissions factor associated with fugitive methane emissions from the natural gas supply chain is given in Exhibit 14 (assuming average fugitive emissions are 1.7% of the total natural gas supplied to the end-user).

GHG emissions factors are provided for both 20- and 100-year time frames. According to the IPCC AR5, methane has a GWP of 28 times that of CO_2 over 100 years and a GWP of 84 times that of CO_2 over 20 years.[50] To align with the latest IPCC reporting, aluminum producers shall use the 100-year GWP in reporting emissions. However, aluminum producers shall also consider the short-term climate impact of methane when prioritizing emissions abatement strategies.

Exhibit 14: Fugitive Methane Emissions Factors

Process	Unit	Fugitive methane emissions (m^3/unit)	Emissions factor (kg CO_2e/unit)		Source
			20-year GWP	100-year GWP	
Coal — Surface mining	kg	0.006	0.34	0.11	Kholod et al., 2020[51]
Coal — Underground mining	kg	0.019	1.08	0.36	Kholod et al., 2020
Natural gas	m^3	0.017	0.97	0.32	Littlefield et al., 2017[52]

There is considerable variability in the amount of fugitive methane emissions, meaning these factors may underestimate the emissions from a specific supply chain. A wide variety of sensors and other methane monitoring equipment could be deployed to measure fugitive methane emissions at the facility and source level and over various time periods.[53] Aluminum producers are encouraged to seek fugitive methane data collected using these various methane monitoring technologies by their suppliers. Aluminum producers can also make use of the MiQ standard to lower the fugitive emissions of supplied gas.

Primary data share

As noted above, in many cases, the use of secondary emissions factors can result in inaccuracies in the overall emissions intensity. This is due to the variability in emissions observed in the processes. This variability can occur depending on the process type and fuel (and energy) sources used for the process.

To incentivize the use of primary data, its share used to calculate the intensity must be reported alongside the full boundary (mine to semi-fabrication) emissions intensity calculated using this framework. This is defined as the share of the emissions intensity that did not rely on the secondary emissions factors provided in this guidance or from other sources. Specifically, it is calculated as follows:

$$\text{Primary data share (\%)} = \frac{\text{Emissions based on primary data } (\mathrm{CO_2e})}{\text{Total emissions } (\mathrm{CO_2e})}$$

Note that this is consistent with the primary data calculation required under the World Business Council for Sustainable Development's Pathfinder framework.[54] The primary data share fraction relates to the share of emissions calculated using a primary data source rather than the share of primary data sources.

The emissions associated with a process are the product of activity data and emissions factor data. To consider certain emissions primary, both activity data and emissions factor data shall be from primary sources. In most cases, activity data (i.e., amount of fuel, energy, and materials used to produce aluminum) is based on primary sources (i.e., measured consumption at the aluminum production facility). As a result, the definition of primary emissions is determined by the type of emissions factor used. The relevant definitions are provided in Exhibit 15. Considering the challenge in acquiring primary data for upstream production emissions of fuels, this guidance recommends interpreting the primary data share within 5% difference with the same level of credibility.

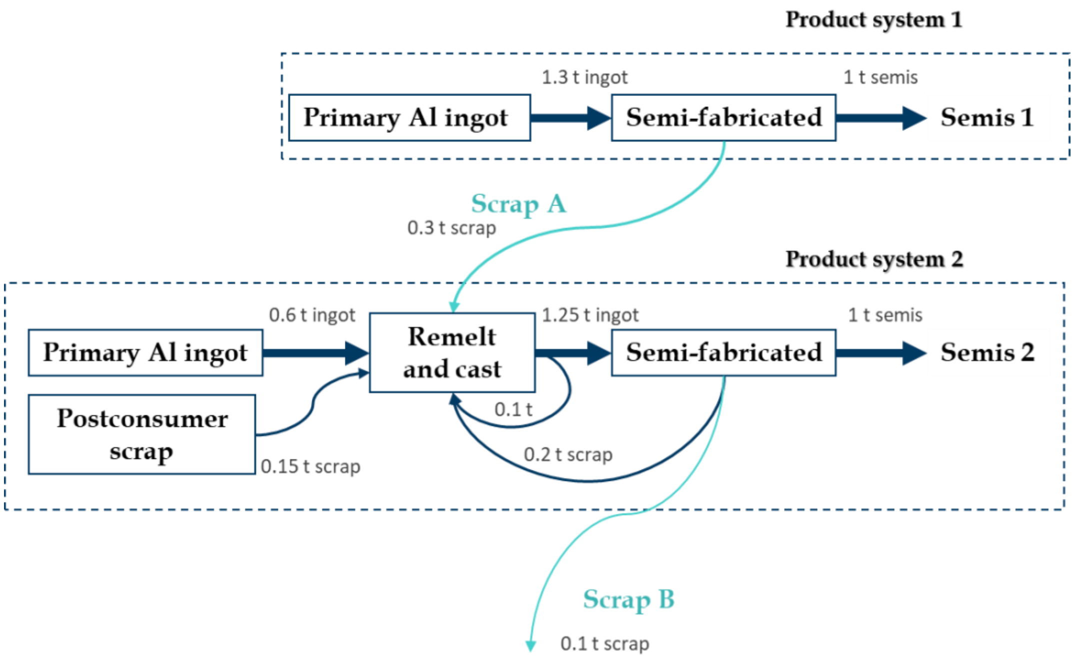
Exhibit 15: Primary Data Definitions

Activity type		Primary data definition	Secondary data definition
Fuels	Combustion/use	Supplier data preferred Standard emissions factors (IAI, IPCC, EPA, etc.) as provided in this guidance or measured carbon content	Not applicable
	Production	Supplier data	Emissions factors in Section 3.6.4 or databases listed in Pathfinder
Other material input		Supplier data	Emissions factors in Section 3.6.4 or databases listed in Pathfinder
Imported heat		Supplier data	Emissions factor based on assumed fuel source for heat
Electricity		For on-site generation: Primary data For purchased electricity: Supplier (utility) data or via registered and retired certificate* Regional location-based grid emissions factor†	Country or global grid emissions factor

Note: *The certificate mechanism only includes contractual instruments that fulfill the high-quality criteria (or follow the decision hierarchy) identified in Section 3.4.1. †Where the connected grid covers an entire country, the country grid factor may be considered primary data.

APPENDIX: Calculation Examples for Section 3.3.3

Exhibit A1: Product Systems for Illustrating Cutoff and Co-product Allocation Method



RMI Graphic.

Cutoff approach:

Product system 1	Emissions intensity ($t\ CO_2e/\ t\ Al$)	Process emissions ($t\ CO_2e$)		
Input flow/process		Total emissions	Semis 1	Scrap A
Primary Al ingot	4	5.2	5.2	0
Semi-fabricated	0.5	0.5	0.5	0
Total			5.7	0
		Calculated PCF ($t\ CO_2e/t\ Al$)	5.7	0

Product system 2	Emissions intensity ($t\ CO_2e/t\ Al$)	Process emissions ($t\ CO_2e$)		
Input flow/process		Total emissions	Semis 2	Scrap B
Primary Al ingot	9	5.4	5.4	0
Postconsumer scrap	0	0	0	0
Scrap A	0	0	0	0
Remelt and recycled	0.3	0.41	0.41	0
Semi-fabricated	0.5	0.5	0.5	0
Total			6.31	0
		Calculated PCF ($t\ CO_2e/t\ Al$)	6.31	0

Co-product allocation approach:

Product system 1	**Emissions intensity ($t\ CO_2e/t\ Al$)**	**Process emissions ($t\ CO_2e$)**		
Input flow/process		Total emissions	Semis 1	Scrap A
Primary Al ingot	4	5.2	5.2 x 1/(1 + 0.3) = 4	5.2 x 0.3/(1 + 0.3) = 1.2
Semi-fabricated	0.5	0.5	0.5	0
Total			4.5	1.2
	Calculated PCF ($t\ CO_2e/\ t\ Al$)		**4.5**	1.2 / 0.3 **= 4**

Product system 2	**Emissions intensity** ($t\ CO_2e/\ t\ Al$)	**Process emissions ($t\ CO_2e$)**		
Input flow/process		Total emissions	Semis 2	Scrap B
Primary Al ingot	9	5.4	5.4 x 1/(1 + 0.1) = 4.91	5.4 x 0.1/(1 + 0.1) = 0.49
Postconsumer scrap	0	0	0	0
Scrap A	4	1.2	1.2 x 1/(1 + 0.1) = 1.09	1.2 x 0.1/(1 + 0.1) = 0.11
Remelt and recycled	0.3	0.4	0.4 x 1/(1 + 0.1) = 0.37	0.4 x 0.1/(1 + 0.1) = 0.04
Semi-fabricated	0.5	0.5	0.5	0
Total			6.87	0.64
	Calculated PCF ($t\ CO_2e/\ t\ Al$)		**6.87**	0.64/0.1 **= 6.4**

Note that the co-product allocation approach is the same as the CP0 method in the IAI scrap embodied emissions reference document.

Consistency check:

If the same approach has been applied to all products, the total emissions sums will be consistent across methods, representing no emissions leakage.

Approach	***Semis 1 ($t\ CO_2e$)***	***Semis 2 ($t\ CO_2e$)***	***Scrap B (left systems) ($t\ CO_2e$)***	***Sum ($t\ CO_2e$)***
Cutoff	5.7	6.31	0	**12.01**
Co-product allocation	4.5	6.87	0.64	**12.01**

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