How to Treat Scrap Flows in Carbon Footprint Calculations for Aluminium Products

October 2025

This document is prepared by the International Aluminium Institute based on: "Reference document on how to treat scrap flows in carbon footprint calculations for aluminium products" prepared by Solinnen for International Aluminium Institute (October 2025, Contract SOL 21-101.4)

Contents

1 Acknowledgement

This “Internal Reference document on how to treat scrap flows in carbon footprint calculations for aluminium products” was prepared by Solinnen for International Aluminium Institute (July 2025, Contract SOL 21-101.4).

2 Preface

The International Aluminium Institute (IAI) seeks industry consensus on how to calculate the cradle-to-gate carbon footprint of aluminium products containing recycled aluminium, if possible. There is agreement in the aluminium sector that in cradle-to-gate carbon footprint communications post-consumer scrap is assigned burden-free. How to treat scrap that is generated during various production stages of aluminium products, before the aluminium product is sold to the final user in cradle-to-gate carbon footprint calculations of products is an issue which is currently widely discussed among IAI members, regional and national aluminium associations and stakeholders, and for which consensus is difficult to reach.

In the interim time: The IAI published guidelines on transparency that state that when reporting the cradle-to-gate carbon footprint of products that contain scrap there should be full transparency on the methodology used for the carbon footprint calculation. This reference document, summarising approaches commonly used in the aluminium industry, should serve aluminium producers to disclose the methodology they are using to calculate the carbon footprint of their products in a transparent way.

This reference document is aimed to be compliant with carbon footprint methodologies in existing ISO standards, especially ISO 14044 and ISO 14067, and defines appropriate terminologies.

Typically, in cradle-to-gate carbon footprint communications post-consumer scrap is assigned burden-free. Further guidance should be given on how to combine the cradle-to-gate approach into a full life cycle, i.e. cradle-to-grave approach, where post-consumer scrap is typically not considered as burden-free by the aluminium sector.

As a general rule, comparative life cycle assessment studies shall include the full life cycle. Cradle-to-gate comparison are permitted by ISO 14067, if specific requirements are met[1]. Otherwise, comparisons based on information modules (cradle-to-gate, gate-to-gate) could lead to incorrect conclusions.

3 Scope

The main topic of this document is how scrap generated during the production of intermediate and finished products can be treated in carbon footprint calculations (both cradle-to-gate). More specifically, clarification is needed on how to allocate carbon emissions to a scrap flow, when the production process of semi-finished or final products which generated the scrap and the recycling process which uses the scrap as input are not part of the same product system.

[1] ISO 14067 § 6.3 :

"Comparisons based on partial carbon footprint […] are permitted if the omitted life cycle stages are identical."

"Comparison based on the declared unit may only be used for business-to-business purposes. If additional functions of any of the product systems are not taken into account in the comparison of functional units, then these omissions shall be explained and documented. As an alternative to this approach, systems associated with the delivery of these functions may be added to the boundary of the other product system to make the product systems more comparable. In these cases, the processes selected shall be explained and documented"

4 Definitions specific to this document

The following definition is specific to this document. Terms and definitions in literature are summarised in § 5 and the need for below definitions is explained in § 6:

4.1 Terms relating to aluminium

4.1.1 New Scrap

Scrap arising from the various production stages of aluminium products before the aluminium product is sold to the final user.

NOTE: New Scrap = Process Scrap + Inside Scrap.

4.1.2 Process Scrap

New scrap from a previous product system and used as input for another product system. The production process and the remelting process are part of two different product systems in terms of LCA.

4.1.3 Inside Scrap

New scrap generated along the production value chain of a product system and used as input within this same product system.

NOTE: Inside Scrap does not exit the product system boundary.

NOTE: Inside Scrap is independent of the process and should not be confused with “pre-consumer scrap that is reclaimed in the same process that generated it”.

4.1.4 Post-consumer scrap

Scrap arising from products after use.

4.1.5 Semis products

Products that need further processing to be used by the end-consumer.

NOTE: For example, an aluminium sheet.

4.1.6 Finished products

Products that are ready for use by the end-consumers.

NOTE: For example, an aluminium can.

4.2 Terms relating to carbon footprint

4.2.1 Cradle-to-gate partial carbon footprint of an aluminium product (CFP)

Partial CFP related to aluminium, compiled from data related to all specific processes from raw material acquisition, including bauxite mining and refining, to the state where the product leaves the factory gate, e.g. as a cast ingot or as a semi-finished product, possibly together with process scrap.

5 Literature review of terms and definitions

5.1 Terms relating to aluminium scrap and recycling operations

The following definitions are extracted from "Global Advisory Group (GAG) – GAG Guidance Document 001 - Terms and Definitions (3rd Edition – 2011-01)":

5.1.1 (aluminium) Scrap

Material, mainly consisting of aluminium resulting from the collection and/or recovery of

- metal scrap that arises at various production stages; or
- products after use

to be used for remelting to aluminium products to be sold on the market.

5.1.2 New scrap

Scrap arising from the various production stages of aluminium products, before the aluminium product is sold to the final user.

5.1.3 Internal scraps

New scrap that is melted in the same company where this scrap has been generated.

NOTE: Internal scrap is not traded on the market and typically does not appear in trade statistics.

NOTE: Internal scrap which is transferred between sites of the same company still is termed "internal scrap".

NOTE: Also known as turn-around scrap, in-house scrap, run-around scrap or home scrap.

5.1.4 Old scrap

Scrap arising from products after use.

5.1.5 Traded scrap

Scrap that is traded on the market.

NOTE: Traded scrap typically meets requirements on characteristics agreed upon between supplier and purchaser.

5.1.6 Primary aluminium

Unalloyed aluminium produced from alumina, typically by electrolysis, and with an aluminium content of 99,7%.

5.1.7 Recycled aluminium ingot

aluminium ingot obtained by recycling of scrap.

NOTE 1: The term "secondary aluminium" should be avoided for this concept.

NOTE 2: The terms "recycled aluminium strip", "recycled aluminium casting", "recycled aluminium profile" are defined accordingly.

5.1.8 Skimmings

Material composed of intimately mixed aluminium, aluminium oxides and gas, which has been removed from the surface of the molten metal or from the bottom and walls of liquid metal containers, e.g. furnaces or transport ladles or transfer channels.

NOTE: This concept is also termed "dross”

5.2 Terms relating to recycled content from ISO 14021:2016

5.2.1 Pre-consumer material

Material diverted from the waste stream during a manufacturing process, excluding reutilization of materials such as rework, regrind or scraps generated in a process and capable of being reclaimed within the same process that generated it.

5.2.2 Post-consumer material

Material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product which can no longer be used for its intended purpose, including returns of material from the distribution chain.

5.2.3 Recycled material

Material that has been reprocessed from recovered [reclaimed] material by means of a manufacturing process and made into a final product or into a component for incorporation into a product.

5.2.4 Recovered [reclaimed] material

Material that would have otherwise been disposed of as waste or used for energy recovery but has instead been collected and recovered [reclaimed] as a material input, in lieu of new primary material, for a recycling or a manufacturing process.

The term internal scrap is not used in ISO 14021:2016.

5.3 Terms relating to recycled content from UL Environment

The following definitions are extracted from Interpreting Pre-Consumer Recycled Content Claims, UL Environment:

5.3.1 Pre-consumer (post-industrial) material

Material diverted from the waste stream during a manufacturing process that has never reached the end user. Excluded is the reutilization of materials generated in a process and capable of being reused as a substitute for a raw material without being modified in any way.

5.3.2 Post-consumer material

Material that has reached its intended end user which is no longer being used for its intended purpose.

5.3.3 Recycled material

Material that has been reprocessed from recovered (reclaimed) material by means of a manufacturing process and made into a final product or into a component for incorporation into a product.

The term internal scrap is not used in UL Environment.

5.4 Terms relating to life cycle assessment found in ISO 14067

The following definitions are extracted from ISO 14067:2018:

5.4.1 Carbon footprint of a product (CFP)

Sum of GHG emissions and GHG removals in a product system, expressed as CO2 equivalents and based on a life cycle assessment using the single impact category of climate change.

5.4.2 Partial carbon footprint of a product (partial CFP)

sum of GHG emissions and GHG removals of one or more selected process(es) in a product system, expressed as CO2 equivalents and based on selected stages or processes within the life cycle

5.4.3 Life cycle assessment

method used to evaluate the environmental impact of a product through its life cycle, often encompassing extraction and processing of the raw materials, manufacturing, distribution, use, recycling, and final disposal.

5.4.4 Product

goods or service

NOTE 1: The product can be categorized as follows:

- service (e.g. transport, implementation of events);
- software (e.g. computer program);
- hardware (e.g. engine mechanical part);
- processed material (e.g. lubricant, ore, fuel);
- unprocessed material (e.g. agricultural product).

NOTE 2: Services have tangible and intangible elements. Provision of a service can involve, for example, the following:

- an activity performed on a customer-supplied tangible product (e.g. automobile to be repaired);
  - an activity performed on a customer-supplied intangible product (e.g. the income statement needed to prepare a tax return);
  - the delivery of an intangible product (e.g. the delivery of information in the context of knowledge transmission);
  - the creation of ambience for the customer (e.g. in hotels and restaurants).

5.4.5 Product system

Collection of unit processes with elementary flows and product flows, performing one or more defined functions and which models the life cycle of a product.

5.4.6 Unit process

Smallest element considered in the life cycle inventory analysis for which input and output data are quantified.

5.4.7 Life cycle

Consecutive and interlinked stages related to a product, from raw material acquisition or generation from natural resources to end-of-life treatment.

5.5 Terms relating to life cycle assessment found in ISO 14044

The following definitions are extracted from ISO 14044:2006:

5.5.1 Elementary flow

Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation.

5.5.2 Intermediate flow

product, material or energy flow occurring between unit processes of the product system being studied.

5.5.3 Co-product

any of two or more products coming from the same unit process or product system.

5.5.4 Waste

Substances or objects which the holder intends or is required to dispose of.

NOTE 1: The definition is taken from the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (22 March 1989) but is not confined in this International Standard to hazardous waste.

5.6 Terms relating to life cycle assessment found in ISO 21930

The following definition is extracted from ISO 21930:2017:

5.6.1 Secondary material

material (ISO 5659-2:2012, 3.6) recovered from previous use or recovered from waste (3.56) derived from another product system (ISO 14040:2006, 3.28) and used as an input (ISO 14040:2006, 3.21) in another product system

EXAMPLES: Recycled scrap metal, crushed concrete, glass cullet, recycled wood chips, recycled plastic granulate.

NOTE 1: Secondary material is measured at the point [i.e. system boundary] where the secondary material enters the product system from another product system.

6 Analysis of key differences between terms and definitions for aluminium scrap and their applicability in LCA studies

Definitions presented in the previous section of this document, come from different backgrounds. Some of these definitions overlap, while there are also some key differences, which can bring about some confusion. In this section, the key differences between definitions are analysed in detail to better understand important nuances.

6.1 New scrap (GAG aluminium definition) ≠ pre-consumer material (recycled-content definition)

New scrap is a much wider term than pre-consumer scrap, since it includes all scrap arising from the various production stages of aluminium products, before the aluminium product is sold to the final user, while pre-consumer scrap excluded scrap if recycled within the process which generated it.

The definition of pre-consumer scrap is independent of the company which has operative control of the processes. Scraps from semis-production being remelted by the same company would be referred as internal scrap (GAG definition) but could be classified as pre-consumer scrap (recycled-content definition) if the process that generated the scrap is different to the process that uses the scrap.

The differences between those two concepts is further detailed in § 6.3.

6.2 Recovered [reclaimed] material (recycled-content definition) ≠ secondary material (LCA definition)

The definition of "secondary material" in ISO 21930 is based on the concept of "product system" defined in ISO 14040. A "secondary material" is therefore a life-cycle assessment concept which requires defining of “product systems” and their “boundaries” in order to be able to identify and measure them. In particular, this means that a flow between two unit processes included in the same product system cannot be considered a secondary material flow: this can be the case for manufacturing scrap recycled into the same product.

Recovered material, as defined in ISO 14021, is a generic concept used to calculate the recycled content of a product. It does not involve any notion related to life-cycle assessment.

The differences between those two concepts is further detailed in § 6.3.

6.3 Overview of scrap flow definitions

An LCA system boundary is illustrated on Figure 1. On this figure, unit processes are represented with grey boxes, while flows are represented with arrows. System boundaries as defined in life cycle assessment are represented with dotted boxes.

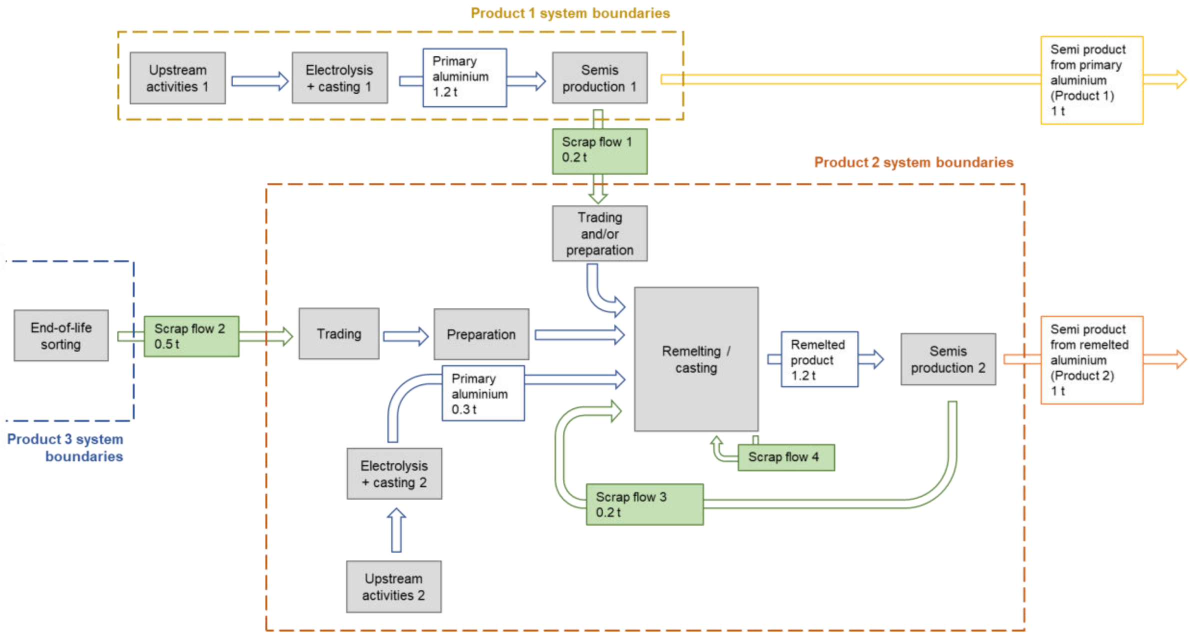

Figure 1: Example of material flows

Four scrap flows are represented on Figure1:

- Scrap flow 1: This scrap is generated at a semis production process of product 1 and remelted (mixed with other scraps and with primary aluminium) to produce a remelted product 2. Two situations are possible: either both products (1 and 2) are produced at the same plant or company, or the scrap is traded between two different companies. In both situations, the semis production process and the remelting process are part of two different product systems in terms of LCA.
- Scrap flow 2: This scrap is recovered from an upstream product which reached its end-of-life and used to make a new product.
- Scrap flow 3: this scrap is generated at a semis production process and remelted at the same remelting process which has generated the aluminium ingot it comes from. Two situations are possible: remelting / casting and semis production are operated by the same company, or the remelted product is sold to a different company and scrap is taken back. In both

situations, the semis production process and the remelting process are part of the same product system in terms of LCA.

- Scrap flow 4: This scrap is generated at the casting step of the remelting process and is reintroduced into the same remelting process.

Those scrap flows fall into different categories depending on the definition which is applied as shown in Table 1.

Flow on diagram	GAG aluminium definition	Recycled-content definition (ISO)	LCA definition	Aluminium LCA (used in this paper)
Flow 1	Internal scrap (same company) or Traded scrap (different companies)	Pre-consumer material	Secondary material or coproduct depending on the reference LCA standard	Process Scrap
Flow 2	Old scrap	Post-consumer material	Secondary material	Post-consumer scrap
Flow 3	Internal scrap (same company) or Traded scrap (different companies)	Pre-consumer material (depending on the definition of a process)	Not a secondary material	Inside Scrap
Flow 4	Internal scrap	Not pre-consumer material	Not a secondary material	Inside Scrap

Table 1: Scrap terminology depending on the definitions applied

NOTE: Recycled content is not focus of this paper, but it is noted that the definitions for pre-consumer scrap are not clearly defined and leave room for different interpretations. ISO does not define the term “process” and UL Environment the term “without being modified in any way”.

For LCAs the system boundary is linked to products, meaning:

- If a scrap flow from the production of a finished product is used for the same finished product, then this scrap flow would not be accounted for a secondary material. It does not exit the system boundary and therefore <u>does not need</u> an allocation method.
- If a scrap flow from the production of a finished product is used for a different finished product, then this scrap flow crosses the system boundary, and an allocation method needs to be defined.
- If scrap is used in the same or a different process, used by the same or a different company is not relevant.

One interpretation is that scrap flow 1 is a secondary material flow in the sense of LCA, crossing the system boundary. However, it can also be considered as a co-product. In this case, this scrap flow is modelled as an intermediate flow, and it carries a part of the impact of the unit processes which have generated it.

7 Modelling requirements for aluminium scrap

7.1 Review of applicable standards

Two main standards provide requirements for the calculation of carbon footprints: ISO 14044 and ISO 14067. Both standards are not precise enough on how to model aluminium scrap in the case of a partial carbon footprint of an aluminium product:

- ISO 14044 provides requirements on how to model recycling in the case of a full life cycle assessment. It does not deal with partial assessments on a limited perimeter (e.g. cradle-to-gate assessment based on a declared unit).
- ISO 14067 provides requirements for the quantification of the carbon footprint of a product, including partial carbon footprints of products based on a declared unit. But ISO 14067 does not provide any specific requirements for allocating carbon emissions to scrap flows which are generated from production value chain, in case of a partial assessment.

ISO 21930 provides requirements related to the development of environmental product declarations (EPDs) for construction products. ISO 21930 defines clear requirements on the modelling of recycling in case of partial assessment. If secondary material is used as input, inputs must be declared in module A1, but no burden is associated to the process scrap flow entering the system. However, ISO 21930 includes an optional information module, called module D, where loads and benefits related to secondary materials can be reported.

In Europe, the EN 15804 standard, which is also applicable to EPDs for construction products, shares most of the modelling requirements with ISO 21930. However, there are diverging requirements regarding the modelling of material recycled during the production stage. EN 15804 states that flows leaving the system at the end-of-waste boundary of the product stage (A1-A3) shall be allocated as co-products, and that loads and benefits from allocated co-products shall not be declared in module D. Therefore, a common interpretation of this standard is to differentiate between pre-consumer and post-consumer materials, pre-consumer material being considered as a co-product (carrying an impact) while post-consumer materials carry no impacts.

ISO 14044 is cited as a normative reference for both ISO 21930 and EN 15804 standards. This illustrates that conflicting interpretations of the generic requirements are possible.

7.2 Aluminium recovered for process scrap

The treatment of aluminium recovered from process scrap varies by standard:

- ISO 21930 clearly states that both pre-consumer and post-consumer materials shall be modelled in the same manner, as secondary materials: process scrap shall therefore be modelled as a secondary material (zero burden). However, ISO 21930 includes an optional information module, called module D, where loads and benefits related to secondary materials can be reported (not zero burden).
- EN 15804 states that flows leaving the system at the end-of-waste boundary of the product stage (A1-A3) shall be allocated as co-products. Process scrap meets the definition of a flow leaving the system at the end-of-waste boundary of the product stage, and therefore shall be allocated as a co-product and not be included in Module D.
- The International EPD System Product Category Rules (PCR) for construction products highlights the differences in requirements between ISO 21930 and EN 15804. Version 1.3.4 of the EPD System PCR provided detailed guidance on the

allocation of scrap (treating pre-consumer and post-consumer scrap differently), referring to the EN 15804 standard as source. The new version 2.0.1 of this PCR (published in June 2025) updated the requirements regarding the allocation of scrap, aligning with requirements from the ISO 21930 standard. This shows that the debate on how to allocate carbon emissions to process scrap is still ongoing.

7.3 Aluminium recovered from dross and skimmings

Dross and skimmings are all classified as pre-consumer material. However, these scrap types always undergo a waste treatment process before being remelted. Therefore, LCA studies shall model dross and skimmings as a secondary material and not a co-product:

- All the steps between the process where dross and skimmings are generated, and the gate of the remelting plant is considered as part of system boundaries of the product generating the dross and skimmings.
- When used as input to a refining process, dross and skimmings come with zero impact into the second product. Only the impacts of the remelting process (mainly energy consumption and air emissions) are included in the carbon footprint of the aluminium product which is recovered from it. If the refining process recovers other metals in addition to aluminium, an allocation shall be applied to distribute the impacts of the process between all its co-products.

8 Review of possible approaches for cradle-to-gate carbon footprint calculations

In this section, three possible approaches for cradle-to-gate carbon footprint of aluminium products made from recycled aluminium are presented, which are currently in use by IAI members. These approaches are illustrated on a simplified case study, presenting the detailed calculation of the carbon footprint. A supporting document complements this reference document and presents the application of the three approaches on a more complex case study.

The calculations presented in the following are made in the form of tables for easier understanding and transparency. The use of a professional LCA software is recommended for actual implementation of these approaches.

8.1 Methodology

8.1.1 Simplified case study for partial carbon footprint

A simplified case-study (presented below) will be used to illustrate the requirements of each approach. This diagram presents two plants[2], producing two products:

- 1 t of semi-finished product from primary aluminium (Product 1)
- 1 t of semi-finished product partly from remelted aluminium (Product 2)

Figure 2 shows a cradle-to-gate module which includes Plant 1 which produces semi-finished products from primary aluminium ingots (Product 1) and sells its process scrap to Plant 2 which remelts this scrap and produces semi-finished products (Product 2).

Process scrap generated during the transformation process of Product 1 is remelted together with some post-consumer scrap and primary aluminium from which a semi-finished products (Product 2) is fabricated.

Scrap is also generated during the transformation step of Product 2: this scrap is sent back to the same remelting step (inside scrap). This assumption has been chosen in order to simplify calculations for this example.

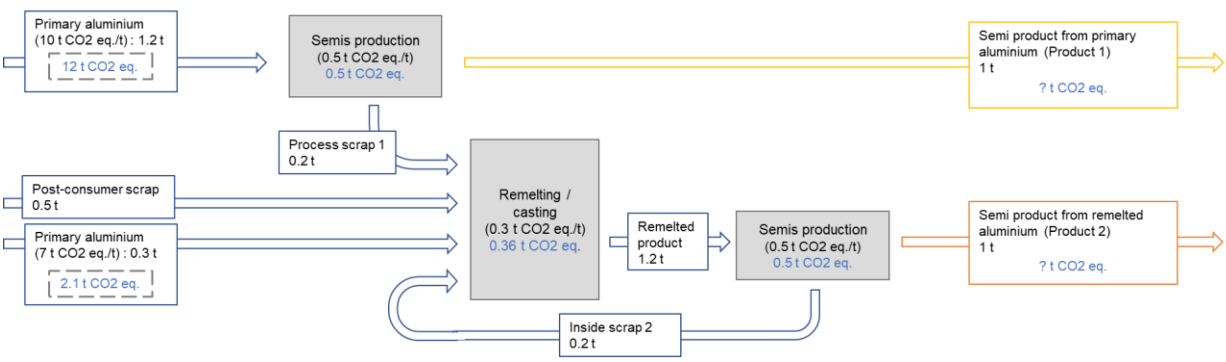

Figure 2: Case study 1 - Fictive simplified case-study

Each activity has related CO2 emissions, and some emissions are also associated to the inputs of those processes. For illustration purposes, different carbon intensities are used for primary aluminium used by the generator of process scrap and by the remelter of process scrap. Post-consumer scrap enters the process with zero burden under all three methodologies. In total, the sum of all emissions is 15,46 t CO2 eq.

[2] There would be no change in applying the methods if these two products would be produced at the same plant.

8.1.2 Assumptions for full life cycle carbon footprint

Partial carbon footprints communicated by aluminium producers can be used to feed a full life cycle carbon footprint calculation. For each approach for partial CFP, a full life cycle CFP calculation is also presented. This calculation is made according to a “net scrap substitution approach”.

Results are calculated assuming that both aluminium products have a recycling rate of 80% at their end-of-life. They are presented using the life cycle stages defined in ISO 21930:

- Module A: Production stage
- Module B: Use stage
- Module C: End-of-life stage
- Module D: Loads and benefits beyond product system boundary

For Module A, we assume no production of finished products and that semis products would enter the use phase (Module B). This is a simplification in order to use the results of the partial carbon footprint.

For simplification, Module B is assumed to have zero impact.

Module D is calculated based on the net output flow of aluminium crossing the system boundary. This net output flow is calculating by:

- Adding all aluminium flow crossing the system boundary as an input (module A only in this case, corresponding to process scrap)
- Subtracting all aluminium flow crossing the system boundary as output (module C for all approaches, and module A for cut-off approach only).

The value declared in module D is calculated through the substitution method, i.e. by multiplying this net output flow by a factor corresponding to the emission intensity of remelting, minus the intensity of the primary aluminium used. Those values are usually chosen as representative values of the geographical area where the finished product is sorted and recycled. As an example, a value of 0.4 (remelting of post consumer scrap) – 10 (primary aluminium used) = -9.6 t CO_2 eq/tonne of aluminium is used in this section (no downcycling considered).

NOTE: In case of downcycling, which is part of Module D, a quality ratio can be used in the calculation of this emission intensity. Further supporting information will be made available on the topic of downcycling.

8.2 Cut-off approach

With the cut-off approach, process scrap is modelled as a secondary material which do not carry environmental burden when used as input to a remelting process (Module A only). It is modelled in the same way as post-consumer materials.

8.2.1 Partial carbon footprint

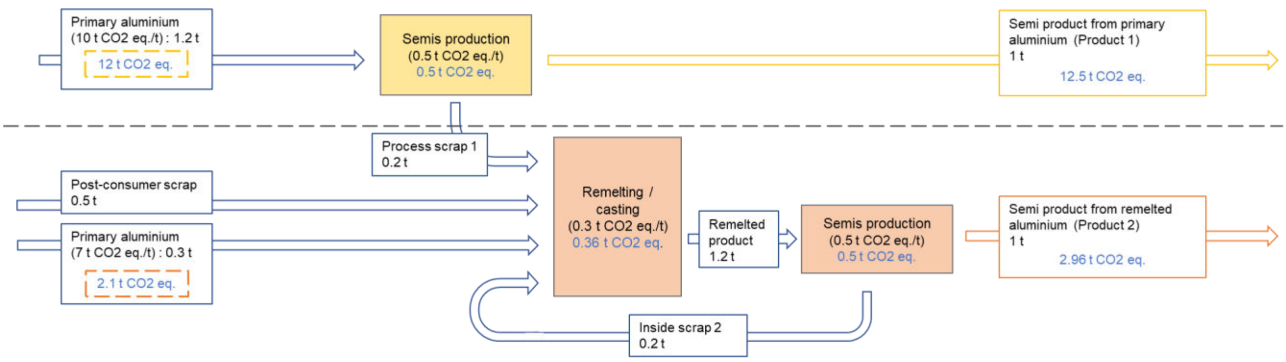

Figure 3: Partial CFP - Flowchart for the Cut-off approach

	Specific CF (t CO2 eq./t)	Product 1		Product 2	
		Flow (t)	CF (t CO2 eq.)	Flow (t)	CF (t CO2 eq.)
Primary aluminium	10	1.2	12		
Semis production	0.5	1	0.5		
Process scrap 1	0	-0.2	0	+0.2	0
Post-consumer scrap	0			0.5	0
Primary aluminium	7			0.3	2.1
Remelting / casting	0.3			1.2	0.36
Semis production	0.5			1	0.50
Total			**12.50**		**2.96**

Table 2: Partial CFP - Data for the cut-off approach

8.2.2 Full life cycle carbon footprint

The full life cycle carbon footprint is calculated using a net-scrap substitution approach (see § 8.1.2). For the cut-off approach, process scrap is a flow crossing the system boundary, it shall be taken into account in the calculation of the net aluminium output flow.

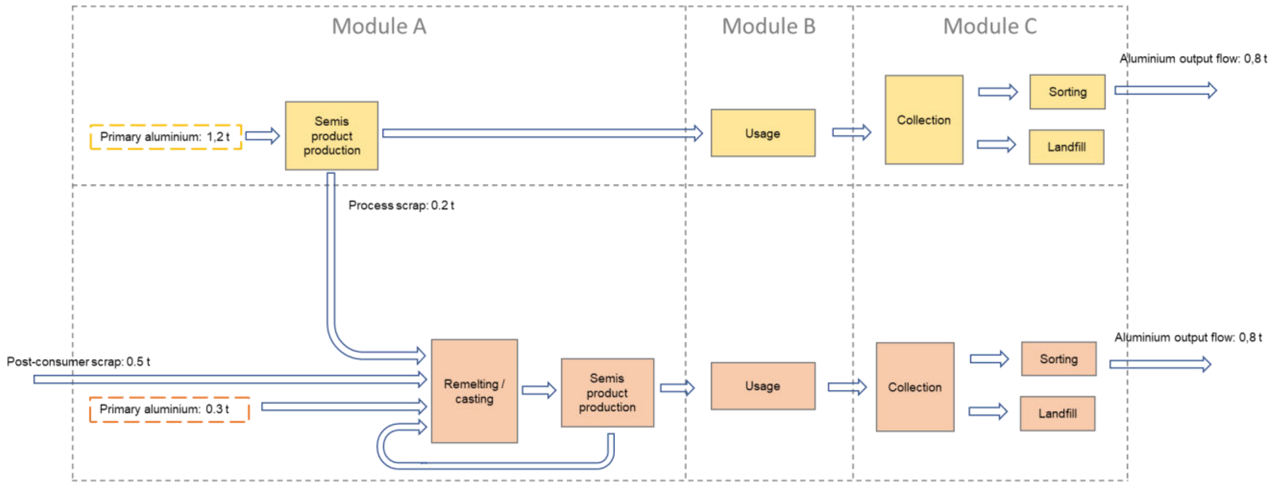

Figure 4: Full CFP - Flowchart for cut-off approach

	Product 1	Product 2
Aluminium output flows	- 0.2 t of aluminium leaving the system in module A, as process scrap - 0.8 t of aluminium leaving the system in module C, after collection and sorting	- 0.8 t of aluminium leaving the system in module C, after collection and sorting
Aluminium input flows	- None	- 0.2 t of process scrap entering module A (input to remelting) - 0.5 t of post-consumer scrap entering module A (input to remelting)
Net aluminium output flow	1 t	0.1 t

Table 3: Mass balance for cut-off approach

	Product 1 (t CO2 eq./t)	**Product 2 (t CO2 eq./t)**
Module A	12.50	2.96
Module D	- 9.60 = *1 * (-9.6)*	- 0.96 = *0.1 * (-9.6)*
Total A+D	2.90	2.00

Table 4: Full CFP - Module results for cut-off approach

NOTE: This approach is not compatible with the EN 15804 standard, as it requires the 0.2 t of aluminium leaving the system in module A not to be taken into account in the calculation of Module D. It is compatible with the ISO 21930 standard.

8.3 Substitution[3] approach

With the substitution approach, process scrap is modelled as a secondary material and a credit is applied when process scrap is generated and sent for recycling (Module D). Reciprocally, process scrap carries an environmental burden when used as an input to a remelting process. Process scrap and post-consumer scrap are therefore not modelled in the same way.

The recycling credits and burdens for process scrap have opposite values, which are calculated considering the impacts of secondary aluminium ingot production through remelting and subtracting the impacts of avoided primary aluminium production. In this example the point of substitution is after remelting and the credit is based on emissions of primary aluminium used by the generator of process scrap. Other substitution methods can be used such as point of substitution is before or after remelting and the credit based on the emissions of primary aluminium purchased by the scrap remelter, on the emissions of the primary aluminium used by the scrap generator or the emissions of primary aluminium used in the region.

8.3.1 Partial carbon footprint

The recycling credits and burdens for process scrap have opposite values, which are calculated considering the impacts of secondary aluminium ingot production through

[3] Also referred to as avoided burden approach.

remelting and subtracting the impacts of primary aluminium purchased by the scrap generator. This is based on the calculation for Module D in ISO 21930 / EN 15804

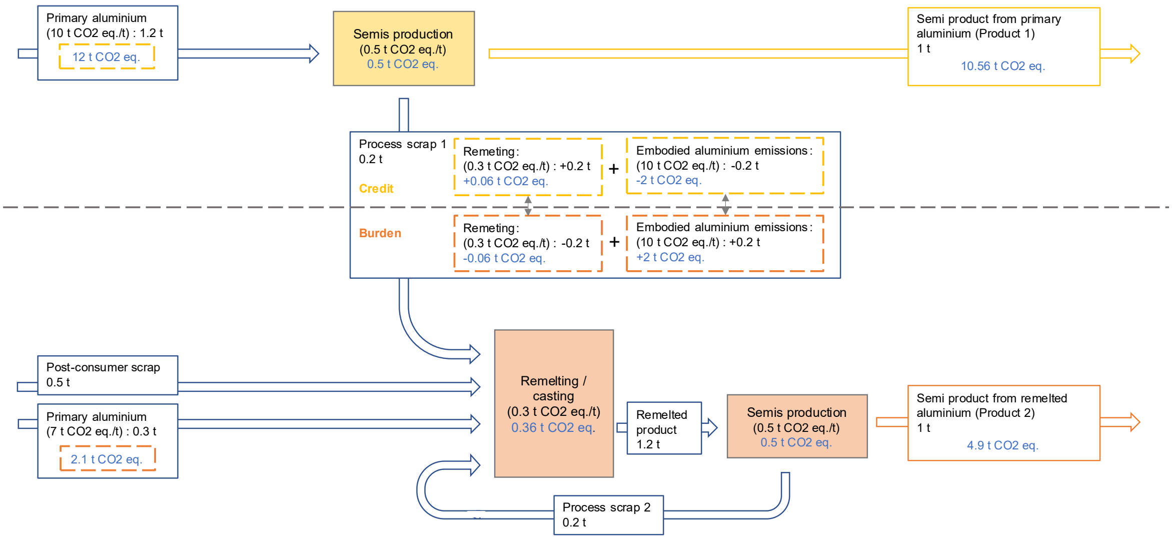

Figure 5: Partial CFP - Flowchart for the substitution approach

	Specific CF (t CO2 eq./t)	Product 1		Product 2	
		Flow (t)	CF (t CO2 eq.)	Flow (t)	CF (t CO2 eq.)
Primary aluminium	10	1.2	12		
Semis production	0.5	1	0.50		
Process scrap remelting	0.3	0.2	0.06	-0.2	-0.06
Substituted primary aluminium (substituted)	10	-0.2	-2	+0.2	+2
Post-consumer scrap	0			0.5	0
Primary aluminium	7			0.3	2.1
Remelting / casting	0.3			1.2	0.36
Semis production	0.5			1	0.50
Total			**10.56**		**4.90**

Table 5: Partial CFP - Data for substitution approach

8.3.2 Full life cycle carbon footprint

The full life cycle carbon footprint is calculated using a net-scrap substitution approach. For the substitution approach, as a credit/burden has already been applied to the process scrap flow when calculating the cradle-to-gate carbon footprint, this flow has already been addressed and shall not be taken into account in the calculation of the net aluminium output flow:

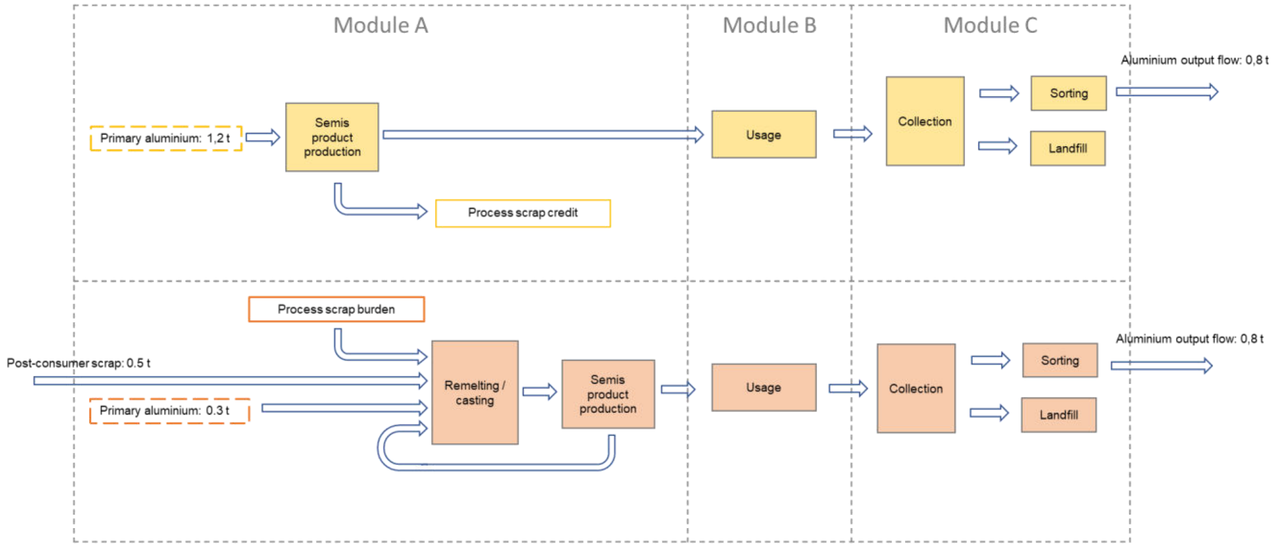

Figure 6: Full CFP - Flowchart for substitution approach

	Product 1	Product 2
Aluminium output flows	- 0.8 t of aluminium leaving the system in module C, after collection and sorting	- 0.8 t of aluminium leaving the system in module C, after collection and sorting
Aluminium input flows	- None	- 0.5 t of post-consumer scrap entering module A (input to remelting)
Net aluminium output flow	0.8 t	0.3 t

Table 6: Full CFP - Mass balance for substitution approach

	Product 1 (t CO2 eq./t)	**Product 2 (t CO2 eq./t)**
Module A	10.56	4.90
Module D	- 7.68 = *0.8 * (-9.6)*	- 2.88 = *0.3 * (-9.6)*
Total A+D	2.88	2.02

Table 7: Full CFP - Module results for substitution approach

8.4 Co-product approach

This approach can be referred as “embodied burden approach”. In this example the impacts of primary material production are allocated between the two products (semis product and process scrap), on the basis of the mass of material which is used in each product. Other co-product allocation rules may be used, e.g. as economic allocation.

Scrap flows between two processes within the system boundaries do not require allocation as they are loops inside the product system. This type of flow is referred to as “inside scrap” in this document

8.4.1 Partial carbon footprint

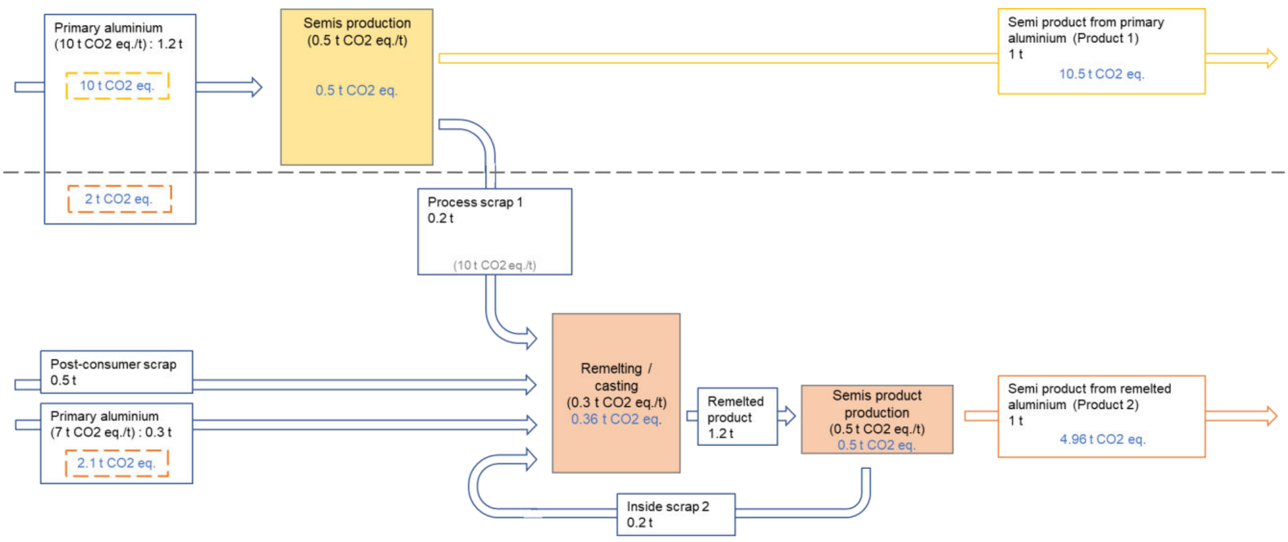

Figure 7: Partial CFP - Flowchart for the co-product approach

	Specific CF (t CO2 eq./t)	Product 1		Product 2	
		Flow (t)	CF (t CO2 eq.)	Flow (t)	CF (t CO2 eq.)
Primary aluminium	10	1.2*(1/1.2)	10	1.2*(0.2/1.2)	2
Semis production	0.5	1*100%	0.5	1*0%	0
Post-consumer scrap	0			0.5	0
Primary aluminium	7			0.3	2.1
Remelting / casting	0.3			1.2	0.36
Semis production	0.5			1	0.50
Total			**10.50**		**4.96**

Table 8: Partial CFP - Data for co-product approach

In case of scrap generated at the manufacturing stage, only the primary aluminium shall be allocated between the main product and the scrap (see example in supporting document). Emissions from any later processing step are fully allocated to the main product and never allocated to the scrap.

8.4.2 Full life cycle carbon footprint

The full life cycle carbon footprint is calculated using a net-scrap substitution approach (see § 8.1.2).:

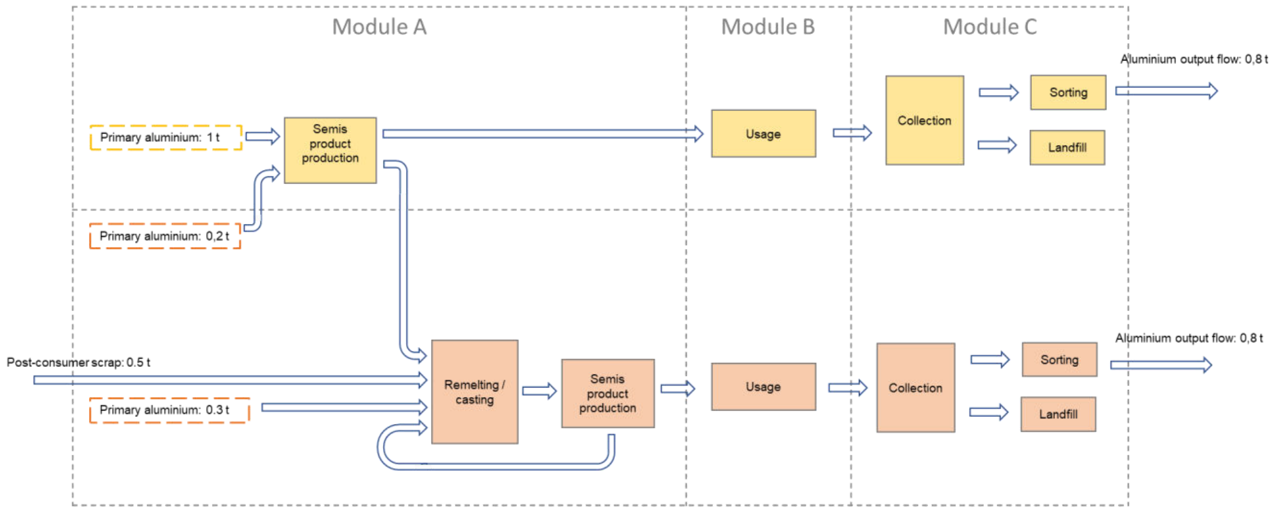

Figure 9: Flowchart for co-product approach

	Product 1	Product 2
Aluminium output flows	- 0.8 t of aluminium leaving the system in module C, after collection and sorting	- 0.8 t of aluminium leaving the system in module C, after collection and sorting
Aluminium input flows	- None	- 0.5 t of post-consumer scrap entering module A (input to remelting)
Net aluminium output flow	0.8 t	0.3 t

Table 10: Mass balance for co-product approach

	Product 1 (t CO2 eq./t)	Product 2 (t CO2 eq./t)
Module A	10.50	4.96
Module D	- 7.68 = *0.8 * (-9.6)*	- 2.88 = *0.3 * (-9.6)*
Total A+D	2.82	2.08

Table 11: Module results for co-product approach

8.5 Comparison of results for full life cycle carbon footprints

8.5.1 Partial carbon footprint

The results obtained with the three approaches for the partial CFP of the two products are summarised in the following table:

	Product 1 (generating process scrap)	Product 2 (from remelted process scrap)	*Check sum*
Cut-off approach	12.50	2.96	*15.46*
Substitution approach	10.56	4.90	*15.46*
Co-product approach	10.50	4.96	*15.46*

Table 12: Overview of the three approaches

The following observations can be made:

- All approaches maintain methodological consistency and avoid omission or double counting of emissions: the sum of the partial carbon footprint of both products is the same for all 3 approaches.
- The choice of a modelling approach has not only an influence on the emissions associated to the product made from remelted aluminium, but also on the emissions of the product which generated scrap.
- With the substitution approach used in this paper (credit is based on emissions of primary aluminium used by the generator of process scrap), in some cases, the value of the credit might be higher than the impacts of producing the aluminium. It is also unclear how to model this substitution approach if no primary aluminium is used by the generator of process scrap.
- In the cut-off method process scrap is treated equivalent to post-consumer scrap, in the substitution method process scrap is close to equivalent to primary aluminium and the mass-based co-product approach is somewhere in the middle on the global level.

* The mass-based co-product approach can lead higher carbon footprints for semis products and final products produced from process scrap compared to semis products and final products produced from primary aluminium. See a more complex case study in the supporting document.
* For consistency, the same approach shall be applied to all products of the same product portfolio. For instance, if a company choose the cut-off approach for communicating on the impacts of products made of recycled aluminium and the substitution approach for communicating on the impacts of products made of primary aluminium would result in some emissions being "lost". The same argument is valid when reporting data at the sector level: if all primary producers use a co-product allocation for the process scrap, they generate and sell on the market and if all remelters using this scrap use the cut-off approach, aggregating this data would lead to omissions.

8.5.2 Full life cycle carbon footprint

The full life cycle carbon footprint is calculated using a net-scrap substitution approach (see § 8.1.2). The results obtained with the three approaches for the full life cycle CFP of the two products are summarised in the following table:

	Product 1 - Module A+D (t CO2 eq./t)	**Product 2 - Module A+D (t CO2 eq./t)**	***Check: Sum of Product 1 and Product 2 (t CO2 eq./t)***
Cut-off	2.90	2.00	4.90
Substitution	2.88	2.02	4.90
Co-product	2.82	2.08	4.90

Table 13: Comparison of three approaches for full life cycle carbon footprints

The following observations can be made:

* The choice of an approach for partial CFP does also affect the results of the full CFP (including Module D). The carbon footprints of two products can be compared only if they both applied the same approach.
* In this example, considering partial CFP results only, Product 1 has higher emissions than Product 2 regardless of the approach. Considering a full life cycle CFP with Module D,this is still true but the emissions difference between Product 1 and Product 2 are shrinking..

- For the substitution approach, the emissions of primary aluminium production are used for the calculation of the substitution credit for process scrap, and for the calculation of Module D. In the example in this report, close to the same values have been used: 9.7 t CO2 eq./t for the process scrap credit, and 9.6 t CO2 eq./t for the calculation of Module D. If the same value had been used for those two calculations, the full life cycle results (including Module D) would have been the same as for the cut-off approach.
- The substitution and co-product approaches assume that post-consumer and process scrap are always identifiable for both cradle-to-gate and full life cycle analysis. This is not necessary for cradle-to-gate and full life cycle analysis using the cut-off methodology. It needs to be investigated if commingled scrap is an issue for the aluminium sector.

9 Regional default values for carbon footprint of process scrap of unknown origin

In case actual data is missing the data in Table 14 can be used. The default value corresponds to the emission factor to be applied to process scrap of unknown origin used as input to remelting.

For the mass-based co-product approach, the values are calculated by using the weighted average of primary aluminium used and domestic recycling from post-consumer scrap (0.4 tonnes CO2e/ tonnes recycled aluminium from post-consumer scrap used for all regions and globally[4])[5].

For the substitution approach, the default value corresponds to the emission factor to be applied for the calculation of the credit to be applied when generating process scrap leaving system boundary, and for the calculation of the burden to be applied to process scrap entering the system boundary. The values are calculated using the carbon footprint of primary aluminium used and deducting the emission for remelting process scrap (0.3tonnes CO2e/ tonnes recycled aluminium from process scrap used for all regions and globally).

[4] Includes remelting of post-consumer scrap only. Collection, processing and any other processes before remelting are not included. This is a theoretic number and will vary depending on the remelting technology and the scrap type.

[5]. An alternative approach would be to use the weighted average of primary aluminium used and domestic recycling from all scrap. For North America this would de-crease the share of primary aluminium from 61% (used in this paper) to 42%.

If the region is known where the process scrap was generated, then the corresponding regional default value is to be applied to process scrap, otherwise the global dataset will be used. The corresponding default value is always determined by the region where the scrap was generated.

Data sources for the carbon footprint of primary aluminium used are European Aluminium (Europe, 2023 data), US Aluminum Associations (North America, 2016 data), IAI (Global, China, Gulf Cooperation Council all 2023 data).

The share of primary versus post-consumer aluminium for co-product allocation is based on Alucycle (https://alucycle.international-aluminium.org/) for Global, Europe, China and Gulf Cooperation Council (2023 data) and the US Aluminum Association for North America (2021 data).

If a plant purchases process scrap from different regions, then an average of the relevant regions can be used.

Regional carbon footprint of primary aluminium used and embodied emissions process scrap (tonnes CO2e/tonne)				
Region	**Carbon footprint - primary aluminium used**	**Embodied emissions process scrap for scrap purchaser**		
		Cut-off approach	**Substitution approach**	**Mass-based Co-product approach**
Global	14.8	0	14.5	11.2
North America	8.5	0	8.2	5.3
Europe	9.7	0	9.4	6.3
China	19.1	0	18.8	16.4
Gulf Cooperation Council	11.4	0	11.1	10.1

Table 14: Regional carbon footprint for process scrap from unknown sources

10 Conclusions

ISO 14044 and ISO 14067 are the international reference standards regarding life cycle assessment and carbon footprint of products. None of these standards provide explicit requirements how to deal with process scrap when performing a cradle-to-gate LCA for a product. Several interpretations are possible, leading to different results: either process scrap can be seen as a co-product of a production process of semis and finished products, or it can be seen as a secondary material flow.

Three approaches for cradle-to-gate partial carbon footprint of recycled aluminium have been identified as possible options:

- Cut-off approach, where process scrap is considered burden-free, and this means that any process scrap generated along the value chain exiting the system boundary won't convey any burden. Hence, all emissions are kept within the system boundary of the process scrap producer.
- Substitution approach, where a recycling credit is calculated when process scrap is generated, and an equivalent burden is given to the scrap when used as an input is the next product. The credit is equivalent to the primary aluminium of the process scrap generator minus emissions during process scrap remelting. In such a case, a tracking system shall be put in place for process scrap flows to secure a consistent carbon accounting between the output flow from one product and the input flow of the other product.
- Co-product allocation, where process scrap is treated as a co-product of semis production or final product manufacturing and carries the emissions of the materials it comes from. In such a case, a tracking system shall be put in place for process scrap flows to secure a consistent carbon accounting between the output flow from one product and the input flow of the other product.

Those three approaches can be used for calculating a full life cycle carbon footprint, including loads and benefits beyond the system boundaries (referred to as Module D in ISO 21930). The calculation of Module D differs depending on the chosen approach.

All these approaches respect the general principles of ISO 14044, and none will cause leakage or double counting if they are applied consistently.

The substitution and co-product approach assume that post-consumer and process scrap are always identifiable and that they never commingle for cradle-to-gate calculations. It needs to be investigated if commingled scrap is an issue for the aluminium sector.