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Harmonizing Product-Level GHG Accounting for Steel and Aluminum

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Columbia Center on Sustainable Investment
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COMET Coalition On Materials Emissions Transparency

The Coalition on Materials Emissions Transparency (COMET) accelerates supply chain decarbonization by enabling producers, consumer-facing companies, investors, and policymakers to better account for greenhouse gas (GHG) emissions throughout materials supply chains, in harmony with existing GHG accounting and disclosure methods and platforms.

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Executive Summary

Greenhouse gas (GHG) accounting methods for steel and aluminum products have begun converging towards common standards within their respective industries in recent years. However, accounting methods for steel products and aluminum products are still not fully comparable with each other. If emissions are measured and allocated differently for these products, then these accounting differences have the potential to influence materials choices for manufacturers concerned about reducing their reported GHG footprint. Companies could therefore be motivated to make a choice between aluminum and steel according to emissions benefits that materialize from differences in accounting frameworks, but which do not actually exist in practice. These incentives will materialize for any substitutable materials which do not use fully comparable GHG accounting frameworks. Bringing product-level accounting methods for substitutable materials such as steel and aluminum into alignment with each other is therefore necessary to eliminate this gap.

This study analyzes the major high-level differences between the International Aluminium Institute's product-level guidance and cradle-to-gate product-level accounting in the steel industry, represented by a synthesis between the ResponsibleSteel International Standard and the Worldsteel Life Cycle Inventory Methodology. Differences in the following key areas were identified:

- **System boundaries:** The methods examined do not apply consistent approaches to determining materiality constraints on the inclusion of emissions sources. The methods also differ by the definition of a final product.
- **Emissions from scrap and other waste products/coproducts:** Treatment of scrap is extremely inconsistent between the methods and reflective of an active debate taking place within both industries. Different categories of scrap are variously treated as waste products, co-products carrying their own emissions burdens to be allocated between producers, and sources of emissions credits estimated according to data on scrap recovery and recycling rates. Other co-products receive emissions treatments that are sometimes difficult to compare due to differences between industries, but they remain reflective of different philosophies around GHG accounting in general.
- **Emissions from energy:** Lifecycle emissions factors from electricity consumption are generally required for aluminum, while location-based and market-based emissions factors generally suffice for steel. Steel methods do not explicitly detail how emissions from electricity exports associated with a combined heat and power facility should be allocated, while the aluminum industry does provide a method for doing so.

Acronyms

BF	Blast Furnace
BOF	Basic Oxygen Furnace
CHP	Combined Heat and Power
EAF	Electric Arc Furnace
EPD	Environmental Product Declaration
GHG	Greenhouse Gas
HVAC	Heating, Ventilation, and Air Conditioning
IAI	International Aluminium Association
LCA	Life Cycle Analysis
LCI	Life Cycle Inventory
PPA	Power Purchase Agreement
REC	Renewable Energy Certificate
T&D	Transmission and Distribution

Introduction

As pressure has grown in recent years to reduce corporate greenhouse gas (GHG) emissions and bring national GHG emissions inventories in line with commitments under the Paris Agreement, GHG accounting methods have come under increased scrutiny. This is particularly the case in the industrial sector, one of the largest contributors to climate change. Recent CCSI studies of GHG accounting methodologies for crude steel and primary aluminum production have illustrated how inconsistent system boundaries, poorly defined calculation methods, and insufficient primary data have hampered efforts to report on emissions from these sectors in a transparent and actionable fashion.[1] Progress has been made in converging towards a single standard within each industry, especially for aluminum, but issues such as allocating emissions from scrap, recording upstream fugitive emissions, assigning credits from exported intermediate products, and estimating additionality of emissions mitigation initiatives still need to be resolved.

In contrast with the corporate reporting landscape, both steel and aluminum producers have gradually converged towards a standard approach in each of their respective industries for measuring and reporting the GHG footprints of discrete products. Yet both industries, and steel in particular, still face conflicts and ambiguities between product accounting methodologies. Furthermore, disclosure practices within both industries for communicating the GHG footprints of products still remain somewhat opaque. These factors complicate efforts by end manufacturers to structure procurement decisions around the GHG footprints of their final products, although both the steel and aluminum industries are in the process of internal debate around clarifying and resolving these gaps.

While steel and aluminum product GHG footprint methodologies are moving towards standardization within their respective industries, they are not consistent with each other. Product GHG accounting methods within the steel and aluminum industries diverge on major active topics of debate within the GHG accounting community, such as the emissions treatment of internal and external scrap, emissions crediting for goods likely to be recycled, netting of emissions associated with the production and export of electricity, and defining the boundary between a coproduct and a waste product. These differences cannot be justified by the differences in the industrial process between the two sectors. As a result, users of both steel and aluminum products, as well as products containing a mix of the two, cannot reliably expect the emissions footprints for each to have been calculated according to the same set of principles.

This inconsistency matters to procurement decision-makers because in many industries, steel and aluminum are highly substitutable inputs. For instance, automakers choose between aluminum and steel components for auto bodies as part of an active balancing act between weight and cost.[2] Hybrid products such as aluminized steel and high-aluminum steel alloys carry attractive benefits for designers such as excellent heat resistance[3] and high strength-to-weight ratios,[4] but calculating a consistent emissions footprint for these products under current conditions is challenging. For all of these applications, assuring that steel and aluminum product-level GHG accounting are as comparable as possible is critical to enabling climate impact to be considered in these procurement and product design decisions.

Methods Examined

This study compares the most commonly used industry standards for product GHG footprint reporting within the steel and aluminum industries. It also examines a third, recently introduced standard within the steel industry currently being piloted which could influence GHG reporting at large for that industry.

- **International Aluminium Institute (IAI)**: IAI is the aluminum industry's main global trade organization. IAI has been heavily involved in developing GHG accounting standards for the aluminum industry, previously authoring the GHG Protocol's module on emissions specific to aluminum production. IAI also continuously engages with its members to refine its guidance according to industry consensus, making draft guidance available for public comment.

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[1] John Biberman, Perrine Toledano, Baihui Lei, Max Lulavy and Rohini Ram Mohan, *Conflicts Between GHG Accounting Methodologies in the Steel Industry* (New York: CCSI, December 2022), https://ccsi.columbia.edu/sites/default/files/content/docs/publications/ccsi-comet-conflicts-ghg-accounting-steel-industry.pdf.

[2] Miklós Tisza and Zsolt Lukacs, "High strength aluminum alloys in car manufacturing," IOP Conference Series: Materials Science and Engineering 418 (September 2018), https://www.researchgate.net/publication/327806384_High_strength_aluminum_alloys_in_car_manufacturing.

[3] W.J. Smith and F.E. Goodwin, "Hot Dip Coatings," Shreir's Corrosion 4 (2010), 2556-2576, https://doi.org/10.1016/B978-0-12-803581-8.09214-6.

[4] Sang-Heon Kim, Hansoo Kim and Nack J. Kim, "Brittle intermediate compound makes ultrastrong low-density steel with large ductility," *Nature* 518 (February 2015), 77-79, https://doi.org/10.1038/nature14144.

- Good Practice Guidance for Calculation of Primary Aluminium and Precursor Product Carbon Footprints: Published in 2021, this is IAI's most recent finalized guidance on product-level accounting for aluminum products, superseding the Aluminium Carbon Footprint Technical Support Document published in 2018. Not all IAI members have yet compiled the cradle-to-gate emissions data specified by the Good Practice Guidance, but the method provides a concise and coherent framework for reporting the cumulative GHG footprints of aluminum precursors and primary aluminum production.
- Reference Document on How to Treat Scrap Flows in Carbon Footprint Calculations for Aluminium Products: While the IAI Good Practice Guidance comprehensively covers emissions reporting for primary aluminum products, it avoids the topic of allocating upstream emissions from scrap incorporated into secondary aluminum production. This is because the international standards IAI builds its recommendations upon are not adequately specific concerning treatment of pre-consumer scrap. This introduces a level of ambiguity that has prevented the aluminum industry from arriving at enough of a consensus for IAI to incorporate these considerations into its formal methodology. In this document, IAI identifies scrap emissions allocation techniques compliant with various interpretations of these underlying standards, illustrates how each technique would influence emissions reporting outcomes within the aluminum industry, and invites readers to provide feedback on these various options for scrap emissions allocation.
- Guidelines on Transparency – Aluminium Scrap: As a means of collecting the data which would inform IAI's ultimate recommended scrap emissions treatment method, IAI requires members to report their usage of different types of scrap according to this document.

- World Steel Association (worldsteel): Worldsteel is the steel industry's key international association. Like IAI, worldsteel has also been involved in crafting international standards for emissions reporting; the ISO 14404 series on calculating facility-level emissions for various steel plant configurations is based almost entirely on the worldsteel CO_2 Data Collection User Guide.
  - Life Cycle Inventory Methodology Report: This worldsteel guidance, published in 2017, is the primary method used by the steel industry in practice to measure and report the emissions footprints of steel products. The Life Cycle Inventory (LCI) Methodology Report encourages users to apply a unique "cradle-to-grave with recycling" approach to calculating the GHG footprint of both primary and secondary steel products, applying worldsteel data on scrap recovery rates by region and category of product to estimate a product's scrap recycling potential and apply this figure to the reported footprint.
- ResponsibleSteel: ResponsibleSteel is a nonprofit partnership among stakeholders in the steel industry that is developing a certification standard for steel production in line with International Social and Environmental Accreditation and Labelling Alliance (ISEAL) guidance on sustainability certifications. ResponsibleSteel's current guidance does not limit itself to issuing benchmarks for emissions intensity but also covers multiple other aspects of sustainable steel production.
  - ResponsibleSteel International Standard Version 2.0: Published in September 2022, this is ResponsibleSteel's most recent version of its standard and the first official version to incorporate specific requirements regarding GHG accounting for steel products. ResponsibleSteel's initial guidance from 2019 only offered general guidance on the need to measure and report industry emissions. The version 1.1 standard provided more granular recommendations on emissions concerns relevant to product GHG footprints, but the version 2.0 guidance is the first produced by the organization with specific target figures for emissions intensity calibrated according to the percentage of scrap used in manufacturing. ResponsibleSteel's version 2.0 guidance is currently in a pilot phase and has not yet entered into force. It also only covers the steel supply chain up until crude steel production.

Methodological Comparison

System Boundaries

All three methods examined claim to apply a "cradle-to-gate" systems boundary to calculating product GHG footprints. Conceptually, a cradle-to-gate footprint measures the emissions associated with manufacturing a product from raw materials to the point it leaves the manufacturing site. However, subtle differences in how these boundaries are defined for each method create disparities within what initially appears to be a set of coherent approaches. Furthermore, worldsteel's methodology introduces an alternate definition of system boundaries lacking parallels with any other method.

IAI's framework communicates the partial GHG footprint of the primary aluminum product from the cast-house according to the system boundary provided in Figure 1. Extraction, processing, and transport of raw materials are all included in addition to the core emissions directly attributable to the primary aluminum producer, as well as emissions from processing of waste generated in the production process. All emissions sources responsible for at least 1% of direct emissions in any unit process according to an IAI assessment are included and recorded.[5]

However, IAI lacks this level of clarity when it comes to defining the final GHG footprint for a product leaving the factory gate. The method only specifies that GHG footprints should be calculated for "alloyed and unalloyed primary aluminium in different forms produced in the cast-house of aluminium smelters from liquid primary aluminium,"[6] and specifies that the system boundary "does not include… production of semi-finished products from raw material."[7] This language fails to specify where emissions related to semi-fabrication, or the shaping of primary aluminum into standardized forms for sale, should be recorded and whether these emissions should factor into the product's ultimate GHG footprint.

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[5] International Aluminium Institute, Good Practice Guidance for Calculation of Primary Aluminium and Precursor Product Carbon Footprints, 12.

[6] Ibid., 7

[7] Ibid., 8.

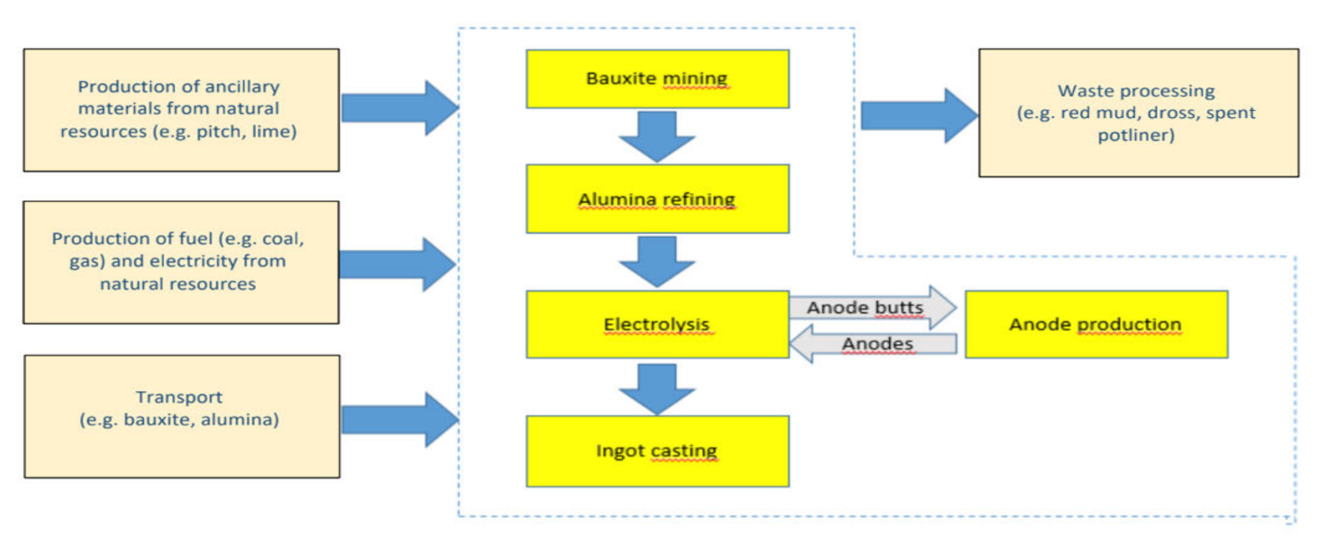

Figure 1. IAI Product GHG Footprint System Boundary.

Source: International Aluminium Institute, Good Practice Guidance for Calculation of Primary Aluminium and Precursor Product Carbon Footprints, 7.

ResponsibleSteel also applies a cradle-to-gate system boundary, including the emissions sources recognized by ISO 14404 and any others associated with imported materials constituting at least 5% of all emissions from imported materials.[8] ResponsibleSteel, like IAI, includes emissions from raw material extraction, processing, and transportation within its boundary. But ResponsibleSteel only assesses GHG emissions intensity for crude steel production, excluding the types of finished products which may be included under the IAI methodology. ResponsibleSteel notes that "the end point of the scope boundary for the determination of the product carbon footprint for steel products…exported from the site may be different to the end point of the scope boundary for the determination of the site's ResponsibleSteel crude steel GHG emissions intensity performance."[9] ResponsibleSteel does not make any specific recommendations on how the GHG footprints of these end products should be calculated, pointing only to a series of reference methodologies including the Worldsteel LCI methodology as well as others such as the European Union Product Environmental Footprint methodology.[10]

Worldsteel also allows users to apply a cradle-to-gate footprint, illustrated in Figure 2. However, worldsteel allows producers the choice of using either a declared unit such as tonnage of steel product or an alternative declared unit relevant to a particular processed steel product, such as a one-meter length of steel section or a square meter of a flat roofing product.[11]

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[8] ResponsibleSteel, International Standard Version 2.0, 102.

[9] Ibid., 104.

[10] Ibid., 120.

[11] Worldsteel Life Cycle Inventory Methodology Report, 5.

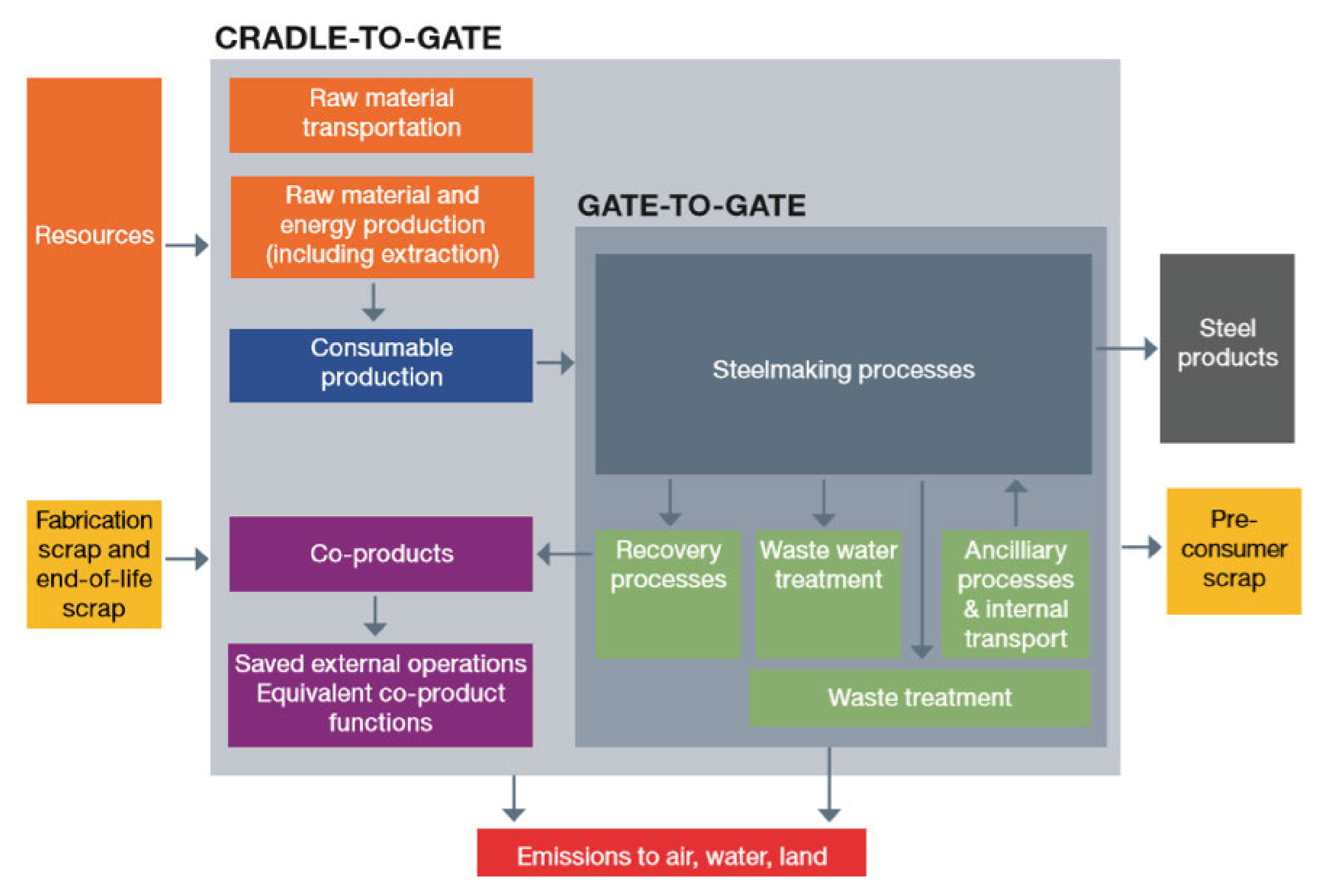

Figure 2. Worldsteel Cradle-to-Gate System Boundary

Source: Worldsteel Life Cycle Inventory Methodology Report, 6.

Worldsteel also allows users the option of reporting product GHG footprints according to a "cradle-to-gate with recycling" boundary, illustrated in Figure 3 and elaborated later in this paper. The cradle-to-gate with recycling approach "considers the cradle-to-gate level as well as the impacts of using steel scrap in the steelmaking process and the credits for the end-of-life recycling of the steel from the final product when it reaches the end of its life… at a specified recycling rate."[12] This approach, which the other methods do not apply, bears similarities to a cradle-to-grave excluding use-phase approach. While worldsteel encourages these recycling credits to be reported separately, it does not strictly require it.[13] In addition, worldsteel applies a different percentage-based approach to materiality as IAI and ResponsibleSteel, requiring that no excluded material flow exceed 1% of emissions for each unit process and that the sum of excluded material flows in the system not exceed 5% of total emissions.[14]

All in all, these differences in system boundaries will create challenges for end users seeking to interpret GHG footprint data when both steel and aluminum products are under consideration.

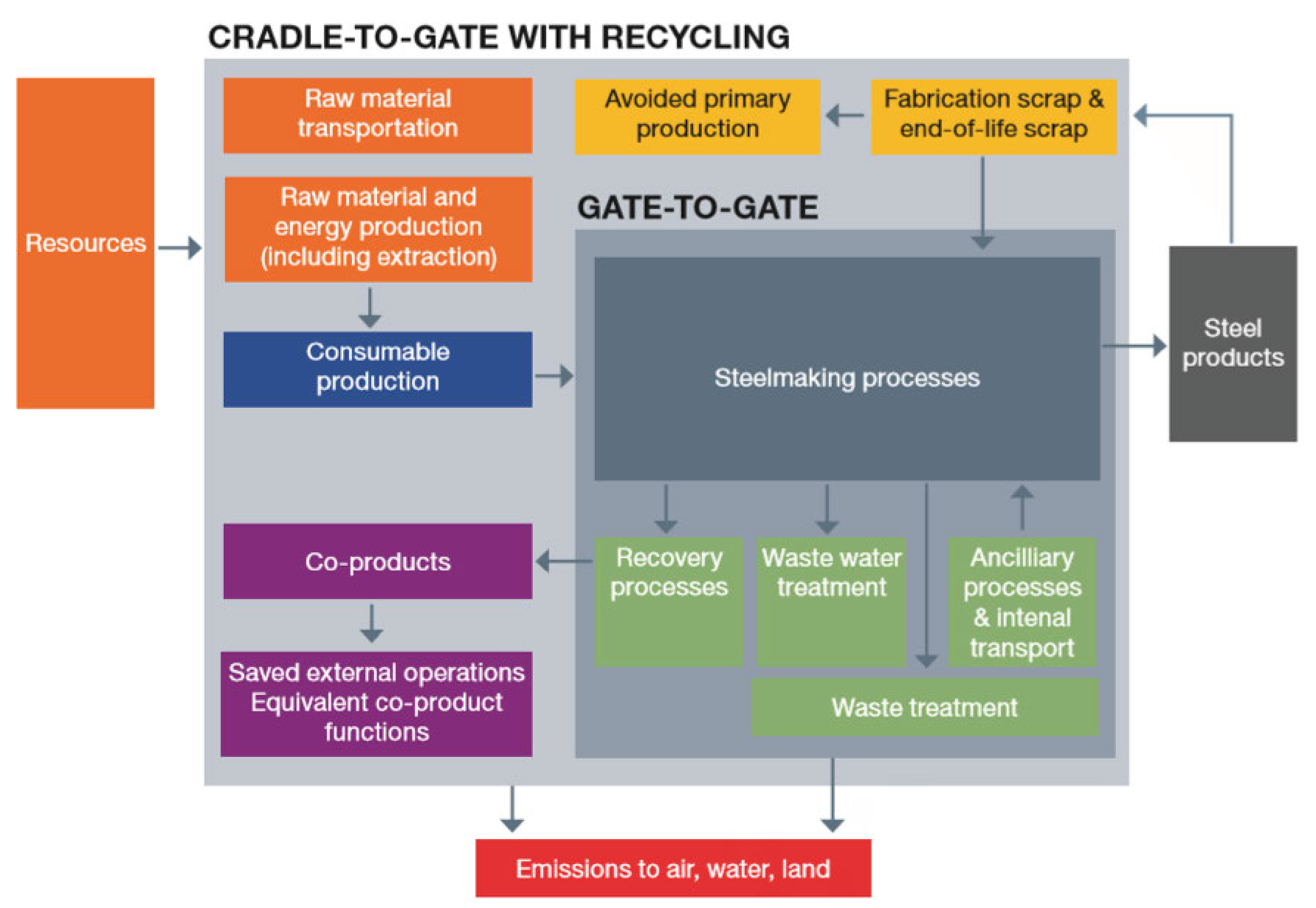

Figure 3. Worldsteel Cradle-To-Gate With Recycling System Boundary

Source: Worldsteel Life Cycle Inventory Methodology Report, 7.

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[12] Ibid., 7.

[13] Ibid., 17.

[14] Ibid., 7.

Allocation of Emissions from Intermediate Products

Determining reporting responsibility for emissions associated with products that depart from the primary stream of production is one of the thorniest challenges in emissions accounting. These products may be sold to a manufacturer producing the same end product as the original producer, or they may serve as useful inputs with the potential to displace GHG emissions from primary production in an entirely different industry. Sometimes, the practicality of using waste products as inputs elsewhere is unproven; other times, waste products substitute only for inputs in production methods for which less GHG-intensive alternatives already exist. Furthermore, pre-consumer scrap removed during shaping can be recycled back into the production stream for any product line. Products can cross facility and corporate boundaries at any point within this cycle, yielding an exceptionally complicated reporting landscape. The steel and aluminum industries diverge on these crucial questions in ways which create ramifications for the GHG footprints of end products and shape the incentives for emissions reduction and material reuse within each sector. Ultimately, building a consistent reporting system will require the steel and aluminum industries to reach agreement on what categories of intermediate products should be considered waste, which types can substitute for primary production elsewhere, how emissions from products crossing system boundaries should be allocated, and what types of incentives should be embedded within this reporting system.

Allocation of Emissions from Scrap

Before exploring how the steel and aluminum industries treat emissions from scrap, it is necessary to categorize the different types of scrap. IAI, ResponsibleSteel, and worldsteel documentation use overlapping terms to define different categories of scrap, creating opportunities for confusion. Scrap definitions can likewise vary between industry associations, guidance, or LCA reports. To ensure consistency of interpretation, the following scrap categories are defined and utilized within this paper. These categories are not mutually exclusive.

- **Pre-consumer scrap**: Scrap which is produced during the production process and prior to the use stage. In this paper, pre-consumer scrap may include inside, internal, and process scrap as defined below, although standardization bodies are still debating whether internal and inside scrap should be considered pre-consumer scrap.
- **Post-consumer scrap**: Scrap made available after products reach the end of life and are discarded.
- **Inside scrap**: Scrap which is removed during the production process and recycled within the same product system. Also referred to as home scrap, turn-around scrap, run-around scrap, and in-house scrap.
- **Internal scrap**: Scrap which is recycled within the same company in which it was produced. Unlike inside scrap, internal scrap does not necessarily need to be recycled within the same product system.
- **Process scrap**: Scrap which is removed during the production process and used as an input for another product system. Also called fabrication or manufacturing scrap. It can be external or internal.
- **Traded scrap**: Scrap which is traded on the market between a specified buyer and seller, according to an agreement on the specified characteristics. Traded scrap can either be pre-consumer or post-consumer scrap. This is in contrast to undifferentiated scrap which is sold on the open market without being subject to any pre-specified quality requirements.

Thus, scrap can be differentiated by whether it is created during the production process or whether it originates from end-of-life recycling. Pre-consumer scrap in particular can be divided according to whether or not it is used in the same process where it originates, as well as whether it is consumed within a different facility from the one where it was produced. Finally, scrap meeting specific requirements can be sold to specific purchasers, as opposed to undifferentiated scrap which is sold on the open market. Not all post-consumer scrap can efficiently be recycled and reused within the most demanding applications, due to impurities and variance in composition from prior use. Figure 4 and Table 1 replicate an IAI case study to illustrate differences between scrap categories and how the same type of scrap can take on multiple names depending on the outside definition used.

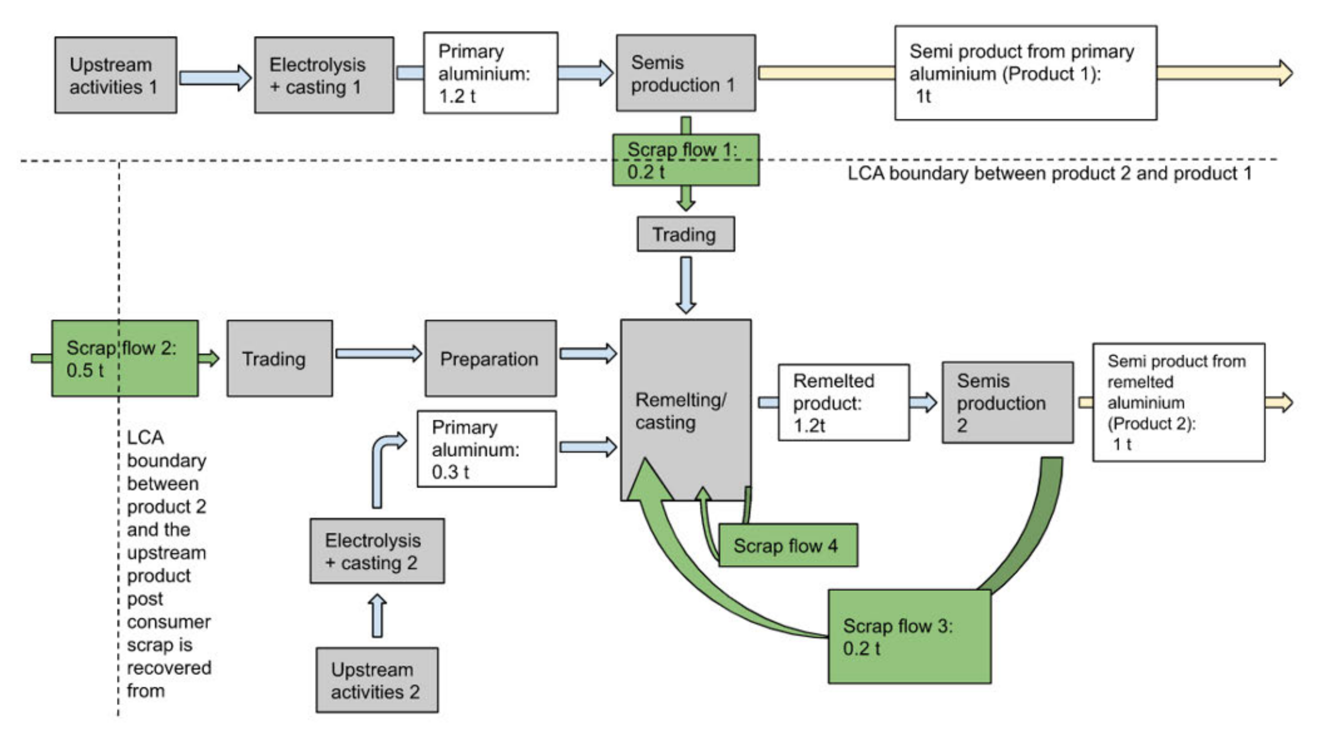

Figure 4. Simplified Case Study of Scrap Material Flows in Aluminum.

Source: Adapted from IAI reference document, 13.

Table 1. Scrap Terminology Used by IAI

Flow on Diagram	Global Advisory Group Guidance	ISO 14021:2016	ISO 14044:2006	Aluminum LCA in IAI
Flow 1	Traded scrap	Pre-consumer material	Secondary material/ intermediate flow	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

Source: Ibid., 14.

Steel Scrap

ResponsibleSteel applies a GHG footprint of zero for all scrap and post-consumer reclaimed material.[15] This cut-off approach does not differentiate between pre-consumer and post-consumer scrap, meaning that scrap which has never entered the use phase may be assigned an emissions footprint of zero. In other words, primary iron and steel originating from outside the facility carry no reported emissions burden, other than emissions associated with transportation of scrap[16] to the facility gate, because ResponsibleSteel treats this process scrap as a waste product from a separate system. Facilities are required to report the tonnage of iron and steel scrap used in their annual crude steel production, defined as the sum of end-of-life scrap, manufacturing scrap, and internal scrap with the exception of inside scrap and scrap which was returned to any industrial process due to not meeting quality standards.[17] The scrap content of the crude steel is ultimately used in an equation that scales the emissions intensity threshold necessary to achieve the ResponsibleSteel certification according to the proportion of scrap used.[18] This is intended to measure the GHG emissions intensity of primary steel production while controlling for the percentage of scrap used. It has the added benefit of preventing companies from meeting the ResponsibleSteel benchmark simply by increasing their usage of scrap, a finite resource which cannot decarbonize the steel industry on its own.

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[15] ResponsibleSteel, International Standard Version 2.0, 109.

[16] ResponsibleSteel refers to scrap from crude steel production which is recycled within the same unit process as internal scrap, but this paper defines it as inside scrap to differentiate it from scrap recycled within different unit processes within a single company. Ibid., 144.

[17] Ibid., 110 and 144.

[18] Ibid., 117.

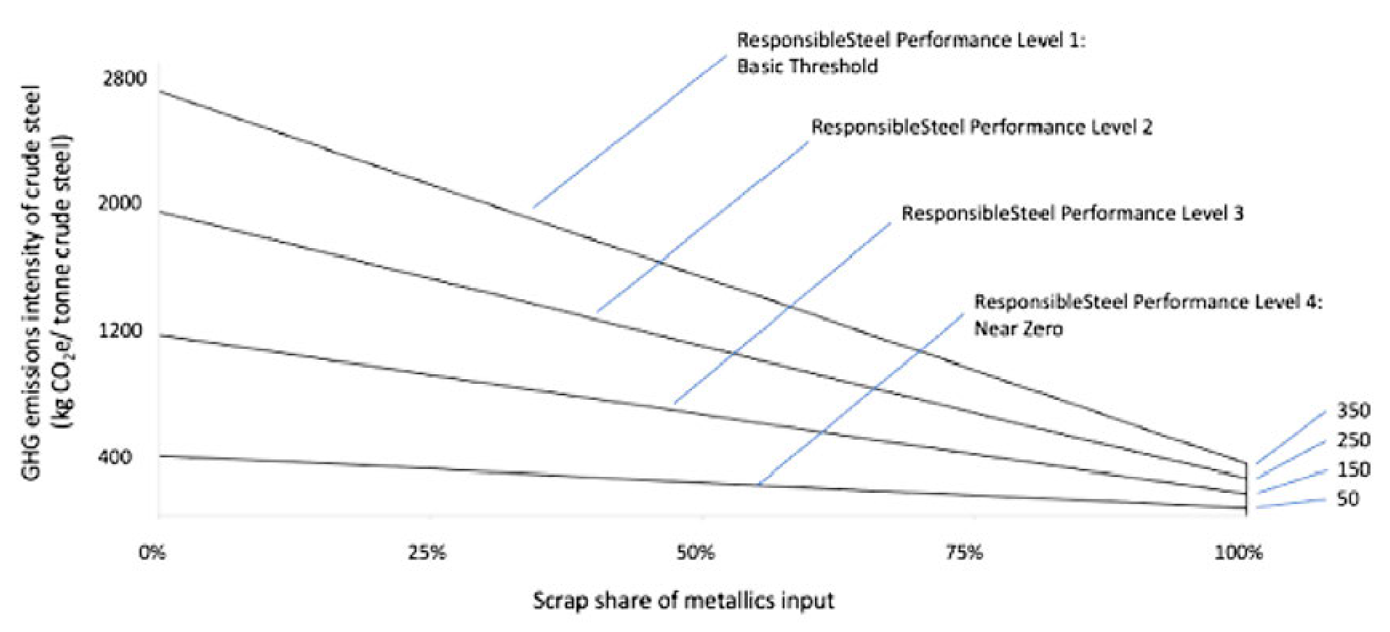

Figure 5. ResponsibleSteel Relationship Between Emissions Benchmarks and Scrap Content.

Source: Adapted from ResponsibleSteel International Standard Version 2.0, 117.

The worldsteel LCI methodology report permits users to apply one of two methods for reporting emissions from scrap. Under the worldsteel cradle-to-gate method, all scrap inputs from different product systems and scrap outputs are outside the system boundary.[19] Inputs of external process scrap and post-consumer scrap carry an emissions burden of zero, incentivizing their use. Exported process scrap also carries an emissions burden of zero, and emissions associated with the production of process scrap are not deducted from the GHG footprint of the end product. This disincentivizes the production and export of excess process scrap because processes that generate process scrap that is not ultimately recycled internally will carry a higher emissions intensity per ton of final product. This cut-off approach aligns with ResponsibleSteel's treatment of scrap.

Under worldsteel's second and preferred method, the cradle-to-gate with recycling approach, net process scrap and end-of-life scrap recovery rates are estimated for individual products. Steel products receive an emissions credit for avoiding future production of primary steel resulting from the generation of this scrap. To balance this credit according to ISO 14044:2006 guidelines on life cycle inventories for closed-loop recycling systems, scrap steel used as an input is assigned an emissions burden according to a theoretical estimate of its emissions footprint from the prior production cycle, whether as pre-consumer fabrication scrap or as post-consumer scrap.[20] Worldsteel claims that this approach promotes the concept of the circular economy by estimating and incorporating the consequential impact of scrap recovery on emissions related to future steel production.[21] This approach can be expected to reduce demand for scrap steel compared to the cradle-to-gate approach and encourage product designs which prioritize ease of scrap recovery, since scrap will carry a higher emissions burden and credits will be assigned according to projected recyclability.

ResponsibleSteel applies a strict cut-off approach to fabrication and post-consumer scrap inputs, assigning them an emissions footprint of zero under the philosophy that they constitute reclaimed waste. Worldsteel permits this approach but also encourages users to adopt the cradle-to-gate with recycling approach described above to encourage the development of a closed-loop recycling system within the steel industry. According to worldsteel, the inherent properties of steel scrap do not change upon recycling, and use of scrap displaces primary steel production, making the closed-loop recycling system described in ISO 14044:2006 an appropriate method for modeling emissions from scrap flows.[22] Worldsteel acknowledges that higher-value grades of steel requiring greater process control typically avoid using scrap for reasons of cost-effectiveness, but maintains that a closed-loop recycling method remains appropriate because scrap steel can still be converted to any grade with proper processing.[23] ResponsibleSteel would not be able to fully implement the worldsteel approach without shifting to certifying end products, since the worldsteel recycling credit is dependent on the type of end product. Finally, ResponsibleSteel records gross scrap input, while worldsteel only records net scrap input.[24] [25] The difference equals the quantity of process scrap exported for use by other steel producers.

Aluminum Scrap

The IAI Good Practice Guidance currently lacks official recommendations on how the emissions footprint of scrap inputs should factor into the GHG footprint of aluminum products, since its scope is limited to primary aluminum products. For now, IAI requires users to report the percentage shares of pre-consumer, post-consumer, and unknown scrap in the cast-house output without specifying how to calculate the emissions footprints of each input type.[26] This preliminary step plays an important role in building a disaggregated information environment for disclosures, and has not yet been replicated by the steel methods examined. IAI does provide special guidance on calculating emissions from remelting scrap within the cast-house to deduct these emissions from the primary aluminum GHG footprint, while the steel methods do not specify a particular approach for measuring emissions from remelting scrap.[27] But solid steel scrap typically does not require measurement of additional energy inputs into the system for remelting, as it is either used as a cooling agent within the basic oxygen furnace (BOF) or these energy demands are measured as part of the electric arc furnace (EAF) process.[28]

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[19] Worldsteel Life Cycle Inventory Methodology Report, 6.

[20] Ibid., 27.

[21] Ibid., 24.

[22] Ibid., 22.

[23] Ibid., 26.

[24] Ibid., 27.

[25] ResponsibleSteel, International Standard Version 2.0, 115.

[26] International Aluminium Institute, Good Practice Guidance for Calculation of Primary Aluminium and Precursor Product Carbon Footprints, 21.

[27] Ibid., 20.

[28] World Steel Association, "Scrap use in the steel industry," May 2021, https://worldsteel.org/wp-content/uploads/Fact-sheet-on-scrap_2021.pdf.

In January 2023, IAI released a draft reference document summarizing thinking within the aluminum industry around how to account for emissions associated with scrap inputs within the cradle-to-gate approach preferred by IAI. In the document, post-consumer scrap is assigned an emissions footprint of zero, under the assumption that all post-consumer scrap is recovered waste.[29] Inside scrap also lacks a separate emissions footprint, with the exception of any emissions from remelting prior to reuse within the cast-house, because emissions from its production are already captured inside the production boundary.[30] But controversy arises concerning the treatment of process scrap. According to IAI, international standards governing life cycle analyses (LCAs) and product carbon footprint calculations offer conflicting answers to the question of whether process scrap should be considered a waste product with no emissions burden or a usable coproduct that does carry an emissions burden.[31] If process scrap is to be considered a coproduct, IAI states that guidance on allocating emissions between both involved product systems is also unclear from these standards.[32]

IAI ultimately identifies eight different approaches to modeling emissions associated with process scrap.[33] These can be divided into three categories:

1. **Cut-off approach**: This model assigns process scrap an emissions footprint of zero, treating it as recyclable waste. This approach will incentivize primary aluminum producers to minimize their production of process scrap, whose associated emissions would not be deducted upon export, and secondary aluminum producers to maximize their use of process scrap, which would carry no upstream footprint.

2. **Co-product approach**: This model assigns process scrap a per-tonne emissions footprint equivalent to the primary aluminum production emissions intensity of the process of origin. The process scrap carries the same embodied emissions as the end-product primary aluminum cast alongside it.

3. **Substitution approach**: This model applies a system expansion approach reminiscent of the worldsteel LCI methodology to estimate global emissions changes from the displacement of primary aluminum production by process scrap inputs. Process scrap carries an emissions burden equal to the avoided emissions associated with producing the same quantity of primary aluminum at the importing facility. The product line generating this process scrap receives an equivalent emissions credit to balance out this burden.

IAI also integrates other, more minor considerations into its proposed methods, namely:

- **How should emissions from semis production, the process which separates process scrap from the primary aluminum end product, be allocated?** IAI considers assigning them entirely to the main product, dividing them according to the respective masses of primary aluminum and process scrap, and allocating them according to the total economic value of each material flow. Since energy consumption from semis production is not likely to correlate with the quantity of process scrap produced, ordinary mass-based allocation of emissions may be less appropriate than alternate approaches such as allocation based on economic value.

- **Does process scrap need to be remelted into an ingot before reaching the point of substitutability with a purchaser's primary aluminum?** Needing to remelt scrap will slightly reduce the avoided emissions credit for the seller of process scrap while also reducing the embodied emissions burden for the purchaser.

- **Should substitutability be based on the purchaser's primary aluminum production emissions intensity or the average for the region, the country, or even the world?** Applying secondary data with higher emissions than expected will increase the avoided emissions credit for the seller, but may be more appropriate in situations where process scrap is bought and sold not as traded scrap (i.e., exchanged directly between a buyer and a seller according to strict specifications), but rather on a fully open market.

Finally, IAI notes that with the exception of the cut-off approach, these proposed methods assume that forms of external scrap, namely process scrap and post-consumer scrap, can be recorded separately from each other. Commingling will threaten the validity of the resulting product GHG footprints since post-consumer scrap and process scrap carry different emissions burdens under IAI methods with the exception of the cut-off approach.[34]

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[29] International Aluminium Institute, Reference document on how to treat scrap flows in carbon footprint calculations for aluminium products, 5.

[30] Ibid., 65.

[31] Ibid., 15.

[32] Ibid., 37.

[33] Ibid., 38.

[34] Ibid., 59.

Cross-Sector Differences of Note

One source of variation between steel and aluminum accounting is how emissions from post-consumer scrap are recorded. IAI's reference document indicates a preference by the aluminum industry to apply a cut-off approach to post-consumer scrap. ResponsibleSteel also applies this cut-off method for its crude steel certification, adding emissions from transportation, but worldsteel provides users with a choice between a cut-off approach under its "cradle-to-gate" method and a substitution approach under its preferred "cradle-to-gate with recycling" method. IAI has not discussed anything similar to worldsteel's cradle-to-gate with recycling approach for post-consumer aluminum scrap.

Emissions from pre-consumer steel and aluminum scrap may also be recorded differently, depending on which approach IAI ultimately recommends. ResponsibleSteel and the worldsteel cradle-to-gate approach apply a cut-off approach to process scrap inputs, reflecting IAI's own cut-off approach which treats process scrap as a waste product. The worldsteel cradle-to-gate with recycling approach models process scrap alongside post-consumer scrap as scrap recovered from production which avoids future primary production. Like IAI's substitution approach, this treats the emissions benefit of process scrap usage as the avoided emissions from primary metals production which would have otherwise taken place, although IAI limits this approach to process scrap without extending it to post-consumer scrap as worldsteel does.

These divergences in scrap treatment between the steel and aluminum sectors point to some implicit philosophical differences regarding the capabilities of metals producers. IAI's allocation-based approaches to calculating the emissions burden of scrap inputs assume that users can access data on the emissions intensity of these upstream scrap suppliers. IAI's allocation-based approaches require "traceability of the embodied aluminium emissions throughout the manufacturing value chain,"[35] and its substitution approaches require "that the company generating scrap and the company remelting scrap exchange information on the emissions of the substituted aluminium."[36] IAI is particularly concerned about commingling because this would jeopardize the chain of scrap custody which its accounting method is dependent upon. In contrast, worldsteel introduces a closed-loop recycling model precisely because it has no expectation that manufacturers will always keep different forms of scrap separate, let alone keep track of emissions information for each incoming shipment. Likewise, IAI continues to examine how the emissions burden of process scrap should be allocated because the allocation method will only alter the GHG footprint of the final product when the buyer and seller produce primary metal at different levels of GHG intensity. Under both a cut-off approach and worldsteel's closed-loop recycling approach, these differences do not matter because they are internalized within the broader system. These differing expectations may also reflect differences in access to traded scrap, which could carry producer-specific emissions information, between steel and aluminum producers.

With that being said, worldsteel's cradle-to-gate with recycling approach also operates under certain contentious assumptions. Worldsteel claims that not only post-consumer scrap but also process scrap recycling rates can be estimated by region and product system.[37] [38] Obtaining consistent data on post-consumer recycling rates for specific products is plausible, but process scrap is only produced as trimmings during the shaping process or due to quality concerns. It may not correlate with individual product types in the way worldsteel claims. Furthermore, a cradle-to-gate recycling approach requires companies to make subjective and potentially inaccurate assumptions about future events, such as specifying a scrap recovery rate. Worldsteel also claims that a closed-loop recycling method is preferable to an allocation approach, which worldsteel states requires questionable theoretical scenarios to determine how emissions burdens should be divided. Worldsteel maintains that the iron and steel industry meets the definition of a closed-loop recycling system under ISO 14044:2006 because the inherent properties of the product do not change during the recycling process. Indeed, steel scrap can be reprocessed to match the characteristics of primary steel once impurities are removed with the aid of technology such as magnetic sorting.[39] However, avoiding some degree of downcycling in steel recycling is often difficult

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[35] International Aluminium Institute, Reference document on how to treat scrap flows in carbon footprint calculations for aluminium products, 39.

[36] Ibid., 46-49.

[37] Worldsteel Life Cycle Inventory Methodology Report, 28.

[38] Worldsteel defines the scrap recovery rate as "the fraction of steel recovered as scrap during the lifetime of a steel product [including] any scrap that is generated after manufacturing the steel product under analysis." This wording is ambiguous as to whether process scrap is included, but ISO 20915:2018, an LCI calculation methodology which follows the worldsteel model, states that the recycling rate includes recovery of both manufacturing scrap and post-consumer scrap. ISO 20915:2018, "Life cycle inventory calculation methodology for steel products," 9.

[39] Javier Bonaplata, "What is steel scrap and how can it help us reach net zero?," World Economic Forum, January 17, 2023, https://www.weforum.org/agenda/2023/01/davos23-steel-scrap-decarbonization/.

and uneconomical.[40] Low-value steel products destined for industries such as construction may follow a closed-loop logic, but high-value steel products are likely to require virgin production under current industrial methods as a matter of economic viability.[41]

Finally, the aluminum and steel industries must reach a consensus on which forms of scrap are waste products and which are not. Post-consumer scrap is treated as waste by IAI and ResponsibleSteel, but not by worldsteel's "cradle-to-gate with recycling" method. Process scrap may or may not be treated as waste within both industries, according to the method used. These questions tie back to how to define a cradle-to-gate system boundary when GHG-intensive inputs similar to, but not identical to, system outputs enter a process.

Allocation of Emissions from Other Coproducts

Fortunately, other coproducts from the steel and aluminum industries do not face the same level of controversy and internal debate as scrap. However, steel and aluminum accounting methods still pursue different approaches to reporting emissions associated with these coproducts which are not always justified by industry differences.

The major byproducts of steel production include process gases from incomplete usage of fuel sources (coke oven gas, blast furnace gas, and Linz-Donawitz converter gas), coke, organic compounds such as benzene and toluene, and slag. These products have outside applications in other industries, such as coproduct gases in thermal power generation and slag in concrete production. With the exception of process gases, which have no parallel in the aluminum industry and which use a special allocation approach, ResponsibleSteel applies a mass allocation approach to emissions from all byproducts which are produced solely for export elsewhere. As "there is no reduction of the ResponsibleSteel crude steel GHG emissions intensity for the site due to the allocation of GHG emissions to the production of steel byproducts or coproducts at the site,"[42] ResponsibleSteel initially applies a process subdivision approach to identify which products are not used for onsite steel production and then only allocate emissions for the sales of those products. Steel byproducts will therefore either receive an emissions treatment as waste or as separate products with GHG footprints according to the outcome of this assessment. If the relationship of coproducts to the steel production process cannot be objectively determined, then this framework would force the GHG footprints of these coproducts to depend on a subjective assessment by the user.

IAI also applies a mass-based allocation approach to coproducts not associated with the core aluminum production process. IAI restricts this allocation to aluminum hydrate which is exported directly to outside users rather than being calcinated for use in an aluminum smelter, applying a conversion to estimate the total mass of hydrate prior to calcination.[43] The aluminum industry does not consider waste products from aluminum production to be reusable in other industries in the same way that the steel industry does, although research has sought out productive uses for waste products such as red mud.[44] This difference in eligibility for waste products to be considered coproducts is likely mainly due to differences in their practical use, although it may also point to an increased willingness within the steel industry to consider certain waste products as inputs for other industries and, thus potential sources of emissions reductions.

This possible increased willingness is consistent with worldsteel's advocacy of a system expansion approach not just for post-consumer scrap but for all steel byproducts. System expansion "is the preferred method of the steel industry as it provides the most consistent solution to avoiding many of the problems of other approaches. It closely represents the real interactions of steel production routes with the environment and avoids unsound theoretical scenarios. Allocation rules are avoided by attributing all system inputs and outputs to the main system function…but credits are given for the production (net output) of [byproducts used outside the product boundary] because their production replaces the alternative production of similar functional products."[45]

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[40] Abel Ortego, Alicia Valero, Antonio Valero, and Marta Iglesias-Émbil, "Downcycling in automobile recycling process: A thermodynamic assessment," *Resources, Conservation and Recycling* 136.4 (September 2018), https://www.researchgate.net/publication/324478484_Downcycling_in_automobile_recycling_process_A_thermodynamic_assessment.

[41] Sabine Dworak and Johann Fellner, "Steel scrap generation in the EU-28 since 1946 – Sources and composition," *Resources, Conservation and Recycling* 173 (October 2021), https://doi.org/10.1016/j.resconrec.2021.105692.

[42] ResponsibleSteel, International Standard Version 2.0, 109.

[43] International Aluminium Institute, Good Practice Guidance for Calculation of Primary Aluminium and Precursor Product Carbon Footprints, 18.

[44] Mengfan Wang and Xiaoming Liu, "Applications of red mud as an environmental remediation material: A review," *Journal of Hazardous Materials* 408 (April 14, 2021), https://doi.org/10.1016/j.jhazmat.2020.124420.

[45] Worldsteel Life Cycle Inventory Methodology Report, 15.

Worldsteel's system expansion approach provides a more consequential examination of the emissions impact of coproduct exports, as opposed to the attributional approach of emissions allocation. However, it creates great potential for double-counting when end-use industries do not properly record an emissions burden from imported coproducts to balance the credit recorded by the steel industry. It also involves assumptions about the usefulness of these coproducts which may not reflect real-world conditions, as well as about the GHG footprints of the inputs these coproducts are replacing. Finally, this approach may incentivize facilities to continue using GHG-intensive production methods such as the blast furnace-basic oxygen furnace (BF-BOF) route as a means of gaining emissions credits for the export of coproducts such as process gases and coal oil, even when cleaner methods are available. On the demand side, inexpensive availability of these coproducts may also prevent outside industries, such as cement, from switching to production methods which do not require these inputs.

Energy Imports and Exports

ResponsibleSteel quantifies emissions from imported electricity according to the most detailed location-based factor possible, based on the average consumption mix of the grid used for reporting.[46] Use of market mechanisms such as Renewable Energy Certificates (RECs), Power Purchase Agreements (PPAs), and green tariffs to calculate emissions from imported electricity are also permitted, provided they comply with ISO 14064-1:2018 requirements to avoid double-counting.[47] Worldsteel applies a similar, slightly more restrictive approach, specifying that the method used must be "the most representative of either a specific supplier…or the most appropriate regional or national grid mix."[48] However, IAI sets itself apart from the two steel methods by requiring lifecycle emissions factors for grid-based electricity imports.[49] This includes not just emissions from consumption of fuels used in power generation, but also emissions associated with both transmission and distribution (T&D) losses and the initial construction of these facilities. Because aluminum production is generally more electricity-intensive than steel production, aluminum smelters often source their energy from captive, purpose-built plants. Aluminum producers therefore have greater access to information about their power facilities and a greater need to record all potential emissions sources associated with their power generation. This is particularly the case when an aluminum smelter derives its power from a hydroelectric dam due to the high level of GHG-intensive materials such as cement used before power even starts being generated which would otherwise go unrecorded. However, the fact remains that recommended emissions factors for these two industries are not comparable.

Aluminum smelters also benefit from a potential loophole in the IAI method. Like ResponsibleSteel and worldsteel, IAI allows users to source their emissions factors from RECs or guarantees of origin.[50] However, IAI does not explicitly require emissions factors provided from these sources to follow the same lifecycle emissions approach that IAI normally requires. This creates opportunities for facilities that would otherwise need to report high lifecycle emissions factors from their power generation to reduce their reported emissions by contracting with an outside provider, or even by placing their own captive power facility under a separate corporate structure and arranging a purchase agreement.

Finally, the two industries incorporate different approaches to allocating emissions associated with electricity exports. While the steel industry generally exports more electricity due to industry-specific factors like process gases, both industries are capable of electricity exports from combined heat and power (CHP) facilities, meaning these methods should be comparable. ResponsibleSteel and worldsteel do not propose a method for allocating emissions from electricity exports not associated with process gases, meaning they apply a cut-off approach to any electricity produced from waste heat. However, IAI proposes an "efficiency method" for allocating emissions from a CHP plant. This method, derived from the GHG Protocol,[51] determines the fuel energy inputs required to produce the steam energy required for the power generation measured on the basis of assumed values. Doing so theoretically determines the quantity of fuels, and therefore emissions, associated with the production of waste heat which is captured by the CHP plant. Assigning an allocation-based credit may incentivize more efficient capture of this waste heat, but it may also disincentivize the design of more efficient systems which avoid waste heat production altogether. The steel and aluminum industries should

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[46] ResponsibleSteel, International Standard Version 2.0, 104.

[47] Ibid., 105.

[48] Worldsteel Life Cycle Inventory Methodology Report, 8.

[49] International Aluminium Institute, Good Practice Guidance for Calculation of Primary Aluminium and Precursor Product Carbon Footprints, 13.

[50] Ibid., 17.

[51] WRI/WBCSD, "Allocation of GHG Emissions from a Combined Heat and Power (CHP) Plant," GHG Protocol guide to calculation worksheets v1.0 (September 2006), https://ghgprotocol.org/sites/default/files/CHP_guidance_v1.0.pdf.

engage in discussion to determine what set of incentives is more desirable, especially as steel plants introduce CHP plants to reduce fuel consumption.[52]

Conclusion

This analysis of product GHG and footprint methodologies in the steel and aluminum industry has identified several crucial differences, independent of industrial process differences, between how emissions from these industries are assigned, quantified, and reported. However, highlighting these differences can be the first step in opening a bilateral industry dialogue to harmonize these methods. Harmonization will not only make steel and aluminum product GHG footprints more comparable, but it will also yield benefits for market transparency and improve confidence in the accuracy of product environmental disclosures. Table 2 summarizes the key differences identified between the methods examined and identifies opportunities for opening this dialogue around harmonization.

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[52] Kari Lydersen, "Combined heat and power is a boon for Midwest steel mills," Energy News Network, June 20, 2014, https://energynews.us/2014/06/20/combined-heat-and-power-is-a-boon-for-midwest-steel-mills/.

Table 2: Summary of Cross-Sector Differences and Key Discussion Topics

	ResponsibleSteel	**Worldsteel**	**IAI**	**Key Questions**
System Boundaries	Cradle-to-gate	Cradle-to-gate OR cradle-to-gate with recycling	Cradle-to-gate	Should a cut-off approach, a mass allocation approach, or a substitution approach be applied to coproducts and recycled upstream inputs?
End Product Definition	Tons of unshaped crude steel	Tons of shaped steel product OR declared unit relevant to specific steel product	Tons of primary cast-house product, excluding semis manufacturing	At what standardized level should methods consider a product to have left the gate?
Process Scrap	Cut-off approach Internal scrap	Cut-off approach for cradle-to-gate; closed loop recycling approach for cradle-to-gate with recycling	Unit allocation (by mass), cut-off approach, or substitution approach	When process scrap is bought or sold, should it be treated as a waste product, a coproduct, or part of a closed-loop recycled system? Can buyers obtain emissions certificates from sellers?
Post-Consumer Scrap			Cut-off approach	For which use cases can post-consumer scrap be considered substitutable for primary metals production? Can commingling between pre-consumer and post-consumer scrap be avoided?
Emissions from Other Coproducts	Mass allocation for products produced solely for export	Credits for net output of exportable coproducts (broadly specified)	Mass allocation for exportable coproducts (narrowly specified)	Can users distinguish between products made for export and sold coproducts? What distinguishes a waste product from a coproduct? How should allocation take place? Can credits be applied without resulting in double-counting in other sectors?
Energy Imports	Most detailed location-based factor possible or sourced from ISO-compliant market mechanism	Emissions factors sourced from specific supplier or most detailed location-based factor possible	Lifecycle emissions factors (except through energy certificates)	Can lifecycle emissions factors be applied for all electricity generation? How would lifecycle emissions factors “depreciate” upfront emissions from sources such as construction to ensure they are applied in all years of operation?
Energy Exports from CHP	Cut-off approach applied to power from a CHP		Efficiency method used for allocating power exports from a CHP	Is waste heat captured by CHP facilities in steel plants generated from industry-specific sources such as coproduct gases?

Source: Compiled by the authors according to the listed sources.

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