Steel GHG Emissions Reporting Guidance

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Together, we are the leading voice of business for sustainability, united by our vision of a world in which 9+ billion people are living well, within planetary boundaries, by mid-century.

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1 BACKGROUND

1.1 Introduction

Steel is critical to the functioning of modern society. It is not only used ubiquitously in buildings, transport, infrastructure, and machinery but is also fundamental to the development of key technologies required by the energy transition, such as wind turbines.

The steel sector is also a major source of greenhouse gas (GHG) emissions.[i] Steel production is directly responsible for ~2.6 gigatons (Gt) of CO_2 emissions in 2020, which is ~7% of global emissions, in addition to ~1.0 Gt CO_2 from the sector's electricity usage. Current production methods rely on fossil fuel for energy and oxygen removal from iron minerals. As a result, fundamental changes to production methods are required to decarbonize the sector.

Due in part to its widespread use, there is significant demand for steel produced with low emissions from end-users concerned with climate mitigation, such as wind turbine and electric vehicle manufacturers. To satisfy this demand, it is necessary for actors in the steel supply chain to provide transparent and comparable information on emissions. This will allow purchasers to confidently procure steel with low embodied emissions and ensure these purchasing decisions drive decarbonization in the steel sector.

This guidance details the emissions calculation and reporting, which steel companies can use to satisfy those requirements and, thus, meet the demand for low-embodied-emissions steel.

1.2 Purpose

The purpose of this guidance is to provide a methodology for steel companies to report emissions in a way that enables the development of a differentiated market for low-embodied-emissions steel that promotes the necessary investments to decarbonize the sector.

The broad outcome of the implementation of this tool is as follows:

1. Accelerate the deployment of low-emissions steel production technologies by ensuring sufficient information is available to link demand with supply.
2. Increase transparency and provide further information on steel production emissions with a methodology that is consistent across geographies and commodities.
3. Enable steel consumers to purchase with a clear embodied emissions association and demonstrate evidence of that emissions performance to their customers.
4. Credibly recognize steel producers leading their peers in terms of emissions performance, particularly in deployment of new technologies.

1.3 Principles

This guidance is developed based on the broad carbon accounting principles of RMI's Horizon Zero project. The overarching principle is the need to report emissions from a specific asset at the product level. This is required because the product is the basis for purchasing decisions, which this guidance seeks to inform.

[i] Throughout this guidance, "emissions" is used as shorthand for global warming potential (GWP) (measured as CO_2 equivalent).

To enable useful product-level emissions disclosures, the Steel Emissions Reporting Guidance uses three key principles:

1. Use primary data – As much as possible, emissions calculations should be based on first-hand information from actors in the supply chain.
2. Create a boundary for comparison – Companies should report emissions against a fixed boundary (i.e., a consistent set of processes) to enable comparability between disclosures.
3. Measurement made for markets – Ensure calculation and reporting decisions provide the transparency necessary to enable the development of a market for low-embodied-emissions products.

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

1.4 Underlying Methods

Significant existing work has been completed on calculating emissions for steel products. Specifically, the worldsteel Lifecycle Inventory methodology provides the basis for calculation of the cradle-to-gate lifecycle footprint and the ResponsibleSteel 2.0 standard provides additional details for GHG emissions calculations at a common (to most steel products) upstream point for benchmarking emissions performance.[1] This document offers guidance on how steel producers can disclose results under these methods as well as additional metrics to support buyers on better understanding and evaluating the emissions footprint of the product and ensure that their purchases promote the decarbonization of the steel sector.

1.5 Terminology

This guidance applies diverse terms to differentiate between requirement, recommendations, and permissible allowable options in line with the Pathfinder Framework.

Term	Definition
"Shall"	Indicates which rules need to be followed by companies applying the RMI Steel Guidance
"Should"	Indicates which rules are recommendations
"May"	Indicates an option that is permissible or allowable

2 EMISSIONS REPORTING

There are four key requirements for reporting steel sector emissions using the Steel Emissions Reporting Guidance:

1. Product level – Emissions from an individual site shall be reported at the product level.
2. Fixed boundary – All emissions from a set of processes shall be reported irrespective of whether the company has ownership or control of these processes.
3. Supply chain transparency – Additional context about scrap-based inputs (e.g., pre-consumer and post-consumer fractions), benchmarking point carbon emissions intensity (refer to Section 3.3) relative to the 1.5°C trajectory, and abatement technology (refer to Section 3.4) can help understand the cradle-to-gate emissions footprint.
4. Data source – Emissions disclosures shall include the fraction of the emissions footprint that is based on primary data (refer to Section 3.7).[2]

Using these key requirements, the data reported for each product is as follows:

- The overall emissions footprint for the steel product on a cradle-to-gate boundary (refer to Section 3.1).
- The fraction of scrap-based inputs used to generate the product (refer to Section 3.2) further divided into the pre-consumer and post-consumer scrap fractions where possible.
- Emissions footprint from cradle to the benchmarking boundary (either crude steel or hot-rolled product; steelmakers should report the one used). This data can be used to benchmark the product (refer to Section 3.3, benchmarking may be performed by either the producer or buyer).
- The fraction of primary data used to calculate the overall emissions footprint (refer to Section 3.7).
- Steelmakers can also report the emissions impact out of the sector boundary separate from the overall footprint (refer to Section 3.5).

This data provides steel purchasers with a set of information required to understand and value emissions reductions by steelmakers across the key changes required to decarbonize the sector.

2.1 Product Level

A core component of this guidance is the reporting of emissions intensity of individual sites/supply chains at the product level (e.g., semi-finished steel products such as hot-rolled coil, rebar, and sections). This enables the emissions information to flow alongside the product and accumulate as products are moved (and transformed) along a supply chain, thereby enabling each actor in the chain to accurately understand the embodied emissions of purchased and sold products.

To achieve this, companies shall report the emissions intensity of steel produced at each asset/supply chain. If parallel independent lines of steelmaking exist at a single asset, companies may separately report the emissions intensity of steel produced from each line. This is intended to ensure that when an operating line uses a substantially different, low-emissions technology, companies are able to demonstrate the low emissions performance of products from that line.

2.2 Fixed System Boundary

The fixed system boundary defines all the process steps from which total emissions shall be reported irrespective of the steel companies' ownership structure. This approach resolves two key issues:

1. **Emissions disclosure at the corporate level varies depending on the degree of vertical integration**. In some instances, vertical integration can extend to emissions-intensive upstream processes such as sintering and coke production. If these processes are operated (and owned) by a steelmaker, emissions are included in Scope 1 (according to the GHG Protocol). For non-integrated operators, the same emissions would count as Scope 3, which may not be reported, presenting challenges to comparing GHG emissions across the sector.
2. **Scopes 1, 2, and 3 will likely become more fluid overtime, further limiting comparability.** For example, as the use of direct reduced iron (DRI) increases to enable a shift to hydrogen-based steelmaking, emissions may be included as Scope 1 (for DRI using green hydrogen produced on-site), Scope 2 (where purchased electricity is used to make hydrogen), or Scope 3 (for DRI produced by a third party).

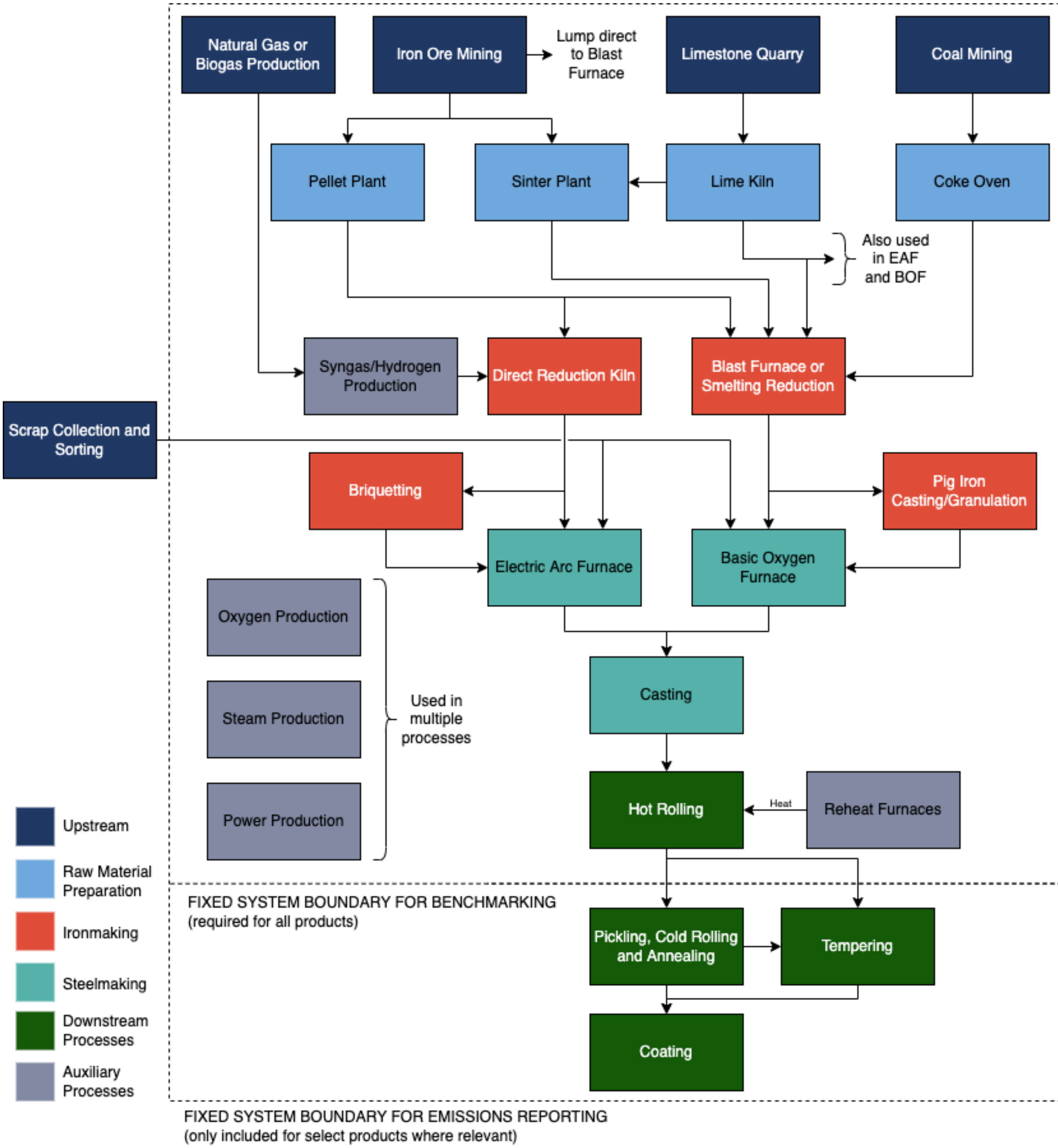
Exhibit 1 shows the proposed system boundary required for reporting. To enable a comparison of steel products and benchmark against the 1.5°C (or other) trajectory (refer to Section 3.3), an emissions footprint at a common upstream point shall also be reported. This common point is either at the crude steel level (i.e., after casting) or after hot-rolling (shown in Exhibit 1). The use of a common upstream point that captures the majority of emissions helps understand the key emissions footprint drivers (e.g., ironmaking) and efforts on abatement technology in steel production, and provides a basis for comparison/benchmarking against the sector's emissions targets (e.g., the IEA Net-Zero Emissions scenario, known as NZE).

Most steel (>95%) is hot-rolled.[3] This process is the last relatively common (to most steel products) and large direct consumer of fuel for heat. As such, products from hot-rolling are a useful point at which emissions should be benchmarked. Using hot-rolling as the benchmarking point also has the advantages of simplifying off-gas accounting (as most off-gas is often used within this boundary), capturing the direct fuel use at standalone electric arc furnaces (EAFs), and aligning directly with the cradle-to-gate boundary for many products (such as hot-rolled coil, sections, and rebar), thereby reducing the need to report two separate emissions footprints for some steelmakers. Use of the hot-rolled products as the benchmarking point also means that innovative technology to reducing heating requirements such as near-net-shape casting can be recognized within the benchmark (instead of only in the cradle-to-gate footprint).

The alternative benchmarking point follows casting (i.e., crude steel such as blooms, billets, and slab) as used by the ResponsibleSteel 2.0 standard. This point still captures the largest emissions sources (e.g., ironmaking, sintering, coke-making, etc.) and is common to all steel products.

Either point can be used provided that the benchmark for comparison (e.g., the 1.5°C trajectory) is also adjusted to align with the reporting boundary (see Section 3.3. and the Appendix for further details).

Exhibit 1: Fixed System Boundary for Steel Sector Emissions Reporting



2.3 Activities and Products Included in the Benchmarking Boundary

The proposed boundary in Exhibit 1 aligns with the NAICS and HS codes provided in Exhibits 2 and 3, respectively.

Exhibit 2: Steel NAICS Codes for Activities Included in the Benchmarking Boundary

NACIS codes	Activities
212210	Iron ore mining
331110	Iron and steel mills and ferroalloy manufacturing
331210	Iron and steel pipes and tube manufacturing from purchased steel
331221	Rolled steel shape manufacturing
331511	Iron foundries
331513	Steel foundries (except investment)
332111	Iron and steel forging

Exhibit 3: Steel HS Codes for Products Included in the Benchmarking Boundary

HS codes	Products
72.06	Iron and non-alloy steel in ingots or other primary forms
72.07	Semi-finished products of iron or non-alloy steel
72.08	Flat-rolled products of iron or non-alloy steel, which is 600-mm or more wide, hot-rolled, not clad, plated, or coated.

2.4 Ore-based and Scrap-based Inputs

Steel is produced using ore-based (mined) and scrap-based (recycled) metallic inputs. Production from ore-based inputs is inherently more energy-intensive as oxygen must be removed from iron minerals (a process known as reduction). Current ore-based processing routes largely use coal as the main energy source and reductant. This combination of high energy requirements and carbon-intensive energy sources means >90% of the sector's direct emissions are associated with steel production from ore.[4]

Today, around one-third of the steel is produced from scrap-based inputs.[5] The supply of scrap steel is dependent on the availability of steel containing products nearing their end of life. In the last quarter century, as urban centers were built in China and elsewhere, a huge amount of iron ore was converted to steel, most of which (a potential source of secondary inputs) is still in existing infrastructure. The latest available modeling, including from the IEA and Mission Possible Partnership,[6] maintains that the scrap to meet the entire annual demand for steel to 2050 is insufficient. For example, under the IEA Net-Zero Emissions (NZE) scenario, only around half of the annual steel demand can be met by scrap in 2050.[7] Due to this constrained supply, it is impossible to realize the net-zero goal within the steel sector by switching to steel produced from secondary sources. It will also be necessary to deploy new zero-emissions ore-based steelmaking technologies.

To overcome this challenge, steelmakers shall disclose the fraction of ore and scrap inputs used to produce steel (refer to Section 3.2). Given these dynamics of scrap supply, the emissions intensity of the steel produced shall be considered in conjunction with the amount of scrap used. A sliding-scale (based on scrap input) can be used to compare products using different fractions of scrap. This sliding-scale can either be static (fixed thresholds such as those proposed by ResponsibleSteel,[8] the minimum criteria of which will be updated (i.e., from Level 1 to Level 2 etc.) with data gathered or dynamic (i.e., changing yearly according to the emissions trajectories for sector decarbonization such as the IEA NZE, which is the approach used by financial institutions in the Sustainable Steel Principles and proposed for SBTi for corporate-level evaluation of steel production). The sliding-scale approach attempts to balance two key levers for the sector's decarbonization — increasing the amount of steel supplied from scrap and deploying new technology for primary steelmaking. Section 3.3 provides implementation details on the sliding-scale.

2.5 Abatement Technology

Models of the steel sector transition such as the IEA NZE and MPP STS identify several clean energy and abatement technologies, which can be used to decarbonize steelmaking:

- Carbon capture and storage – Where steelmaking processes continue to be based on carbon-containing fossil fuels, but the resulting emissions are captured and stored permanently in geological formations.
- Carbon capture and use – Same as above but where the captured emissions are used to produce an alternative carbon-containing product (e.g., methanol) or replace current applications of carbon dioxide (e.g., enhanced oil recovery).
- Renewable hydrogen – Where steelmaking processes shift to use hydrogen produced through electrolysis powered renewable electricity.
- Renewable electricity – Where steelmakers use renewable electricity (e.g., solar and wind) directly within the steelmaking process (e.g., electric arc furnace, rolling mills, etc.).
- Bioenergy – Where fossil fuels are replaced by drop-in alternatives produced from biomass (e.g., charcoal).

Steelmakers will likely deploy a range of these technologies at different sites depending on the local context (e.g., availability of renewable hydrogen, capacity factors for solar/wind, or presence of suitable locations for carbon dioxide storage). Each technology also carries some risk, for example, the use of biomass can have indirect land-use impact or carbon capture and storage may not adequately address upstream fugitive methane emissions. As a result, steel buyers may tailor purchasing strategies to achieve specific levels of supply chain exposure to different abatement technologies. To facilitate this, steelmakers shall label products accordingly to the abatement technology used (noting that more than one label may be applied) based on the thresholds/definitions in Section 3.4.

2.6 Data Sources

To ensure emissions performance-based decisions drive investments in low-emissions technologies, it is necessary to use primary data — data provided directly from the entity responsible for those emissions (i.e., Scope 1 or 2 of these entities). Producers shall report the fraction of emissions calculated using primary data. This may require companies to also request the fraction of primary data used in emissions estimates from upstream suppliers or downstream customers. The definition of primary data and methodology for companies to calculate the fraction of primary data are provided in Section 3.7.

As recommended in Section 4.4.2 of ISO 20915, the temporal coverage of the data shall be for one full year to avoid the impact of seasonal variations. The geographic coverage shall relate to a single facility where the products are produced (noting that this could extend to several dispersed sites that provide the inputs to that facility).

3 EMISSIONS CALCULATION REQUIREMENTS

3.1 Emissions Calculation Procedure

The emissions calculations shall be performed as per ISO 14044, which provides instructions for conducting a Life Cycle Assessment (LCA), which includes defining the Life Cycle Inventory (LCI) at the granular process-level. This granular process-level data specification lays the foundation for the product-level emission calculation. For each process (e.g., cokemaking, sintering, etc.) defined within the system boundary (refer to Exhibit 1), an inventory shall be developed as per Section 4.3 in ISO 14044:2006. Where possible, the inventory should be over-specified (i.e., include measures of inputs and outputs) to enable a validation check on the data via mass/energy balances (as per 4.3.3.2 of ISO 14044:2006). Where this is impossible, the mass/energy balance can be used to calculate inputs/outputs of the process (e.g., calculating process CO_2 output based on input carbon mass). The definition of inventories at the process-level allows for process sub-division to be used, eliminating the need to allocate emissions to by-products or co-products.

As noted in ISO 14044:2006 Section 4.3, all major inputs (energy, raw material, and ancillary) and outputs (products, co-products, waste, releases to air, water and soil, and other environmental aspects) shall be collected to obtain a holistic understanding of the environmental impact of the process/product system. In general, all inputs/outputs from the defined system (or process) boundary should be collected. Section 5.4 of ISO 20915 provides additional details on relevant data for steel product systems.

3.2 Share of Metallic Inputs

The metallic inputs to produce steel can be sourced from iron ore or scrap. Scrap is typically sourced as follows:

- Pre-consumer scrap – Material diverted as a waste stream during manufacturing (e.g., off-cuts from a stamping process). Pre-consumer scrap is further categorized as follows:
  - Home scrap – Generated at the same site that re-uses the scrap.
  - Fabrication scrap (external scrap) – Produced outside of the steel plant through downstream manufacturing processes.
- Post-consumer scrap – Recovered from end-of-life steel containing products (e.g., recycling of steel from cars).

To align the steel sector with appropriate decarbonization trajectories (e.g., IEA NZE or MPP STS), it is necessary to minimize the production of pre-consumer scrap and maximize the recycling of post-consumer scrap. The largest environmental benefit is derived from the use of post-consumer scrap to displace the production of steel from iron ore. However, defining the share of metallic inputs based on the use of post-consumer scrap may be challenging as post- and pre-consumer scrap may be mixed in collection and sorting.

The share of metallic inputs used at a given steel production site is required to provide purchasers with information on the fraction of recycled content used and utilized as an input to calculations and for benchmarking/comparison (refer to Section 3.3).

Scrap types (such as those referred to above) have often been defined with respect to the site boundary. However, because the level of vertical integration varies between sites (e.g., sites may or may not include rolling activities that generate scrap), this approach can lead to confusion. For example, scrap recycled from on-site hot-rolling might be excluded from the scrap fraction calculation, whereas purchased scrap from an equivalent standalone rolling mill might be included.

To avoid this confusion, any scrap from processes external to the benchmarking boundary (i.e., after casting, refer to Exhibit 1), shall be considered part of the scrap fraction. The ore-based inputs are based on the mass and iron content of purchased ore-based metallic inputs (i.e., iron ore, pellets, sinter, pig iron, and DRI/hot briquetted iron). As such, the fraction of scrap-based inputs is calculated as follows:

$$F_s = \frac{M_s}{\left(M_S + \sum_{i=1}^{N} M_p \times x_p\right)}$$

where M_s is the mass of scrap, and M_p and x_p are the mass and iron grade of each primary input used, respectively.

In the above calculation, any scrap external to the benchmarking boundary is included, meaning a portion of home scrap (e.g., from an on-site cold-rolling process) would be included for some steelmakers. This approach ensures that the recycled content is comparable irrespective of integration levels for a specific site and consistent with the scrap definition in the trajectories used for benchmarking (refer to Section 3.3).

To provide further understanding of the scrap-use, the steelmaker should also report on the fraction and pre- and post-consumer scrap used where possible. For this disclosure, post-consumer is defined as any steel recovered from products at their end of life, and all other scrap is treated as pre-consumer.

3.3 Emissions Intensity with Scrap Fraction Context

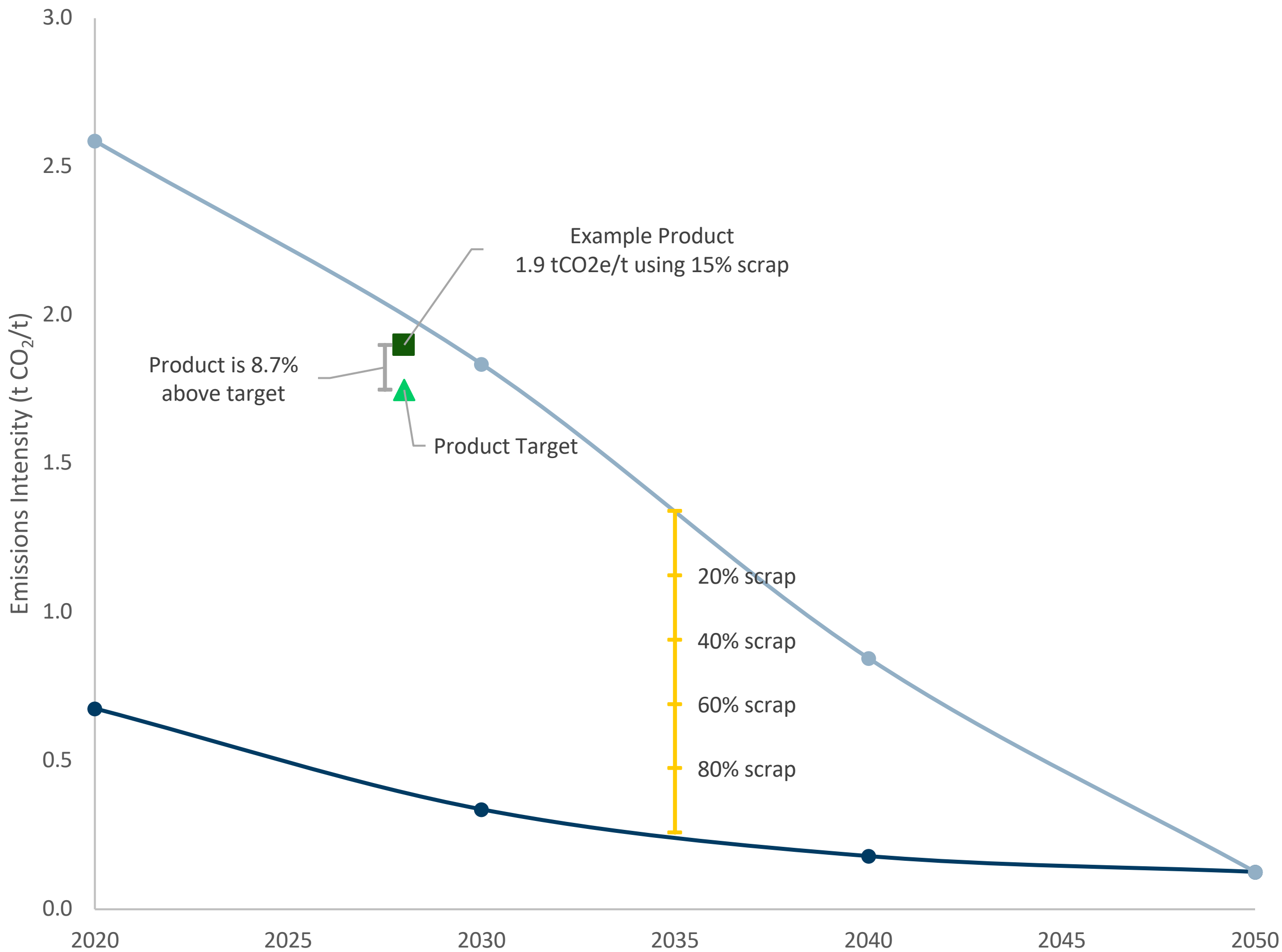
Analyzing the emissions intensity of steel products by considering the amount of scrap used to generate the product is critical because of the following:

- Production of steel from scrap is inherently less energy- and emissions-intensive than production from ore.
- Supply of scrap will be insufficient to meet steel demand to 2050, and therefore, switching to scrap cannot be the only vector for decarbonisation of the sector.

The sliding-scale approach was developed to address this issue and aims to create a framework to balance the requirements to increase the amount of scrap used and deploy new low-emissions ore-based steelmaking technology. This approach has been implemented (or proposed) at the corporate-level through the Science-Based Targets Initiative steel sector framework and the Sustainable Steel Principles (a disclosure framework for lenders to the steel sector). At the product level, it is used in the ResponsibleSteel framework and was proposed by the IEA. There are two implementations of the sliding-scale approach: dynamic and static.

The dynamic approach involves calculating the portion of a steel sector 1.5°C-aligned carbon budget (such as that under the IEA NZE scenario) associated with ore-based and scrap-based production (see Exhibit 5). To effectively balance the need to incentivize both increasing scrap-use and low-emissions ore-based technology, the budget is split assuming above-average emissions for scrap-based production (in this case, the 80th percentile estimated from country-level grid emissions and steel production data; see Appendix). Using the above-average emissions for scrap-based production makes targets/benchmarks for products utilizing higher fractions of scrap relatively easy to achieve, thereby incentivizing the increased use of scrap.

Exhibit 4: Dynamic Sliding-Scale for Measuring Product Emissions Performance based on Scrap Use



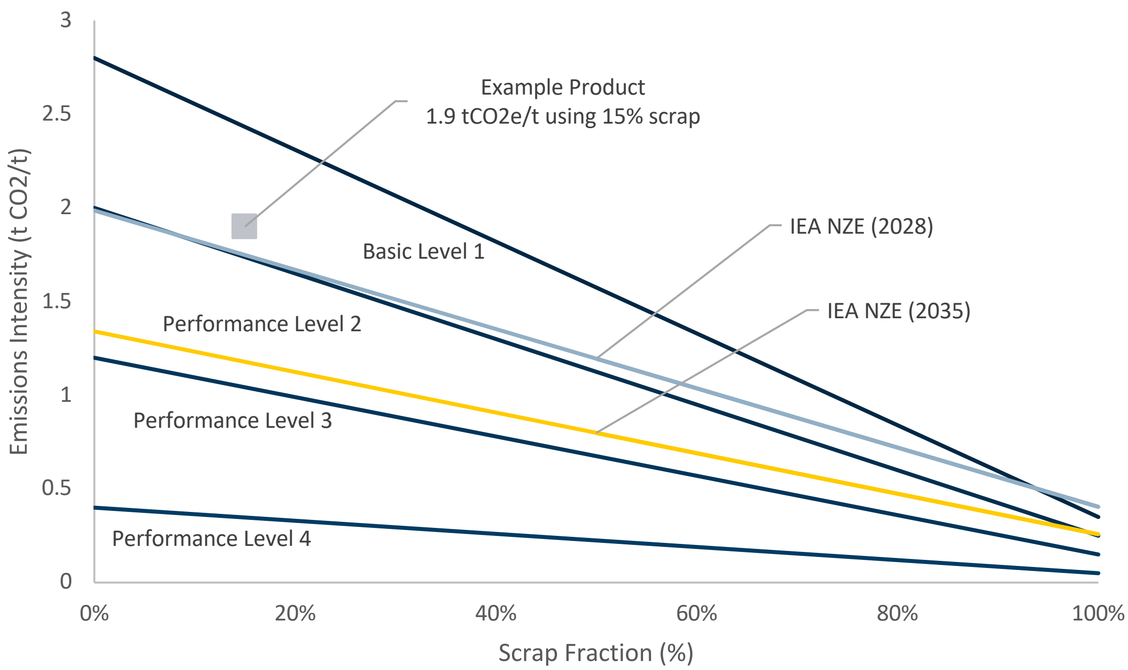
The emissions intensity of the product can then be compared to the relevant target based on these trajectories. The target is defined as the weighted (by scrap content) average of the two trajectories (where the upper trajectory is with 100% ore-based input and the lower trajectory is with 100% scrap-based input). For the example product shown in Exhibit 4, the calculation to compare it with the dynamic sliding-scale target is shown in Exhibit 5.

Exhibit 5: Example Calculation for Dynamic Sliding-Scale

PARAMETER	VALUE	SOURCE
Production year	2028	-
Product emissions intensity	1.90 t CO2e/t	Reported by steelmaker
Scrap content	15%	Reported by steelmaker
Ore-based intensity target	1.99 t CO2e/t	IEA NZE
Scrap-based intensity target	0.40 t CO2e/t	IEA NZE
Product-specific target	1.75 = (15% * 0.40 + 85% * 1.99)	Calculated
Comparison to target	8.7% above = (1.90 – 1.75)/1.75	Calculated

The static sliding scale uses the same concept but instead applies a series of categories (instead of a percentage difference) to measure the gap between the product's emissions intensity and the target defined by the trajectories. This is shown in Exhibit 6, which has the static sliding-scale categories proposed by ResponsibleSteel overlayed with the IEA NZE target in 2028, and the same product example as shown in Exhibits 4 and 5. Using the static sliding-scale, the example product would be in the Basic Level 1 category. Therefore, the above target — given that according to the IEA NZE steel products on average by 2028 — will need to be in the Performance Level 2 category.

Exhibit 6: Static Sliding Scale for Measuring Product Emissions Performance based on Scrap Use



Exhibits 4 and 6 show the link between the dynamic and static sliding-scale approaches. The IEA NZE targets shown in Exhibit 6 are defined by taking the relevant year's ore-based target (for the 0% scrap point) and scrap-based target (for the 100% scrap point) and linking these with a straight line. Each method has advantages/disadvantages that may lead to preferences for different organizations (e.g., dynamic sliding-scale approach more clearly links to the 1.5°C trajectory, whereas the static sliding-scale provides more stability in that the targets do not need to be updated every year). Given that both methods implement the same concept (i.e., balancing incentives between increased scrap-use and new low-emissions ore-based technologies), either is a valid approach to evaluating a product's emissions intensity.

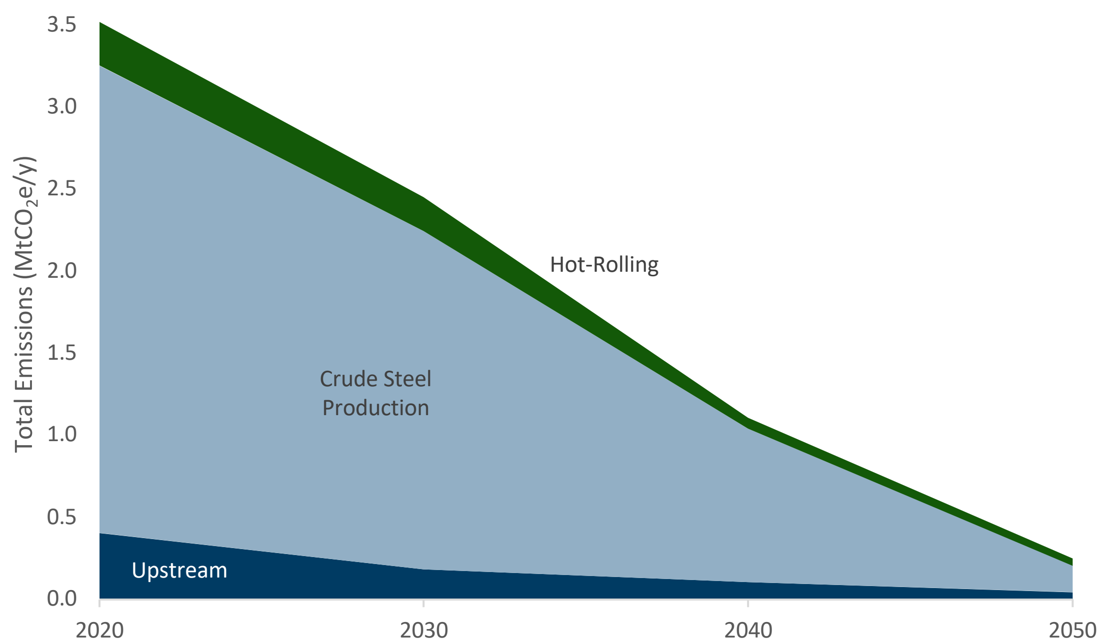
If steelmakers disclose the emissions footprint and scrap-content, either (static or dynamic) method can be applied. The emissions thresholds used for comparison need to align with the benchmark boundary against which emissions are reported (i.e., either crude steel or hot-rolled product). For the IEA NZE, this requires estimation of emissions excluded in reported steel sector emissions, specifically the following:

- Upstream emissions associated with raw material and fuel extraction, processing, and transport (inclusive of fugitive methane emissions).
- Emissions associated with electricity-use by the steel sector (reported by the IEA as part of power sector emissions).

- Determination of emissions after crude-steel production as these are not delineated.

The resulting steel sector emissions trajectories (aligned to reporting boundaries) are shown in Exhibit 7 (calculation details and assumptions are provided in the Appendix). This overall emission threshold to each boundary is then split into primary and secondary thresholds using the 80th percentile approach — the resulting thresholds are provided in the Appendix.

Exhibit 7: IEA NZE Emissions Trajectory for Steel to Alternative Boundaries



Note that comparison against the sliding-scale benchmark should not be the only metric considered in comparing steel products. This approach can show emissions changes independently (to some degree) of the scrap used, but purchasers should still consider the technology used to reduce emissions (refer to Section 3.4) as well as the overall emissions footprint (as this will likely feed into subsequent product-level reporting or corporate inventories) and proportion of post-consumer scrap used.

3.4 Abatement Technology Definition and Criteria

Reporting on abatement technology applied to a specific product shall be as per the definitions in Exhibit 8. These thresholds are intended to ensure that the label is applied only where the technology is implemented at a commercial scale (as opposed to a pilot/demonstration), and the actual emissions performance following abatement is still captured in the report emissions footprint.

Exhibit 8: Abatement Technology and Criteria

Abatement Technology	Definition
Carbon capture and storage	Applies where a carbon capture system designed for capturing >50% of the emissions (on a point source basis) is deployed either at the site where ironmaking or steelmaking occurs or at the site where fuel is produced and subsequently used in ironmaking (e.g., production of hydrogen via steam methane reforming). The resulting carbon dioxide stream must be permanently stored in a geological reservoir not associated with active oil production.
Carbon capture and use	Applies where a carbon capture system designed for capturing >50% of the emissions (on a point source basis) is deployed either at the site where ironmaking or steelmaking occurs or at the site where fuel is produced and subsequently used in ironmaking (e.g., production of hydrogen via steam methane reforming). The resulting carbon dioxide stream is used to either manufacture a carbon containing product (e.g., methanol, concrete cured with CO_2) or replace an existing use of carbon dioxide (e.g., enhanced oil recovery).
Renewable hydrogen	Applies where renewable hydrogen supplies >20% of the energy needed for iron ore reduction or where >50% of energy needed for heat in a duty separate to iron reduction (e.g., pelletization, hot-rolling, etc.). Renewable hydrogen is defined as hydrogen produced through the electrolysis of water with electricity either supplied directly from renewable energy or via the grid coupled with a project-specific market-mechanism to procure renewable energy (e.g., power purchase agreement, utility green tariff, etc.).
Renewable electricity	Applies where renewable electricity supplies >50% of the electricity demand at the site of ironmaking or steelmaking. Renewable electricity is either supplied directly from renewable energy or supplied via the grid coupled with a project-specific market-mechanism to procure renewable energy (e.g., power purchase agreement, utility green tariff, etc.).
Bioenergy	Applies where bioenergy supplies >20% of the energy needed for iron ore reduction or biomass supplies >50% of the energy needed for heat in a duty separate to iron reduction and in the steelmaking process at the site (e.g., hot-rolling, melting scrap, etc.). Biomass is supplied from bioenergy coupled with sustainable biomass verification[19] (e.g., biomass feedstock's impact on sustainable land use).

3.5 Exported Products

Emissions associated with products generated by processes within the fixed boundary but are not used in the final steel product shall be excluded from the steel product carbon footprint. As per the ISO 14404 hierarchy (Section 4.3.4.2), the preferred methods to calculate the emissions associated with the exported products are as follows:

- Process subdivision (i.e., dividing processes into two or more sub-processes with associated inventories to enable calculation of the product-carbon footprint of an intermediate product).

- System expansion (i.e., expanding the system to include the additional functions related to the exported products).[ii]

Process subdivision is most easily applied to intermediate products (e.g., coke, pellets, etc.) as the processes used to produce these are clearly defined. For by-products of steelmaking processes (e.g., blast furnace slag, coke ovens, gas), this subdivision is impossible, leading to the use of system expansion.

In either case, there is some risk of emissions double-counting/leakage if the purchaser of the exported product does not utilize the equivalent emissions footprint as assigned to the exported product in calculating the steel product footprint. This mismatch is most pertinent for by-products that are often assumed as waste with zero-burden by the purchaser (e.g., a cement producer buying blast furnace slag) but assigned a footprint by the steel producer (e.g., emissions prevented by not producing traditional cement), leading to leakage. To avoid this, steelmakers shall ensure that the emissions footprint for the exported product assigned in the steel product carbon footprint (PCF) is communicated (i.e., included as a written disclosure together with the purchasing) to the buyer of the exported product. To minimize the burden of this requirement, the communication is only required where the exported production emissions footprint reaches the system-wide cut-off criteria defined in ISO 20915[9] (i.e., 5% of the environmental relevance).

In addition to disclosing the exported product footprint (where relevant), steelmakers shall ensure that the assumed displaced product used in the system expansion calculation is as accurate as possible. Ideally, this should be based on a consequential (inclusive of market-mediated effects) lifecycle assessment study of the exported product, which would determine the products displaced by its production. Where this is impossible, the steelmaker should consult with the purchaser to determine the emissions footprint of displaced products or use average emissions factors.

3.5.1 Intermediate Products for Use in the Steel Supply Chain

Emissions incurred to produce exported intermediate products that can be used within the steel supply chain shall not be included in the overall emissions footprint, as outlined in Section 3.1. This is designed to ensure the reported emissions are focused only on those applied for the targeted steel product.

As outlined in the ISO 14044 hierarchy, the preferred method for this calculation is process subdivision (to avoid the need for allocation). This involves defining an inventory against only the process(es) used to produce the intermediate product and then including only that fraction of the emissions from that sub-inventory that went into making the steel product(s), which are the focus of the reporting. For example, if a site producing a specific steel product operates a pellet plant that also exports a fraction of these pellets, the emissions associated with those exported pellets shall be excluded from the steel product footprint (and would instead be included as part of the steel product that consumes the exported pellets).

In line with the process subdivision approach, steelmakers shall determine the emissions intensity from the manufacture of intermediate products. This involves determining the emissions associated with all processes within the boundary, which are required to produce the intermediate product (e.g., iron ore mining and pelletization for pellets). The emissions intensity is then determined by the sum of emissions from the selected processes divided by the total volume of the intermediate product. An example of this calculation is provided in Exhibit 9.

[ii] In practice, system expansion is almost always applied through the substitution method. Refer to https://www.frontiersin.org/articles/10.3389/frsus.2021.692055/full for further background.

Exhibit 9: Example Calculation for Intermediate Product Credits

PARAMETER	VALUE
Total pellet production (Mt)	4.0
Total emissions to produce pellets (Mt CO_2)	0.5
Pellet emissions intensity (t CO_2/t pellets)	0.125 = (0.5 / 4.0)
Pellets exported (Mt)	1.0
Total site emissions (Mt CO_2)	5.625
Exported pellets emissions subtraction (Mt CO_2)	0.125 = (0.125 * 1.0)
Total site emissions (Mt CO_2) after subtraction	5.5

3.5.2 By-products Used in Other Supply Chains

Steel plants can produce several by-products such as ground granulated blast furnace slag (GGBFS) and coal tar, which can be used in the supply chains for other products. For example, GGBFS can be used as a clinker substitute in cement to lower the embodied emissions of that product.

These by-products are often treated as having zero-emissions burden by the consuming sector (e.g., GGBFS is assumed to have zero embodied emissions by concrete manufacturers). As a result, the consuming sector is incentivized to use this by-product as an input to lower emissions.

Both ISO 14404 and 20915 recommend the use of system expansion for these by-products (assuming that process sub-division is impossible). Alternative approaches (such as allocation based on physical processes) can be used provided these are documented and justified according to the requirements of ISO 14044:2006. The system expansion approach relies on identifying the emissions intensity of functional products similar to the co-product (e.g., clinker for GGBFS) and applying a credit to the steel production emissions footprint based on the difference between the identified similar product emissions intensity (e.g., clinker) and the emissions intensity of the co-product (e.g., GGBFS).

This approach avoids the use of allocation in the steel emissions footprint calculation but results in emissions reductions outside the fixed boundary (e.g., within the cement production process) being included in the footprint. The benchmarks (e.g., IEA NZE targets or ResponsibleSteel thresholds) used for comparison against PCF up to the benchmarking boundary do not include the emissions impact from outside the boundary. For this reason, any system expansion-based calculations shall not be included in calculation of the PCF to the benchmarking boundary. The system expansion calculations shall be included in the overall PCF (subject to the disclosure requirement outlined in Section 3.5).

Emissions associated with processes to upgrade by-products (i.e., processes not included in the fixed system boundary shown in Exhibit 1) do not need to be included in the steel emissions calculation. For example, emissions associated with blast furnace slag granulation and grinding do not need to be included in the steel product emissions footprint. Steel producers are encouraged to provide data on emissions from these processes in the exported product footprint to by-product purchasers.

3.5.2 Energy Exports

Some steelmaking operations, particularly cokemaking and blast furnace operations, produce off-gases containing hydrogen, carbon monoxide, and carbon dioxide, which can be combusted to produce heat or electricity. In most integrated facilities, these off-gases are used to provide energy inputs to other parts of the process (e.g., pre-heating coal fed into coke ovens).

Many steel production facilities also use these off-gases to produce electricity via a facility on-site owned by the steelmaker or by exporting these to a nearby third-party power producer and purchasing electricity back from the third party. In some cases, the steel production site may be a net exporter of electricity (using either of the above ownership mechanisms). Where this is the case, a steel producer can also apply the system expansion methodology to those electricity exports similar to the above approach for by-production:

$$E = V_e \times \left(EF_{off-gas} - EF_{displaced}\right)$$

where E is the emissions from net-export of electricity, V_e is the volume of exported electricity (MWh), $EF_{off\text{-}gas}$ is the emissions factor to produce electricity from the off-gases (tCO_2e/MWh), and $EF_{displaced}$ is the emissions factor of electricity displaced by the steelmaker's export.

The emissions intensity of electricity generated from steel plant off-gases is dependent on the mix of gases. For example, coke oven gas is less carbon-intensive (44 kg CO_2/GJ) compared with blast furnace gas (260 kg CO_2/GJ). For a typical mix (e.g., 60% blast furnace and 40% coke oven gas) and conversion efficiency (37%), the resulting electricity generation emissions intensity is ~1.7 t CO_2/MWh. This is ~3x higher than the global grid (0.438 tCO_2/MWh) emissions intensity and higher than production from a coal-fired power plant (~1 tCO_2/MWh).[10] As a result, the system expansion calculation for exported electricity will likely be negative (i.e., increase the steel PCF) because the displaced electricity would have had a lower emissions intensity. As a result, the strategy to minimize off-gas generation and maximize the use of off-gases on-site for heat (resulting in net electricity import) will minimize the steel PCF.

As outlined in Section 3.5, a consequential LCA is ideal for determining the displaced electricity sources, however given this is often not available, steelmakers shall instead use:

1. Country/regional grid average – The average grid emissions (e.g., using IEA data) for the country or region can be used.
2. Global grid average – Where the above data sources are unavailable, the global grid average emissions from the IEA may be used.

Steelmakers shall not use renewable energy certificates or guarantees of origin to cover any portion of electricity (used on-site or exported) that is generated from off-gases. These mechanisms shall only be used against the electricity that is physically imported from the grid. As with other exported products, any system expansion calculation related to electricity shall not be included in the PCF reported to the benchmarking boundary because the equivalent calculation is not included in the benchmarks (e.g., IEA NZE).

3.6 Data Sources

3.6.1 Direct Emissions Factors

Direct emissions sources refer to fuel (solid, liquid, or gas) used on-site in the production of steel. Where possible, steelmakers shall determine a site-specific emissions factor based on measurement of the combustion products. If this is impossible, the standard emissions factors for various fuel types provided in Exhibits 10 and 11 can be used or emissions can be determined based on the measured carbon content of the fuel (assuming complete conversion to CO_2).

Exhibit 10: Emissions Factors for Solid Fuel Sources

GHG EMISSIONS SOURCE	UNIT	EMISSIONS FACTOR (tCO_2e/UNIT)	SOURCE
Coking coal	t	2.69	IPCC, 2019[20]
Ironmaking coal[iii]	t	2.98	IPCC, 2019
Sinter/BOF coal	t	2.64	IPCC, 2006
Steam coal	t	2.48	IPCC, 2019
Charcoal	t	3.48	IPCC, 2006
Petroleum coke	t	3.26	IPCC, 2019
EAF coal	t	3.28	IPCC, 2019

Exhibit 11: Emissions Factors for Liquid and Gas Fuel Sources

GHG EMISSIONS SOURCE	UNIT	EMISSIONS FACTOR ($kgCO_2e$/UNIT)	SOURCE
Diesel	L	2.69	IPCC, 2006[11]
LPG	L	1.62	IPCC,2006
Natural gas	GJ	56.27	IPCC, 2006

These emissions factors refer to the emissions associated with the conversion of the carbon content of each fuel to carbon dioxide and non-CO_2 GHG emissions. When data was not available from the IPCC, the non-CO_2 GHG emissions for each source were estimated using values from the EPA emission factors hub.[12] The production process for each fuel also involves emissions, most notably, fugitive methane emissions, particularly in coal and natural gas production. Given that fuel production processes are covered in the fixed boundary, these emissions shall also be reported. If possible, the fuel provider should determine the methane emissions and provide this information to the steelmaker. There are several methodologies for determining fugitive methane emissions, and the fuel producer should use an existing standard (such as the MiQ standard for natural gas or the EPA methodology for coal) to determine methane emissions.[13] If this is impossible, the steel producer may use the standard emissions factor provided in Section 3.6.4 to determine fugitive methane emissions (note that the use of these factors reduces the primary data fraction, as per Section 3.7).

Several other direct inputs with carbon content are used in the steelmaking process. As with fuel, if possible, the carbon content of these inputs shall be measured to determine a site-specific emissions factor. If this is impossible, the emissions

[iii] Refers to coal used directly in a blast furnace, direct reduction kiln, and smelting reduction process.

factors in Exhibit 12 can be used. When data was not available from the IPCC, the non-CO_2 GHG emissions for each source were estimated using standard conversion factors from the EPA emission factors hub.[14]

Exhibit 12: Emissions Factors for Other Inputs

GHG EMISSIONS SOURCE	UNIT	EMISSIONS FACTOR (tCO_2e/UNIT)	SOURCE
Limestone	t	0.44	IPCC, 2019
Dolomite	t	0.48	IPCC, 2019
EAF electrodes	t	3.7	IPCC, 2019

3.6.2 Electricity Emissions Factor

The GHG protocol provides two methods (location- and market-based) for determining an electricity emissions factor. The location-based emissions factor is obtained using the average emissions for the grid where the consumer is located, whereas the market-based factor accounts for contractual mechanisms (such as renewable energy certificates) that a consumer may use to reduce electricity-based emissions. The GHG protocol corporate standard encourages companies to report electricity-based emissions using both the methods, as each provides different information.

For reporting using this guidance, the location- and market-based methods are acceptable. The combined use of these methods has the potential to lead to double-counting, which underreports overall emissions (e.g., a facility connected to a low-emissions grid uses the location-based method, while another facility connected to a high-emissions grid uses the market-based method to claim the same low-emissions generation sources as an input). To overcome this issue, a residual emissions factor (i.e., the average of all generation sources connected to the grid, except for those that separately sold the emissions attribute through a market mechanism) shall be used. If an electric utility (or other source) provides these residual emissions factors, steelmakers shall utilize these in-lieu of the location factor. Utilities are encouraged to ensure wide availability of the residual emissions factor data.

With regard to electricity emissions, the unique aspect for steel producers relates to the ability to produce electricity using off-gases from the steelmaking processes (e.g., coke oven gas, blast furnace gas, etc.). Generally, the steelmaker will use these off-gases to produce electricity via one of the following:

- On-site electricity generation owned and operated by the steel producer.
- Selling the off-gas to an independent power producer (IPP) located adjacent to the steel plant and then purchasing the electricity back from the IPP.

For steel producers that export off-gases to an IPP, a calculation is required to determine if the steel plant is a net-producer or consumer of electricity (for on-site producers, this is likely not required as electricity exports or imports to/from the grid would be metered).

Steel producers should measure the volume of off-gases exported and combine this with measured energy content and conversion efficiency (reported by the IPP). If this is impossible, the values in Exhibit 13 can be used. The total amount of electricity generated from the exported off-gases should be the sum of the energy content for each off-gas multiplied by the volume of each off-gas exported multiplied by the conversion efficiency.

Exhibit 13: Default Values for Electricity Calculations

PARAMETER	UNIT	VALUE	SOURCE
Coke oven gas energy content	MJ/Nm³	22.3	US EPA, 2022[15]
Blast furnace gas energy content	MJ/Nm³	3.43	US EPA, 2022
Conversion efficiency	%	37	IEA, 2020[16]

If the total amount of electricity produced from off-gas exports exceeds the total electricity consumed, the steel producer shall report the emissions from all the fuel consumed on-site (as this will be inclusive of the emissions in subsequent combustion of the off-gases). Conversely, if the total amount of electricity produced from off-gases is less than the total electricity consumed, the location-based factor shall be applied to the net import of electricity (emissions from the off-gas combustion are again captured based on the fuel used on-site).

Note that a steelmaker shall not use a market-based emissions factor to reduce the emissions from off-gases-based electricity generation.

3.6.3 Secondary Data Emissions Factors

Secondary data emissions factors refer to those that are based on the average emissions intensity for a given production process as opposed to the carbon content of a fuel that is combusted.[17] These factors can be used to estimate the emissions for processes that the steelmaker does not operate but are required as part of the fixed boundary.

If possible, steelmakers shall request actual emissions from the supplier or customer operating these processes (note that this may not be a direct supplier to the steelmaker in multi-tiered supply chains) instead of using these emissions factors. If the emissions factors listed in this section are used, the primary data fraction will be reduced (see Section 3.7).

Processes that may not be directly operated by the steelmaker include those required to prepare the feed materials for ironmaking and steelmaking processes such as coking and sintering and some emissions-intensive downstream processes such as hot-rolling. The emissions from these processes occur due to fuel use (primarily for heat), electricity consumption, and some direct process emissions (e.g., production of lime from limestone). If the steelmaker does not operate these processes, emissions data shall be obtained from suppliers/customers. If this is impossible, the default emissions factors in Exhibit 14 can be used.

Exhibit 14: Indirect Processing Emissions

PROCESS	UNIT	EMISSIONS FACTOR (tCO_2e/UNIT)	SOURCE
Iron ore mining	t iron ore	0.013	Ferreira and Leite, 2015[18]
Coal mining	t coal	0.04	Mutchek et al., 2016[19]
Coke production	t coke	0.3	IPCC, 2019[20]
Sintering	t sinter	0.21	IPCC, 2019
Pelletization	t pellet	0.19*	IPCC, 2019
Pig iron production	t hot metal	1.43*	IPCC, 2019
DRI (natural gas) production	t DRI	0.7	IPCC, 2019
Burnt lime production	t lime	0.75*	IPCC, 2006
Burnt dolomite production	t dolomite	0.86*	IPCC, 2006
Oxygen production	t oxygen	0.09	Chisalita et al., 2019[21]
Casting and rolling	t HRC	0.084	Backes et al., 2021[22]
Natural gas production	t methane	0.6	NETL, 2019[23]

** The non-CO_2 GHG emissions for these processes are not provided in the source document; however, these are assumed to be minimal.*

Note that for iron ore mining that involves the extraction of relatively low-grade ore and requires more preliminary ore processing (i.e., grinding and concentration), the emissions from the iron ore mining process could be as high as 0.09 tCO_2/t of iron ore.

The emissions factor from coal mining could also vary based on the mining process used. Typically, most of the energy consumed in coal mining is electrical, implying that the emissions intensity can vary significantly depending on the energy mix of the grid. Methane emissions from the coal mine are not included in the emissions factor for the coal mining process. Methane emissions from natural gas processing and transmission are also not included in the emissions factor for the natural gas production process. These fugitive methane emissions are discussed in Section 3.6.4.

To convert natural gas from mass units to energy units, it can be assumed that a metric ton of natural gas is equivalent to 55.58 GJ of energy and 1470.3 cubic meters. As with all secondary data sources, due to this high level of variability in process emissions factors, steel producers are encouraged to request emissions information directly from suppliers.

3.6.4 Fugitive Methane

Fugitive methane refers to the methane gas released into the atmosphere during coal mining and along the natural gas supply chain. Fugitive methane emissions from coal mining come from methane that is trapped in the coal seams and escapes during the mining process. The amount of methane released during the coal mining process depends on various factors such as type of coal being mined, mine depth, and method of mining. Typical values of the emissions factors for fugitive methane emissions from coal mines are given in the table below. These values are estimates, and the actual values can vary by as much as ±15%.[24]

Fugitive methane emissions can also come from different stages in the natural gas supply chain such as production, processing, transmission, and distribution. About 1.3%–2.2% of the natural gas supplied to end consumers escapes into the atmosphere as fugitive methane. The emissions factor associated with fugitive methane emissions from the natural gas supply chain is given in the table below (assuming average fugitive emissions are 1.7% of the total natural gas supplied to the end-user).[25]

In Exhibit 15, the GHG emissions factors are given for a 20-year and a 100-year timeframe. According to the Fifth Assessment Report of the IPCC, methane has a Global Warming Potential (GWP) of 28 times that of carbon dioxide over 100 years and a GWP of 84 times that of carbon dioxide over 20 years.[26] Due to the variation in GWP values, GHG emissions associated with fugitive methane are calculated for both the time periods. Fugitive methane emissions (expressed in standard cubic feet) are also provided for reference.

Exhibit 15: Fugitive Methane Emissions Factors

PROCESS	UNIT	FUGITIVE METHANE (CU.FT/UNIT)	EMISSIONS FACTOR (tCO_2e/UNIT)		SOURCE
			20-year GWP	100-year GWP	
Coal – Surface mining	t coal	212	0.34	0.11	Kholod et al., 2020[27]
Coal – Underground mining	t coal	667	1.08	0.36	Kholod et al., 2020
Natural gas	t methane	881	1.43	0.48	Littlefield et al., 2017[28]

As mentioned previously, there is considerable variability in the amount of fugitive methane emissions, especially along the natural gas supply chain. The actual fugitive methane emissions can be rather high compared with the values in the table because of various factors. There is a wide range of sensors and other methane monitoring equipment that could be deployed to measure fugitive methane emissions at the facility and source levels and in various time periods. Steel producers are encouraged to seek fugitive methane data collected using these methane monitoring technologies by their suppliers. If this is impossible, the default emissions factors in Exhibit 13 can be used. For consistency with other reporting standards, the 100-year GWP emissions factors shall be used.

3.7 Share of Primary Data

As noted above, the use of indirect emissions factors can result in inaccuracies in the overall emissions intensity due to the variability in emissions observed in these processes depending on the process type and fuel (and/or energy) sources used.

As a result, it is required that, along with the emissions intensity developed using this framework, the share of primary data used to calculate the intensity shall also be reported. This is defined as the fraction of the emissions intensity that does not rely on the indirect emissions factors provided in Section 3.6. Specifically, it is calculated as follows:

$$Primary\ Data\ Share\ (\%) = \frac{Emissions\ based\ on\ primary\ data\ (CO_2e)}{Total\ emissions\ (CO_2e)}$$

Note that this is consistent with the primary data share calculation required under the WBCSD's Pathfinder framework.[29] This framework also includes other data quality indicators that steelmakers can use to communicate the data sources used for the PCF (refer to Section 4.2.3 of the Pathfinder framework).

Activity data (i.e., amount of fuel, energy, and materials used to produce steel) shall always be based on primary data (i.e., measured consumption at the steel production asset). As a result, the definition of primary data is determined by the emissions factor used. The relevant definitions are provided in Exhibit 16. Note that supplier data refers to the primary data from suppliers operating the relevant processes within the fixed system boundary.

Exhibit 16: Primary Data Definitions

ACTIVITY TYPE		PRIMARY DATA DEFINITION	SECONDARY DATA DEFINITION
Fuels	Combustion/Use	Standard emissions factors (WSA, IPCC, EPA) or measured carbon content	-
	Production	Supplier data	Emissions factors in Section 3.6.3 or databases listed in Pathfinder
Other material inputs		Supplier data	Emissions factors in Section 3.6.1 or databases listed in Pathfinder
Imported heat		Supplier data	Emissions factor based on assumed fuel source for heat
Electricity		Supplier (utility) data, regional location-based grid emissions factor or market-based (complying with GHG Scope 2 addendum quality criteria) grid emissions factor[iv]	Country or global grid emissions factor

[iv] Note that if the connected grid covers an entire country, the country grid factor may be considered primary data.

4 APPENDIX

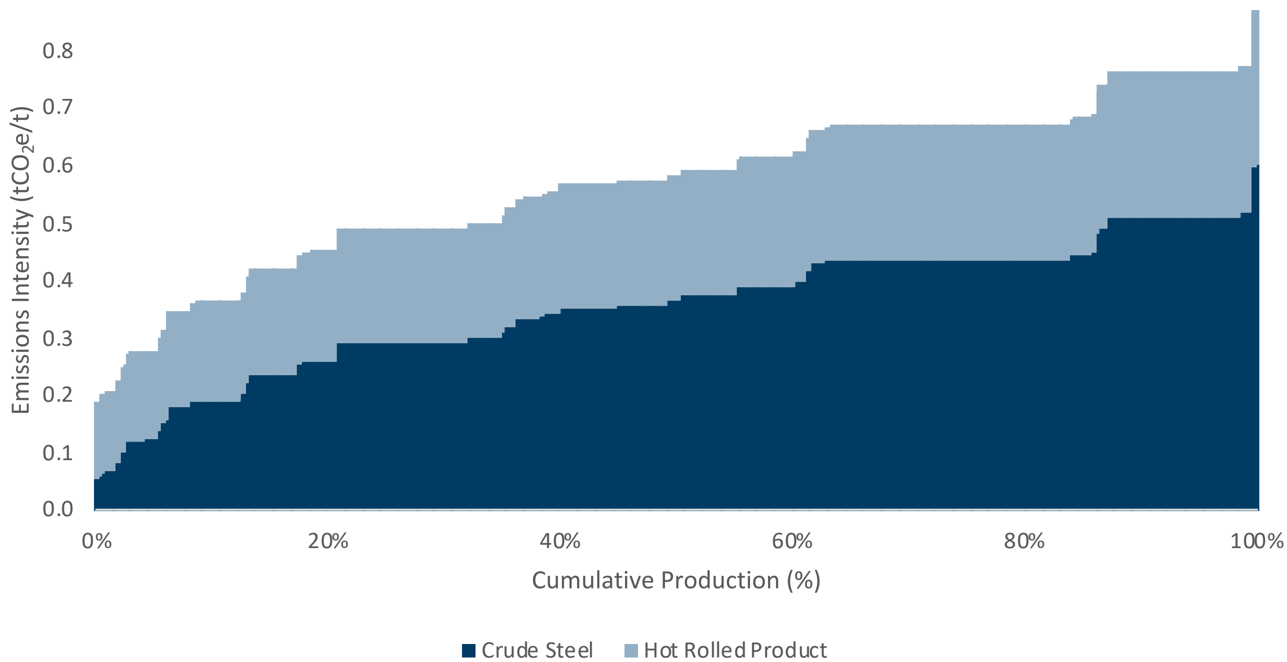
IEA NZE trajectory, including upstream emissions, split using 80th percentile secondary starting point.

YEAR	CRUDE STEEL (tCO_2e/t)		HOT-ROLLED PRODUCT (tCO_2e/t)	
	Primary	Secondary	Primary	Secondary
2020	2.37	0.44	2.59	0.68
2021	2.30	0.42	2.51	0.64
2022	2.23	0.39	2.44	0.61
2023	2.16	0.37	2.36	0.57
2024	2.08	0.35	2.29	0.54
2025	2.01	0.32	2.21	0.51
2026	1.94	0.30	2.14	0.47
2027	1.87	0.28	2.06	0.44
2028	1.80	0.26	1.99	0.40
2029	1.73	0.23	1.91	0.37
2030	1.66	0.21	1.84	0.34
2031	1.57	0.20	1.74	0.32
2032	1.49	0.19	1.64	0.31
2033	1.40	0.18	1.54	0.29
2034	1.31	0.17	1.44	0.27
2035	1.22	0.16	1.34	0.26
2036	1.14	0.15	1.24	0.24
2037	1.05	0.13	1.14	0.23
2038	0.96	0.12	1.04	0.21
2039	0.87	0.11	0.94	0.19
2040	0.79	0.10	0.85	0.18
2041	0.72	0.10	0.77	0.17
2042	0.65	0.10	0.70	0.17
2043	0.58	0.10	0.63	0.16
2044	0.51	0.10	0.56	0.16
2045	0.44	0.10	0.49	0.15
2046	0.38	0.10	0.41	0.15
2047	0.31	0.10	0.34	0.14
2048	0.24	0.10	0.27	0.14
2049	0.17	0.10	0.20	0.13
2050	0.10	0.10	0.13	0.13

IEA NZE steel trajectory, excluding upstream emissions, split into primary and secondary using an 80th percentile starting point for secondary steel emissions. Note that excluding upstream emissions is not recommended (refer to Section 2.2).

YEAR	CRUDE STEEL (tCO_2e/t)		HOT-ROLLED PRODUCT (tCO_2e/t)	
	Primary	Secondary	Primary	Secondary
2020	2.14	0.44	2.28	0.62
2021	2.09	0.41	2.22	0.59
2022	2.04	0.39	2.17	0.55
2023	1.98	0.36	2.11	0.52
2024	1.93	0.34	2.05	0.49
2025	1.87	0.32	2.00	0.45
2026	1.82	0.29	1.94	0.42
2027	1.76	0.27	1.88	0.39
2028	1.71	0.24	1.83	0.35
2029	1.65	0.22	1.77	0.32
2030	1.60	0.19	1.72	0.28
2031	1.51	0.18	1.62	0.27
2032	1.43	0.17	1.53	0.25
2033	1.35	0.16	1.44	0.24
2034	1.26	0.15	1.35	0.22
2035	1.18	0.14	1.25	0.20
2036	1.10	0.13	1.16	0.19
2037	1.01	0.11	1.07	0.17
2038	0.93	0.10	0.98	0.16
2039	0.85	0.09	0.88	0.14
2040	0.77	0.08	0.79	0.13
2041	0.70	0.08	0.72	0.12
2042	0.63	0.08	0.65	0.12
2043	0.56	0.08	0.58	0.12
2044	0.49	0.08	0.52	0.12
2045	0.42	0.08	0.45	0.11
2046	0.35	0.08	0.38	0.11
2047	0.29	0.08	0.31	0.11
2048	0.22	0.08	0.24	0.11
2049	0.15	0.08	0.17	0.11
2050	0.08	0.08	0.10	0.10

Distribution of emissions intensity for scrap-based EAF production taken to calculate the 80th percentile threshold is used to split the steel sector budget into primary and secondary production. Distribution is calculated using country-level electricity emissions factors (from national reports such as EU commission and US EPA or from Ember data on power production mix) and country-level EAF production data (from worldsteel).



Notes on methodology to construction emissions budgets:

- Calculation of total electricity use by the sector over the forecast period of the IEA NZE (i.e., to 2050) is based on assumed constant electricity for each technology archetype (i.e., BF-BOF, DRI-EAF, scrap-based EAF, H2 DRI-EAF, Direct Electrolysis, BF-BOF with CCS, and DRI-EAF with CCS) and the fraction of steel produced by each technology as reported by the IEA.
- Global average grid emissions for the forecast period in the IEA NZE are used to covert total electricity use into emissions. The only exception is the ~36% (estimated based on indirect emissions intensity by technology type reported in the IEA Iron and Steel Technology Roadmap) of electricity assumed to be self-generation from BF-BOF off-gases. Emissions intensity for off-gas generated electricity is based on an 80/20 mix of blast furnace and coke ovens gas and a 37% conversion efficiency.
- Upstream emissions for iron ore, coal, and natural gas production are estimated based on IEA data (supplemented with some LCA data to determine breakdown for direct and electricity-based emissions). All electricity emissions in upstream production are assumed to reduce in-line with IEA NZE reported grid emissions. Fugitive methane is assumed to reduce as is reported by IEA NZE (~75% by 2030). Overall natural gas use in the steel sector is assumed to be replaced with some biomethane in-line with the industrial replacement rate reported in the IEA NZE.

Notes on methodology to split emissions budgets into primary and secondary intensities:

- Total primary and secondary steel production is based on total steel production and scrap fraction reported in the IEA NZE.
- Initial starting point for secondary steel emissions intensity is based on the 80th percentile of the distribution (see above). The electricity portion of the emissions intensity is reduced in-line with the grid reduction reported by the IEA NZE (i.e., 68% and 100% reduction by 2030 and 2040, respectively).
- Remaining budget is assigned to primary production and the resulting emissions intensity is calculated.

5 ENDNOTES

[1] "Life Cycle Inventory Methodology Report", World Steel Association (WSA), 2017. https://worldsteel.org/wp-content/uploads/Life-cycle-inventory-methodology-report.pdf.

[2] *Pathfinder Framework: Guidance for the Accounting and Exchange of Product Life Cycle Emissions, Version 2.0,* WBCSD, 2023. https://www.wbcsd.org/PFV2.0

[3] Jonathan M. Cullen, Julian M. Allwood, and Margarita D. Bambach, "Mapping the Global Flow of Steel: From Steelmaking to End-Use Goods," *Environmental Science and Technology* 46 (24) (December 2012): 13048–55. doi:10.1021/es302433p.

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