COMET Coalition On Materials Emissions Transparency

Conflicts Between GHG Accounting Methodologies in the Steel Industry

DECEMBER 2022
John Biberman, Perrine Toledano, Baihui Lei,
Max Lulavy, and Rohini Ram Mohan

Columbia Center on Sustainable Investment
A JOINT CENTER OF COLUMBIA LAW SCHOOL AND COLUMBIA CLIMATE SCHOOL

About

The Coalition on Materials Emissions Transparency (COMET) is an initiative between the Columbia Center on Sustainable Investment (CCSI), the Payne Institute for Public Policy at the Colorado School of Mines, RMI, and the United Nations Framework Convention on Climate Change (UNFCCC).

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.

The Columbia Center on Sustainable Investment (CCSI), a joint center of Columbia Law School and the Earth Institute at Columbia University, is a leading applied research center and forum dedicated to the study, practice, and discussion of sustainable international investment. Our mission is to develop and disseminate practical approaches and solutions, as well as to analyze topical policy-oriented issues, in order to maximize the impact of international investment for sustainable development. The Center undertakes its mission through interdisciplinary research, advisory projects, multistakeholder dialogue, educational programs, and the development of resources and tools.

For more information, visit us at http://ccsi.columbia.edu.

Acknowledgements

The authors would like to thank Jordy Lee for his guidance on designing the case study, and Lachlan Wright for his comments and feedback on aligning this report with RMI/Horizon Zero's Steel Accounting Guidance. The authors would also like to thank Emmanuel De Moor and Zheqi Li for sharing a wealth of useful knowledge grounded in their deep knowledge of the steel industry. Finally, the authors are grateful to Martin Dietrich Brauch and Reet Chatterjee for their invaluable editorial support.

Suggested Citation

John Biberman, Perrine Toledano, Baihui Lei, Max Lulavy, and Rohini Ram Mohan. *Conflicts Between GHG Accounting Methodologies in the Steel Industry*. New York: Columbia Center on Sustainable Investment (CCSI), December 2022.

Table of Contents

Executive Summary

Accurate, verifiable, and comparable greenhouse gas (GHG) emissions data throughout supply chains in the materials sector are necessary to drive decarbonization. This is particularly the case for the steel supply chain, a major source of GHG emissions with untapped potential for reduction. However, emissions accounting methods used by the steel industry suffer from gaps and misalignment, resulting in significant differences in reported GHG emissions. The result is a patchwork reporting landscape vulnerable to manipulation and miscommunication, generating little actionable data for policymakers, producers, customers, and investors. These shortcomings highlight the need for a harmonized carbon accounting framework for the steel industry that bridges these disparities. Such a framework is urgently needed to guide time- and capital-intensive investments towards decarbonizing steel supply chains.

A leading partner of the Coalition on Materials Emissions Transparency (COMET), the Columbia Center on Sustainable Investment (CCSI) conducted a comprehensive comparison of GHG accounting frameworks pertinent to the steel industry. This comparison identified the critical discrepancies existing between the methods examined and resulted in proposed solutions to be detailed in further research. The six most significant issues identified and solutions proposed are as follows:

- **System boundaries:** Various methods define different facility boundaries, creating significant differences in emissions calculations by including or excluding certain facilities. Several methods also fail to include a diagram to illustrate the accounting boundary, creating ambiguities regarding what activities must be incorporated into the accounting process. Using a fixed system boundary schematic across the industry, which should feature detailed production flows and embrace all critical processes for all production techniques in the steel industry, would resolve these boundary-related issues.
- **Upstream emissions from materials:** There are major discrepancies in how different methods consider indirect emissions from imported materials consumed onsite. Methods also differ on how to approach emissions from mining and transportation of raw materials, both onsite and offsite. Furthermore, there is no consistently approach to measuring upstream fugitive emissions. Finally, many methods assume that biofuels carry no carbon footprint without accounting for emissions from the land-use changes arising from biofuel production.
- **Emissions from import and export of energy:** Significant discrepancies arise from guidance on selecting appropriate emissions factors for electricity and steam, and there are varied levels of attention across methods to the potential of artificially lowering emissions through double counting. Imposing additional reporting requirements on using appropriate emissions factors for upstream and downstream power generation, and on calculating the impact of coproduct gas exports on emissions from downstream power generation, would make electricity emissions data more comparable.
- **Credit emissions:** Discrepancies arise around whether and how to report emissions associated with exported byproducts made available for downstream industries, particularly for partially combusted gases such as coke oven gas, blast furnace gas, and Linz-Donawitz converter gas. Furthermore, practices in claiming these credits are not always aligned with practices in other sectors, creating a risk of double-counting emissions reductions. Avoiding a system expansion approach to identifying credit emissions can reduce this risk.
- **Scrap-based production:** Scrap-based steel production is far less carbon-intensive than primary steel production. The difference is even wider when it comes to post-consumer scrap. Accounting for scrap-based production and primary steel production differently is therefore important to net-zero planning for the sector. However, no methodology requires separate reporting of scrap-based production-related emissions. Grading the carbon footprints of various types of pre-consumer and post-consumer scrap would contribute to making this adjustment.
- **Calculation methodology:** The fragmented and voluntary carbon accounting landscape in the steel industry discourages countries and companies from compiling the data that would allow for more granular calculation of sector emissions. Methods differ by specific equations used for calculations, default emissions factors based on outdated or inaccurate data, and even the basic approach to calculating emissions — with some methods using primary data based on carbon content and others using secondary data based on heat or even total output generation. Systematizing the general approach to emissions reporting, including by taking advantage of the data-rich environments in which many steel companies operate, would address these differences.

Acronyms

BFG	Blast Furnace Gas
BOF	Basic Oxygen Furnace
CCS	Carbon Capture and Storage
CEMS	Continuous Emissions Monitoring System
COG	Coke Oven Gas
COMET	Coalition on Materials Emissions Transparency
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EU ETS	European Union Emissions Trading Scheme
GHG	Greenhouse Gas
GWP	Global Warming Potential
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
ISO	International Organization for Standardization
LDG	Linz-Donawitz Converter Gas, also known as BOFG (Basic Oxygen Furnace Gas)
MRR	Monitoring and Reporting Regulation (under EU ETS)
NGO	Non-Governmental Organization
OHF	Open-Hearth Furnace
PPA	Power Purchase Agreement
REC	Renewable Energy Certificate
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

1 The Steel Industry

In many respects, steel is the backbone of modern society. An alloy of iron and carbon dating as far back as 1800 BCE, steel has been used for millennia whenever a strong, fracture-resistant, and hard material was needed. However, steel use was historically limited to applications where there was no alternative, namely springs in mechanical devices and hard, sharp objects that needed to keep their edge. It was only in 1856, with the invention of the Bessemer process, and the subsequent introduction of modern industrial processes, that mass production of steel became possible. Today, steel is divided into dozens of different grades according to its content of carbon and other elements such as aluminum, chromium, copper, manganese, nickel, silicon, and titanium, as well as its specific heat treatment, microstructure, finishing method, and numerous other factors. These grades vary according to their hardness, toughness, tensile strength, malleability, and ductility, opening up a broad palette of potential uses for steel and its alloys. These contemporary uses range from reinforcement for modern building construction to manufacture of precision instruments such as scalpels and spacecraft components, demonstrating the material's incredible usefulness, versatility, and ubiquity in the modern world.[1]

Steel may boast a remarkable range of potential uses, but its manufacturing process contributes massively to greenhouse gas (GHG) emissions that cause climate change. As one of the top-three global sources of carbon dioxide (CO_2) emissions, steel production led to emissions of an approximate average of 1.85 metric tons of CO_2 per ton of output in 2018, accounting for approximately 8% of global CO_2 emissions.[2] Because steel is produced in such high quantities through a highly GHG-intensive process involving multiple sources and types of emissions, reducing steel emissions represents one of the greatest challenges to reducing global GHG emissions to sustainable levels.

1 "About Steel," Worldsteel Association, https://worldsteel.org/about-steel/about-steel/.

2 Decarbonization challenge for steel," McKinsey & Company, Christian Hoffman, Michael Van Hoey, and Benedikt Zeumer, June 3, 2020, https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel.

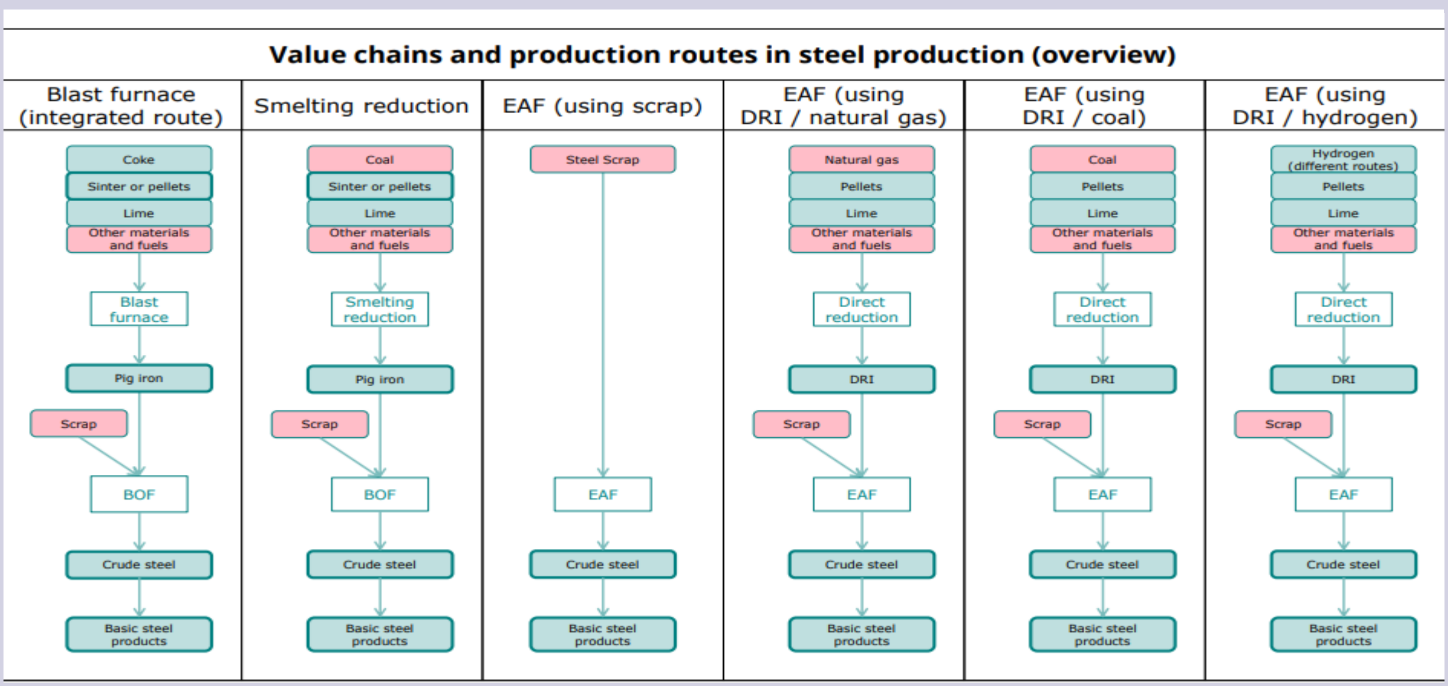


Figure 1: Value Chains and Production Routes in Steel Production (overview)[a]

Source: Umweltbundesamt.

a Hubert Fallman, Christian Heller, Hanna Schreiber, and Chris Green, *Review of calculation methods for embedded emissions for the purpose of the CBAM (Version for discussion with stakeholders)* (Vienna: Umweltbundesamt and Ricardo PLC, September 2022).

Properly accounting for the sources of GHG emissions in steel production and assessing solutions to the challenges inherent in reducing the sector's carbon footprint are essential for both a thriving steel industry and a stable global climate system.

1.1 The Steel Production Process

Primary steelmaking begins with the extraction of raw materials used in the production process. This includes forms of iron ore including hematite (Fe_2O_3) and magnetite (Fe_3O_4), metallurgical coal, and fluxes like limestone and dolomite. Ores and fluxes are typically crushed, powdered, heated by a flame (a process known as sintering), and pelletized for transportation and use inside blast furnaces. Sinter plants can also support the recovery of waste products generated throughout the steelmaking process into products that can be charged to the blast furnace as well. Blast furnaces are typically fueled by a mixture of pulverized coal and coke, with co-injection of methane (CH_4) in certain cases.[3] Coke is produced either in coproduct recovery coke ovens, which capture the off-gassed coproducts, or non-recovery coke ovens, which burn these coproducts to generate steam and electricity. Coke oven gas (COG) can also be mixed in with other fuels to generate heat for other stages of the industrial process.[4]

Once these raw materials are gathered and transported, the first step in the steel production process is the reduction of the iron ore into metal. This can be done through two main routes: the blast furnace route and the direct reduction route.

The blast furnace route, the older and more traditional approach, uses a blast furnace to smelt iron ore into pig iron. Blast furnaces force heated air at high pressures through the fuel, iron ore pellets, sinter, and flux loaded into the furnace, after which molten pig iron with a relatively high carbon content collects at the bottom of the furnace for further use. Fluxes like limestone and dolomite, which are fed into the blast furnace to remove impurities, are responsible for substantial GHG emissions from the calcination process.[5] Fluxes can also be imported from offsite in the form of lime and burnt dolomite, in which case emissions from calcination take place upstream. Blast furnaces also produce carbon monoxide, the flux waste product slag, which has uses in the cement industry,[6] and blast furnace gas (BFG), which is recovered as a fuel for use throughout the steelmaking process.[7]

Direct reduction uses reducing agents to remove oxygen from iron ore without melting, resulting in direct reduced iron (DRI) or "sponge" iron. This method has lower heat requirements and produces a higher grade of product than the blast furnace method. DRI is typically produced using a mixture of carbon monoxide and gray hydrogen, which is processed from natural gas.[8] The process can be fully decarbonized by using green hydrogen produced from renewable energy as the reducing agent, without the presence of carbon monoxide.[9] As green hydrogen production becomes more competitive relative to gray hydrogen, new economies of production could lead to the decarbonization of this entire stage of steel production.[10]

The pig iron and DRI produced through blast furnaces or direct reduction are mostly unsuitable for industrial use until they are processed into steel by further reducing their carbon content. This production step takes place in either a basic oxygen furnace (BOF) or an electric arc furnace (EAF).

The BOF process blows oxygen through molten pig iron in a nitrogen-charged chamber to ignite the carbon dissolved within at a temperature of 1700°C, emitting a mixture of carbon monoxide, CO_2, oxygen, and nitrogen known as Linz-Donawitz Converter Gas (LDG) or Basic Oxygen Furnace Gas (BOFG).[11] LDG can be released directly or used as a fuel for electricity production or other industrial processes, being similar to BFG, but with reduced nitrogen content. The BOF process represents 70.8% of total global steel production as of 2022.[12]

3 Adrian Majeski, Allan Runstedtler, John D'Alessio, and Neil Macfadyen, "Injection of Pulverized Coal and Natural Gas into Blast Furnaces for Iron-making: Lance Positioning and Design," ISIJ International no. 55 (2015), 1377-1383, https://www.jstage.jst.go.jp/article/isijinternational/55/7/55_1377/_pdf/-char/en.

4 "Steel Production Gas for Power Production," Clarke Energy, https://www.clarke-energy.com/steel-production-gas/.

5 Gupta Sudhir Kumar, Anushuya Ramakrishnan, and Yung-Tse Hung, "Lime Calcination," Advanced Physicochemical Treatment Technologies (New Jersey: Humana Totowa, 2007), 611-633, https://doi.org/10.1007/978-1-59745-173-4_14.

6 Panesar, Daman K., "Supplementary Cementing Materials," Developments in the Formulation and Reinforcement of Concrete, 2019, https://www.sciencedirect.com/topics/engineering/slag-cement.

7 "Steel Production Gas for Power Production," Clarke Energy.

8 "DRI Production," International Iron Metallics Association, https://www.metallics.org/dri-production.html.

9 European Parliament Briefing, "The potential of hydrogen for decarbonizing steel production," European Parliamentary Research Service PE 641.552 (December 2020), https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/641552/EPRS_BRI(2020)641552_EN.pdf.

10 Emily Beagle, Stephen Doig, Chathurika Gamage, Thomas Koch Blank, Cato Koole, Patrick Molloy, and Tessa Weiss, "Fueling the Transition: Accelerating Cost-Competitive Green Hydrogen," RMI, 2021, https://rmi.org/insight/fueling-the-transition-accelerating-cost-competitive-green-hydrogen/.

11 Shawn Martin, "What's 'good-quality' steel and how do you achieve it?" Engineering 360, April 18, 2018, https://insights.globalspec.com/article/8565/what-s-good-quality-steel-and-how-do-you-achieve-it.

12 "2022 World Steel in Figures," Worldsteel Association, April 2022, https://worldsteel.org/wp-content/uploads/World-Steel-in-Figures-2022.pdf.

In contrast, EAF steel production passes an electric arc through a graphite electrode into a furnace charged with pig iron, scrap steel, or DRI to first melt the contents, potentially with the aid of an auxiliary burner, then reduce the carbon content of the resulting steel to the desired level. EAF is responsible for 28.9% of global steel production as of 2022, and over half of production in the European Union (EU) and United States-Mexico-Canada Agreement (USMCA) zones, but in China, the world's largest crude steel producer by nearly a factor of ten, EAF accounts for only 10.6% of production.[13]

EAF is substantially less GHG-intensive than the BOF process: 0.37 tCO_2/t crude steel produced through EAF compared to 1.67 tCO_2/t crude steel produced through BOF.[14 15] This is especially the case when steel scrap rather than DRI or pig iron is used as the feedstock, as discussed below. However, the high electricity demands of EAF make stable and plentiful power supplies necessary, underlining the importance of properly accounting for electricity-related emissions from EAF facilities. While BOF processes use similar levels of total electricity as EAF processes, much of that electricity is generated onsite either from waste heat or from coproduct gases; EAF facilities do not typically engage in onsite electricity production or cogeneration, importing their electricity instead.[16] Additionally, the availability of scrap further limits the use of EAF.

The last stages of steelmaking in the primary process involve shaping and finishing. Crude steel is frequently alloyed with other metals to meet the desired properties of a final product. It can then be cast, hot-rolled, cold-rolled, or extruded to meet the desired shape. Finishing can involve steps such as hot-dip galvanization, which applies a protective coating of molten zinc,[17] or scarfing, which uses a torch to remove surface defects.[18] Shaping and finishing generates GHG emissions from both heat requirements and electricity consumption. In addition, the 2019 Intergovernmental Panel on Climate Change (IPCC) guidelines consider flaring from any process within the supply chain to be a potential source of nitrous oxide (N_2O), a potent GHG with a 100-year Global Warming Potential (GWP) almost 300 times that of CO_2.

Finally, while primary steelmaking is highly carbon-intensive as described above, secondary steelmaking processes utilizing scrap materials can be far less GHG-intensive. Scrap is preferred to iron in the BOF process because it can help control costs, but scrap usage is capped at roughly 30% at most sites due to technological constraints. EAF production, on the other hand, can run entirely on scrap.[19] Because iron reduction, the most energy-intensive part of the production process, has already been completed for scrap, use of scrap is one of the primary drivers of reduced carbon intensity for EAF production compared to BOF production. Scrap-based steel production can be expected to increase as policy steps are taken to limit carbon emissions from the steel industry, but global limitations on the supply of scrap prevent this pathway from meeting the entirety of global demand.[20]

2 Carbon Accounting Methods for Steel

Pressure to monitor the high GHG output of the steel industry has led to a proliferation of methods produced by different organizations for reporting on the emissions from the sector. Each of these methods vary in their focus, purpose, and scope. When compared against each other, these different approaches lead to accounting disparities that dramatically affect the levels of GHG emissions assigned to steel producers under each framework. The methods and sub-methods examined are outlined below (see also Table 1).

Environment Canada, Primary Iron and Steel Production, Guidance Manual for Estimating Greenhouse Gas Emissions

Developed under the Government of Canada's Action Plan 2000 on Climate Change, Environment Canada's guidance manual for estimating GHG emissions from primary iron and steel production is one of a series of manuals targeted toward primary mineral and metal producers who aim

13 Ibid.

14 "Steelmaking Emissions Report 2022," Steel Manufacturers Association, June 14, 2022, https://steelnet.org/steelmaking-emissions-report-2022/.

15 Figure provided according to reported scope 1 and 2 emissions.

16 Bause, Tim, "Cogeneration with ORC at Elbe-Stahlwerke Feralpi EAF Shop," Iron and Steel Technology 1.5 (January 2014), 1101-1111, https://www.researchgate.net/publication/288773518_Cogeneration_with_ORC_at_Elbe-Stahlwerke_Feralpi_EAF_shop.

17 "Hot Dipped Steel vs. Galvanized Steel," Avanti Engineering, September 23, 2020 , https://www.avantiengineering.com/hot-dipped-galvanized-vs-galvanized-steel/.

18 M.S. Showalter, V.A. Nemchinsky, and J.A. Khan, Fundamental study of oxygen scarfing process (Houston, 1996) , https://www.osti.gov/biblio/428104 .

19 Bernhard Voraberger, Uxia Dieguez Salgado, Erich Wimmer, Gerald Wimmer, Krzysztof Pastucha, and Alexander Fleischanderl, "Green LD (BOF) Steelmaking – Reduced CO_2 Emissions Via Increased Scrap Rate," Metals 12.3 (2022), 466, https://doi.org/10.3390/met12030466.

20 "Decarbonization challenge for steel," McKinsey & Company.

to assemble facility-level GHG inventories. The manual aligns with guidance that Environment Canada provides to producers in other sectors.

EU ETS Monitoring and Reporting Regulation (MRR)

The European Union Emissions Trading System (EU ETS) is one of the world's oldest and most developed GHG markets, with regulations covering CO_2 and N_2O emissions from electricity and heat generation as well as energy-intensive industry sectors, including iron and steel production. The EU ETS compliance system is detailed in the Monitoring and Reporting Regulation (MRR), which lays out accounting standards and adherence requirements through a series of regulations and electronic templates.

Greenhouse Gas Protocol

The GHG Protocol, created by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), is an open effort to provide a set of widely used GHG accounting standards and templates for use in many industries. Under the GHG Protocol, relevant frameworks examined include:

- **Corporate Accounting and Reporting Standard (Corporate Standard):** The Corporate Standard provides general principles of carbon accounting under the GHG Protocol for use by companies, non-governmental organizations (NGOs), government agencies, and other institutions preparing an emissions inventory. Under these umbrella guidelines, the GHG Protocol defines concepts, such as emissions scopes, that other accounting methods have widely adopted.
- **GHG Emissions from Iron and Steel Production:** The GHG Protocol provides sector-specific guidance for calculating iron and steel emissions outside the scope of the general guidance provided in the Corporate Standard. GHG Protocol Iron and Steel guidance provides equations for calculating emissions from processes specific to the iron and steel industry, as well as instructions on managing sector-specific accounting challenges, such as coproduct gas emissions.
- **Scope 2 Guidance:** This guidance provides updated guidelines for reporting indirect emissions from energy and heat consumption, or scope 2 emissions as defined under the Corporate Standard. These can be used to set targets, track emission reductions, and communicate progress to stakeholders.

IPCC Guidelines for National Greenhouse Gas Inventories

This guidance, first published in 2006, provides directions on compiling national GHG inventories, including guidance on estimating emissions from iron, steel, and metallurgical coke production. Appendix I provides a full overview of how IPCC reporting for iron and steel is divided between its various volumes of guidance.

- **2019 Refinement to the 2006 IPCC Guidelines:** The 2019 Refinement provides updated guidelines on compiling national GHG inventories, featuring accommodation for new technologies requiring new calculation techniques, supplementary methodologies for GHG sources and sinks which were poorly accounted for under the 2006 guidelines, and updated emissions factors according to more recent research. This includes new guidance specifically addressing iron and steel manufacturing.

ISO 14404 Series

ISO 14404, published by the International Organization for Standardization (ISO), provides guidance for calculating CO_2 emissions from steel plants using various technologies and facility configurations. ISO 14404-1 concerns steel plants with blast furnaces, ISO 14404-2 covers EAF steel plants, and ISO-14404-3 discusses EAF steel plants with coal or gas-based DRI facilities.

ResponsibleSteel Standard, version 2.0

The ResponsibleSteel Standard is a broad set of sustainability principles for steel sourcing and production, covering topics including corporate leadership; environmental, social, and governance (ESG) management systems; occupational health and safety; labor rights; human rights; stakeholder engagement and communication; local communities; climate change and GHG; noise; emissions; effluents and waste; water stewardship; biodiversity; and decommissioning and closure. Version 2.0 includes guidance on measuring and benchmarking GHG emissions for crude steel production.

Worldsteel CO_2 Data Collection User Guide, version 10

The World Steel Association, or Worldsteel, is the iron and steel industry's international trade association. Worldsteel has published guidelines for facility-level CO_2 emissions reporting to help members track their emissions

Table 1: Overview of Examined Carbon Accounting Methodologies

Methodology	Notable Characteristics
Environment Canada, Primary Iron and Steel Production, Guidance Manual for Estimating Greenhouse Gas Emissions	Comprises part of a suite of facility-level GHG inventory methodologies developed by the Canadian government, with a heavy emphasis on measuring direct emissions.
EU ETS Monitoring and Reporting Regulation (MRR)	Forms the cornerstone of an international regional carbon market, which enforces its regulations at the company level.
GHG Protocol Corporate Accounting and Reporting Standard (Corporate Standard)	Provides cross-sectoral guidance on general principles of GHG accounting.
GHG Protocol Calculating Greenhouse Gas Emissions from Iron and Steel Production	Covers sector-specific emissions sources from iron and steel production, intended to be used in conjunction with the GHG Protocol Corporate Standard.
GHG Protocol Scope 2 Guidance	Describes updated approach to indirect emissions under the GHG Protocol with a focus on electricity, heat, and steam.
2006 IPCC Guidelines for National Greenhouse Gas Inventories, Metal Industry Emissions	Offers comprehensive guidance for developing national, rather than corporate emissions inventories for the iron and steel sector. Divides guidance relevant to iron and steel industry emissions between a volume dedicated to industrial process and product emissions and one concerning emissions from energy production.
2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2019 Refinement), Metal Industry Emissions	Updates figures and clarifies existing guidance from the 2006 IPCC Guidelines.
ISO 14404-1, 14404-2, 14404-3	Applies a simplified version of the Worldsteel calculation approach, with strict divisions between different types of processes.
ResponsibleSteel Standard version 2.0	Outlines a holistic sustainability framework whose climate component integrates multiple GHG accounting methodologies with its own requirements to create benchmarks for a certification system.
Worldsteel CO_2 Data Collection User Guide, version 10	Calculates emissions according to basic import and export data, with no requirement for measurement of individual processes or heat and energy flows within the system. This allows for simplicity and widespread ease of application, but at the expense of comparing processes in different regions.

Source: Prepared by the authors based on the listed guidelines.

reductions, estimate site-specific CO_2 intensity for steel production, and keep track of their progress relative to industry-wide trends. Worldsteel's guidelines form the foundation of ISO 14404, with minor differences between the two.

3 Methodological Comparison

GHG accounting methodologies in use in the steel industry differ across a wide variety of metrics. Accounting boundaries are inconsistent between the methods examined, particularly regarding treatment of coproduct gases, and methods often provide unclear direction on which industrial processes belong within the system boundary, especially when no accompanying system diagram is included. Methods diverge on treatment of fugitive emissions, and do not align on which indirect emissions from offsite processes require inclusion. Default emissions factors, already based on old and unreliable data with little methodological transparency, vary substantially between the frameworks examined. Methods differ according to which imported materials to count and the appropriateness of materiality thresholds, which limit reporting requirements for emissions sources falling below a certain percentage of total emissions. Coverage of GHGs other than CO_2 also varies between methods (see Table 2). Finally, several methods provide wide and ambiguous latitude for claiming offsets and credits—a challenge that demands not just examination of the validity of these credits, but also tight coordination with reporting standards in industries linked to steel to avoid double counting of both emissions and claimed emissions reductions.

3.1 System Boundaries

To compare industry GHG emissions, and the accounting techniques associated with them, the first step is to compare the accounting boundaries applied under each framework. Accounting boundaries refer to how a system is defined for purposes of emissions reporting, demarcating facilities and activities inside and outside that system. A lack of clear accounting boundaries can create ambiguity regarding which emissions from which activities are under examination, particularly regarding mobile combustion and transportation, indirect off-site emissions from processes necessary for production, and the specific GHGs accounted for, including fugitive emissions.

3.1.1 Direct Emissions

Direct emissions arise onsite, within the boundary of the steel plant. Some methods always include certain processes in their direct emissions calculation, while other methods always exclude certain processes, even when they

Table 2: GHGs Covered by Methods

GHG covered outside of CO_2	CH4	N2O	HFC/PFC/SF6
Environment Canada	No	No	Yes
EU ETS	Yes	Yes	Yes
GHG Protocol Iron and Steel	Yes	Yes	No
IPCC Guideline (2019)	Yes	Yes	No
ISO 14404 series	No	No	No
ResponsibleSteel[a]	Yes	Yes	Yes
Worldsteel	No	No	No

Source: Prepared by the authors based on the listed guidelines.

a ResponsibleSteel additionally allows for the inclusion of the GHG nitrogen trifluoride (NF3). However, ResponsibleSteel also only requires a particular GHG to be accounted for when it is estimated to account for at least 0.5% of direct CO_2e emissions or 5% of embodied CO_2e emissions for a particular source of indirect upstream emissions.

Table 3: Boundaries Guidance Comparison

	Does it provide a boundary diagram?	If no, can a complete boundary be estimated from emission sources and equations?
Environment Canada	No	Yes
EU ETS	No	No
GHG Protocol Iron and Steel	No	Yes
IPCC Guideline (2019)	Yes	N/A
ISO 14404 series	Yes	N/A
ResponsibleSteel	No	Yes
Worldsteel	Yes	N/A

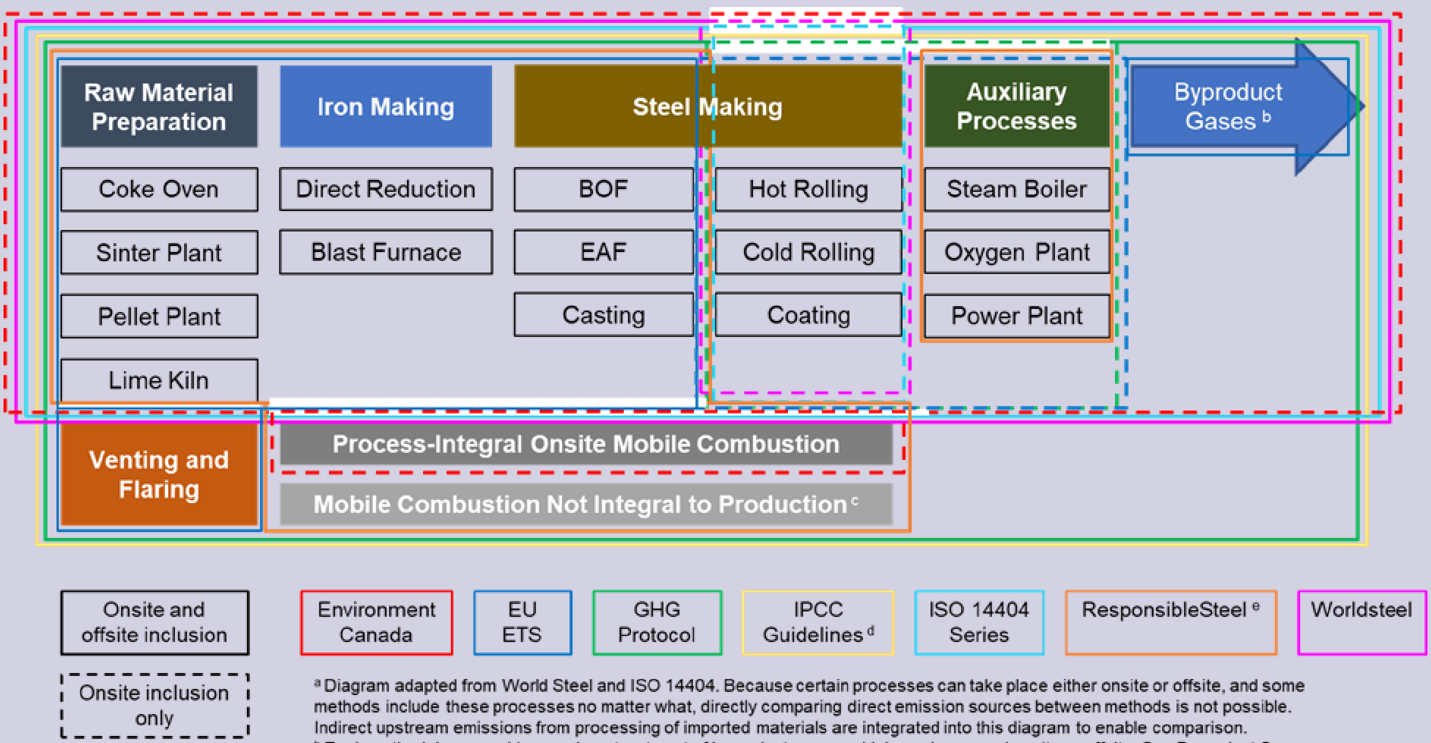
Source: Prepared by the authors based on the listed guidelines.

occur onsite. Additionally, some methods only account for emissions from certain processes when they occur onsite, while other methods account for the emissions from these processes whether they occur onsite or offsite.

One way to examine how clearly each methodology communicates which emissions sources are to be counted is to publish a system boundary diagram, corresponding with an accounting method's reporting requirements. While some methodologies include such a diagram, others do not, to the detriment of clarity regarding their accounting boundaries. In particular, EU ETS includes a list of CO_2 sources that must be included, without providing detailed instructions on which processes to include. ResponsibleSteel's original guidance recognized system boundaries from multiple accounting standards, namely the GHG Protocol and ISO 14404, but ResponsibleSteel's updated guidance imposes new system boundary requirements that override the boundaries applied by those standards.

ISO 14404 provides a clear set of site boundary diagrams according to separate production technologies and site layouts, featuring process flows that offer further clarity regarding input materials, key processes, and output products and emissions. On the other hand, Environment Canada invites users to create their own diagram, and the GHG Protocol describes its system boundary through text divided between separate documents. This lack of explicit, illustrated detail creates a source of uncertainty for practitioners regarding processes taking place at the perceived edge of their system boundary, leading to inconsistent data.

Turning to the system boundaries themselves, several major differences stand out. First, some methodologies apply a fixed boundary to certain processes regardless of whether they take place onsite or offsite. For instance,



[a] Diagram adapted from World Steel and ISO 14404. Because certain processes can take place either onsite or offsite, and some methods include these processes no matter what, directly comparing direct emission sources between methods is not possible. Indirect upstream emissions from processing of imported materials are integrated into this diagram to enable comparison.
[b] Each methodology provides a unique treatment of byproduct gases, which can be reused onsite or offsite. See Byproduct Gas Emissions for more information.
[c] Includes offsite transportation.
[d] Because IPCC is intended for national GHG inventories, many sources are listed outside the iron and steel supply chain. Volume 2, Chapter 1 covers emissions from mobile machinery in manufacturing, while Volume 2, Chapter 3 covers "combustion emissions from all remaining transport activities…not otherwise reported under…Manufacturing Industries and Construction."
[e] ResponsibleSteel recognizes multiple methodologies, including GHG Protocol, EN 19694, and ISO 14404, but imposes its own system boundary requirements which override those required by these methodologies. ResponsibleSteel guidance for calculating overall site emissions intensity and product carbon footprints also differs according to system boundary; the boundary for site emissions intensity is illustrated in this diagram.

Figure 2: System Boundaries for Direct and Material Emissions.

Source: prepared by the authors according to the listed guidelines. [a]

ResponsibleSteel and ISO 14404-1 mandate inclusion of emissions from blast furnaces, basic oxygen furnaces, and casting in all reporting of direct emissions from plants based on blast furnace production. Emissions from sinter plants, lime kilns, pellet plants, and coke ovens must also be included, whether they are onsite or export materials to the facility from offsite. Other processes under these same standards only require reporting when they do take place onsite. In the same ISO standard, emissions from hot rolling, cold rolling, and coating are only counted when they take place in onsite facilities. Finally, some types of direct emissions are excluded from consideration under some methodologies but not under others. For instance, ResponsibleSteel does not include any emissions from processing of crude steel after casting, regardless of whether these processes take place onsite. The delineation between which typically direct emission sources require inclusion no matter what, which ones only need to be reported when they exist onsite, and which ones should not be reported is highly inconsistent between the various methods examined.

Finally, certain other narrow and specific differences in reporting boundaries are found between the methodologies. Environment Canada requires accounting for emissions from onsite mobile combustion integral to the production process, such as onsite transport of raw materials or intermediate goods, while the GHG Protocol Corporate Standard expands consideration of direct emissions from mobile combustion to include all company-owned or operated vehicles. Both the GHG Protocol Corporate Standard and EU ETS require accounting for emissions from onsite venting and flaring, with the GHG Protocol including scope for reporting upstream fugitive emissions, but other methodologies do not mandate reporting of fugitive emissions. Finally, Worldsteel and ISO make reporting of hot rolling, cold rolling, and coating specific to each facility, while GHG Protocol iron and steel guidance and EU ETS additionally include site-specific reporting of emissions from steam boilers, oxygen plants, and power plants.

Lastly, the methods feature different approaches to the use of biomass as a fuel. Environment Canada, the GHG Protocol Stationary Combustion Guidance, Worldsteel, and IPCC each provide emissions factors for biomass. However, Environment Canada directs users not to include CO_2 emissions from biomass in the final calculation, since they are instead to be categorized as a loss of biomass under land use and forestry guidance. The EU ETS takes a more aggressive tack by specifying an emissions factor of zero for biomass, while ISO does not specify any particular treatment. ResponsibleSteel assigns a default embodied GHG value of zero for all biological fuels, but simultaneously requires direct emissions from all biological sources of carbon to be accounted in full.

It is challenging to quantify the true impact of biomass consumption on total emissions because these impacts are so specific to the land used for biomass production. Recognizing that biomass consumption is linked to GHG emissions from land-use changes, ResponsibleSteel allows facilities to claim a negative upstream embodied GHG value for biomass inputs in certain cases. To claim this, the facility must report primary data for these inputs including emissions from harvesting, processing, and transportation in addition to a detailed accounting of emissions from land-use change and forest or agricultural management tied to the production of these inputs over the 20 years prior to harvest. Such stringent requirements are meant to mitigate the risks posed to natural carbon sinks by incautious development of biomass energy. However, they do not address other impacts to sustainability, such as habitat loss and air and water pollution.[21]

3.1.2 Indirect Emissions

Indirect or imported emissions occur outside of a reporting facility but within its supply chain. These can be emissions from energy, such as electricity or steam imported onsite, or from materials that underwent GHG-intensive processing before their arrival onsite.

Guidance on reporting emissions from both imported materials and energy can vary significantly. Worldsteel, ISO 14404, and ResponsibleSteel guidelines require upstream emissions from material processing to be included for a wide range of imported materials.[22] ResponsibleSteel also directs users to include emissions from other imported material sources constituting at least 5% of total emissions from imported materials at a minimum and requires reporting indirect emissions associated with transportation of materials and inputs to the site. Worldsteel includes emissions from petroleum products for oil refining, but it excludes upstream emissions from mining and transportation.

21 Bettina Kampman, Geert Bergsma, Benno Schepers, Harry Croezen, Uwe R. Fritsche, Klaus Henneberg, Katja Huenecke, Jan Willem Molenaar, Jan Joost Kessler, Stephan Slingerland, Coby van der Linde, BUBE: Better Use of Biomass for Energy Background Report to the Position Paper of IEA RETD and IEA Bioenergy (Delft: CE Delft, July 2010), 68, https://www.ieabioenergy.com/wp-content/uploads/2013/10/Better-Use-of-Biomass-for-Energy-Background-Report.pdf.

22 These imported materials requiring accounting for upstream emissions are listed in ISO 14404-1:2013 Table 2, provided in Appendix II.

The other methods studied fail to specify a specific accounting approach for emissions from mining and offsite transportation, despite the substantial indirect emissions these activities contribute within the supply chain. GHG Protocol iron and steel guidance draws a narrower boundary around inclusion of indirect material emissions, directing users to consider offsite production of coke, limestone, and dolomite, but without explicitly excluding any other specific materials. At the most exclusive end of the spectrum, Environment Canada and EU ETS are silent on imported materials, and even direct users not to include upstream emissions from imported electricity, heat, and steam.

Overall, while most steel accounting standards include emissions from imported materials, they diverge on which imported materials to include. These materials produced offsite could include fuels; auxiliary materials like fluxes, oxygen, and nitrogen; ferrous materials; alloys; and coproducts such as coal tar and benzole. Nor is there agreement around the boundaries on emissions of imported materials or whether to impose materiality thresholds. Table 4 summarizes how these facility-level accounting methodologies approach the problem of indirect upstream emissions.

3.1.3 Credit Emissions

When steel producers engage in activities expected to result in reductions of emissions outside the reporting boundary, various methodologies allow them to claim credits to represent this alleged reduction of emissions. Credit emissions can be classified into two broad categories: those claimed from within the specified boundary and those claimed from outside the specified boundary. Excess production of a certain output, such as electricity or burnt lime exported for use in another facility, are examples of credits from processes within the boundary. On the other hand, claiming a credit from outside the boundary touches on inputs for processes outside the system and is justified by the displacement of emissions in another process. An example would be claiming a credit for slag exported for cement production. Claiming this credit requires defining a counterfactual baseline of emissions that would have otherwise taken place without those exports. Several risks arise from applying credits from outside the boundary. Multiple sectors could claim credits for the same hypothetical reduction, for instance, if accounting methodologies are not harmonized between sectors. Baseline emissions may also be inflated to claim a greater credit than is realistic.

Table 4: Treatment of Indirect Emissions

	Imported electricity and steam	Imported materials	Upstream Fugitive Emissions	Does it specify type of imported materials to be reported?	Does it provide a materiality threshold for imported materials?
Environment Canada	No	No	No	No	Yes
EU ETS	No	No	N/A	N/A	N/A
GHG Protocol Iron and Steel	Included	Included	Included	No	No
ISO 14404 series	Included	Included	N/A	Yes	No
ResponsibleSteel	Included	Included	No	Yes	
Worldsteel	Included	Included	N/A	Yes [a]	No

Source: Prepared by the authors based on the listed guidelines.

a Worldsteel provides a list of upstream emissions factors on various fuels, materials, etc., which can be interpreted as the list of imported materials to consider.

Acceptable credit emission sources and specified factors for credit emissions vary widely between methodologies. ISO 14404 and Worldsteel allow crediting for any exported form of energy or material contained in the ISO table in Annex II, including an associated "upstream" emissions factor identical to that used for the same material when imported. Both methods also allot credits for direct export of "ingredient" CO_2 for use in other industries such as soft drink manufacturing. This surprising inclusion requires a deeper comparison with carbon accounting methodologies for these sectors that import carbon dioxide for industrial use. Worldsteel also specifies emissions factors for exports of BF, EAF, and BOF slag for use in sectors such as the cement industry, but with the caveat that "since the accountability of these factors still remain undecided, they are quantified and used in specific analysis, but they are not incorporated in calculated final carbon intensity of a site."[23] Unlike the above methods, ResponsibleSteel, GHG Protocol iron and steel guidance, and EU ETS do not credit electricity exports—a crucial difference for steel plants, which often export vast quantities of electricity produced from excess heat onsite. In addition, ResponsibleSteel does not permit netting emissions according to exports of byproducts, with the exception of excess intermediate products; claiming

23 Worldsteel, "CO_2 Data Collection User Guide, version 10," 20.

Table 5: Credit Emission Sources

Environment Canada	Not specified
EU ETS	Exported electricity does not give rise to credits. No other credit type is specified.
GHG Protocol Iron and Steel	Does not define credit for steel in particular, but clarifies in general that emissions associated with the sale of own-generated electricity to another company are not netted from direct emissions and may be reported in optional information.
ISO 14404 series	Raw materials, intermediate products, and energy exported to outside users as credit emission sources: • Gas fuel, liquid fuel, and solid fuel • Auxiliary material (e.g., limestone and crude dolomite) • Energy carriers (e.g., electricity, steam) • Ferrous-containing material (e.g., pellets and sinter) • Alloys (e.g., ferro-nickel) • Product and by-product (e.g., CO_2 for external use, coal tar, and benzol)
ResponsibleSteel	• Credits may only be claimed for exported intermediate products when they have been purchased in excess, or when intermediate energy products that have not played a role in crude steel production are exported. Netting is otherwise not permitted. • Reductions from CCS, whether this takes place onsite or offsite, may only be claimed when justification can be provided that the emissions will be captured permanently and will be monitored for leakage. Leakage must be reported and added to the steel producer's emissions intensity in the year when it takes place. • Credits may be assigned for use of biomass inputs based on the carbon sequestered during growth, but only when accompanied by an accounting of the GHG emissions from land-use changes and management for the 20 years prior to harvest.
Worldsteel	Four credits emission sources, including blast furnace slag, basic oxygen furnace slag, electric arc furnace slag and CO_2 to external. CO_2 to external is scope 1, while the other three belong to scope 3. Credits are related to procurement or delivery of pre-processed materials or coproducts from the site, without details.

Source: Prepared by the authors based on the listed guidelines.

credits for process gases exported or captured onsite is only permitted when effective carbon capture and storage (CCS) can be demonstrated to be in place either onsite or offsite. Finally, ResponsibleSteel has an additional layer of verification by requiring separate reporting of any GHG emissions considered credit emissions by the reporting entity, in addition to descriptions of any offset arrangements. Table 5 compares accepted credit emission sources between the different methodologies.

ResponsibleSteel does not allow credits to be claimed for exported carbon-intensive byproducts, with the exception of process gases under certain conditions, even if they reduce emissions elsewhere, because its methodology is intended to measure site emissions intensity rather than total emissions attributable to the site. Under this logic, these carbon-intensive byproducts only exist because a site has greater GHG intensity than its peers, and allowing them to be used as emissions credits would reward these producers for their inefficiency. A similar logic applies for energy produced onsite that is eligible for export. This energy, ordinarily electricity or steam, is typically generated to capture a plant's waste heat. Since waste heat can be a driver of higher GHG emissions intensity at the plant, allowing producers to export this electricity and claim it as a credit would again reward these producers for inefficient processes.

3.1.4 Coproduct Gas Emissions

Combustible coproduct gases generated during the iron and steel production process comprise a separate class of emission sources requiring a special accounting treatment, which each methodology approaches in its own way. COG, BFG, and LDG/BOFG can variously be directly vented, combusted onsite for additional heat generation (particularly in steam and sintering plants), or exported offsite either for heat and power generation or for use in further production processes. Because they are the partial combustion products of inputs whose emissions have typically already been accounted for, but can be delivered offsite for further combustion, it is critical to prevent either double-counting or omission of emissions from certain industrial processes.[24]

24 "Steel Production Gas for Power Production," Clarke Energy.

Table 6: Coproduct Gas Emissions

Environment Canada	• Onsite combustion emissions from COG and BFG are already counted in the calculations from the use of coke as a reducing agent. Therefore, COG and BFG should not be listed as a fuel for onsite stationary combustion to avoid double-counting. • CO_2 emissions from COG and BFG that is exported off-site should be calculated and credited.
EU ETS	• Process gases should be included as potential sources of GHG emissions from onsite combustion. • Emissions from production of process gases are assigned to the producer when produced within the boundaries of a product benchmark, and to the consumer when waste gas is produced outside the boundaries of a product benchmark. • Emissions from consumption of process gases are always allocated to the consumer.[25] • Facilities should account for emissions from venting and flaring.
GHG Protocol Corporate Standard & Project Accounting Iron and Steel Guidance	• While the GHG Protocol invites a cautious approach when it comes to gases that are both a product and a supply of energy, it does not specify any specific approach. • Explicitly directs users not to account for coproduct emissions from coke-consuming facilities operating offsite to avoid double-counting. • Exported coproduct gases are credited. • Flaring of produced coproduct gas is counted as a source of stationary combustion, with equations included to calculate CO_2 and CH_4 emissions from flaring at iron and steel operations.
IPCC Guidelines	• Emissions from combustion of coproduct gases in sinter plants, coke ovens, blast furnaces, basic oxygen furnaces, and internal power plants are reported under Industrial Processes and Product Use (IPPU) guidelines. • When coproduct gases are exported off-site for external combustion, their emissions are reported in the subcategories 1A2f or 1A1a under energy sector guidelines. Default emissions factors are provided. • Emissions from venting and flaring of COG at coke ovens are allotted to the energy sector. • Flaring and venting from facilities downstream from coke production, such as blast furnaces, sinter plants, and BOF plants, are allotted to IPPU.
ISO 14404 Series	• Exported by-product gases are credited according to an indirect emissions factor identical to that applied to their imports. • ISO provides two separate sets of default credit emissions factors for coproduct gases, one according to natural gas equivalents and one according to world average electricity equivalents under Worldsteel methodology. • When steel plants import by-product gas from other steel plants, coke plants, or both, direct emissions factors based on their carbon content are adopted.
Responsible Steel	• Baseline emissions from coproduct gases are allocated as if they had been flared in their entirety. The following credits are then applied until the baseline is reached: – When coproduct gases are used for power generation onsite or offsite, emissions are credited according to the power generated by them. When primary data on the amount of power generated is not available, it may be estimated according to the quantity of coproduct gases exported on the basis of Worldsteel default values. – When coproduct gases which are captured and reused downstream for purposes other than power generation, emissions are credited according to the GHG emissions that would have otherwise been generated from using natural gas in their place. – When coproduct gases are used and sequestered in end products, credits are assigned according to the net GHG emissions sequestered as well as the baseline GHG emissions which would have resulted from other production methods, measuring both the emissions saved within the end product and during the production process. • GHG emissions from imported electricity are not considered when generated from the use of a site's own coproduct gases which have been exported to that generator. • The above guidance on credits from process gases is subject to a 12-month trial period as of September 2022.
Worldsteel	• Emissions from coproduct gases consumed onsite are calculated in scope 1, then fully credited back in scope 1.1, which serves as a subcategory for reporting the volume of emissions from coproduct gas consumption. • Emissions from net exports of coproduct gases are calculated according to an electricity-equivalent indirect emissions factor. • Total indirect emissions from electricity are calculated according to the net power consumed by a plant, subtracting power produced by exported coproduct gases from the power purchased by the plant.

Source: Prepared by the authors based on the listed guidelines.

25 European Commission, Guidance Document no. 8 on the harmonized free allocation methodology for the EU ETS post 2020: Waste gases and process emissions sub-installation, February 14, 2019, https://ec.europa.eu/clima/system/files/2019-02/p4_gd8_waste_gases_process_emissions_en.pdf.

While exported coproduct gases are credited in some form under all methods, with Environment Canada, ResponsibleSteel, and GHG Protocol iron and steel guidance highlighting the importance of avoiding double counting, methods diverge in their specific recommendations. Furthermore, only IPCC, EU ETS, and the GHG Protocol deal with fugitive emissions. Environment Canada, Worldsteel, and ISO 14404 do not separate out emissions from coproduct gases produced and combusted onsite, assigning their emissions to the full combustion of other fuels. Only ResponsibleSteel and Worldsteel consider the challenge of imported electricity produced from coproduct gas, issuing subtly different guidance. Worldsteel issues an "upstream" emissions factor for the electricity-equivalent value of power produced from these gases, while ResponsibleSteel specifies that emissions should not be counted when imported electricity has been generated from a facility's own coproduct gases to prevent facilities from reporting reductions from displacing electricity production that ordinarily would have taken place onsite. Worldsteel applies the same emissions factor both to purchased electricity generated from coproduct gases and to coproduct gases exported for electricity production. As a result, it assumes that both upstream and downstream electricity producers using byproduct gas generate power at the same GHG intensity, reporting emissions from net coproduct gas exports separately as "scope 1.1," while ultimately using the net calculated emissions as either a credit or a debit on the reporting company's scope 2 emissions. Finally, ISO only considers indirect material emissions from imported coproduct gases without applying separate consideration for imported electricity generated from coproduct gases.

ResponsibleSteel guidance goes above and beyond in providing detail on the different ways in which using process gases downstream can result in potential credits. Under this framework, exported process gases are first assigned a baseline emissions value representing the emissions that would result if they were flared in their entirety. This concept is equivalent to Worldsteel's "scope 1.1." Credits can then be claimed up to the value of the baseline, provided process gases are used downstream under certain conditions. If they are used for electricity production, the quantity of electricity produced from process gases is calculated, and the emissions that would have resulted from production of that electricity from natural gas, according to the most recent International Energy Agency (IEA) global intensity value, is assigned as a credit. If the process gases are consumed downstream to fuel a different process, a credit is assigned on the basis of the quantity of natural gas that would have otherwise been consumed. If process gases are used to produce a different organic product, credits are assigned both for the net carbon sequestered within that product and according to the GHG emissions saved by using process gases instead of other production methods. Finally, process gases directly captured for permanent storage, whether onsite or offsite, are eligible for credits, provided the storage technique can be demonstrated to be permanent, the CCS site will be monitored, and any leakages will be reported. Any leakage increases the reported emissions intensity for the steel producer in the year it occurs.

3.1.5 Electricity Emissions

All methodologies recommend applying different emissions factors for purchased or imported electricity and electricity directly produced onsite, but they recommend different levels of detail for these emissions factors. Worldsteel applies world averages, encouraging users to input their own local site supply information where possible, while the GHG Protocol – Scope 2 Guidance recommends calculating emissions factors based either on Power Purchase Agreements (PPAs) from specific sources or on a location grid to determine regional averages. ResponsibleSteel specifies the use of grid-average emissions factors for imported consumed electricity based on the average consumption mix of the grid from which the electricity is consumed. Table 7 summarizes the differences between approaches to calculating emissions factors from electricity.

ResponsibleSteel authorizes GHG emissions reductions based on contractual instruments such as Renewable Energy Certificates (RECs) or virtual PPAs in compliance with ISO 14064-1:2018. This standard permits the use of RECs for emissions reductions when the unit of power is packaged together with its certification and assigned a unique claim; when the reporting entity tracks and redeems or retires that claim itself; when the energy is produced either within the country or within the market boundaries of the grid; and when the energy is claimed at as close as possible of a time period to when the contract is applied.

The GHG Protocol – Scope 2 Guidance provides similar, but subtly different guidance. Purchasers can only claim certificates when they are purchased together with the unit of power. When certificates are not accompanied by a tracking system, the PPA must attribute the power generated to a specific recipient, accompanied by an audit to ensure no other purchasers are claiming the same units of power. Companies are advised to report their power consumption and emissions associated with such contracts to bodies calculating residual mix (i.e., grid emissions averages excluding claims) for use in location-based calculation to avoid double-counting. Putting this

Table 7: Electricity Emissions Factors Comparison

Environment Canada	Only considers emissions from onsite stationary combustion activities for the purpose of generating electricity. Indirect emissions from electricity consumption are not covered.
EU ETS	Emissions from electricity imported from offsite are not assigned to the reporting operator. Emissions from electricity exported to other installations are assigned to the reporting operator according entirely to the emissions from the fuels used to produce this electricity. No indirect emissions factor is used in either case.
GHG Protocol Scope 2 Guidance	Two methods for determining electricity emissions factors are applied: • Market-based emissions factors based on contractual mechanisms (e.g., PPAs or renewable energy certificates) that customers may use to reduce electricity emissions; and • A location-based factor based on average emissions for the local grid. Provides a decision diagram for the choice of method. Market-based emissions factors are generally preferred provided they meet the Quality Criteria[a] to ensure their integrity. Sometimes, both can be used.
IPCC Guidelines	• Defines autoproducers of electricity as enterprises such as iron and steel producers that generate electricity or heat in support of their primary activities, but not as their main business. • Assigns emissions from autoproducers to the sectors where they were generated, rather than the energy sector. • Assigns emissions from electricity imported to or exported from industrial plants to the energy sector, not to the IPPU sector.
ISO 14404 Series	• Provide both an upstream emission factor and credit emission factor of electricity, corresponding to the world average CO_2 intensity of electricity production provided by IEA 2006.
Responsible-Steel	• Location-based emissions factors for imported electricity are assigned according to the average consumption mix of the local grid for the current year, if possible. Indirect emissions from electricity may also be measured by PPAs or RECs compliant with ISO 14064-1 requirements. Netting of indirect emissions from electricity is not permitted.
Worldsteel	• Like ISO 14404, emissions factors of electricity are world average values based on IEA 2006 values. • Users can also input emissions factors based on yearly updated IEA world averages or by providing their own local site information.

Source: Prepared by the authors based on the listed guidelines.

a The Quality Criteria provides guidance on drafting contracts that reliably convey information about GHG emissions claims without resulting in duplication or omission. Please refer to the GHG Protocol – Scope 2 Guidance, page 60 for more details.

burden on companies makes this unlikely, but some third-party renewable certification bodies may do this automatically. Furthermore, the GHG Protocol does not permit companies that purchase RECs, then resell the power to markets that do not use certificates, to then claim reductions made by the end users. However, companies may resell power associated with certificates within a market using certificates while keeping the certificates for themselves.

3.1.6 Summary of Emission Sources

Table 8 summarizes the treatment of different potential direct and indirect emissions sources according to the various accounting methods compared.

Table 8: Comparison of Emission Sources

	Environment Canada	EU ETS	GHG Protocol	IPCC	ISO 14404	Responsible Steel	Worldsteel
Stationary Combustion Emissions							
Electricity Generation	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Reheating Furnaces	Yes	No	Yes	Yes	Yes	No	Yes
Coke production	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flaring of coproduct gas	Yes	Yes	Yes	Yes	N/A	No	N/A
Biomass	No	No	Yes	Yes	N/A	Yes	Yes
Process-Related Emissions							
CO_2 from Lime Production	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CO_2 from Pellet Production	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CO_2 from Sinter Production	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CO_2 from DRI Production	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CH_4 from Sinter Production	No	Yes	Yes	Yes	No	Yes	No
CH_4 from Pig Iron Production	No	Yes	Yes	Yes	No	Yes	No
CH_4 from DRI Production	No	Yes	Yes	Yes	No	Yes	No
Fugitive Emissions [a]	No	Yes	Yes	Yes	No	N/A	No
Indirect and other offsite emissions							
Production of imported materials	Yes	No	Yes	Yes	Yes	Yes	Yes
Electricity consumption	No	No	Yes	Yes	Yes	Yes	Yes
Offsite mobile combustion	No	No	N/A	N/A [b]	No	Yes	No
Onsite mobile combustion	Yes [c]	No	Yes	Yes	No	Yes	No

Source: Prepared by the authors based on the listed guidelines.

a Fugitive emissions include diffuse emissions from coke production and from venting or flaring of coproduct gases.
b The IPCC recommends the inclusion of offsite combustion and process emissions in the context of its Tier 3 framework.
c Environment Canada does not include onsite mobile combustion that is not integral to the production process.

3.1.7 Scrap Iron and Steel

Of particular interest is scrap metal, which is widely used both in EAF and BOF steel production. Scrap can serve as a preprocessed source of ferrous material or a replacement for pig iron, potentially displacing the emissions from smelting raw iron ore and making scrap-based steel production fundamentally less emissions-intensive than primary steel production. However, scrap-based production is constrained by the supply of both pre-consumer and post-consumer scrap, limiting the scale at which individual sites can rely on scrap to decarbonize their operations. According to IEA projections, there is not enough scrap to meet global demand for steel through 2050, with only half of steel demand met under their net-zero scenario.[26] Furthermore, EAF production from scrap metal still consumes energy in the form of electricity, and pre-consumer scrap is more carbon-intensive than post-consumer scrap. Finally, different carbon contents between input scrap steel and output crude steel could require a mass-balance adjustment. These differences underline a need to report emissions from primary steel production and scrap steel production separately. However, no methodology explicitly requires this separate reporting. Instead, each methodology applies implicit treatments to account for differences in emissions and any potential credits.

IPCC, Environment Canada, and EU ETS all contain relatively detailed notes on the inclusion of scrap steel. The IPCC Guidelines call for the reporting of all carbon used in scrap-based EAFs under process-related IPPU emissions. The guidelines also acknowledge the existence of specialty steel production units which entirely consume scrap without consuming any carbon electrodes, in which case direct CO_2 and CH_4 emissions do not apply. Environment Canada bases the calculation of direct emissions from consumption of scrap steel on the difference between the carbon content of the scrap steel and the raw steel produced as output. EU ETS accounts for emissions from scrap iron and steel by providing both emissions factors and calculations based on the carbon content of the scrap and of the final product.

Worldsteel recommends the use of default emissions factors for imported scrap crude steel, and the GHG Protocol Iron and Steel Tool includes emissions from consumption of scrap steel as direct emissions and specifies an emissions factor for scrap iron. However, the GHG Protocol does not allow iron and steel manufacturers to claim emissions from incidental production of scrap iron and steel as a credit. Meanwhile, ISO 14404 acknowledges scrap under "other emission sources," without indicating specific guidelines on measuring emissions linked to its use. ResponsibleSteel requires the site to separately account for the quantity of scrap used in annual production of steel, assigning an embodied GHG emissions factor of zero and requiring the estimation of GHG emissions associated with the transportation of the scrap to the steel mill.

$$E_{CO2} =$$
$$\sum_{t=1}^{N} K_{t,d,CO2} \times Q_{t,d,CO2} + \sum_{t=1}^{N} K_{t,i,CO2} \times Q_{t,i,CO2} - \sum_{t=1}^{N} K_{t,c,CO2} \times Q_{t,c,CO2}$$

t (1-N) = fuel, energy, or other input
k = emissions factor
Q = quantity on site
D = direct emissions
I = indirect emissions
C = credit emissions

No methodology examined touches on the differences in carbon footprints between different categories of scrap. Furthermore, no methodology explicitly requires separately reporting steel primary production from scrap-based production. Because steel production from scrap, particularly post-consumer scrap, is so much less GHG-intensive than primary steel production, revised carbon accounting methodologies should require reporting both of total production of scrap and of the grades of scrap inputs used (i.e., manufacturing scrap outside of steelworks and post-consumer scrap).

3.2 Emissions Calculation Methods

After determining the extent of the emissions to be reported and identifying any credits are identified, the reporting entity takes the final step in reporting: calculating and adding up its total emissions. It can do so on a step-by-step process basis using emissions factors, imputed by measuring inflows and outflows through a mass-balance approach, or directly measuring through technology such as Continuous Emission Monitoring Systems (CEMS).

No single standard exists for calculating emissions, applying default factors, or determining which specific class of emissions factors to use. Table 10 outlines the discrepancies between the various calculation methods applied by each methodology. The simplest class of calculation method, illustrated by the equation adapted from ISO 14404 below, simply adds up the total direct,

26 Mission Possible Partnership, "Net-Zero Steel Sector Transition Strategy," October 2021, 6, https://missionpossiblepartnership.org/wp-content/uploads/2022/09/Making-Net-Zero-Steel-possible.pdf .

indirect, and credit emissions according to the quantity of fuels, energy or other inputs used and the appropriate emissions factor for each fuel, energy, or other input. This type of equation gives a bird's eye CO_2 intensity approach through an aggregated CO_2 inventory that abstracts away contributions from individual processes.

Other methodologies echo guidance provided by IPCC and summarized in Appendix VI by dividing calculation methods into "tiers" of granularity and data quality. The goal of this approach is to encourage companies to take advantage of data at hand to measure their emissions more accurately and transparently, and to discourage the use of generalized, default emissions factors based on outdated data and not based on the carbon contents of the associated inputs. While the IPCC presumes Tier 3 approaches based on direct measurement of emissions through CEMS to be more reliable than Tier 2 approaches estimating site-specific emissions based on carbon content, Tier 2 approaches may in some cases be more accurate. GHG reporting under Tier 2 and Tier 3 approaches typically vary by 1 to 2%,[27] and under German guidelines, using a CEMS requires validation by a mass-balance approach to ensure the meeting of accuracy requirements.[28] While the GHG Protocol Corporate Standard, IPCC, EU ETS, and Environment Canada provide a framework for determining what caliber or tier of data to use, no single method guarantees that the data used under these methods are of the highest quality reasonably available, allowing producers whose emissions control is far inferior to the world average to rely excessively on secondary data.

3.2.1 Tier 1 and Default Emissions factors

Emissions factors, which describe the quantity of various types of GHG output resulting from usage of units of a particular input, are essential components of GHG emissions reporting conducted at the level of individual fuels or activities. Some emissions factors are calculated through a stoichiometric analysis of the carbon contents of fuels and inputs and the estimated oxidation rate, while others lack such transparency in their methodologies.

27 Cassandra B. Drotman, Raymond H. Huff, Patrick S. Sullivan, "Best Practices Learned from Greenhouse Gas Reporting," A&WMA's 110th Annual Conference & Exhibition (June 5-8, 2017), 5, https://www.scsengineers.com/wp-content/uploads/2017/07/CDROTMAN-Abstract-2017.pdf.

28 German Emissions Trading Authority (DEHSt), German Environment Agency, "Application of continuous emissions measurement systems (CEMS) for the determination of CO_2 emissions," November 2019, 8, https://www.dehst.de/SharedDocs/downloads/EN/publications/Experience_report-KEMS.pdf?__blob=publicationFile&v=2.

Table 9: Comparison of Default Emissions Factors Used by Select Methods

	EU ETS [a]	IPCC 2006	IPCC 2019	ISO 14404 – Direct [c]	ISO 14404 – Upstream [c]	Worldsteel Scope 1	Worldsteel Scope 3
Pig Iron	0.15 (t)	1.35 (t)	1.43 (t)	-	-	[a] 0.172 (t)	1.855 (t)
Coke	-	0.56 (t)	[d] 0.51 or 1.23 (t)	3.257 (t)	0.224 (t)	3.257 (t)	0.224 (t)
Petroleum Coke	3.19 (t)	-	-	-	-	3.115 (t)	-
Gas-based DRI	0.07 (t)	0.70 (t)	0.70 (t)	0.073 (t)	0.780 (t)	[a] 0.073 (t)	0.780 (t)
Sinter	-	0.20 (t)	0.21 (t)	-	0.262 (t)	[b] 2.785 (t)	0.262 (t)
Pellets	-	0.03 (t)	0.19 (t)	-	0.137 (t)	-	0.137 (t)
LDG	-	1.46 (t)	1.58 (t)	1.512 (k.NM3)	-	1.513 (k.NM3)	-
OHF Steel	-	1.72 (t)	1.72 (t)	-	-	-	-
EAF Steel	-	0.08 (t)	0.18 (t)	-	-	-	-

Source: Prepared by the authors based on the listed guidelines.

a IPCC reference value. All cell values given as tCO_2 per unit in parentheses.
b IEA reference value.
c Credit emissions factors based on Worldsteel methodology.
d 0.51 with product recovery tech, 1.23 without product recovery tech.

Many carbon accounting methodologies publish default emissions factors, intended for use when more site-specific measurement of emissions factors is not possible and developed by author organizations or outside research institutions. When these default emissions factors are not based on carbon content, serious discrepancies can emerge, such as inconsistencies between direct and offsite emissions, with little justification provided. Applying a default emissions factor to an entire product chain, for instance by calculating total emissions from pig iron production on the basis of the quantity of pig iron produced, ignores many potential sources of technological and emission variation.

The default emissions factors provided by each method vary according to their original sources, their reporting units, and the final values given after conversion. Despite the GHG Protocol Corporate Standard's admonition that emissions factors based on fuel energy content are more accurate than those based on mass or volume, all other methods publish their default emissions factors in terms of mass or volume, creating problems related to the accuracy of conversion between units and to the precision of comparing quantities within the same set of accounting standards.

Default emissions factors may facilitate reporting where data are lacking, but they are often based on unsupported assumptions that fail to hold up across diverse contexts. Outside of the differences mentioned above between source materials, units, and the age of data used, default emissions factors often do not account for different combustion technologies, facility layouts, varying grades of the same fuels, and oxidation percentages. For these reasons, applying default emissions factors to emissions calculations serves as a limiting factor. Their use obscure fuel and facility details that may be causes of outsized emissions and inhibits the overall accuracy of reporting. Because of their inherent shortcomings, default emissions factors may fail to provide users with actionable data even if they were perfectly up to date and harmonized between methods. For these reasons, plants are strongly encouraged to pursue higher tiers of data quality. ResponsibleSteel attempts to address the moral hazard risks of using default emissions factors by basing its own not on averages, but on top-decile figures, to avoid giving an emissions reporting advantage to facilities that are more carbon-intensive than most. ResponsibleSteel's default upstream emissions factors are also designed to measure "embodied carbon," which includes emissions related

Table 10: Emissions Calculation Methodology Discrepancies

	Is a tiered approach adopted?	Are detailed calculation equations provided for different sources and production processes?	Are emissions factors provided based on direct/ upstream/ credit emission scopes?	Do they specify when default emissions factors can't be used?	Do they require uncertainty assessment or provide uncertainty assessment on default parameters?
Environment Canada	Yes	Yes	Yes	No	Yes
EU ETS	Yes	Yes	Yes	No	Yes
GHG Protocol	Yes	Yes	No	No	No
IPCC	Yes	Yes	Yes	Yes	Yes
ISO 14404 series	No	No	Yes	No	No
ResponsibleSteel	Yes	No	Yes	Yes	No
Worldsteel	No	No	Yes	No	No

Source: Prepared by the authors based on the listed guidelines.

Table 11: Uncertainty Ranges from IPCC 2019

Method	Data Source	Uncertainty Range
Tier 1	CO_2 default emissions factors	± 10%
	CH_4 default emissions factors	± 400%
	N_2O default emissions factors	± 300%
	National production data	± 10%
	Material-specific default carbon contents	± 10%
Tier 2	Material country-specific carbon contents	± 10%
	National reducing agent and process materials data	± 10%
Tier 3	Company-derived process materials data	± 5%
	Company-specific measured CO_2 and CH_4 data	± 5%
	Company-specific emissions factors	± 5%

Source: IPCC.

both to production and to transportation of intermediate goods between locations along the supply chain.

Even so, some methods specify standards for when default emissions factors may or may not be used. Under the IPCC Guidelines, usage of default emissions factors is considered inappropriate for any process that is a major source of emissions. For pig iron that is not processed into steel, the IPCC also specifies that emissions should be estimated separately when using default emissions factors, since the included default emissions factors cover emissions from both iron and steel production. ResponsibleSteel does not permit usage of default emissions factors for any pig iron or steel (including scrap metal) imported to the site, requiring them to be accounted for using primary data specific to the input material's site of production.

The uncertainty ranges that IPCC attaches to each tier (see Table 11) underlines the importance of using the highest possible tier of data quality. While the uncertainty range for Tier 3 data sources is considered to remain within 5%, uncertainty for Tier 1 sources can reach an estimated 10% for CO_2 emissions and as high as 300–400% for other GHGs. For CH_4 and N_2O in particular, default emissions factors are insufficient because they do not account for differences in the emissions control technologies that ultimately define how much of these gases is released into the atmosphere.

IPCC, EU ETS, and Environment Canada hedge against the risk of inaccurate calculations by requiring uncertainty assessments when default parameters are used. Environment Canada also warns users that uncertainty can arise from activity data, miscalibrated sampling equipment, and nonrepresentative datasets. In contrast, ISO 14404 and Worldsteel neither discuss the risks of using default factors nor encourage users to conduct uncertainty assessments, outside of an exhortation from ISO to "reduce bias and uncertainties of the data being collected and used for the calculation and methodologies of the calculations as much as appropriate."[29]

3.2.2 Tier 2 and the Mass-Balance Approach

To reconcile the need for accurate data with the challenges in obtaining site-specific data for certain producers, the IPCC provides the option of applying a carbon mass-balance approach in its Tier 2 guidance. Using the law of conservation of mass and stoichiometry, the carbon mass-balance method measures the difference in carbon content between the inputs that go into the steelmaking process and the outputs of that process through equations similar to that applied by the U.S. Environmental Protection Agency and reproduced below. Under mass

29 ISO 14404-1, 7.

balance–based methodologies, emissions from source streams are calculated either from default values for the carbon contents of particular inputs and outputs, or via data obtained directly through measurement systems and laboratory analyses of parameters such as carbon content, calorific factor, and biomass percentage. The outcome is a highly accurate measurement of the carbon lost during the process.

The Tier 2 methodology equation is as follows:

$$E_{CO_2} = \left[\sum_a (Q_a \times C_a) - \sum_b (Q_b \times C_b)\right] \times \frac{44}{12}$$

where,

E_{CO_2} = Emissions from coke, pig iron, EAF steel, or BOF steel production, metric tons
a = Input material a
b = Output material b
Q_a = Quantity of input material a, metrics tons
C_a = Carbon content of input material a, metric tons C/metric ton material
Q_b = Quantity of output material b, metric tons
C_b = Carbon content of output material b, metric tons C/metric ton material
44/12 = Stoichiometric ratio of CO_2 to C

Source: EPA.[30]

Rather than depending on unreliable upstream emissions factors not calculated based on carbon content, the mass-balance approach offers a potential shortcut to calculating carbon emissions for producers who lack information from their suppliers for imported inputs or who have not invested in CEMS to directly measure emissions as detailed in Tier 3. This is particularly the case for the steel industry, whose plants often feature in-house mass-balance models for controlling process parameters.[31] Indeed "the carbon content of the substance not only determines its strength and its brittleness in application, but it affects how the metal can be worked."[32] The carbon content of different grades of steel can vary from as low as .05% for low-carbon grades used for machining to 1.5% or even higher for high-carbon grades which emphasize strength, hardness, and wear resistance.[33] Faulty information on carbon content leads to mechanical failure and waste.

GHG Protocol iron and steel guidance indicates that mass-balance approaches are particularly suited for calculated CO_2 emissions "because CO_2 emissions are largely determined by the carbon contents of the consumed materials."[34] Conversely, GHG Protocol iron and steel guidance notes that "N_2O and CH_4 emissions are much more influenced by the combustion or emission control technologies employed by the industrial apparatus."[35] Thus, the GHG Protocol encourages a hybrid approach between applying a mass-balance approach for CO_2 emissions and process-based emissions factors for other GHG emissions, only reverting to default emissions factors when the appropriate data for this approach cannot be obtained.

As noted above, Worldsteel and ISO do not encourage a mass-balance approach, instead listing a wider and more detailed range of default emissions factors for Tier 1–style usage. While Worldsteel states that scope 1 emissions should be determined through a carbon-balance approach, no further information is provided on this, and ISO does not mention the approach at all. By contrast, EU ETS, Environment Canada, and GHG Protocol iron and steel guidance match the example of the IPCC by providing mass-balance equations for each process and guidance for implementation.

Both Tier 1– and Tier 2–style calculations require an oxidation factor to express incomplete combustion and account for the carbon that is neither emitted nor incorporated into the final output, instead being left behind in the form of ash or soot. No method provides guidance for this other than EU ETS and Environment Canada, and methods do not provide documentation on whether the provided default emissions factors take the oxidation factor into account, which will vary widely between facilities.

3.2.3 Tier 3 and Continuous Emission Monitoring Systems (CEMS)

Under the uppermost tier of data quality under the IPCC framework, plants use CEMS to automatically measure and report the entirety of the direct emissions from the facility. CEMS usually record the levels of carbon-14, a radioactive isotope of carbon occurring at fixed natural ratios, in flue gas flows.[36] In theory, this tier has clear-cut advantages

30 U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016: Industrial Processes and Product Use, 68, https://www.epa.gov/sites/default/files/2018-01/documents/2018_chapter_4_industrial_processes_and_product_use.pdf.

31 Brooks, G., Madhavan, N., Rhamdhani, M., Rout, B., Schrama, F., and Overbosch, A., "General mass balance for oxygen steelmaking," Ironmaking & Steelmaking, 48:1, (2020): 40-54, https://doi.org/10.1080/03019233.2020.1731252.

32 "Measuring carbon in steel – absolute reliability matters," Hitachi Corporation, Willy Sanders, December 1, 2017, https://hha.hitachi-hightech.com/en/blogs-events/blogs/2017/12/01/measuring-carbon-in-steel-%E2%80%93-absolute-reliability-matters/.

33 "The different categories of carbon steel plate," Leeco Steel, August 17, 2020, https://www.leecosteel.com/news/post/carbon-steel-categories/.

34 "The Greenhouse Gas Protocol: GHG Emissions from Iron and Steel Production," 9.

35 Ibid., 9.

36 "Application of continuous emissions measurement systems (CEMS) for the determination of CO_2 emissions." German Emissions Trading Authority, 11.

to the tiers below it. No calculations are required, and no assumptions about emissions factors or carbon content are needed, leading to theoretical improvements in accuracy. However, CEMS represent significant investments that plants are unlikely to undertake unless they operate in strict regulatory environments. Plants may also avoid making this investment unless they believe that using CEMS will allow them to substantially reduce the emissions they otherwise would have needed to report.

For these reasons, usage of CEMS is highly regulated within countries and international environments that enforce industrial emission regulations. The US EPA requires both steel and aluminum producers to install CEMS to measure and record SO_2, N_2O, and CO_2 emissions from coal-burning equipment with a minimum heat input capacity of 100 million BTU per hour. This mainly applies to steam boilers and process heaters using steam within steel-producing facilities.[37] Under EU ETS, facilities are permitted to use CEMS to monitor all CO_2 emissions from onsite, but only under certain quality assurance conditions. Namely, CEMS may only be used when they can be demonstrated to measure CO_2 flow within 2.5% of the site's true value. Accordingly, facilities can augment CEMS with verification via indirect measurement through a mass balance approach when flue gas volume flows are particularly high and inaccuracies in the CEMS system have the potential to multiply.[38] This combination approach provides value by validating emissions reporting against alternative calculation methods.

4 Case Study

How would the differences between accounting methodologies affect the volume of emissions reported by a steel plant? To find out, CCSI adapted sample figures provided by ISO to design a simplified integrated steel facility producing a total of 7,000,000 metric tons of crude steel per year, as outlined in the diagram in Figure 3. In addition to the stationary processes listed, the facility is responsible for 55,738 metric tons of CO_2e emissions from process-critical onsite mobile combustion and 36,927 metric tons of CO_2e emissions from other mobile combustion sources under company control. The Environment Canada, GHG Protocol, ISO 14404, ResponsibleSteel, and Worldsteel methodologies were then applied to this activity data. Appendix VII contains a detailed description of the methodology applied to construct this case study.

37 Maryland, Continuous Emission Monitoring Requirements, Maryland Code of Regulations 26.11.01.11, April 8, 2022, https://www.law.cornell.edu/regulations/maryland/COMAR-26-11-01-11.

38 "Application of continuous emissions measurement systems (CEMS) for the determination of CO2 emissions," German Emissions Trading Authority, 8.

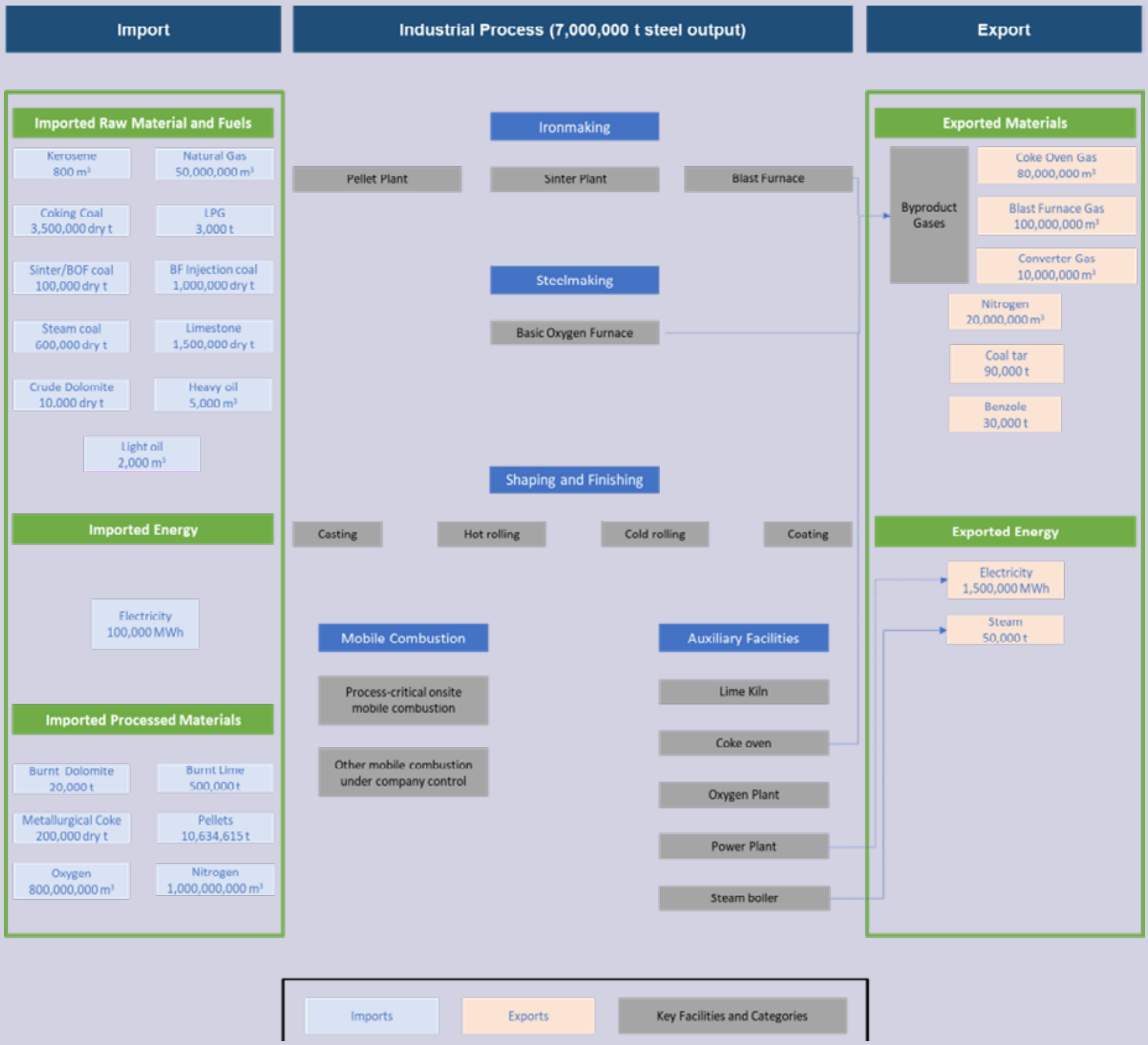


Figure 3: Simplified Inputs and Outputs for a Steel Plant.

Source: Adapted from data provided in ISO 14404-1, Annex C

Emissions reported under ISO 14404 and Worldsteel are relatively similar, as expected. The only sources of discrepancy between the two methods under the data used were the emissions factors applied for emissions from exported byproduct gases, as well as the relatively insignificant inclusion of upstream emissions from imported heavy oil, light oil, and kerosene under Worldsteel. However, substantially higher emissions are reported under these two methods than under methods provided by Environment Canada and the GHG Protocol. The first major cause of this difference, found under onsite stationary processes, is that the default emissions factors provided by ISO 14404 and Worldsteel are considerably greater than those used by Environment Canada and the GHG Protocol. In fact, the range of calculation outcomes for emissions according to these default emissions factors falls roughly within the ±10% expected range of uncertainty for use of default emissions factors anticipated by the IPCC Guidelines. Reported direct emissions under ResponsibleSteel are nominally higher than those under the GHG Protocol, with the caveat that its emissions factors reflect the "embodied carbon" of inputs. This measure additionally includes emissions related to extraction and transportation of these inputs.

Table 12: Comparison of Calculated Emissions in tCO_2e

CO_2e Emissions Category	ISO 14404	Worldsteel	Environment Canada	GHG Protocol	Responsible Steel
Onsite Stationary Processes	16,863,987	16,866,287	13,579,633	15,365,804	16,345,458
Process-Critical Onsite Mobile Combustion	N/A	N/A	55,738	55,738	N/A[a]
Other Mobile Combustion under Company Control	N/A	N/A	N/A	36,927	N/A[a]
Credit from Byproduct Gas Export	(99,360)	(108,320)	(103,620)	(200,200)	(98,049)
Net Indirect Emissions from Other Materials	1,977,212	1,979,284	N/A	378,675	3,569,255
Net Indirect Emissions from Energy	(715,350)	(715,350)	N/A	47,157	50,400
Total tCO_2e Emissions	**18,026,489**	**18,021,901**	**13,531,750**	**15,684,101**	**19,867,063**

Source: Prepared by the authors based on the listed guidelines.

a ResponsibleSteel uses emissions factors reflecting the "embodied carbon" in inputs, which includes emissions from extraction and transportation of raw materials. Therefore, emissions from mobile combustion are already embedded in the given emissions factors and are not counted separately as under the other methodologies.

The second major source of discrepancy is the inclusion of vastly more indirect emissions from imported materials. Unlike Environment Canada, which does not account for emissions from imported materials, and the GHG Protocol, which only accounts for emissions from upstream lime production, ISO 14404 and Worldsteel account for upstream emissions from imported sources such as nitrogen, oxygen, and crucially, pellets, which account for nearly 1.5 million tCO_2e of the calculated difference. The difference from upstream material emissions is so great that even though ISO 14404 and Worldsteel provide far more leniency in awarding credits for exported electricity, heat, and steam than the GHG Protocol (Environment Canada does not calculate any form of indirect emissions other than those linked to byproduct gas exports), the net indirect emissions under Worldsteel and ISO 14404 still exceed those under the GHG Protocol. ResponsibleSteel does not permit any netting from exported energy or materials, with the exception of process gases under certain conditions, which makes its reported net indirect emissions of all types higher than those reported under the other methods.

The third notable area of difference is mobile emissions, which are reported under Environment Canada and the GHG Protocol but not under ISO 14404 or Worldsteel. Environment Canada only considers onsite mobile combustion critical to the production process, such as the transport of raw and intermediate materials between locations at the facility. The GHG Protocol expands its consideration to encompass all mobile combustion from vehicles under company ownership or control.

5 Future Topics of Research

The methods examined account for certain upstream processes in the form of indirect emissions from imported electricity and from imported processed materials. However, most do not account for emissions from mining and transportation of raw materials. With the exception of the GHG Protocol, they also fail to account for upstream fugitive emissions from coal mining and natural gas. Even as use of green hydrogen in the steelmaking process becomes more prevalent in the future, the question of measuring and reducing fugitive emissions from upstream processes such as transportation of hydrogen will remain.[39] Biomass poses a similar challenge, with most methods failing to properly integrate emissions impacts from land-use change. Further research should examine how well carbon accounting standards within the steel sector integrate with methodologies for any upstream sectors to understand whether any accounting gaps or potential for double-counting could emerge.

39 Fugitive Hydrogen Emissions in a Future Hydrogen Economy (Frazer-Nash Consultancy, March 2022), 5, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067137/fugitive-hydrogen-emissions-future-hydrogen-economy.pdf.

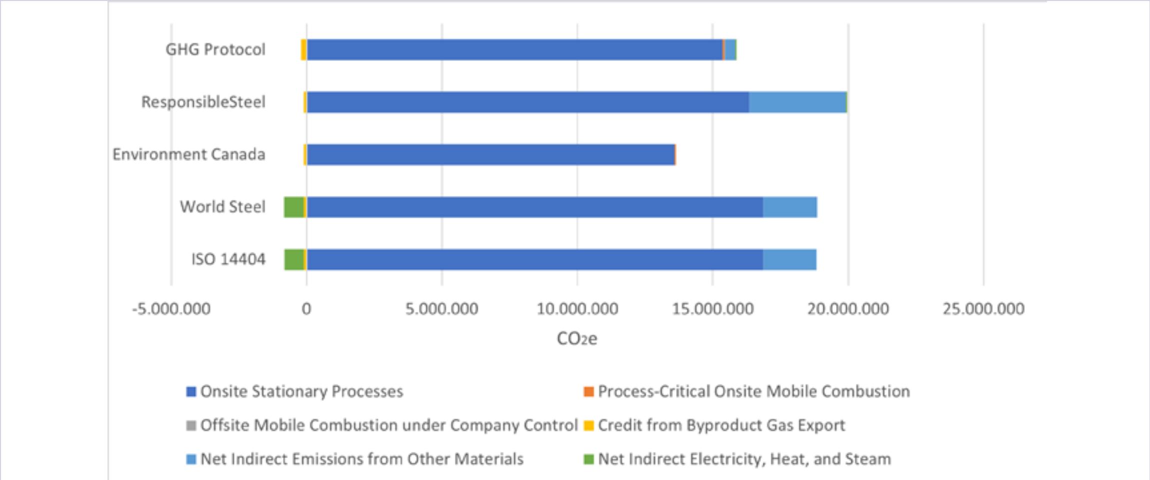


Figure 4: Visualization of Case Study Emissions Sources

Source: Prepared by the authors based on the listed guidelines.

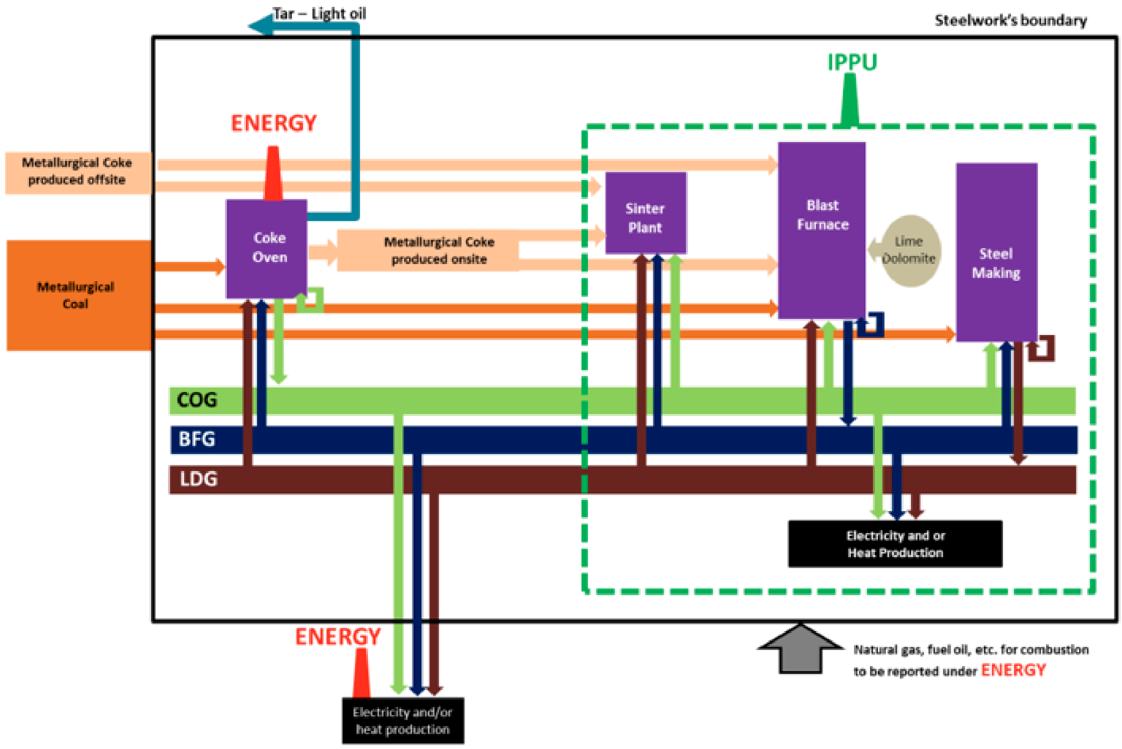
Another topic to investigate further concerning credits is the application of an emissions credit for exported CO_2 under Worldsteel and ISO 14404 methodology. Key markets for this "ingredient" CO_2 include the food and beverage industry, the medical industry, the oil and gas industry, and the mining industry. Further analysis of carbon accounting frameworks in these industries will be required to determine whether or applying such a credit remains valid. The validity of a credit depends on its additionality (whether exporting CO_2 prevents the production of CO_2 elsewhere) and permanence (whether CO_2 sequestered in such a way remains out of the atmosphere). If CO_2 is exported to operations which ultimately release it into the atmosphere, life cycle analyses will need to determine whether the responsibility for these emissions should be assigned to the selling or the purchasing company. ResponsibleSteel, for one, has answered this question by requiring any credit claims on the basis of CCS to be accompanied by documentation demonstrating that the reduction will be permanent, and by adding any GHG leakage at CCS projects to emissions from the steel site for the year. Methodologies will also need to consider whether it is reasonable to apply credits when carbon sequestration is used as a means of increasing fossil fuel production, e.g., by pumping CO_2 into shale gas formations.

Third, while more advanced techniques for calculating emissions factors for electricity consumption incorporate specific location-based calculations or data directly from electricity suppliers in the form of PPAs, outside of ResponsibleSteel and the GHG Protocol, no method discusses the potential for double-counting introduced by renewable energy and green certificates. In addition, no methodologies were found to incorporate any level of time analysis into determining these emissions factors, although ResponsibleSteel requires grid-average emissions factors produced during the reporting year to be used. Emissions intensity from electricity producers varies significantly over the course of the day and year as shifts between modes take place, demand rises and falls, and renewable energy installations go online and offline. A recent study found that time variation in electricity consumption can bias carbon inventories by as much as 35%, with variation expected to increase as intermittently produced renewable energy becomes increasingly prevalent.[40] As green hydrogen becomes more predominant in steel production, more precisely measuring temporal differences in the overall carbon footprint of steel will become increasingly important. New research will need to determine the implication of time-based variation in emissions from electricity consumption for the field of carbon accounting as a whole, and for iron and steel facilities in particular.

Finally, much of the apparent disconnect between the IPCC methodology and the other methodologies examined owes to its status as a system for building national, rather than corporate GHG inventories. A full accounting of the differences between corporate GHG inventory systems and national GHG inventory systems will need to take place before corporate GHG reporting can seamlessly feed into national GHG reduction pledges and international emission trading systems.

40 Gregory J. Miller, Kevin Novan, and Alan Jenn, "Hourly accounting of carbon emissions from electricity consumption," Environmental Research Letters 17, no. 4 (April 8, 2022), https://iopscience.iop.org/article/10.1088/1748-9326/ac6147.

Appendix I – Breakdown of IPCC Emissions Reporting for Steel by Sector



Source: IPCC.

Energy Sector	IPPU Sector
1. Stack emissions from coke production: • Stack emissions which comprise GHG emissions from both the carbonization (fuel transformation) of the coal, and from fuel combustion. 2. Fugitive emissions from coke production: • Diffuse emissions (i.e. not emitted via stacks or vents) that occur during regular or irregular operations, originating from the transportation of coke, the use of ascension pipes, coke pushing, quenching, and leakages in the battery. • Flaring or venting of gases at coke ovens. 3. Derived gases (including blast furnace gas, coke oven gas and converter gas) which are exported off-site for subsequent combustion at another facility, such as a nearby brick works for heat production or a main electricity producer.	4. The emissions from the combustion of blast furnace gas, coke oven gas and converter gas **for sintering** in the blast furnace and for steel making. 5. The emissions from the combustion of blast furnace gas, coke oven gas and converter gas to **produce heat for different uses within the steelworks** (rolling mill, hot rolling mill, plate mill, bar mill, cold rolling mill, coating, pipe). 6. The emissions from the combustion of derived gases (including blast furnace gas, coke oven gas and converter gas) to **produce electricity in an internal power plant.** 7. Fugitive emissions from other production process: • The emissions from flaring or venting of gases elsewhere in the Iron and Steel industry (e.g., **blast furnace, sinter plant, basic oxygen furnace**) are reported under IPPU.

Appendix II – Export Products Eligible for Credits under ISO 14404

Subscript designa-tor for Q t	Emission sources	Unit	Quantities of credit emission source $Q_{t,c,CO2}$
19	Nitrogen	10^3m^3(stp)	$Q_{19,c,CO2}$
20	Argon	10^3m^3(stp)	$Q_{20,c,CO2}$
21	Oxygen	10^3m^3(stp)	$Q_{21,c,CO2}$
Energy carriers			
22	Electricity	MWh	$Q_{22,c,CO2}$
23	Steam	t	$Q_{23,c,CO2}$
Ferrous-containing material			
24	Pellets	t	$Q_{24,c,CO2}$
25	Sinter	t	$Q_{25,c,CO2}$
26	Hot metal	t	$Q_{26,c,CO2}$
27	Cold iron	t	$Q_{27,c,CO2}$
28	Gas-based DRI	t	$Q_{28,c,CO2}$
29	Coal-based DRI	t	$Q_{29,c,CO2}$
Alloys			
30	Ferro-nickel	t	$Q_{30,c,CO2}$
31	Ferro-chromium	t	$Q_{31,c,CO2}$
32	Ferro-molybdenum	t	$Q_{32,c,CO2}$
Product and by-product			
33	CO_2 for external use	t	$Q_{33,c,CO2}$
34	Coal tar	t	$Q_{34,c,CO2}$
35	Benzole (coal light oil)	t	$Q_{35,c,CO2}$
Others			
N	Other emission sources	—	$Q_{N,c,CO2}$

[a] 10^3=1000

[b] Standard temperature and pressure.

Subscript designa-tor for Q t	Emission sources	Unit	Quantities of credit emission source $Q_{t,c,CO2}$
Gas fuel			
1	Natural gas	$10^{3\ a}$ m^3(stp [b])	$Q_{1,c,CO2}$
2	Coke oven gas	10^3m^3(stp)	$Q_{2,c,CO2}$
3	Blast furnace gas	10^3m^3(stp)	$Q_{3,c,CO2}$
4	BOF gas	10^3m^3(stp)	$Q_{4,c,CO2}$
Liquid fuel			
5	Heavy oil	m^3	$Q_{5c\ CO2}$
6	Light oil	m^3	$Q_{6,c,CO2}$
7	Kerosene	m^3	$Q_{7,c,CO2}$
8	LPG	t	$Q_{8,c,CO2}$
Solid fuel			
9	Coking coal	dry t	$Q_{9,c,CO2}$
10	BF injection coal	dry t	$Q_{10,c,CO2}$
11	Sinter/BOF coal	dry t	$Q_{11,c,CO2}$
12	Steam coal	dry t	$Q_{12,c,CO2}$
13	Coke	dry t	$Q_{13,c,CO2}$
14	Charcoal	dry t	$Q_{14,c,CO2}$
Auxiliary material			
15	Limestone	dry t	$Q_{15c\ CO2}$
16	Burnt lime	t	$Q_{16,c,CO2}$
17	Crude dolomite	dry t	$Q_{17,c,CO2}$
18	Burnt dolomite	t	$Q_{18,c,CO2}$

Appendix III – Tier 1 and 2 Equations Used by IPCC

IPCC Tier 1 Equations:

EQUATION 4.4
CO₂ EMISSIONS FROM IRON AND STEEL PRODUCTION (TIER 1)

$$\text{Iron \& Steel: } E_{CO_2,\,non-energy} = BOF \bullet EF_{BOF} + EAF \bullet EF_{EAF} + OHF \bullet EF_{OHF}$$

EQUATION 4.5
CO₂ EMISSIONS FROM PRODUCTION OF PIG IRON NOT PROCESSED INTO STEEL (TIER 1)

$$\text{Pig Iron Production: } E_{CO_2,\,non-energy} = IP \bullet EF_{IP}$$

EQUATION 4.6
CO₂ EMISSIONS FROM PRODUCTION OF DIRECT REDUCED IRON (TIER 1)

$$\text{Direct Reduced Iron: } E_{CO_2,\,non-energy} = DRI \bullet EF_{DRI}$$

EQUATION 4.7
CO₂ EMISSIONS FROM SINTER PRODUCTION (TIER 1)

$$\text{Sinter Production: } E_{CO_2,\,non-energy} = SI \bullet EF_{SI}$$

EQUATION 4.8
CO₂ EMISSIONS FROM PELLET PRODUCTION (TIER 1)

$$\text{Pellet Production: } E_{CO_2,\,non-energy} = P \bullet EF_{P}$$

EQUATION 4.8A (NEW)
CO₂ EMISSIONS FROM BFG AND LDG FLARING (TIER 1)

$$E_{CO_2,\,non-energy} = BFG \bullet (EF_{CO_2})_{BFG\ flaring} + LDG \bullet (EF_{CO_2})_{LDG\ flaring}$$
$$= BFG \bullet (R_{BFG\ flared} \bullet CC_{BFG} \bullet \frac{44}{12}) + LDG \bullet (R_{LDG\ flared} \bullet CC_{LDG} \bullet \frac{44}{12})$$

$E_{CO_2,\ non\text{-}energy}$	= emissions of CO_2 to be reported in IPPU Sector, tonnes
BOF	= quantity of BOF crude steel produced, tonnes
EAF	= quantity of EAF crude steel produced, tonnes
OHF	= quantity of OHF crude steel produced, tonnes
IP	= quantity of pig iron production not converted to steel, tonnes
DRI	= quantity of Direct Reduced Iron produced nationally, tonnes
SI	= quantity of sinter produced nationally, tonnes
P	= quantity of pellet produced nationally, tonnes
EF_x	= emission factor, tonnes CO_2/tonne *x* produced

IPCC Tier 2 Equations:

EQUATION 4.9 (UPDATED)
CO_2 EMISSIONS FROM IRON AND STEEL PRODUCTION (TIER 2)

$$E_{CO_2,non-energy} = [PC \bullet C_{PC} + \sum_a (COB_a \bullet C_a) + CI \bullet C_{CI} + L \bullet C_L + D \bullet C_D + CE \bullet C_{CE} + \sum_b (O_b C_b) + COG \bullet C_{COG} - S \bullet C_S - IP \bullet C_{IP} - BFG \bullet C_{BFG}] \bullet \frac{44}{12}$$

$E_{CO_2, non-energy}$ = emissions of CO_2 to be reported in IPPU Sector, tonnes

PC = quantity of coke consumed in iron and steel production (not including sinter production), tonnes

COB_a = quantity of onsite coke oven by-product *a*, consumed in blast furnace, tonnes

CI = quantity of coal directly injected into blast furnace, tonnes

L = quantity of limestone consumed in iron and steel production, tonnes

D = quantity of dolomite consumed in iron and steel production, tonnes

CE = quantity of carbon electrodes consumed in EAFs, tonnes

O_b = quantity of other carbonaceous and process material *b*, consumed in iron and steel production, such as sinter, steel and pig iron scrap or waste plastic, tonnes

COG = quantity of coke oven gas consumed in stationary combustion equipment in iron and steel production (such as cowpers, pre-heating ladles etc.), tonnes (or other unit such as GJ. Conversion of the unit should be consistent with Volume 2 Energy)

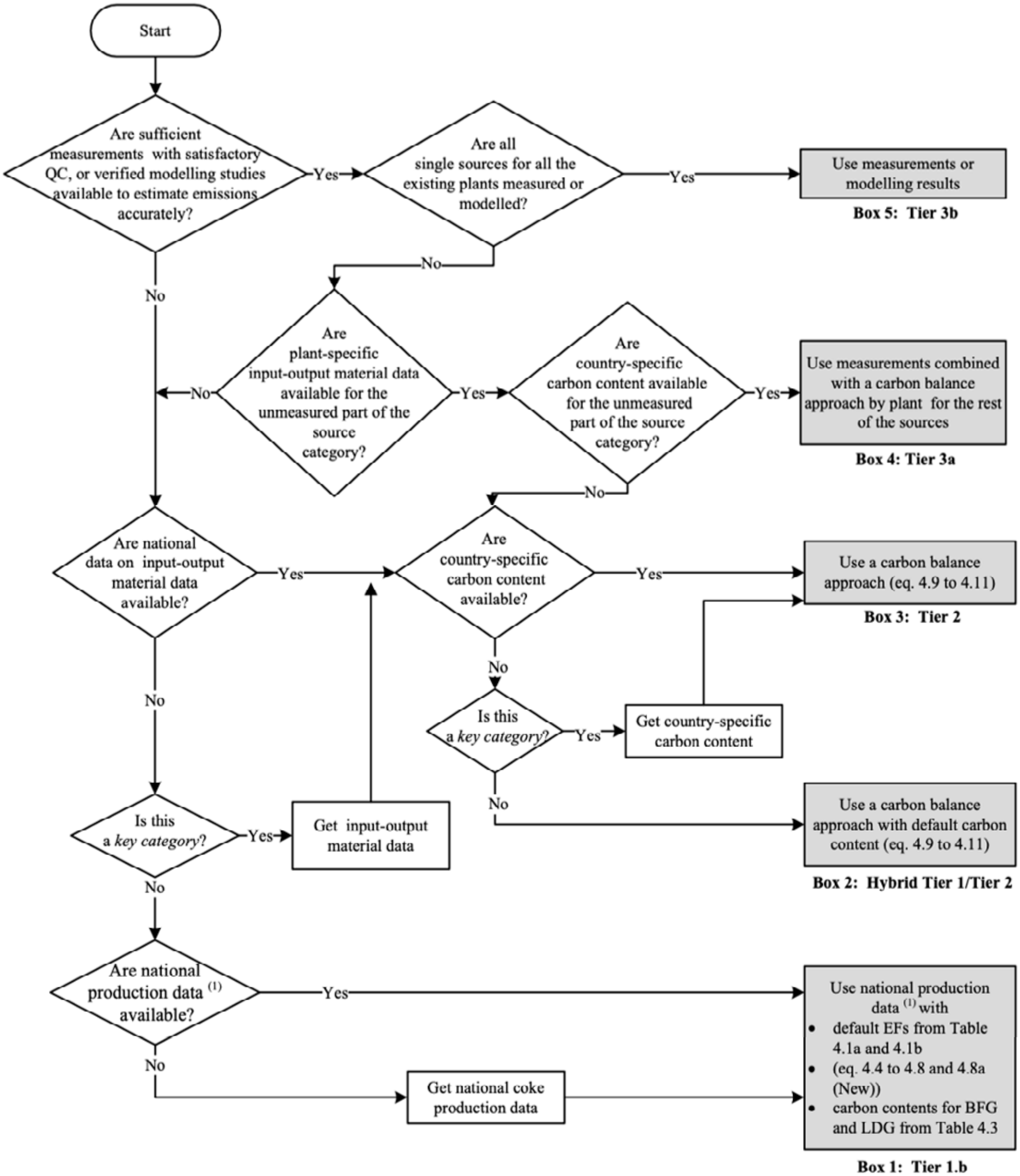
S = quantity of steel produced, tonnes

IP = quantity of iron produced not converted to steel, tonnes

BFG = quantity of blast furnace gas transferred off site or to other facilities in an integrated plant, tonnes (or other unit such as GJ. Conversion of the unit should be consistent with Volume 2 Energy)

C_x = carbon content of material input or output *x*, tonnes C/(unit for material *x*) [e.g., tonnes C/tonne]

Appendix IV – IPCC Data Tier Flowchart



Note:
(1) National production data refers to the productions of (1) steel; (2) pig iron not processed into steel; (3) direct reduced iron; (4) sinter; (5) pellet; (6) blast furnace gas and (7) converter gas.

Appendix V – Comparison of Mass Balance Approach and EU ETS Standard

1. **Combustion emissions:**

$$\boxed{Em = AD \cdot EF \cdot OF} \quad (1)$$

Where:

Em ...... Emissions [t CO_2]

AD .... Activity data [TJ, t or Nm^3]

EF .... Emission factor [t CO_2/TJ, t CO_2/t or t CO_2/Nm^3]

OF .... Oxidation factor [dimensionless]

Factors with units in tonnes are usually to be used for solids and liquids. Nm^3 are usually used for gaseous fuels. In order to achieve numbers of similar magnitude, values are usually given in [1000 Nm^3] in practice.

Activity data of fuels (including if fuels are used as process input) has to be expressed as net calorific value:

$$\boxed{AD = FQ \cdot NCV} \quad (2)$$

Where:

FQ .... Fuel quantity [t or Nm^3]

NCV .... Net Calorific Value [TJ/t or TJ/Nm^3]

Under certain conditions (where the use of an emission factor expressed as t CO_2/TJ incurs unreasonable costs or where at least equivalent accuracy of the calculated emissions can be achieved) the CA may allow the operator to use an emission factor expressed as t CO_2/t fuel or t CO_2/Nm^3 (Article 36(2)). In that case, activity data is expressed as tonnes or Nm^3 fuel, instead using equation (2), and the NCV may be determined using a lower tier than in other cases (Article 26(5)).

Where biomass is involved, the emission factor must be determined from the preliminary emission factor and the biomass fraction of the fuel:

$$\boxed{EF = EF_{pre} \cdot (1 - BF)} \quad (3)$$

Where:

EF .... Emission factor;

EF_{pre} ... Preliminary emission factor (i.e. according to Article 3(35), "the assumed total emission factor of a mixed fuel or material based on the total carbon content composed of biomass fraction and fossil fraction before multiplying it with the fossil fraction to result in the emission factor");

BF .... biomass fraction [dimensionless].

Therefore, the overall standard formula for combustion emissions is:

$$\boxed{Em = FQ \cdot NCV \cdot EF_{pre} \cdot (1 - BF) \cdot OF} \quad (4)$$

2. **Process emissions** are calculated as:

$$\boxed{Em = AD \cdot EF \cdot CF} \quad (5)$$

Where:

Em ...... Emissions [t CO_2]

AD .... Activity data [t or Nm^3]

EF .... Emission factor [t CO_2/t or t CO_2/Nm^3]

CF .... Conversion factor [dimensionless].

The following formula is applicable for mass balances:

$$\boxed{Em_{MB} = \sum_i (f \cdot AD_i \cdot CC_i)} \quad (6)$$

Where:

EM_{MB} .. Emissions from all source streams included in the mass balance [t CO_2]

f .... factor for converting the molar mass of carbon to CO_2. The value of *f* is 3.664 t CO_2/t C (Article 25(1)).

i .... index for the material or fuel under consideration.

AD_i ...... Activity data (i.e. the mass in tonnes) of the material or fuel under consideration. Ingoing materials or fuels taken into account as positive, outgoing materials or fuels have negative activity data. Mass streams to and from stock piles must be taken into account appropriately in order to give correct results for the calendar year.

CC_i ...... The carbon content of the component under consideration. Always dimensionless and positive.

If the carbon content of a fuel is to be calculated from an emission factor expressed as t CO_2/TJ, the following equation is used:

$$\boxed{CC_i = EF_i \cdot NCV_i / f} \quad (7)$$

If the carbon content of a material or fuel is to be calculated from an emission factor expressed as t CO_2/t, the following equation is used:

$$\boxed{CC_i = EF_i / f} \quad (8)$$

If the emission factor of a fuel expressed as t CO_2/TJ is to be calculated from the carbon content, the following equation is used:

$$\boxed{EF = CC \cdot f / NCV} \quad (11)$$

If the emission factor of a material or fuel expressed as t CO_2/t is to be calculated from the carbon content, the following equation is used:

$$\boxed{EF = CC \cdot f} \quad (12)$$

6.3.3 Oxidation factor and conversion factors

These two factors are used to account for incomplete reaction. Thus, if they are to be determined based on laboratory analyses, the factor would be determined as follows (oxidation factor):

$$\boxed{OF = 1 - C_{ash} / C_{comb}} \quad (13)$$

Where:

OF .... Oxidation factor [dimensionless]

C_{ash} ..... carbon contained in ash, soot and other non-oxidised forms of carbon (excluding carbon monoxide, which is considered as molar equivalent of CO_2 emissions)

C_{comb} ... (total) carbon combusted.

For calculating $CO_{2(e)}$ emissions from CF_4 and C_2F_6 emissions, the operator shall use the following formula:

$$\boxed{Em = Em(CF_4) \cdot GWP_{CF_4} + Em(C_2F_6) \cdot GWP_{C_2F_6}} \quad (14)$$

Where

Em .... *emissions expressed as* t $CO_{2(e)}$

Appendix VI – IPCC Tier Definitions

Tier	Definition	Information Needed	Advantages	Limitations
1	Uses readily available default emissions factors multiplied by sufficiently approximate activity data.	• Default emissions factors • Amount of steel, associated materials, and fuel used and produced	• Default emissions factors are readily available for different materials and steel making processes • Limited data collection effort	• Default emissions factors lead to high degrees of scientific uncertainty
2	An intermediate level of complexity found using calculations with site specific emissions factors and carbon contents. Recommends a carbon balance approach for processes in particular.	• Site specific emissions factors and carbon content factors • Data on input and output types and quantities	• Higher degree of scientific certainty than Tier 1 with lower measurement efforts than in Tier 3	• More extensive and time consuming than Tier 1 or hybrid
Hybrid (Tier 1/2)	Carbon balance approach with the use of default carbon contents for process emissions.	• Default carbon content • Activity Data	• Mass carbon balance approach for processes leads to more accurate reporting	• Similar to Tier 1, default values lead to reporting with higher levels of scientific uncertainty
3	Most specific data required, using a site monitoring system such as a Continuous Emissions Monitoring System (CEMS).	• Site-specific monitoring system that tracks real time data	• Mass carbon balance approach for processes leads to more accurate reporting	• Expensive • Only large steel manufacturers have installed install a CEMS

Appendix VII – Case Study Methodology

The case study was constructed according to data from ISO 14404-1 Annex C on inputs and outputs at a typical steel plant producing 7,000,000 tons of crude steel annually. This data was not included without certain changes, though. First, the quantity of imported pellets was increased from 1,000,000 tons to 10,634,615 tons. With an assumed pellet iron content of 65% and a desired crude steel carbon content of 1.25%, this was the quantity of pellets needed to produce 7,000,000 tons of crude steel. As the original quantity of pellets in the annex was likely a typo that omitted a digit from the actual figure, no other input or output quantities have been changed.

Methodologies such as Environment Canada and the GHG Protocol ordinarily require calculation of mobile combustion emissions on the basis of fuel quantities consumed, but as ISO does not make calculations for mobile combustion, no figures related to mobile combustion were provided. Instead, we drew upon data providing the CO_2 emission contributions of every industrial category associated with the production of one kilogram of chromium steel. We obtained the figures for CO_2 eq emissions per kg of steel production from transport and divided them into three categories: emissions from passenger cars, emissions from freight transport up to 32 tons, and emissions from freight transport exceeding 32 tons. We then summed the figures within each category and multiplied the result for each by 1000 to obtain the total emissions (tCO_2 eq) associated with the production of one ton of chromium steel for each category. We arbitrarily assigned freight transportation under 32 tons to process-critical onsite mobile transportation and passenger cars and freight transportation over 32 tons to other mobile transportation under company ownership or control. Such a division is intended to be illustrative of variations in accounting outcomes, not to be a perfectly accurate reflection of how emissions from these two categories of mobile combustion would be divided.

Further assumptions were necessary to fit calculations for Environment Canada and the GHG Protocol into data intended for use by ISO 14404 and Worldsteel. Many of Environment Canada's default emissions factors are provided according to specific combustion environments, and emissions factors for specific fuels can vary widely within Canada's own guidance as well. Providing this additional context is in line with best practices for providing default emissions factors, but it does require making additional assumptions not provided by the initial data. As a result, the Canadian emissions factor for LPG is taken from LPG-Propane for industrial uses on page 61. Conversion is calculated at the rate of 493 kg/m3 at 1 atm and 25° C. Likewise, Canadian emissions factors for all types of coal are adopted from emissions factors for bituminous coal in Ontario, 1995-2000, found on page 53. Additionally, fugitive emissions from upstream operations were not considered in the case study. The GHG Protocol is the only method which stipulates inclusion of these upstream emissions under scope 3 reporting, but while Environment Canada does not consider any fugitive emissions, the remainder of the methods do not clarify whether they should be included or not.

Emissions factors provided in GHG Protocol worksheets are issued in units of heat and energy, while the emissions factors in ISO 14404 are in units of mass and volume. To adapt the quantities provided in the data to units which could support GHG Protocol calculations, outside conversion factors from engineeringtoolbox.com were applied. Distillate fuel oil no. 1 was classified as light oil, while residual fuel oil no. 6 was categorized as heavy oil. All grades of coal were classified as high volatile A bituminous coal.

Finally, we assume that 100% of iron reduction at this facility is done through coke and none through coal, we define coke oven gas as the only exported coke oven byproduct, and we do not attempt to calculate the quantities of byproduct gases which are both produced and consumed onsite. Environment Canada guidelines are equivocal on assigning emissions from fuels burned for both heat production and for process reasons, i.e. iron reduction, to their stationary combustion section vs. their process emissions section, so assigning fuels in their entirety either to stationary combustion or to process emissions was necessary. The GHG Protocol allots a credit for exported coke oven byproducts other than COG, but without any specifics. ISO calculates byproduct gas emissions on the basis of the quantity exported subtracted from the quantity imported, with no intermediate step to calculate the quantity of coproduct gas produced and burned onsite. This is because ISO-provided default emissions factors already account for emissions from combustion of coproduct gases in their emissions factors for the complete combustion of the fuels which produce them, so for ISO calculations, these quantities are not necessary. Allocating a specific quantity of coproduct gases on the basis of input fuels alone to be produced and burned onsite was one assumption too far for the available data to support, and an unnecessary one given the goal of simply illustrating differences between accounting methods.

Coalition On Materials Emissions Transparency

The Coalition on Materials Emissions Transparency (COMET) is an initiative between the Columbia Center on Sustainable Investment (CCSI), the Payne Institute for Public Policy at the Colorado School of Mines, and RMI.

Design: Michael Morgan

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

cometframework.org