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LIFE CYCLE ASSESSMENT OF HOT-ROLLED STRUCTURAL STEEL SECTIONS

Report # 298-001

Industry-average life cycle assessment of hot-rolled structural steel sections, commissioned by the American Institute of Steel Construction, according to ISO 14040, ISO 14044, ISO 21930, UL Environment PCR Part A (v4.0, 2022) and Part B: Designated Steel Construction Products (v2.0, 2020), with alignment to Smart EPD PCR Part B (draft, 2025).

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This report was prepared by John Beath Environmental, LLC. The company was founded in 2015 to provide sustainability and environmental consulting services. With staff dispersed across the US, the company provides consulting services with a focus on a unique combination of the life cycle perspective and deep knowledge of process modeling and regulatory obligations.

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List of Abbreviations

ADP_f	Abiotic Depletion Potential, Fossil Resources
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
AP	Acidification Potential
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide Equivalent
CRU	Components for Re-Use
EAF	Electric Arc Furnace
EE	Recovered Energy Exported
eGRID	Emissions & Generation Resource Integrated Database
EP	Eutrophication Potential
EPD	Environmental Product Declaration
FW	Use of Net Freshwater Resources
GHG	Greenhouse Gas
GLO	Global
GWP	Global Warming Potential
HLRW	High-Level Radioactive Waste
HWD	Hazardous Waste Disposed
ILLRW	Intermediate and Low Level Radioactive Waste
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
JBE	John Beath Environmental, LLC
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
m^3	Cubic Meters
MER	Materials for Energy Recovery
MJ	Megajoules
MR	Materials for Recycling
MT	Metric Ton
N	Nitrogen
NERC	North American Electric Reliability Corporation
NHWD	Non-Hazardous Waste Disposed
$NRPR_E$	Non-Renewable Primary Resources – Energy
$NRPR_M$	Non-Renewable Primary Resources – Material
NRSF	Non-Renewable Secondary Fuels
O_3	Ozone
ODP	Ozone Depletion Potential
PCR	Product Category Rule
PED	Primary Energy Demand
RE	Recovered Energy
RoW	Rest of World
RSRM	Rolling Mill
RPR_E	Renewable Primary Resources – Energy
RPRM	Renewable Primary Resources – Material
RSF	Renewable Secondary Fuels
SFP	Smog Formation Potential
SM	Secondary Materials
SO_2	Sulfur Dioxide
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
VOC	Volatile Organic Compound

1 Goal of the Study

The American Institute of Steel Construction (AISC) is a not-for-profit technical institute and trade association in the U.S. serving the structural steel community. AISC is interested in quantifying potential environmental impacts of its fabricator and hot-rolled structural steel sections producer member's products and processes through a cradle-to-mill-gate life cycle assessment (LCA), and in communicating potential environmental impacts to customers through an updated industry-average environmental product declaration (EPD). LCA is used to evaluate potential environmental impacts and various resource, energy, water, and waste indicators for a product over its life cycle.

AISC commissioned John Beath Environmental, LLC (JBE) to conduct an industry-average cradle-to-mill-gate LCA of U.S.-produced hot-rolled structural steel sections, including a refresh of the U.S.-average transportation to fabricator and fabrication process impacts. The cradle-to-mill-gate scope includes the procurement of raw materials and fuels, and steel mill operations. The study was conducted according to the requirements of ISO 14040:2006 (ISO, 2006a), ISO 14044:2006 (ISO, 2006b), ISO 21930 (ISO, 2017), Product Category Rule (PCR) Part A: Life Cycle Assessment Calculation Rules and Report Requirements (UL Environment, 2022), and PCR Part B: Designated Steel Construction Products (UL Environment, 2020). This study also aimed to align with key methodology, data transparency, and data quality requirements of the forthcoming Smart EPD PCR Part B, which was in draft stage at the time of completion of this study.

The intended application for this study is to understand improvement, identify hotspots, and share updated potential environmental impacts of the U.S. industry's hot-rolled structural steel sections with customers and potential future customers (business-to-business communications), and the industry at large. The primary audience for this study is internal stakeholders at AISC as well as broad-ranging external stakeholders.

This study report has not undergone critical review by an independent expert, though will be subjected to external critical review in accordance with ISO 14040:2006, ISO 14044:2006, ISO 14025:2006, ISO 21930:2017, and the applicable PCRs to ensure accuracy and quality, and adherence to the specified standards prior to EPD development.

2 Scope of the Study

2.1 Product System

Hot-rolled structural steel sections are typically used in construction applications in buildings, bridges, and industrial projects. This industry-average, cradle-to-mill-gate study represents the production-weighted average hot-rolled structural steel sections produced by mills in the U.S. in 2023 and subsequently fabricated at facilities throughout the U.S. The mills and fabricators participating in this study are members of AISC.

While a variety of steel products may be produced via hot-rolling, in the context of structural steel construction, this study's product scope is limited to the following definition.

Hot-rolled structural steel sections are:

- *W-, S-, C-, and MC- shapes, angles, and*
- *Produced at a mill whose primary output is heavy structural sections intended for subsequent fabrication and installation in buildings, bridges, and other structural applications*

Hot-rolled structural steel sections specifically exclude:

- *Products that do not meet the definition of structural steel per AISC's Code of Standard Practice for Steel Buildings and Bridges (ANSI/AISC 303-22), such as H-piles, sheet pile, railroad rail, and crane rail*
- *Products originating from a "Bar Mill", such as rebar, MBQ, SBQ, rod, and wire*
- *"Junior" sections, such as those under 8 inches in depth*
- *Miscellaneous M- shapes*

The mill sites included in this study, representing 100% of U.S. hot-rolled structural steel sections production in the study year, are:

- Steel Dynamics, Inc. (SDI) Columbia City, IN
- Gerdau Petersburg, VA
- Gerdau Midlothian, TX
- Gerdau Cartersville, GA
- Nucor Yamato, AR
- Nucor Berkeley, SC

Also included in the study were 80 fabricator sites out of AISC's approximately 1,000 fabricator members. The participating companies represent approximately 19% of the total steel tonnage fabricated by AISC's membership, which makes up approximately 75% of the total fabrication tonnage in the U.S. These facilities provided data for the AISC 2021 EPD background report (Sphera, 2021), representing 2019-2020 production. The average, 10^{th} percentile, and 90^{th} percentile primary data aggregated for that study was updated with background data representative for 2023 in this study.

Hot-rolled structural steel sections fall under CSI and UNSPSC codes:

- CSI 05 12 00 Structural Steel Framing
- CSI 05 12 13 Architecturally-Exposed Structural Steel Framing
- CSI 05 12 23 Structural Steel for Buildings
- UNSPSC 30103618 – Steel framework

Additional information on products produced by AISC's members are provided on the AISC website: https://www.aisc.org/.

2.1.1 Production Processes

Hot-rolled structural steel sections in the U.S. are produced exclusively by electric arc furnace (EAF) steel mills. Feedstock materials, including steel scrap with smaller amounts of pig iron, direct-reduced iron (DRI), and alloying elements, arrive at the mills via ship, barge, rail, and truck. Steel scrap, pig iron, and DRI are charged into EAFs where they are melted using electric current applied through high-carbon electrodes. Lime, charge carbon, and process-related gases like oxygen are added during the melting process to remove impurities from the steel and achieve the desired steel grade. Slag is formed as a co-product during the EAF process. Molten steel is transferred to a ladle metallurgy furnace (LMF) where more additives and alloy materials are added to achieve the desired composition of the final product. The steel then enters the continuous casting process where the first solid form of steel (termed raw steel or crude steel) is produced in long shapes termed "blooms" or "billets". Steel scrap generated during this process is "internal scrap" and is returned to the EAF for re-melting.

Typically, at the same mill facility, but not always, blooms/billets are transferred to the hot-rolling mill where they are reheated using primarily natural gas and rolled into a variety of structural shapes. Scrap generated downstream from the casting process within a facility, such as at the rolling mill, is termed "home scrap" and is returned to the EAF for re-melting. Hot-rolled structural steel sections are cooled, cut to standard lengths, and then transported off-site for use or further processing.

Prior to installation, hot-rolled structural steel sections commonly undergo a scenario-specific fabrication process. This process entails inspection, material handling, cutting, drilling, fit-up, welding, and bolting; all according to the AISC Code of Standard Practice for Steel Buildings and Bridges (ANSI/AISC 303-22, 2022). In addition to the steel itself, inputs to fabrication include relatively small amounts of process materials, such as lubricants, gases, electrodes, and welding fluxes. Some facilities also conduct surface preparation using mechanical processes or compressed air blasting in order to clean the surface and prepare it for coating. Surface preparation for the application of coatings, the coatings themselves, and galvanization are not included in the scope of this study. Scrap generated during the fabrication processes is considered manufacturing scrap and is returned to steel mills as a pre-consumer external scrap input.

2.1.2 Product Composition

The hot-rolled structural steel sections analyzed in this study are made primarily of recycled steel scrap, with some mills additionally utilizing varying percentages of virgin iron inputs, including pig iron and DRI, as well as up to 2% alloying elements. The production-weighted average recycled content of the product is 92%. The product has a typical density of approximately 7,850 kg/m^3.

The products do not contain any hazardous substances according to the Resource Conservation and Recovery Act (RCRA), Subtitle 3. The products do not release dangerous substances to the environment, including indoor air emissions, gamma or ionizing radiation, or chemicals released to air or leached to water and soil. Therefore, no substances required to be reported as hazardous are associated with the production of this product.

2.2 Declared Unit

The declared unit for this study is **one (1) metric ton (1,000 kg) of hot-rolled structural steel sections.**

The functional unit of an LCA is the quantification of a product's performance characteristics and is the reference unit for which all results are presented. As this study has a cradle-to-mill-gate scope, the product can have varying applications, and for consistency with the governing PCR, a declared unit is used instead of a functional unit. Because this is a cradle-to-mill-gate study that excludes the use phase, a reference service life was not specified and is not necessary for this analysis.

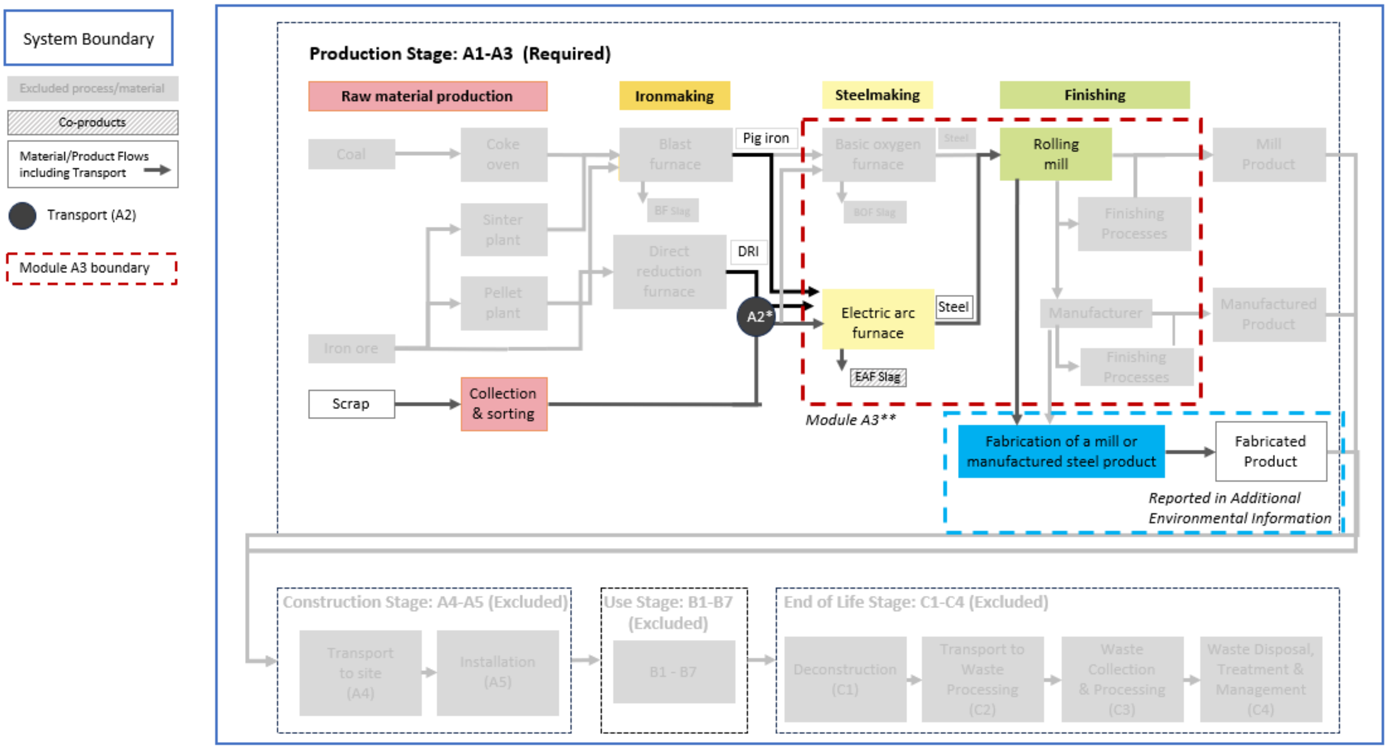
Please note that comparisons of environmental impact results on a mass basis alone are insufficient and should consider the technical performance of the product to establish comparisons.

2.3 System Boundaries

The system boundary in an LCA defines which unit processes are considered in the modeled system. Unit processes are one or several operations in a manufacturing system. Processes are organized into modules per ISO 21930:2017 and the governing PCR. This analysis is based on a cradle-to-mill-gate scope (modules A1-A3). The specific processes and life cycle stages included, and those that are excluded, are detailed in Table 1 and in Figure 1. The intent of this study is to capture all known and material product-specific impacts from raw material extraction to mill gate, the subsequent scenario of fabrication, and all associated releases to the environment.

Table 1: Items included in and excluded from the system boundary

Included	Excluded
• Mill processes, including procurement of scrap, virgin inputs (e.g. pig iron and scrap), alloying elements, and other process materials, utilities, and all associated production and inbound transport. Additionally, waste treatment processes and outbound transport. The slag co-product is also included at this stage. • Transport of the hot-rolled structural sections to the fabricators • Fabrication, including material requirements (e.g. electrodes), as well as other process materials and utilities, and the production and inbound transport of all of these. Additionally, waste treatment processes and outbound transport of these.	• Manufacturing equipment maintenance • Capital equipment, infrastructure, and maintenance • Human labor and employee commute • Downstream life cycle stages: distribution, installation, product use, end-of-life, and recycling credits/burdens



Source: Smart EPD draft Part B PCR (draft, 2025)
Notes: Each unit process includes resource inputs (fuels, electricity, water, materials, etc.) and emissions to air/land/water, wastes and co-products, if relevant.
* A2 transportation is represented by any grey arrow that crosses A1 / A3 boundary.
** Processes inside the red dashed line are in module A3 and include specific data. Processes outside of the dashed red line indicate processes in module A1.

Figure 1: Hot-rolled structural steel sections system boundaries, with fabrication

2.3.1 Time Coverage

This study is intended to represent the 2023 calendar year. Primary data was collected for steel mill facilities for 12 consecutive months of production during 2023, apart from one mill providing data for July 2023 to June 2024.

The data from fabrication facilities represents primary data collected for the 2019 and 2020 calendar years and used in AISC's 2021 industry-average EPD. The production-weighted fabrication life cycle inventory (LCI) data was updated for this study in two ways to improve time coverage. First, the fabrication tonnage for each state was provided by AISC for the 2023 calendar year, which was used to update the mix of region-specific electricity datasets paired with the inventory. Second, all background datasets were updated to the ecoinvent database v3.10, representing the 2023 calendar year. See Section 3.1.3 for additional details.

2.3.2 Technology Coverage

This study aims to represent the industry-average of manufacturing technologies used by AISC's members to manufacture hot-rolled structural steel sections in the U.S., including a fabrication scenario. Hot-rolled structural steel sections are produced exclusively by EAF steelmaking processes in the U.S., and 100% of production is represented in this study. In addition, a total of 80 fabrication facilities are included in the study utilizing a representative mix of current fabrication techniques for the U.S.

2.3.3 Geographic Coverage

This study aims to represent the industry-average of hot-rolled structural steel sections produced and fabricated in the U.S. The study includes 100% of hot-rolled structural steel sections production in the U.S., as well as 80 fabricator facilities dispersed throughout the U.S. The electricity mix for the U.S.-fabricator population was modeled in this study.

2.4 Cut-off Criteria

No cut-off criteria we re defined for this analysis. All known energy and material flow data were included in accordance with the system boundary. Proxy data were used as needed in the model to capture all considered life cycle impacts, as is detailed in Annex A.

2.5 Allocation Procedures

2.5.1 Facility-level Allocation

Data from the mills was requested for two distinct unit processes: 1) EAF steelmaking (cradle-to-crude steel), and 2) section rolling (crude steel to hot-rolled sections). The majority of data was provided by the facilities separately for the two unit processes. Where data was provided on a facility-wide basis, including some on-site transportation fuels, non-CO_2 air emissions, and wastes, allocation was performed to assign each item into the unit processes at a ratio of 50:50 before accounting for the share of in-scope production.

Additionally, data was requested from each mill on the production of products that were deemed out-of-scope. In-scope products were defined for this study as described in Section 2.1. For facilities where out-of-scope products were also produced, impacts were scaled to the share of in-scope products based on production masses.

2.5.2 Co-product Allocation

A process, sub-system, or system may produce co-products in excess of the necessary reference flow or intermediate product. Such co-products leave the system to be used beneficially in other systems and may carry a portion of the burden of their production system. To allocate burden in a meaningful way between co-products, allocation procedures are needed.

During the EAF process at the mills, slag is produced via a joint co-production process per ISO 21930:2017 along with steel blooms/billets. EAF slag is sold directly from the mills for beneficial use as an aggregate among other applications. In accordance with the governing PCR and with the forthcoming Smart EPD PCR, physical partitioning was used to allocate a share of each of the inputs and outputs at the EAF to the steel and the slag based on the energy demand required to form each co-product and other physical relationships. The ratios applied to each flow were sourced from the World Steel Association and EUROFER's 2014 slag LCI methodology report (The World Steel Association, 2014), and are summarized in Table 2 below. These values were entered as causal allocation factors in openLCA.

Table 2: Allocation ratios for slag and steel products at the mill sites

Item Category	Allocation Share to Slag	Allocation Share to Steel
Scrap	N/A	N/A
Pig Iron	0.0091	0.9909
DRI	0.04	0.96
Alloying Elements	0	1
Fluorspar	1	0
Ancillary Materials (e.g., Refractories, Electrodes)	0.14	0.86
Oxygen, Argon, Nitrogen Gases	0	1
Energy Inputs	0.14	0.86
Water Inputs	0.14	0.86
Air Emissions	0.14	0.86
Wastes	0	1

Other materials recovered for recycling at the mills, such as mill scale and EAF dust, were modeled with the cut-off approach (polluter pays principle), whereby the burden of the recycling processes was not included, however the burden of transporting the recyclable wastes to the waste treatment location was included. A sensitivity was conducted on co-product allocation in Section 4.6.

No co-product allocation was required for the fabrication process, as no co-products are produced. Furthermore, background data for the study used a cut-off approach for co-product allocation.

2.5.3 Steel Scrap Allocation

The largest raw material input for hot-rolled structural steel sections production is external steel scrap. Relatively small amounts of internal scrap, which is generated at the EAF process and fed back into the EAF, and home scrap, which is scrap generated downstream of the castor within a steelmaking facility, are also consumed as inputs. In accordance with the governing PCR and ISO 21930's "polluter pays principle", external steel scrap was assigned no upstream burden from its production. The inbound transportation of scrap and any on-site mobile fuels or energy consumption necessary to sort and move scrap at the mills were included. Both internal and home scrap were modeled as secondary materials receiving no burden as they stay within the facility's bounds and impacts associated with their production and processing were captured in the site-wide inventories.

2.5.4 End-of-life Allocation

No end-of-life allocation was applied in this study as the system boundary is defined as cradle-to-mill-gate. Background data for the study used a cut-off approach for end-of-life allocation.

2.6 LCIA Methodology

The impact assessment categories and other metrics used in the assessment are based on the requirements of the PCR and are shown below. The impact categories are calculated using globally accepted methods: Intergovernmental Panel on Climate Change (IPCC), Fifth Assessment Report (AR5), Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) (Bare, 2011), version 2.1, and Institute of Environmental Sciences (CML) in the Netherlands, version 4.7. This study is intended to quantify global warming potential (GWP-100), ozone depletion potential (ODP), acidification potential (AP), eutrophication potential (EP), smog formation potential (SFP), and abiotic depletion of fossil fuel resources (ADP_f) of AISC's industry-average hot-rolled structural steel sections. These six impact categories are globally deemed mature enough to be included in Type III environmental declarations. Other categories are being developed and defined and LCA should continue making advances in their development. However, the EPD users shall not use additional measures for comparative purposes.

In accordance with the PCR and ISO 21930, 17 inventory metrics were also calculated, as shown in Table 3 below. The inventory metrics were calculated using the recommendation of ACLCA 21930 guidance document (ACLCA, 2018). The characterization models (IPCC AR5, TRACI 2.1, and CML v4.7) and characterization factors are identified according to the requirements of the PCR Part A.

Table 3: Impact Categories and ISO 21930 Indicators

Abbreviation	Indicator	Unit
LCIA Impact Categories		
GWP	Global warming potential (GWP-100), IPCC 2013	kg CO_2e
ODP	Ozone depletion potential	kg CFC 11 eq
AP	Acidification potential	kg SO_2 eq
EP	Eutrophication potential	kg N eq
SFP	Smog formation potential	kg O_3 eq
ADP_f	Abiotic resource depletion potential of non-renewable (fossil) energy resources	MJ, LHV
Resource Use		
RPR_E	Renewable primary resources used as energy carrier (fuel)	MJ
RPR_M	Renewable primary resources with energy content used as material	MJ
$NRPR_E$	Non-renewable primary resources used as an energy carrier (fuel)	MJ
$NRPR_M$	Non-renewable primary resources with energy content used as material	MJ
SM	Secondary materials	kg
RSF	Renewable secondary fuels	MJ
NRSF	Non-renewable secondary fuels	MJ
RE	Recovered energy	MJ
FW	Use of net freshwater resources	m^3
Output Flows and Wastes		
HWD	Hazardous waste disposed	kg
NHWD	Non-hazardous waste disposed	kg
HLRW	High-level radioactive waste, conditioned, to final repository	kg
ILLRW	Intermediate- and low-level radioactive waste, conditioned, to final repository	kg
CRU	Components for re-use	kg
MR	Materials for recycling	kg
MER	Materials for energy recovery	kg
EE	Recovered energy exported from the product system	MJ, LHV

The product does not contain significant amounts of biogenic carbon, nor does the manufacturing process use biomass or biofuels as a major energy source. Some mills used relatively small amounts of pig iron produced from biochar; however, this was excluded from the study due to data limitations with all pig iron modeled as conventionally produced pig iron. Results for carbon emissions and removals (PCR Part A, Section 4.6) are not relevant to this LCA and EPD and, therefore, are not reported. Furthermore, the production and fabrication of hot-rolled structural steel sections does not involve calcining or carbonation processes.

This study does not address other environmental indicators or impact categories, nor does it consider social impacts, land use, biodiversity, human health or ecotoxicity, or local impacts such as noise.

2.7 Data Quality Requirements

The key requirement for data quality is that data be as accurate and representative as possible. Data quality requirements are based on the ISO 14040:2006 and ISO 14044:2006 standards and include time-related, geographical, technological, precision, completeness, representativeness, consistency, reproducibility, sources of data, and uncertainty criteria. To fulfill these requirements and to ensure reliable results, primary data in combination with representative secondary literature, and consistent background LCI data from ecoinvent v3.10 (Wernet, et al., 2016) and other sources were used. The data quality assessment is described in Section 3.3 and all background datasets are identified in Annex B.

2.8 Type of Document

This report is written to conform to the requirements of ISO 14040:2006, ISO 14044:2006, ISO 21930:2017, UL Environment's PCR Part A: Life Cycle Assessment Calculation Rules and Report Requirements, and PCR Part B: Designated Steel Construction Products. The report is also written to align with the (draft) Smart EPD PCR Part B: Designated Steel Construction Products as much as possible. As such, this document aims to report the results and conclusions of the LCA completely and accurately, without bias to the intended audience. The results, data, methods, assumptions, and limitations are presented in a transparent manner with the intention to provide sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent to the LCA. The report aims to be used in a manner consistent with the goals of the study.

2.9 Critical Review

An external review of this report was not conducted. Prior to EPD development, an external review process will be conducted to ensure consistency between the completed LCA and the requirements of ISO 14040:2006, ISO 14044:2006, ISO 21930:2017, and the relevant PCRs.

3 Life Cycle Inventory Analysis

3.1 Data Collection and Modeling

The following sections describe data collection processes and modeling approaches for the study. The study utilized openLCA v2.3.1 to model primary data paired with data from the ecoinvent v3.10 and the U.S. Life Cycle Inventory Database (USLCI) version 1.2024-06.0 (Federal LCA Commons, 2024) secondary databases.

3.1.1 Steel Mill Data Collection and Modeling

As described in Section 2.5.1, primary data was collected from six steel mills for two unit processes: 1) EAF steelmaking, and 2) section rolling. One year of production data was provided representing the 2023 calendar year. Allocation procedures were performed as-needed to assign facility data to the EAF and section rolling stages and also to scale to the share of in-scope products, as described in Section 2.5.1. Mills provided all virgin iron and recycled steel inputs, alloy materials, process materials, packaging, utilities and energy requirements, waste and waste fates, and emissions.

As part of the rigorous QA process, primary data was checked for mass balance, water balance, and completeness. Once all site data was received, efforts were made to cross-check key raw material, energy, and emissions data provided from each mill, identify gaps and outliers, and seek clarifications and data from the mills or gap-fill with average data from the other sites.

Most sites provided complete inbound transportation distances and modes. One site provided only scrap transportation distances (comprising the majority of in-bound transportation) and requested that JBE use transportation modes and distances from another site at their company as proxy data. Where needed, gap-filling took place whereby the distances and modes shown in Table 4 were applied based on average data provided by raw material type for all sites unless otherwise specified.

Table 4: Transport data for gap-filling

Item Category	Distance (km), Mode
Alloying Elements	1,500 truck; 6,000 ship
All Other Inputs*	250 truck; 1,000 rail
Waste Flows	50 truck
Material for Recycling	50 truck

* *Aligns with AISI's 2017 industry-average LCI data study assumptions* (American Iron and Steel Institute, 2020).

Where sites did not provide air emissions data that included fuel combustion at the mill sites, combustion datasets for natural gas (used as a fuel) which account for the impact of producing and burning the fuel were used. For all sites, fuels used for on-site transportation and equipment, including propane, gasoline, and diesel, were modeled with fuel production and consumption datasets.

Datasets were mapped to all inputs and outputs primarily in ecoinvent v3.10. To align with the draft Smart EPD PCR requirements, transportation datasets were modeled using the USLCI database, with non-elementary flows matched to ecoinvent datasets in openLCA. See Annex B for a complete list of background datasets used in this study.

For purchased electricity datasets, each mill site was designated an Emissions & Generation Resource Integrated Database (eGRID) subregion based on its location in the U.S. (United States Environment

Protection Agency, 2025). The percentage of each type of power used in the subregion was sourced from the most recent eGRID data, representing calendar year 2022. Each power type was then mapped to ecoinvent datasets for electricity production by electricity source type for that subregion. If a power type did not have a subregion-specific dataset, the next closest geographic region was chosen. An openLCA process was generated for each mill using the subregion-specific datasets for each power type and percentage contribution. Table 5 shows the mapping of mill sites to eGRID subregions and ecoinvent dataset subregions. Figure 2 shows the power mix types and percentage split for each mill location.

Table 5: eGRID and ecoinvent/NERC subregions for each mill site

Mill Site	eGRID Subregion	ecoinvent Subregion
SDI	RFCW	RF
Gerdau Petersburg	SRVC	SERC
Gerdau Midlothian	SRMV	SERC
Gerdau Cartersville	SRSO	SERC
Nucor Yamato	SRVC	SERC
Nucor Berkeley	ERCT	TERC

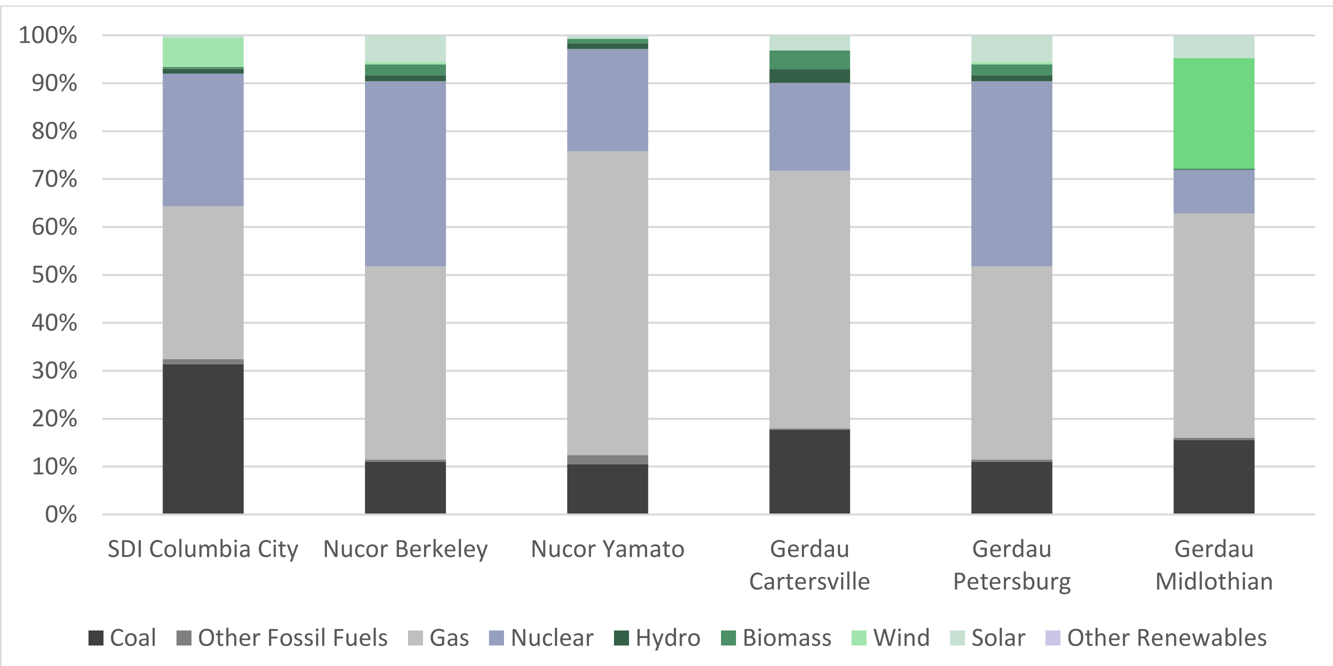


Figure 2: eGRID power mix split for each mill site

One site has a dedicated on-site solar facility operated by a third party with a documented power purchase agreement (PPA) and bundled Renewable Energy Certificates (RECs). This electricity was modeled using a region-specific solar dataset. The facility began operation in June 2023 and the mill purchased 100% of the electricity generated during the study period, with exclusive rights/responsibility to purchase the power generated. One other facility purchased unbundled RECs during the study production year for the product in-scope; however, per the UL Part A and Part B PCR requirements, they were not included in the baseline results. Note that the draft Smart EPD Part A and B allowed the use of RECs and virtual PPAs in baseline EPD results at the time of report drafting.

Inventory data for each site was then scaled down from an annual production level to a per metric ton of hot-rolled structural steel sections leaving the site. To account for home scrap generated in the section rolling unit process, the amount of the EAF unit process for each site was increased based on the amount of home scrap generated at that site. Therefore, more than 1 metric ton of the EAF process was modeled per 1 metric ton of the section rolling process. The production-weighted average was 1.06 metric tons of crude steel input (blooms/billets) per metric ton of hot-rolled structural sections produced.

To generate the average inventory and results from the six sites, a top-level process was modeled using production data in metric tons of the in-scope product produced from each site. The proportion of total production was calculated by dividing each individual site's production by the total production from all six sites. These percentages were then used in the top-level openLCA process to create 1 metric ton of average product output. Table 6 provides a summary LCI for the average EAF unit process, and Table 7 provides a summary LCI for the average section rolling process to produce 1 metric ton of hot-rolled structural sections at the mills. As discussed previously, different natural gas datasets were used depending on whether each site provided emissions data that included fuel combustion. The complete inventory is included in Annex A.

Table 6: Summary LCI for the production-weighted average EAF steelmaking unit process

Item	Quantity	Units
Inputs		
External Scrap	9.93E-01	MT
Internal Scrap	1.35E-02	MT
Home Scrap	6.76E-02	MT
DRI	3.96E-02	MT
Pig Iron	2.92E-02	MT
Silicomanganese	1.28E-02	MT
Ferro Silicon	1.23E-03	MT
Other Alloying Elements	2.29E-03	MT
Lime (Total)	3.17E-02	MT
Refractories	3.40E-03	MT
Electrodes	1.79E-03	MT
Oxygen	6.07E-02	MT
Argon	1.30E-03	MT
Nitrogen	1.13E-02	MT
Municipal Water	2.11E-01	m^3
Ground Water	8.93E-01	m^3
Surface Water	1.21E-02	m^3
Purchased Electricity	5.54E+02	kWh
Electricity Generated On-site	1.01E+01	kWh
Natural Gas Production	5.93E+02	MJ
Natural Gas Combustion	9.01E+01	MJ
Gasoline - for Internal Transport	2.32E+00	MJ
Diesel - for Internal Transport	5.49E+01	MJ
Propane - for Internal Transport	7.99E-01	MJ
Outputs		
Product Output (Steel Blooms)	1.00E+00	MT
Internal Scrap	1.35E-02	MT
Slag	1.46E-01	MT
Hazardous Waste	1.27E-03	MT
Non-Hazardous Waste	6.34E-03	MT
Recycled Waste	2.22E-02	MT
Mill Scale	1.28E-02	MT
CO_2 Emissions to Air	7.91E-02	MT
Other Emissions to Air	See Annex A	MT
Emissions to Water	See Annex A	MT
Water Emissions to Air	1.01E+00	m^3
Water Emissions to Water	7.06E-02	m^3
Wastewater to POTW	3.91E-02	m^3

Table 7: Summary LCI for the production-weighted average section rolling unit process

Item	Quantity	Units
Inputs		
Steel Blooms	1.06E+00	MT
Purchased Electricity	1.13E+02	kWh
Electricity Generated On-site	1.69E+00	kWh
Natural Gas Production	1.65E+03	MJ
Natural Gas Combustion	2.27E+02	MJ
Municipal Water	1.49E-01	m^3
Ground Water	5.43E-01	m^3
Surface Water	7.90E-03	m^3
Outputs		
Product Output	1.00E+00	MT
Internal Scrap	5.61E-02	MT
CO_2 Emissions to Air	1.09E-01	MT
Other Emissions to Air	See Annex A	MT
Emissions to Water	See Annex A	MT
Water Emissions to Air	6.16E-01	m^3
Water Emissions to Water	5.10E-02	m^3
Wastewater to POTW	3.38E-02	m^3

3.1.2 Transport from Mills to Fabrication Data Collection and Modeling

In the original fabrication study conducted to inform AISC's 2021 EPD background report (Sphera, 2021), the production-weighted average transportation distance for 1 metric ton of hot-rolled structural steel sections shipped from the mills to fabrication sites was 945 km. The mode split of 25% by truck and 75% by rail was provided by AISC in consultation with steel producers participating in this study. The additional mass of steel product required to account for the fabrication scrap was also modeled based on 1.077 MT of steel product required per 1 MT fabricated steel product. Therefore, total transport of 1,017 MT.km (945 km * 1.077 MT = 1.017 MT.km) was modeled for the A2 stage as shown in Table 8.

Table 8: A2 unit process for transporting 1.077 metric tons of hot-rolled structural steel from the mills to the fabricators

Item	Quantity	Units
Truck Transport	1017 * 0.25 = 254	MT.km
Rail Transport	1017 * 0.75 = 763	MT.km

3.1.3 Fabrication Data Collection and Modeling

Primary data on product fabrication was collected from a subset of AISC's member fabricators for 12 continuous months of production in 2019 and 2020 as part of AISC's 2021 industry-average fabricated structural sections and plate EPDs (Sphera, 2021). The data collection process entailed sending a survey to AISC's approximately 1,000 fabricator members. In total, 80 fabrication facilities provided primary data for their facilities, which were aggregated into a production-weighted average inventory for the average, 10^{th}, and 90^{th} percentile. The average inventory was used in AISC's 2021 EPD to model A3 impacts.

For the current study, as described in Section 2.1, the previously collected fabrication LCI dataset was updated with background datasets from the ecoinvent v3.10 database. The datasets that were the closest match to those selected by Sphera from the GaBi database were chosen. Several datasets were used to model the different electrode types and the electricity consumed at the fabricators. The AISC 2021 EPD background report did not report the composition shares of materials required to make the electrodes; therefore, research was conducted to determine the closest match for each type of electrode and the constituent parts. Safety data sheets (SDS) were used to estimate the percent composition. If the SDS provided a range for the amount of a constituent, the average value was used. Global average background data on steel cold rolled coil (CRC) and wire rod was supplied by The World Steel Association from their 2022 average LCI data release. The complete list of background datasets modeled for the fabrication process is included in Annex B. Table 9 shows the types of electrodes mapped, the constituent parts, and percentage each part represents of the total mass.

Table 9: Electrode composition by type

Electrode Type	Constituents	% of Total Mass
Stick Welding Electrodes (Washington Alloy, 2023)		
	Steel Cold Rolled Coil (CRC)	78.25 (balance)
	Calcium Carbonate	1.25
	Titanium Oxide	5.00
	Manganese	1.50
	Zircon	1.00
	Cellulose	2.50
	Potassium Silicate	2.00
	Sodium Silicate	2.00
	Kaolin	2.50
	Titanium Oxide Dust	2.50
	Zirconium	0.50
	Total	**100%**
Flux Core Electrodes (Washington Alloy, 2023)		
	CRC	82.75 (balance)
	Calcium Carbonate	1.25
	Titanium Oxide	5.00
	Manganese	2.50
	Silicon	2.50
	Sodium Silicate	2.00
	Aluminum	1.50
	Titanium Oxide Dust	2.50
	Total	**100%**
Submerged Arc Electrodes (Pinnacle Alloys, 2022)		
	CRC	89.90 (balance)
	Silica	1.50
	Aluminum Oxide	1.50
	Barium	4.50
	Manganese	2.00
	Magnesium	0.60
	Total	**100%**
Metal Core Electrodes (Washington Alloy, 2023)		
	CRC	96.25 (balance)
	Calcium Carbonate	1.25
	Manganese	2.50
	Total	**100%**
Gas Metal Arc Electrodes (Pinnacle Alloys, 2022)		
	CRC	98.00 (balance)
	Manganese	2.00
	Total	**100%**

A similar process was conducted for mapping the welding flux. Table 10 shows the welding flux constituent parts, and the percentage each part represents of the total mass.

Table 10: Welding flux composition

Electrode Type	Constituents	% of Total Mass
Welding Flux (Aufhauser, n.d)		
	Steel Wire Rod	75.00 (balance)
	Aluminum	2.50
	Barium Fluoride	7.50
	Fluorspar	5.00
	Magnesium Oxide	1.50
	Manganese	2.50
	Silica	1.00
	Titanium Dioxide	5.00
	Total	**100%**

The fabrication study, as part of AISC's 2021 EPD, modeled electricity based on the U.S. subregional grid mix for each of the 80 fabricator facility locations for which data was provided. The EPD background report provided a list of grid mix regions that were modeled, but did not include the percentage share for each region represented by the industry-average LCI. In order to fill this gap and to better represent a U.S.-average process, AISC provided fabrication throughput in mass for all fabricator members for the 2023 calendar year, split by U.S. state. These states were then mapped to North American Electric Reliability Corporation (NERC) subregions, which are the most granular electricity subregions for the U.S. available in ecoinvent, based on location. If a state spanned more than one subregion, AISC provided guidance on where the majority of fabricators in that state were located, which allowed one NERC subregion to be chosen for each state. To make the top-level process in openLCA, each subregion was assigned a percent of total annual fabrication, and those proportions were used to model 1 metric ton of the fabrication process. Table 11 shows each state in the U.S. and the mapped subregions modeled.

Table 11: U.S. states and mapped NERC subregions based on fabricator geography

State in U.S.	Mapped NERC Region	State in U.S.	Mapped NERC Region
AL	SERC	NC	SERC
AR	SERC	ND	MRO
AZ	WECC	NE	MRO
CA	WECC	NH	NPCC
CO	WECC	NJ	RF
CT	NPCC	NM	WECC
DE	RF	NV	WECC
FL	SERC	NY	NPCC
GA	SERC	OH	RF
HI	HICC	OK	MRO
IA	MRO	OR	WECC
ID	WECC	PA	RF
IL	RF	PR	PR
IN	RF	RI	NPCC
KS	MRO	SC	SERC
KY	SERC	SD	MRO
LA	SERC	TN	SERC
MA	NPCC	TX	TRE
MD	RF	UT	WECC
ME	NPCC	VA	SERC
MI	RF	VT	NPCC
MN	MRO	WA	WECC
MO	SERC	WI	MRO
MS	SERC	WV	RF
MT	WECC	WY	WECC

Table 12 shows the percentage split of each NERC subregion based on total fabrication throughput. These shares were used to create an industry-average electricity grid mix for the fabrication process.

Table 12: Percent of electricity share based on fabrication throughput by NERC subregion

NERC Subregion	% of Total Fabrication
SERC	34%
WECC	15%
NPCC	6.4%
RF	16%
HICC	0.0032%
MRO	20%
PR	0.097%
TRE	8.4%
Total	100%

Table 13 shows the unit process for the average, 10th, and 90th percentile of 1 metric ton of fabricated hot-rolled structural steel sections. Where 10th and 90th percentile values were shown as a 'N/A' in the AISC 2021 EPD background report, the average value was used as a proxy. This was the case for 'fluids & oil' and 'welding flux' on the input side, and all outputs excluding 'steel scrap' and 'shop waste'.

Table 13: Unit process for average, 10th percentile, and 90th percentile for 1 metric ton of fabricated hot-rolled structural steel sections

Item	Average Amount	10th Percentile Amount	90th Percentile Amount	Units
Inputs				
Structural Steel (from Mills)	1.08E+03	1.00E+03	1.14E+03	kg
Fluids & Oil	3.32E-01	3.32E-01	3.32E-01	kg
Stick Welding Electrodes	4.88E-02	2.72E-03	5.32E-01	kg
Flux Core Electrodes	1.36E+00	4.74E-02	3.24E+00	kg
Submerged Arc Electrodes	2.00E-01	1.22E-02	1.69E+00	kg
Metal Core Electrodes	4.78E-01	1.91E-01	3.43E+00	kg
Gas Metal Arc Electrodes	5.75E-01	1.68E-02	2.89E+00	kg
Steel Wire	2.09E-03	8.33E-04	5.77E-01	kg
Welding Flux	1.59E-02	1.59E-02	1.59E-02	kg
Acetylene, Compressed	1.02E-01	9.19E-04	2.55E-01	kg
Argon, Compressed	3.35E-01	1.87E-03	1.10E+00	kg
Argon, Liquid	1.27E+00	1.06E-02	7.73E+00	kg
Carbon Dioxide, Compressed	3.80E-01	1.34E-02	2.47E+00	kg
Carbon Dioxide, Liquid	1.60E+00	9.78E-02	5.77E+00	kg
Helium, Compressed	1.78E-04	1.89E-01	1.67E+00	kg
Natural Gas, Compressed	5.57E-02	1.54E-02	1.20E+00	kg
Nitrogen, Compressed	1.00E-01	1.83E-03	5.06E-01	kg
Nitrogen, Liquid	8.04E-02	6.04E-03	1.06E+00	kg
Oxygen, Compressed	3.33E-01	7.55E-03	1.54E+00	kg
Oxygen, Liquid	3.04E+00	4.50E-03	7.05E+00	kg
Propane, Compressed	3.43E-01	2.68E-03	5.97E-01	kg
Propane, Liquid	7.79E-02	3.10E-03	1.63E-01	kg
Propylene, Compressed	8.95E-02	2.41E-02	4.83E-01	kg
Propylene, Liquid	9.19E-02	3.07E-02	6.89E-01	kg
Electricity	4.64E+02	1.70E+02	8.41E+02	MJ
Propane, Internal Transport	5.65E-01	3.52E-02	2.28E+00	kg
Gasoline, Internal Transport	1.68E-01	3.31E-02	8.99E-01	kg
Diesel, Internal Transport	2.12E+00	2.91E-01	5.23E+00	kg
Kerosene, Internal Transport	3.05E-01	4.12E-02	3.02E+01	kg
Thermal Energy from Natural Gas	1.58E+01	2.50E+00	6.49E+02	MJ
Inbound Truck Transport	2.16E+00	2.94E-03	1.86E-03	MT.km

Item	Average Amount	10th Percentile Amount	90th Percentile Amount	Units
Outputs				
Fabricated Structural Steel	1.00E+03	1.00E+03	1.00E+03	kg
Steel scrap	7.71E+01	7.77E+00	1.58E+02	kg
Shop Waste	9.66E+00	1.83E+00	2.76E+01	kg
Used Oil	3.32E-01	3.32E-01	3.32E-01	kg
Argon Emissions to Air	7.92E-02	7.92E-02	7.92E-02	kg
Carbon Dioxide Emissions to Air	2.43E+00	2.43E+00	2.43E+00	kg
Helium Emissions to Air	1.78E-04	1.78E-04	1.78E-04	kg
Nitrogen Emissions to Air	1.81E-01	1.81E-01	1.81E-01	kg
Oxygen Emissions to Air	6.84E-01	6.84E-01	6.84E-01	kg
Water Emissions to Air	1.12E+00	1.12E+00	1.12E+00	kg

3.2 Background Data

Background data was sourced from the USLCI and ecoinvent v3.10. All background datasets modeled in this study are listed in Annex A.

3.3 Data Quality

3.3.1 Requirements

The key requirement for data quality is that data be as accurate and representative as possible. Data quality evaluations are described in Table 14 and are based on the ISO 14044:2006 standard. To fulfill these requirements and to ensure reliable results, primary data in combination with representative, industry association data and consistent background LCI information from ecoinvent (v3.10) were used.

Table 14: Data quality requirements and evaluation of data quality

Parameter	Evaluation of Data Quality for this Study
Time-related coverage	Manufacturing data from the six mill sites (A1) is representative of the 2023 calendar year. Primary data was collected from the six sites for 12 consecutive months representing the production year 2023. Background data from ecoinvent v3.10 represents the year 2023 (based on the release date of the database). Temporal representativeness for the mills is considered to be high. Primary data for the A2 transportation stage is representative of the years 2019 and 2020. While those distances were utilized in this assessment, the proportional split of transport by mode was updated per information from AISC and its members to reflect current industry practices. Additionally, datasets were updated using the USLCI and mapped to ecoinvent v3.10, which is representative of the 2023 year of data. Therefore, the temporal representativeness of the A2 stage data is considered to be moderate. Fabrication data (A3) was collected from the fabricator sites representing the 2019 and 2020 production years. For this study, the primary data was mapped to updated background datasets to approximate the 2023 year of data. Temporal representativeness of the fabricator sites is considered to be moderate.
Geographical coverage	All primary data is representative of the U.S. with 100% coverage of hot-rolled structural steel sections production included in the study. U.S. and U.S. subregion-specific datasets were utilized where possible, such as for electricity modeling. Rest of World (RoW) and Global (GLO) datasets were used where appropriate for raw material sourcing locations and when specific regional datasets were unavailable. Geographical representativeness is considered to be high.
Technology coverage	Data from each of the six mill sites and 80 fabricator sites were collected and are representative of the manufacturing and fabrication processes from those sites. As the analysis represents AISC's industry-average hot-rolled structural steel sections, and the six mills represent a majority share of manufacturing, and the 80 fabricator sites represent good coverage of the fabrication process, the technology coverage of the assessment is considered to be high.

Parameter	Evaluation of Data Quality for this Study
Precision	Primary data is based on actual manufacturing data for the in-scope products produced at the mills and fabricators. Where specific data points were unavailable, reasonable estimates were developed and documented.
Completeness	All relevant process steps within the study boundary were considered and included within this study. Efforts were made to cross-check data provided from each mill, identify gaps, and seek data from the mills or gap-fill with average data from the other sites. Where specific data points were unavailable, representative estimates were used.
Representativeness	Data collected and modeled in this study is considered to be representative of the defined time-related, geographical, and technological scope.
Consistency	The study methodology conforms to the relevant ISO standards and PCRs and is applied to all components of the analysis. Additionally, to ensure consistency, only primary and secondary data of the same level of detail and granularity were used.
Reproducibility	The study results would be reproducible through the provision of this report, along with supplemental and confidential documentation that was developed throughout this assessment.
Sources of the data	Data is derived from credible sources and databases, with reference to the primary or secondary nature of the data. Data sources are in conformance with the PCR requirements.
Uncertainty	The primary fabrication data is representative of the 2019 and 2020 years of fabrication. It was assumed that the data is still representative of fabrication currently; however, current values may differ in reality. Other sources of uncertainty are associated with data gaps and assumptions. One mill site did not provide the amount of electrodes used; however, as all other mill sites provided electrodes data, the missing value was supplemented with conservative proxy data from the other sites. Another mill requested the use of upstream transportation assumptions from another mill owned by the same company as a proxy. These values may differ in reality.

3.3.2 Gaps, Assumptions, and Limitations

This section identifies data gaps, assumptions, and limitations, and discusses how they are anticipated to affect results.

Table 15: Data gaps, assumptions, and limitations

Description	Potential Implication
Use of proxy data for inbound transport distances and modes	Although the mill sites provided the majority of their inbound transport data, transportation data for some inputs were not provided. When this occurred, gap-filling took place by applying the values in Table 4, differentiating between alloying elements (based on average transport data for all sites) and other material inputs (aligned with the 2020 AISI steel LCI project report). For one mill site, the company provided transportation distances for steel scrap, which is the largest material input at the site, and requested that average transportation mode and distance data be used otherwise from another site owned by the company. These modes and distances may not be the case in reality. As upstream transportation is a relatively minor contributor to the impacts assessed in this study, this assumption is expected to have a minor effect on overall cradle-to-gate results.
Use of proxy data for missing steel mill material inputs	Where mill sites did not provide data on key materials, proxy values were used based on average values from other sites. One mill site did not provide the amount of electrodes used; therefore, the missing value was supplemented with average data from other sites as a proxy. Another site provided two sets of water input data that were orders of magnitude too high and then too low, so average data from other sites was assigned as a proxy. These values may be different in reality. This applied to only minor inputs and average values were used from other sites; therefore, this assumption is expected to have a minor effect on overall cradle-to-gate results.
Use of assumption for allocation ratio between EAF and section rolling processes at mill sites	Where mill sites provided certain data points for the entire facility, an allocation assumption of 50:50 split across the EAF steelmaking and section rolling unit processes was applied prior to scaling to in-scope production. This occurred most commonly for on-site transportation fuels, wastes, and non-CO_2 air emissions. While this may slightly affect the

	amount of impact assigned to the EAF vs the section rolling processes, this assumption is expected to have a minor impact on overall site-level results.
Use of USLCI transportation factors	Per the Smart EPD (draft) PCR requirements, the USLCI database was used for transportation datasets. Transport datasets were identified in the USLCI for each mode (truck, rail, ship, barge), and then mapped to best-fit upstream datasets using ecoinvent v3.10 for all non-elementary flows. USLCI transportation data is derived from source data greater than 10 years old. For example, the diesel truck transport dataset originates from a 2003 Franklin Associates study. However, the database is publicly available and is required for transportation impacts in the Smart EPD PCR. As inbound and outbound transportation is a relatively small contributor to the impacts assessed herein, this assumption is expected to have a minor effect on overall cradle-to-gate results.
Use of proxy data to gap-fill fabrication values	Fabrication data supplied by the 2021 AISC EPD background report contained some 'N/A' values for the 10^{th} and 90^{th} percentile fabrication ranges for certain inputs, wastes, and emissions. These missing values were supplemented with average values as a proxy; however, they would likely be different in reality. Fabrication is not a major contributor to overall cradle-to-gate results and the average value was used in the baseline results for this study; therefore, this assumption is expected to have a minor effect on overall cradle-to-gate results.
Use of assumptions for fabrication material input compositions	Electrode and welding flux datasets were mapped using SDS documents as these items contained multiple components and the 2021 AISC EPD background report did not report the material composition shares. When a percentage of an ingredient was given as a range, half of the maximum value was used, and any remaining percent of the total was balanced with steel inputs. This may not be the case in reality. As electrodes and welding flux were only minor contributors to impact and the SDS's enabled reasonable approximations of the composition, this assumption is expected to have a minor impact on overall cradle-to-gate product results.

4 LCIA Results

The life cycle impact assessment (LCIA) phase connects the LCI results to potential environmental impacts. This section presents the potential environmental impact and inventory metric results described in the goal and scope for this study and accompanying discussion to interpret the results. All results are presented per 1 metric ton of production-weighted average hot-rolled structural steel sections, unfabricated and with fabrication, as described in Section 2.1.2.

These LCIA results are relative expressions and do not predict impacts on category endpoints, the exceedance of thresholds, safety margins, or risks.

4.1 Industry-Average Hot-Rolled Structural Steel Sections Results (Excluding Fabrication)

The baseline results for this study are for 1 MT of production-weighted hot-rolled structural steel sections produced in the U.S., excluding fabrication. Per the draft Smart EPD PCR guidance for unfabricated mill products, results categories are organized as follows:

- A1 – "Extraction and processing of feedstock materials", i.e. this category includes the upstream production of iron and steel inputs, as well as alloy materials.
- A2 – "Transportation of the feedstock to the mill facility", i.e. this category includes the inbound transportation of feedstock materials to the EAF process.
- A3 – "Mill operations", i.e. this category includes production of ancillary materials (e.g., refractory, lubricants, electrodes, etc.), energy requirements (e.g., electricity, natural gas, mobile fuels), water use, packaging (after section rolling), transport of non-A1 materials to the mill, waste and waste transport, and emissions.

Figure 3 shows the results of the industry-average hot-rolled structural steel sections, excluding fabrication, produced by the mills for each LCIA impact category under study, with sub-categories shown as percentages of the total result. Table 16 shows the LCIA results for 1 metric ton of industry-average hot-rolled structural steel sections, split by sub-category. Table 17 through Table 19 show resource use, output flows and wastes, and carbon emissions and removals results for 1 metric ton of industry-average hot-rolled structural steel sections.

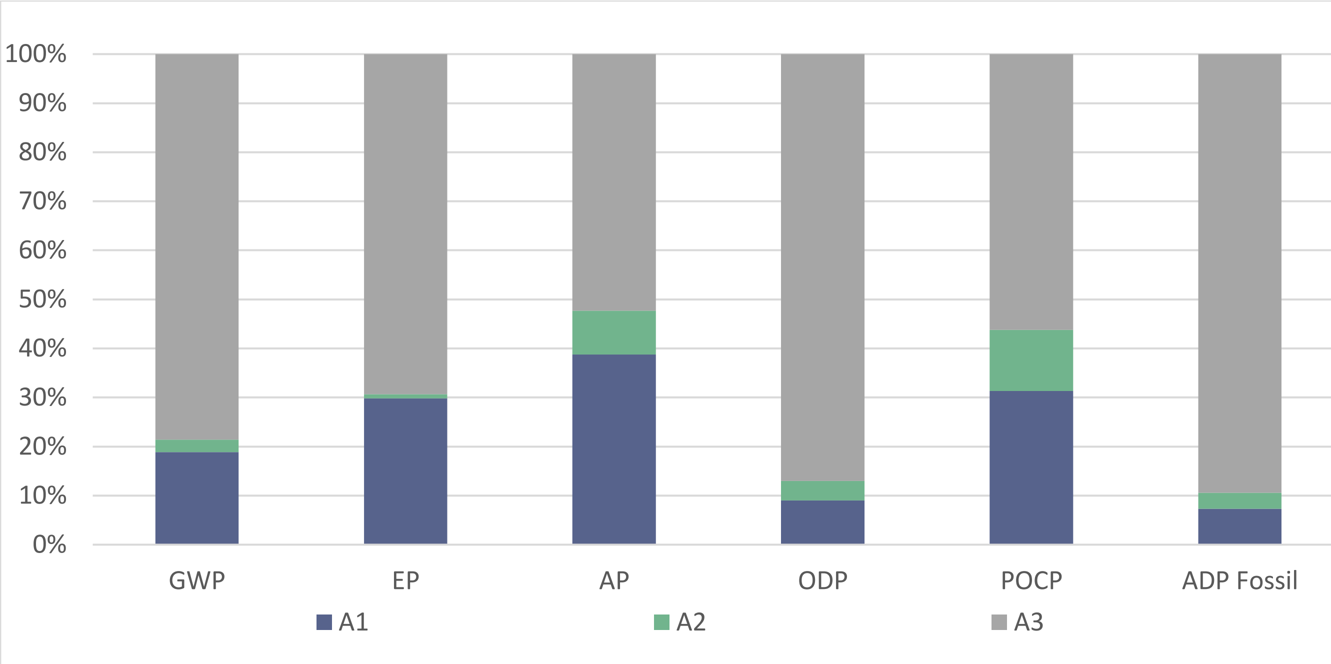


Figure 3: LCIA results of industry-average hot-rolled structural steel sections, in percent contribution

Table 16: LCIA results for 1 metric ton of industry-average hot-rolled structural steel sections

Impact Category	Units	A1	A2	A3	Total
GWP	kg CO_2-Eq	1.70E+02	2.28E+01	7.08E+02	9.01E+02
EP	kg N-Eq	5.35E-01	1.57E-02	1.24E+00	1.79E+00
AP	kg SO_2-Eq	1.07E+00	2.46E-01	1.44E+00	2.75E+00
ODP	kg CFC-11-Eq	8.40E-07	3.73E-07	8.12E-06	9.33E-06
POCP	kg O_3-Eq	1.45E+01	5.81E+00	2.61E+01	4.65E+01
ADP_f	MJ	7.53E+02	3.36E+02	9.20E+03	1.03E+04

Table 17: Resource use results for 1 metric ton of industry-average hot-rolled structural steel sections

Indicator	Units	A1	A2	A3	Total
RPR_E	MJ	0.00E+00	0.00E+00	1.67E+03	1.67E+03
RPR_M	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
$NRPR_E$	MJ	9.38E+02	4.19E+02	1.15E+04	1.28E+04
$NRPR_M$	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SM	kg	9.90E+02	0.00E+00	0.00E+00	9.90E+02
RSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RE	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FW	m^3	3.11E-01	3.46E-02	3.11E+00	3.46E+00

Table 18: Waste and output results for 1 metric ton of industry-average hot-rolled structural steel sections

Indicator	Units	A1	A2	A3	Total
HWD	kg	2.95E-02	3.27E-03	2.95E-01	3.27E-01
NHWD	kg	5.58E+00	6.20E-01	5.58E+01	6.20E+01
HLRW*	kg	N/A	N/A	N/A	N/A
ILLRW*	kg	N/A	N/A	N/A	N/A
CRU	kg	N/A	N/A	N/A	N/A
MR	kg	0.00E+00	0.00E+00	5.61E+01	5.61E+01
MER	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EE	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00

*Data on radioactive waste disposal is not available in ecoinvent as an elementary flow. As such, impacts for HLRW and ILLRW are not reported by ACLCA guidance (ACLCA, 2018).

Table 19: Carbon emissions and removals results for 1 metric ton of industry-average hot-rolled structural steel sections

Indicator	Units	A1	A2	A3	Total
BCRP	kg CO_2-eq	N/A	N/A	N/A	N/A
BCEP	kg CO_2-eq	N/A	N/A	N/A	N/A
BCRK	kg CO_2-eq	N/A	N/A	N/A	N/A
BCEK	kg CO_2-eq	N/A	N/A	N/A	N/A
BCEW	kg CO_2-eq	N/A	N/A	N/A	N/A
CCE	kg CO_2-eq	N/A	N/A	N/A	N/A
CCR	kg CO_2-eq	N/A	N/A	N/A	N/A
CWNR	kg CO_2-eq	N/A	N/A	N/A	N/A

* Refer to Section 2.6 for discussion of carbon emissions and removals.

Results Disclaimer: Comparisons cannot be made between product-specific or industry-average EPDs at the design stage of a project, before a building has been specified. Comparisons may be made between product-specific or industry-average EPDs at the time of product purchase when product performance and specifications have been established and serve as a functional unit for comparison. Environmental impact results shall be converted to a functional unit basis before any comparison is attempted.

Any comparison of EPDs shall be subject to the requirements of ISO 21930. EPDs are not comparative assertions and are either not comparable or have limited comparability when they have different system boundaries, are based on different product category rules, or are missing relevant environmental impacts. Such comparison can be inaccurate and could lead to erroneous selection of materials or products which are higher impact, at least in some impact categories.

4.2 Contribution Analysis Results

Figure 4 shows the mill-level product results, inclusive of the EAF steelmaking and section rolling processes, in summarized categories to identify key contributors to LCIA results. Results are presented for each LCIA impact category under study, with the following sub-categories shown as percentages of the total result:

- Energy – Electricity: Electricity consumed at the mill sites.
- Energy – Natural Gas: Natural gas consumed at the mills.
- Energy – Other: All other energy used at the mills.
- Alloy Materials: Alloy materials used as an input to the EAF steelmaking stage.
- Iron, Steel: Iron and steel inputs, including pig iron and DRI, used as an input to the EAF steelmaking stage.
- Ancillary Materials: All other materials used at the mills, including process related gases (e.g., oxygen and argon), refractories, and electrodes.
- Facility Water: All water inputs at the mills.
- Transport: All inbound transport of materials from suppliers to the mills.

- Emissions: All emissions to air and water resulting from the mills.
- Waste & Waste Transport: All waste fates and the transport of wastes from the mills.
- Packaging: Packaging materials used to package finished products leaving the mills.

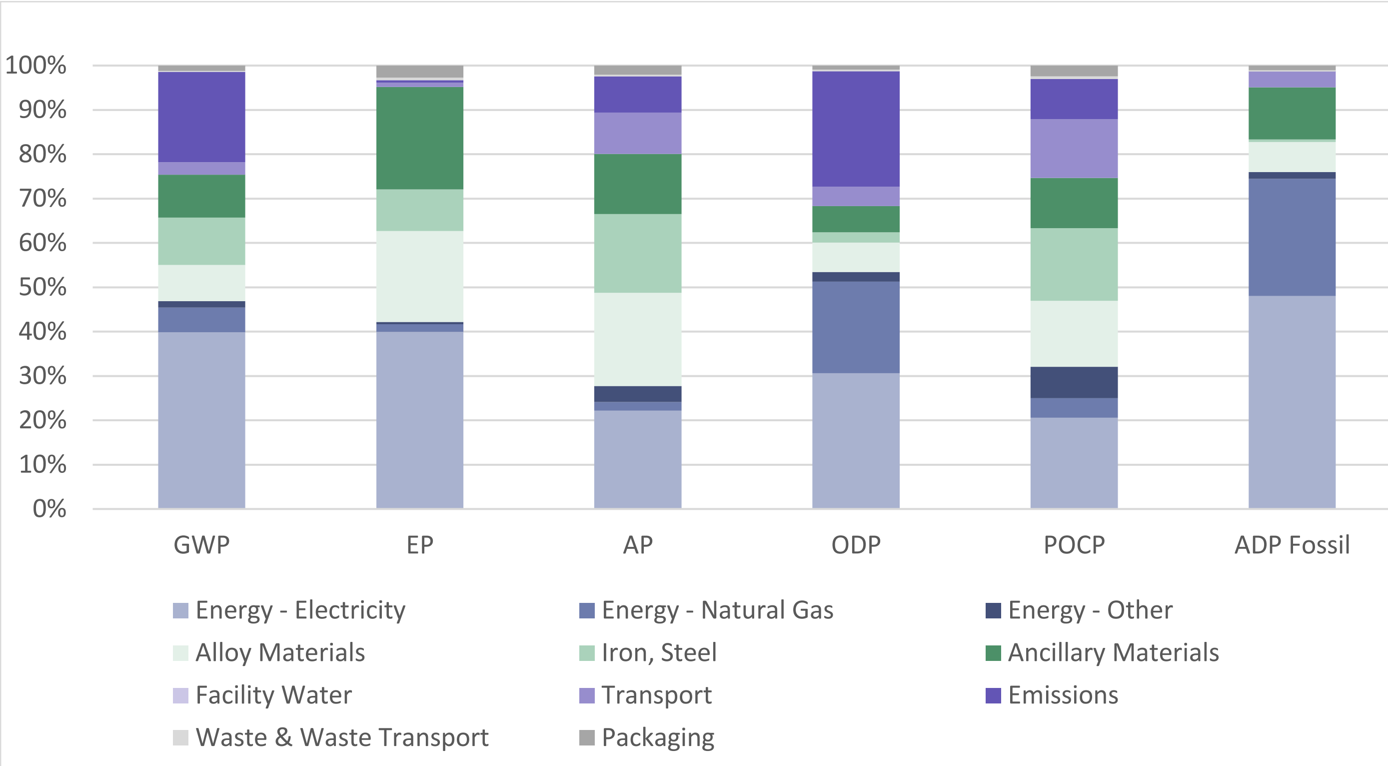


Figure 4: Contribution analysis results for production-weighted average hot-rolled structural sections (unfabricated)

Results show that electricity usage at the mill sites is the largest contributor to each impact category: 40% to GWP and EP, 22% to AP, 31% to ODP, 21% to POCP, and 48% to ADP_f. Electricity contributes 44% of the GWP impact for the EAF steelmaking process and 27% to the section rolling process. Other significant contributors to mill-level impact include natural gas consumption (ranging from 2% to EP to 26% for ADP_f), alloy materials (ranging from 7% to ODP and ADP_f to 21% to EP and AP), iron and steel inputs (pig iron and DRI) (ranging from 1% to ADP_f to 18% to AP), ancillary materials (ranging from 6% to ODP to 23% to EP), and facility emissions (ranging from <1% to ADP_f to 26% to ODP).

4.3 Steel Product Fabrication Results

The results for the fabrication process are presented in this section. There is steel scrap created during product fabrication; therefore, 1.0771 MT of structural steel produced at the mill sites are required to produce 1 MT of fabricated product output. Therefore, the A1 results in the tables below show a multiplier of 7.71% which is the structural steel that must be generated by the mills to account for fabrication scrap. Transportation results shown in A2 reflect the transportation of 1.0771 MT of structural steel per Section 3.1.2. Table 20 through Table 23 show the industry-average LCIA impact categories, resource use, output flows and wastes, and carbon emissions and removals results for 1 metric ton of fabricated hot-rolled structural steel sections.

Table 20: LCIA results for the industry-average structural steel fabrication process to produce 1 MT of fabricated steel products

Indicator	Unit	A1*	A2	A3
GWP	kg CO_2 eq.	7.71%	2.87E+01	8.25E+01
EP	kg N eq.	7.71%	1.51E-02	4.14E-01
AP	kg SO_2 eq.	7.71%	1.70E-01	2.15E-01
ODP	kg CFC 11 eq.	7.71%	5.55E-07	7.71E-07
POCP	kg O_3 eq.	7.71%	5.37E+00	2.99E+00
ADP_f	MJ	7.71%	5.19E+02	1.13E+03

* The % values in this column represent the additional mill material needed to account for fabrication scrap generated in A3.

Table 21: Resource use results for 1 metric ton of industry-average structural steel fabrication

Indicator	Units	A1*	A2	A3
RPR_E	MJ	7.71%	1.14E+00	1.50E+02
RPR_M	MJ	7.71%	0.00E+00	0.00E+00
$NRPR_E$	MJ	7.71%	1.38E+04	5.17E+02
$NRPR_M$	MJ	7.71%	0.00E+00	0.00E+00
SM	kg	7.71%	0.00E+00	0.00E+00
RSF	MJ	7.71%	0.00E+00	0.00E+00
NRSF	MJ	7.71%	0.00E+00	0.00E+00
RE	MJ	7.71%	0.00E+00	0.00E+00
FW	m^3	7.71%	5.66E-03	3.72E-01

* The % values in this column represent the additional mill material needed to account for fabrication scrap generated in A3.

Table 22: Waste and output results for 1 metric ton of industry-average structural steel fabrication

Indicator	Units	A1*	A2	A3
HWD	kg	7.71%	3.63E-03	4.07E-03
NHWD	kg	7.71%	7.23E-02	1.23E+01
HLRW**	kg	7.71%	N/A	N/A
ILLRW**	kg	7.71%	N/A	N/A
CRU	kg	7.71%	N/A	N/A
MR	kg	7.71%	0.00E+00	7.71E+01
MER	kg	7.71%	0.00E+00	0.00E+00
EE	MJ	7.71%	0.00E+00	0.00E+00

* The % values in this column represent the additional mill material needed to account for fabrication scrap generated in A3.
**Data on radioactive waste disposal is not available in ecoinvent as an elementary flow. As such, impacts for HLRW and ILLRW are not reported by ACLCA guidance (ACLCA, 2018).

Table 23: Carbon emissions and removals results for 1 metric ton of industry-average structural steel fabrication

Indicator	Units	A1	A2	A3	Total
BCRP	kg CO_2-eq	N/A	N/A	N/A	N/A
BCEP	kg CO_2-eq	N/A	N/A	N/A	N/A
BCRK	kg CO_2-eq	N/A	N/A	N/A	N/A
BCEK	kg CO_2-eq	N/A	N/A	N/A	N/A
BCEW	kg CO_2-eq	N/A	N/A	N/A	N/A
CCE	kg CO_2-eq	N/A	N/A	N/A	N/A
CCR	kg CO_2-eq	N/A	N/A	N/A	N/A
CWNR	kg CO_2-eq	N/A	N/A	N/A	N/A

** Refer to Section 2.6 for discussion of carbon emissions and removals.*

Results Disclaimer: Comparisons cannot be made between product-specific or industry-average EPDs at the design stage of a project, before a building has been specified. Comparisons may be made between product-specific or industry-average EPDs at the time of product purchase when product performance and specifications have been established and serve as a functional unit for comparison. Environmental impact results shall be converted to a functional unit basis before any comparison is attempted.

Any comparison of EPDs shall be subject to the requirements of ISO 21930. EPDs are not comparative assertions and are either not comparable or have limited comparability when they have different system boundaries, are based on different product category rules, or are missing relevant environmental impacts. Such comparison can be inaccurate and could lead to erroneous selection of materials or products which are higher-impact, at least in some impact categories.

Figure 5 shows the contribution analysis for the fabrication stage (A3) to better understand the sources and their magnitude of potential environmental impacts. The impacts are presented for the gate-to-gate fabrication process; therefore, excluding the production (A1) and transportation (A2) of structural steel to the fabricator facilities. The largest contributor to all impacts is electricity consumption (52-81%).

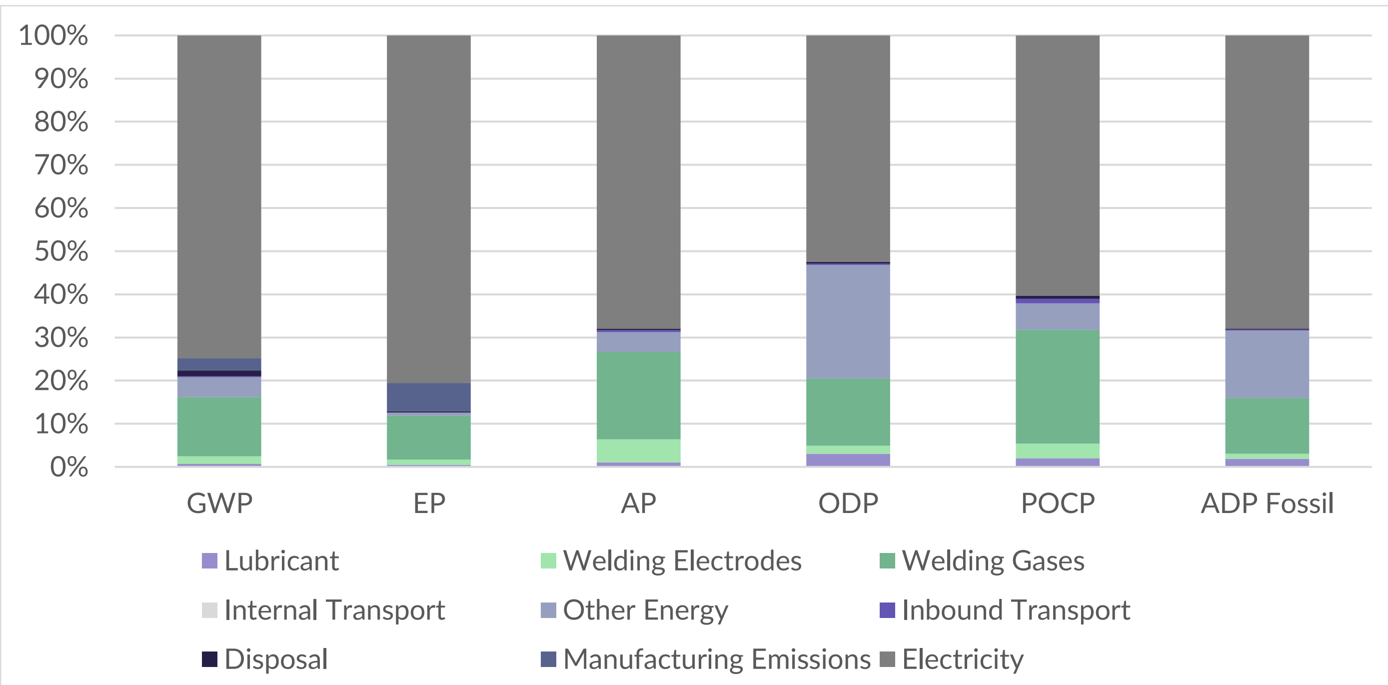


Figure 5: Contribution analysis results for the U.S. average fabrication process

4.4 Fabricated Hot-Rolled Structural Steel Sections Results

As discussed in Section 4.3, to account for steel scrap created during product fabrication, 1.0771 MT of hot-rolled structural steel sections produced at the mill sites are required to produce 1 MT of fabricated product output. Therefore, the A1 results in the tables below have been multiplied by a factor of 1.0771. Transportation results shown in A2 also reflect the transportation of 1.0771 MT of structural steel sections.

Table 24 through Table 27 show the industry-average LCIA impact categories, resource use, output flows and wastes, and carbon emissions and removals results for 1 metric ton of fabricated hot-rolled structural steel sections.

Table 24: LCIA results for 1 metric ton of industry-average fabricated hot-rolled structural steel sections

Indicator	Unit	A1	A2	A3	Total
GWP	kg CO_2 eq.	9.71E+02	2.87E+01	8.25E+01	1.08E+03
EP	kg N eq.	1.93E+00	1.51E-02	4.14E-01	2.36E+00
AP	kg SO_2 eq.	2.97E+00	1.70E-01	2.15E-01	3.35E+00
ODP	kg CFC 11 eq.	1.01E-05	5.55E-07	7.71E-07	1.14E-05
POCP	kg O_3 eq.	5.00E+01	5.37E+00	2.99E+00	5.84E+01
ADP_f	MJ	1.11E+04	5.19E+02	1.13E+03	1.27E+04

Table 25: Resource use results for 1 metric ton of industry-average fabricated hot-rolled structural steel sections

Indicator	Units	A1	A2	A3	Total
RPR_E	MJ	1.80E+03	1.14E+00	1.50E+02	1.95E+03
RPR_M	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
$NRPR_E$	MJ	1.28E+04	1.38E+04	5.17E+02	1.46E+03
$NRPR_M$	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SM	kg	1.07E+03	0.00E+00	0.00E+00	1.07E+03
RSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NRSF	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RE	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FW	m^3	3.73E+00	5.66E-03	3.72E-01	4.10E+00

Table 26: Waste and output results for 1 metric ton of industry-average fabricated hot-rolled structural steel sections

Indicator	Units	A1	A2	A3	Total
HWD	kg	3.53E-01	3.63E-03	4.07E-03	3.60E-01
NHWD	kg	6.68E+01	7.23E-02	1.23E+01	7.91E+01
HLRW*	kg	N/A	N/A	N/A	N/A
ILLRW*	kg	N/A	N/A	N/A	N/A
CRU	kg	N/A	N/A	N/A	N/A
MR	kg	6.04E+01	0.00E+00	7.71E+01	1.38E+02
MER	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
EE	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00

**Data on radioactive waste disposal is not available in ecoinvent as an elementary flow. As such, impacts for HLRW and ILLRW are not reported by ACLCA guidance* (ACLCA, 2018).

Table 27: Carbon emissions and removals results for 1 metric ton of industry-average fabricated hot-rolled structural steel sections

Indicator	Units	A1	A2	A3	Total
BCRP	kg CO_2-eq	N/A	N/A	N/A	N/A
BCEP	kg CO_2-eq	N/A	N/A	N/A	N/A
BCRK	kg CO_2-eq	N/A	N/A	N/A	N/A
BCEK	kg CO_2-eq	N/A	N/A	N/A	N/A
BCEW	kg CO_2-eq	N/A	N/A	N/A	N/A
CCE	kg CO_2-eq	N/A	N/A	N/A	N/A
CCR	kg CO_2-eq	N/A	N/A	N/A	N/A
CWNR	kg CO_2-eq	N/A	N/A	N/A	N/A

** Refer to Section 2.6 for discussion of carbon emissions and removals.*

Results Disclaimer: Comparisons cannot be made between product-specific or industry-average EPDs at the design stage of a project, before a building has been specified. Comparisons may be made between product-specific or industry-average EPDs at the time of product purchase when product performance and specifications have been established and serve as a functional unit for comparison. Environmental impact results shall be converted to a functional unit basis before any comparison is attempted.

Any comparison of EPDs shall be subject to the requirements of ISO 21930. EPDs are not comparative assertions and are either not comparable or have limited comparability when they have different system boundaries, are based on different product category rules, or are missing relevant environmental impacts. Such comparison can be inaccurate and could lead to erroneous selection of materials or products which are higher-impact, at least in some impact categories.

Figure 6 shows the industry-average GWP result, per 1 metric ton of fabricated hot-rolled structural steel sections, with average fabrication, 90th percentile fabrication, and 10th percentile fabrication. Mill site results (A1) are split into the EAF and section rolling processes. Table 28 shows the GWP results in Figure 6 in tabular format. As discussed in Section 4.3, the variation in A3 results is to be expected as fabrication impacts are a function of the project type and design of the structure being fabricated rather than a reflection of an individual fabricator's performance.

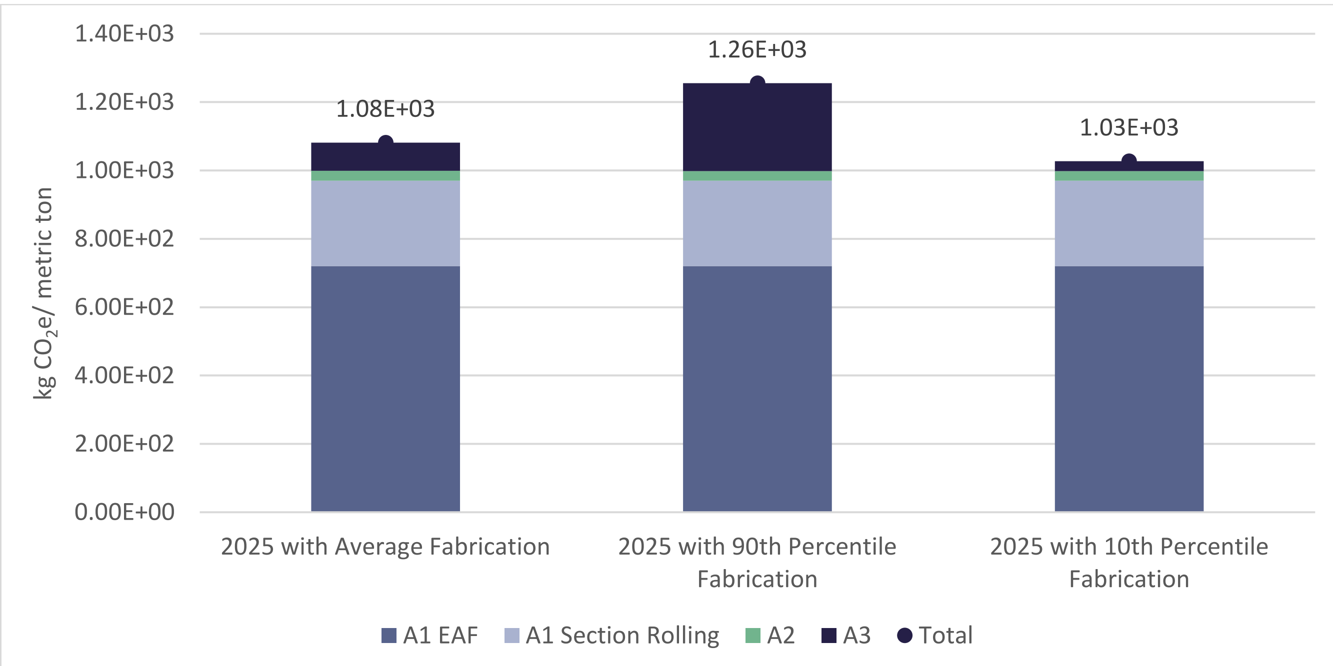


Figure 6: GWP results for 1 metric ton of industry-average fabricated hot-rolled structural steel sections with average, 90th percentile, and 10th percentile fabrication impacts

Table 28: GWP results for 1 metric ton of industry-average fabricated hot-rolled structural steel sections with average, 90th percentile, and 10th percentile fabrication impacts

Product	A1 EAF	A1 Section Rolling	A2	A3	Total ($kgCO_2e/MT$)
Average product - Average fabrication	7.20E+02	2.51E+02	2.87E+01	8.25E+01	1.08E+03
Average product – 90th percentile fabrication	7.20E+02	2.51E+02	2.78E+01	2.57E+02	1.26E+03
Average product – 10th percentile fabrication	7.20E+02	2.51E+02	2.78E+01	2.86E+01	1.03E+03

Results show that the A1 stage, specifically the EAF process at the mill sites, contributes most significantly to the overall cradle-to-gate industry-average results for fabricated hot-rolled structural steel sections.

4.5 Statistics

In accordance with PCR requirements (UL PCR Part A section 2.5.1), Table 29below shows the minimum, maximum, mean, and median values for each LCIA impact category. These values represent the span of data for the structural sections production (A1), transportation (A2), and fabrication spanning average, 10th, and 90th percentiles (A3). The min and max values represent the lowest and highest steel mill result. The mean and median values do not include production volumes, instead considering each facility as an individual result.

Table 29: Statistical metrics for 1 metric ton of fabricated hot-rolled structural steel sections across all facilities

Indicator	Unit	Min (A1-A3)	Max (A1-A3)	Max/Min Ratio (A1-A3)	Mean (A1-A3)	Median (A1-A3)
GWP	kg CO_2 eq.	7.20E+02	1.40E+03	1.94E+00	1.03E+03	9.23E+02
EP	kg N eq.	1.57E+00	3.13E+00	1.99E+00	1.49E+02	2.28E+00
AP	kg SO_2 eq.	2.02E+00	3.72E+00	1.85E+00	1.05E+02	3.25E+00
ODP	kg CFC 11 eq.	7.32E-06	3.31E-05	4.52E+00	1.72E+02	9.27E-06
POCP	kg O_3 eq.	3.64E+01	6.61E+01	1.82E+00	2.60E+02	5.62E+01
ADP_f	MJ	1.14E+04	1.25E+04	1.09E+00	1.12E+04	1.08E+04

4.6 Sensitivity Analysis

At the mill sites in the EAF process, slag is produced and sold for beneficial use. As discussed in Section 2.5.2, co-product allocation has been performed to assign a share of the steelmaking burden to the slag from each input and output. This sensitivity analysis was conducted in order to understand the potential difference in impact results if no burden were given to the slag, i.e., if all burden were allocated to the steel product. This analysis is also a requirement in (ISO, 2006b) Section 4.3.4.1, where more than one allocation procedure may be applicable.

Table 30 below provides the LCIA results for the mill product (A1) if no allocation to the slag co-product occurred.

Table 30: LCIA results for 1 metric ton of fabricated hot-rolled structural steel sections, with no burden assigned to slag co-product

Indicator	Unit	A1	A2	A3	Total
GWP	kg CO_2 eq.	9.76E+02	2.87E+01	8.25E+01	1.09E+03
EP	kg N eq.	1.94E+00	1.51E-02	4.14E-01	2.37E+00
AP	kg SO_2 eq.	2.95E+00	1.70E-01	2.15E-01	3.33E+00
ODP	kg CFC 11 eq.	1.28E-05	5.55E-07	7.71E-07	1.41E-05
POCP	kg O_3 eq.	5.01E+01	5.37E+00	2.99E+00	5.85E+01
ADP_f	MJ	1.13E+04	5.19E+02	1.13E+03	1.29E+04

Table 31 shows the burden assigned to slag, first in terms of slag burden per MT steel, representing the difference between results with and without slag allocation, and secondly per kg slag produced. The production weighted slag output per 1 metric ton of steel was 146 kg.

Table 31: LCIA results showing allocation burden assigned to slag

Indicator	Unit	Allocation to Slag (per MT steel)	Allocation to Slag (per kg slag)
GWP	kg CO_2 eq.	7.48E+01	5.13E-01
EP	kg N eq.	1.51E-01	1.04E-03
AP	kg SO_2 eq.	1.95E-01	1.34E-03
ODP	kg CFC 11 eq.	3.47E-06	2.38E-08
POCP	kg O_3 eq.	3.68E+00	2.53E-02
ADP_f	MJ	1.01E+03	6.95E+00

Figure 7 shows the percentage difference between the base case A1 results with physical partitioning allocation to slag applied and the scenario case A1 excluding co-product allocation. Results are shown as a percentage of the base case.

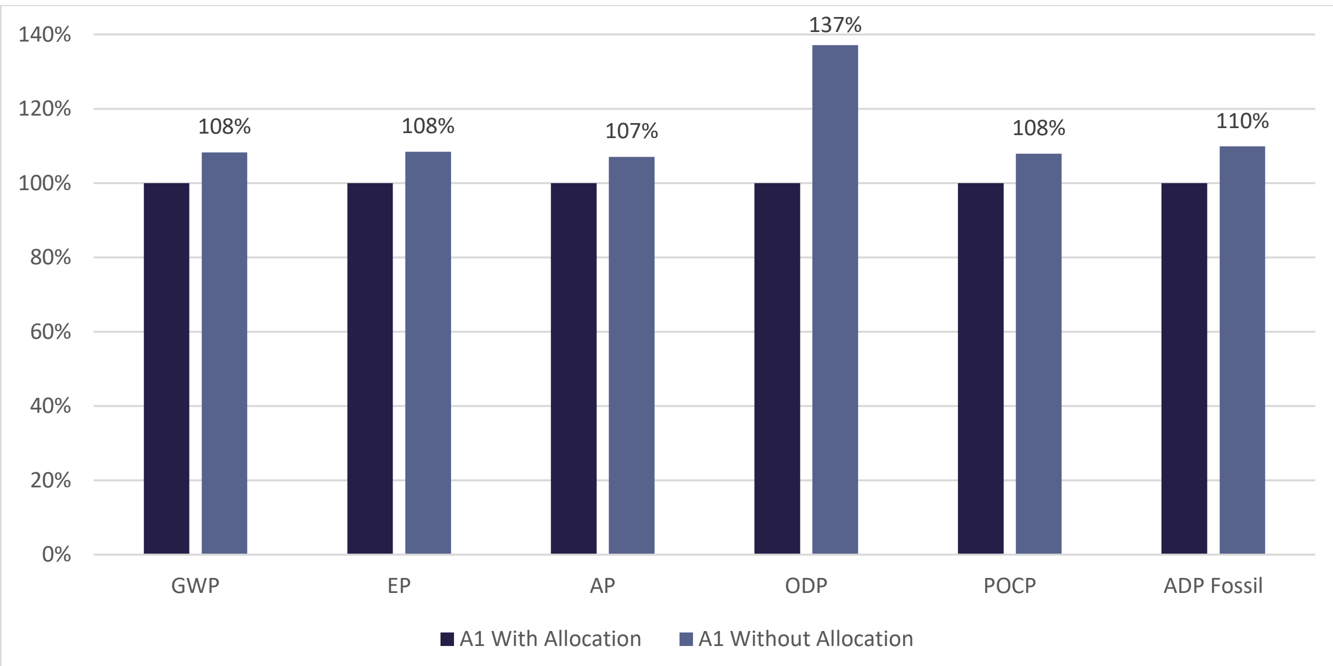


Figure 7: LCIA results of the baseline case (allocation to slag co-product) and scenario case (no co-product allocation), shown as percent of baseline

Results of the scenario analysis show that when no burden is allocated to the slag co-product, the LCIA results increase across all indicators. This increase is 7% - 10% for GWP, EP, AP, POCP, and ADP_f, and 37% for ODP.

5 Interpretation

5.1 Identification of Relevant Findings

The LCA results indicate that the A1 stage is the most significant contributor to overall results, representing 90% of the overall cradle-to-fabricator-gate GWP footprint. It represents 82-89% of the results for all other categories. The A2 stage is a minor contributor, representing 2.7% of overall cradle-to-gate GWP results, largely due to the significant share of rail transport. The A3 stage is also a relatively minor contributor, representing 7.6% of overall cradle-to-fabricator-gate GWP footprint for average fabrication impacts. At the 90^{th} percentile of fabrication impacts, the A3 stage contributes up to 24% of total cradle-to-gate GWP and drops to only 3.4% for the 10^{th} percentile, highlighting the large variances in fabrication impacts due to project-specific designs.

Within A1 at the mill sites, the EAF steelmaking process is the largest contributor, representing 69% of the mill stage GWP results. It is also the most significant contributor to all other impacts (67% - 86%) with the exception of ODP where the section rolling process contributes 54% of the total category. Electricity usage at the mills represents the highest contribution to each LCIA impact category, ranging from 21% - 48% of the overall A1 stage and contributing 40% of the GWP impact. On a unit process basis, electricity contributes 44% to the EAF steelmaking process GWP and 27% to the section rolling process GWP. Site emissions, mainly CO_2, contributed 20% of the A1 GWP impacts, and were a significant contributor (26%) to ODP. Aside from electricity, the key contributors to EP were ancillary materials (23%) and alloy materials (21%); to AP were iron and steel inputs (18%) and ancillary materials (14%); to POCP were iron and steel inputs (16%), alloy materials (15%), and transport (13%); and to ADP_f was natural gas (26%).

Within A2, though it makes up only 25% of the total transport distance, transporting hot-rolled structural steel sections from the mills to fabrication sites by truck contributes 88% of the GWP impacts. Truck transportation contributes 58% - 68% to all other impacts in this study.

For the A3 stage representing the fabrication process, the largest contributor to all results categories is electricity, ranging from 52% - 81%. Welding gases are also significant contributors to all impacts (up to 26%) and other energy consumed at the sites is significant for ODP and ADP_f.

5.2 Conclusions, Limitations, and Recommendations

The goal of this study was to quantify the potential environmental impacts of industry-average hot-rolled structural steel sections produced by AISC's members in the U.S. to support the preparation of an updated industry-average EPD. The LCIA results were assessed relative to the production of one metric ton of hot-rolled structural steel sections. ISO 14040, ISO 14044, ISO 21930, UL's PCR Part A: Life Cycle Assessment Calculation Rules and Report Requirements and UL's PCR Part B: Designated Steel Construction Products were used as the basis for calculation and reporting of the environmental impacts. The study aimed to align with the draft Smart EPD PCR Part B: Designated Steel Construction Products to the extent possible, in anticipation of its upcoming publication.

The results of the LCIA indicate that the potential environmental impacts for fabricated hot-rolled structural steel sections produced in the U.S. are driven by the steelmaking process at the mills, with virgin iron inputs, electricity usage, and alloying materials contributing most significantly to impact.

The study included the physical partitioning approach to allocate burden to slag produced as a co-product alongside steel production. Results of the scenario analysis showed that if no burden is allocated to slag, LCIA results increased by 7% - 8% for GWP, AP, EP, POCP, and ADP_f, and 37% for ODP.

5.2.1 Limitations

The results are limited to the specific processes and materials under study, at EAF steelmaking and fabrication sites located in the U.S., and more general conclusions about hot-rolled structural steel sections produced in other regions, other structural steel products, and fabrication processes outside of the U.S. may not be drawn. Additionally, individual site results should not be assumed from the average results. When reviewing the results, care should be taken to consider potential trade-offs between impact categories, particularly if the results are used to inform future product or process development.

The study aimed to establish a full picture of potential environmental impacts; however, it does not consider human or ecological toxicity or other impacts outside of those explicitly discussed in this report. The study is limited to the environmental impacts of fabricated hot-rolled structural steel sections and does not account for downstream life cycle stages or specific uses of the product.

Data quality and limitations pertaining to data and analysis assumptions are discussed in Section 3.3.

5.2.2 Recommendations

Pig iron and DRI were key contributors to overall results, even though they comprised a relatively small share of the overall raw materials used in steelmaking on average. DRI was modeled using primary data. Pig iron was modelled with RoW average data representing conventional pig iron production from ecoinvent v3.10. A share of the pig iron consumed in 2023 is produced using charcoal with a subset derived from sustainably managed biochar. A reduction in impact could be seen with more differentiation of pig iron by type, if data were made available. In addition, minimizing the amount of both virgin iron and alloying element inputs could reduce environmental impacts.

Electricity was the most significant contributor to impact for both the steelmaking and fabrication processes. On-site renewable energy systems and purchased high-quality renewable electricity contractual instruments that meet the forthcoming Smart EPD PCR requirements could reduce environmental impacts.

As stated in Section 3.1, not all mill sites provided complete emissions data for fuels combusted at their sites. Therefore, combustion was modeled with fuel datasets including production and combustion of the fuels. A recommendation for the future of the study is to request and support sites in providing complete and consistent emissions data.

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Annex A: Unit Processes

Table 32: Complete unit process for 1 metric ton of the industry-average EAF process

Material	Amount	Units
Inputs – Raw Materials		
DRI	3.96E-02	MT
PigIron	2.92E-02	MT
External Scrap	9.93E-01	MT
Home Scrap	6.76E-02	MT
Internal Scrap	1.35E-02	MT
Aluminum	2.57E-05	MT
Aluminum Oxide	1.82E-05	MT
Calcium Silicide	5.90E-05	MT
Columbium	2.96E-05	MT
Copper	7.19E-06	MT
Ferro Boron	1.09E-07	MT
Ferro Chromium	1.31E-04	MT
Ferro Manganese	3.66E-04	MT
Ferro Molybdenum	1.26E-05	MT
Ferro Niobium	3.38E-05	MT
Ferro Silicon	1.23E-03	MT
Fluorspar	9.18E-04	MT
Iron Phosphide	2.20E-06	MT
Iron Silicide	3.07E-04	MT
Molybdenum Oxide	1.55E-05	MT
Nickel	9.67E-05	MT
Phosphorous	4.50E-06	MT
Silicomanganese	1.28E-02	MT
Silicon Carbide	3.74E-06	MT
Sulfur	4.94E-06	MT
Titanium	6.02E-07	MT
Vanadium	2.38E-04	MT
Vanadium Nitrite	1.16E-05	MT
Inputs – Ancillary and Process Materials		
Acetylene	1.09E-09	MT
AlWire	1.35E-06	MT
Anthracite	1.95E-03	MT
Argon Gas	1.06E-03	MT
Argon Gas Produced On-Site	2.36E-04	MT
C wire	1.12E-05	MT
Ca Wire	8.45E-07	MT
Calcium	3.75E-05	MT
Calcium Carbide	1.42E-04	MT
CaSi Wire	1.69E-07	MT
CaSISIC Cored Wire	2.97E-06	MT
Charge Carbon	5.62E-04	MT
Coke	3.28E-03	MT
Dolomite	1.46E-02	MT
Graphite	2.18E-04	MT
Graphite Electrodes	1.79E-03	MT
Injection Carbon	1.32E-02	MT
Ladle Carbon	9.21E-07	MT
Lime	2.95E-02	MT

Material	Amount	Units
Nitrogen Gas	1.13E-02	MT
Oils & Lubricants	6.94E-05	MT
Oxygen Gas	4.84E-02	MT
Oxygen Gas Produced On-Site	1.24E-02	MT
Quick Lime	2.11E-03	MT
Refractory	3.40E-03	MT
S wire	0.00E+00	MT
Samplers	1.26E-05	MT
Sand	3.01E-04	MT
Inputs – Energy		
Electricity Generated On-site	1.01E+01	kWh
Purchased Electricity	5.54E+02	kWh
Natural Gas	5.93E+02	MJ
Natural Gas Combusted	9.01E+01	MJ
Diesel	5.49E+01	MJ
Gasoline	2.32E+00	MJ
Propane	7.99E-01	MJ
Inputs – Water		
Ground Water	8.93E-01	m3
Municipal Water	2.11E-01	m3
Surface Water	1.21E-02	m3
Inputs – Transportation		
Inbound Barge	2.29E+01	MT.km
Inbound Rail	2.96E+02	MT.km
Inbound Ship	6.70E+02	MT.km
Inbound Truck	1.67E+02	MT.km
Outputs – Product & Co-Products		
Product Output (Steel Blooms)	1.00E+00	MT
Internal Scrap	1.35E-02	MT
Mill Scale	1.28E-02	MT
Slag	1.46E-01	MT
Outputs – Water		
Wastewater POTW	3.91E-02	m3
Water Discharged	7.06E-02	m3
Water Emissions to Air	1.01E+00	m3
Outputs – Emissions to Air		
1,3-Butadiene	3.77E-07	MT
1,4-Dichlorobenzene	9.51E-11	MT
2-Methylnaphthalene	1.91E-12	MT
Acetaldehyde	7.46E-08	MT
Acrolein	3.04E-08	MT
Aluminum Oxide	7.31E-08	MT
Ammonia	2.46E-07	MT
Antimony	4.23E-09	MT
Arsenic	9.96E-10	MT
Benzene	5.54E-09	MT
Beryllium	5.15E-14	MT
Cadmium	2.57E-09	MT
Calcium Oxide	6.42E-07	MT
Carbon Dioxide	7.91E-02	MT
Carbon Disulfide	3.89E-08	MT
Carbon Monoxide	6.15E-04	MT
Carbon Tetrachloride	3.51E-09	MT
Chlorine	1.20E-08	MT
Chloroform	1.02E-08	MT
Chromium	8.27E-09	MT
Copper Oxide	1.57E-08	MT

Material	Amount	Units
Ethane	2.73E-07	MT
Ethyl Benzene	2.45E-09	MT
Fluorides	1.41E-08	MT
Fluorine	6.77E-07	MT
Formaldehyde	2.87E-08	MT
HAPs	1.69E-07	MT
Hydrochloric Acid	3.45E-11	MT
Hydrogen Fluoride	4.25E-08	MT
Iron Oxide	3.66E-07	MT
Lead	8.75E-08	MT
Lead Oxide	5.76E-08	MT
Magnesium Oxide	4.27E-07	MT
Manganese Oxide	1.08E-07	MT
Manganese	3.76E-07	MT
Mercury	5.24E-08	MT
Methane	7.29E-08	MT
Methanol	4.22E-08	MT
Methyl Chloride	5.85E-09	MT
Methyl Ethyl Ketone	5.12E-08	MT
Methyl Isobutyl Ketone	2.45E-09	MT
Naphthalene	2.57E-09	MT
Nickel	2.93E-09	MT
Nitrogen Dioxide	4.62E-11	MT
Nitrous Oxide	8.35E-05	MT
PAH	2.89E-11	MT
PM10	4.48E-05	MT
PM25	2.05E-05	MT
Styrene	2.02E-09	MT
Sulfur Dioxide	6.58E-05	MT
Sulfuric Acid	1.61E-10	MT
Toluene	1.73E-08	MT
Trichloroethylene	2.35E-09	MT
VOC	3.56E-05	MT
Zinc Oxide	1.06E-06	MT
Outputs – Emissions to Water		
Barium	9.98E-10	MT
Chromium	2.03E-09	MT
Copper	4.19E-09	MT
Iron	8.66E-15	MT
Lead	1.16E-10	MT
Lithium Carbonate	3.85E-09	MT
Manganese	1.46E-09	MT
Nickel	5.55E-08	MT
Suspended Soils	1.71E-06	MT
Zinc	6.74E-13	MT
Outputs – Wastes and Materials for Recovery		
Haz Waste Incineration	1.14E-03	MT
Haz Waste Landfill	1.28E-04	MT
Non Haz Waste Landfill	6.40E-03	MT
Recycled Waste	2.22E-02	MT
Sludge Solidification	4.85E-04	MT
Outputs – Transportation		
Outbound Rail	2.96E+00	MT.km
Outbound Truck	9.36E+00	MT.km

Table 33: Complete unit process for 1 metric ton of the industry-average section rolling process

Material	Amount	Units
Inputs - Materials		
Steel Blooms	1.06E+00	MT
Oils & Lubricants	2.60E-03	MT
Refractory	1.83E-04	MT
Inputs - Energy		
Electricity Generated On-site	1.69E+00	kWh
Purchased Electricity	1.13E+02	kWh
Natural Gas	1.65E+03	MJ
Natural Gas Combusted	2.27E+02	MJ
Diesel	6.60E+01	MJ
Gasoline	3.27E+00	MJ
Propane	8.41E-01	MJ
Inputs - Water		
Ground Water	5.43E-01	m3
Municipal Water	1.49E-01	m3
Surface Water	7.90E-03	m3
Inputs - Transportation		
Inbound Rail	1.06E+00	MT.km
Inbound Truck	2.25E+01	MT.km
Outputs – Product & Packaging		
Product Output (Hot-rolled Steel Sections)	1.00E+00	MT
Internal Scrap	5.61E-02	MT
Dunnage	5.08E-02	MT
Steel Banding	1.21E-03	MT
VCI Bag	5.86E-07	MT
Outputs - Water		
Wastewater POTW	3.38E-02	m3
Water Discharged	5.10E-02	m3
Water Emissions to Air	6.16E-01	m3
Outputs – Emissions to Air		
1,3-Butadiene	3.43E-07	MT
1,4-Dichlorobenzene	8.67E-11	MT
2-Methylnaphthalene	1.74E-12	MT
Acetaldehyde	6.79E-08	MT
Acrolein	2.77E-08	MT
Ammonia	2.24E-07	MT
Benzene	5.05E-09	MT
Carbon Dioxide	1.09E-01	MT
Carbon Disulfide	3.54E-08	MT
Carbon Monoxide	1.10E-04	MT
Carbon Tetrachloride	3.20E-09	MT
Chlorine	1.10E-08	MT
Chloroform	9.25E-09	MT
Ethane	2.48E-07	MT
Ethyl Benzene	2.23E-09	MT
Fluorides	1.28E-08	MT
Formaldehyde	2.62E-08	MT
Hydrochloric Acid	3.14E-11	MT
Hydrogen Fluoride	3.87E-08	MT
Lead Oxide	4.00E-11	MT
Methane	8.87E-08	MT
Methanol	3.85E-08	MT
Methyl Chloride	5.33E-09	MT
Methyl Ethyl Ketone	4.67E-08	MT

Material	Amount	Units
Methyl Isobutyl Ketone	2.23E-09	MT
Naphthalene	2.34E-09	MT
Nitrous Oxide	8.53E-05	MT
PAH	5.69E-14	MT
PM10	3.06E-05	MT
PM25	9.65E-06	MT
Styrene	1.84E-09	MT
Sulfur Dioxide	5.00E-05	MT
Sulfuric Acid	1.47E-10	MT
Toluene	1.58E-08	MT
Trichloroethylene	2.14E-09	MT
VOC	3.01E-05	MT
Outputs – Emissions to Water		
Barium	5.48E-10	MT
Chromium	1.12E-09	MT
Copper	6.31E-09	MT
Iron	1.13E-14	MT
Lead	1.14E-10	MT
Lithium Carbonate	8.05E-10	MT
Manganese	3.05E-08	MT
Nickel	2.12E-09	MT
Suspended Soils	9.37E-07	MT
Zinc	4.18E-09	MT
Outputs – Wastes and Materials for Recovery		
Haz Waste Incineration	1.13E-07	MT
Haz Waste Landfill	1.44E-04	MT
Non Haz Waste Landfill	6.59E-03	MT
Sludge Solidification	3.24E-04	MT
Outbound Truck	3.13E+00	MT.km

Annex B: Background Data

Table 34: Key process data source reporting, from Smart EPD's draft Part B PCR, Table D-1

Input / Unit Process	Origin of Material or Process	LCI data source reference
Coal	RNA, RoW	hard coal mine operation and hard coal preparation | hard coal | Cutoff, U - RNA (ecoinvent v3.10) market for hard coal | hard coal | Cutoff, U - RoW (ecoinvent v3.10)
Iron ore	N/A	N/A
Limestone	N/A	N/A
Lime	RoW RNA	lime production, milled, loose | lime | Cutoff, U - RoW (ecoinvent v3.10) Quicklime, at plant (US LCI, matched to ecoinvent v3.10 upstreams)
Coke	RoW	coke production | coke | Cutoff, U - RoW (ecoinvent v3.10)
Sinter	N/A	N/A
Ferroalloys / other alloying elements	RoW, GLO	All from ecoinvent v3.10, unless indicated otherwise: aluminum, primary ingot, at plant, RNA (US LCI, matched to ecoinvent v3.10 upstreams) copper, anode to generic market for copper-rich materials | copper-rich materials | Cutoff, U - GLO ferrochromium production, high-carbon, 55% Cr | ferrochromium, high-carbon, 55% Cr | Cutoff, U - RoW ferromanganese production, high-coal, 74.5% Mn | ferromanganese, high-coal, 74.5% Mn | Cutoff, U - RoW ferroniobium production, from pyrochlore concentrate, 66% Nb | ferroniobium, 66% Nb | Cutoff, U - RoW ferrosilicon production | ferrosilicon | Cutoff, U - RoW molybdenum production | molybdenum | Cutoff, U - RoW molybdenum trioxide production | molybdenum trioxide | Cutoff, U - GLO silicon carbide production | silicon carbide | Cutoff, U - RoW smelting and refining of nickel concentrate, 16% Ni | nickel, class 1 | Cutoff, U - GLO titanium production | titanium | Cutoff, U - GLO
Zinc	N/A	N/A
Pig iron	RoW	pig iron production | pig iron | Cutoff, U - RoW (ecoinvent v3.10)
Sponge iron	Confidential primary data	Confidential primary data
Iron pellets	N/A	N/A
Semi-finished steel products: billets, slabs, blooms, beam blanks, rounds	USA	Primary data
Semi-finished steel products: billets, slabs, blooms, beam blanks, rounds	Not USA/Canada	N/A
Steel cold rolled coil	GLO	The World Steel Association; used as minor input to welding electrodes
Hot-rolled sections	USA	Primary data
Steel rod, wire	GLO	The World Steel Association; used as minor input to welding electrodes

<table>
<tr><td>Grid electricity - delivered</td><td>USA - Subregion specific (SERC, RF, TERC)</td><td>eGRID 2022 subregion power type mixes. Mapped to ecoinvent v3.10 sub-region specific datasets:
electricity production, deep geothermal | electricity, high voltage | Cutoff, U - US
electricity production, hard coal | electricity, high voltage | Cutoff, U - US
electricity production, hydro, run-of-river | electricity, high voltage | Cutoff, U - US
electricity production, lignite | electricity, high voltage | Cutoff, U - US
electricity production, natural gas, conventional power plant | electricity, high voltage | Cutoff, U - US
electricity production, nuclear, boiling water reactor | electricity, high voltage | Cutoff, U - US
electricity production, oil | electricity, high voltage | Cutoff, U - US
electricity production, photovoltaic, 570kWp open ground installation, multi-Si | electricity, low voltage | Cutoff, U - US
electricity production, wind, >3MW turbine, onshore | electricity, high voltage | Cutoff, U - US
electricity production, wind, <1MW turbine, onshore | electricity, high voltage | Cutoff, U - US
heat and power co-generation, biogas, gas engine | electricity, high voltage | Cutoff, U - US</td></tr>
<tr><td>Grid electricity - delivered</td><td>Canada</td><td>N/A</td></tr>
<tr><td>Grid electricity - delivered</td><td>Not USA/Canada</td><td>N/A</td></tr>
<tr><td>Grid electricity - Energy Attribute Certificates (EACs) (e.g. RECs, PPAs, Gos)</td><td>USA</td><td>electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel, mounted | electricity, low voltage | Cutoff, U - US-SERC (ecoinvent v3.10)</td></tr>
<tr><td>Transportation</td><td>USA (incl. to/from USA)</td><td>Transport, barge, average fuel mix (US LCI, mapped to ecoinvent v3.10: transport, freight, inland waterways, barge tanker | transport, freight, inland waterways, barge tanker | Cutoff, U - RoW)
Transport, combination truck, diesel powered (US LCI, mapped to ecoinvent v3.10: diesel production, petroleum refinery operation | diesel | Cutoff, U - RoW)
Transport, ocean freighter, average fuel mix (US LCI, mapped to ecoinvent v3.10: transport, freight, sea, container ship | transport, freight, sea, container ship | Cutoff, U - GLO)
Transport, train, diesel powered (US LCI, mapped to ecoinvent v3.10: diesel production, petroleum refinery operation | diesel | Cutoff, U - RoW)</td></tr>
<tr><td>Transportation</td><td>Other</td><td>N/A</td></tr>
<tr><td>Fabrication (including fabrication scrap rate that determines the quantity of inputted unfabricated steel product in A1; transport to fabricator impacts (A2); and fabrication operations impacts (A3))</td><td>Hot-rolled sections, plate, HSS</td><td>Primary data</td></tr>
<tr><td>Other (any input not listed above that contributes at least 10% to total A1:A3 result for any impact measure)</td><td>N/A</td><td>N/A</td></tr>
</table>

Table 35: A1 background data - EAF (ecoinvent v3.10, cutoff unit process models)

Material	Geographic Region	Dataset	Provider	Proxy*
Pig Iron	RoW	pig iron production | pig iron | Cutoff, U - RoW	ecoinvent	No
DRI	Confidential primary data			No
Natural Gas Production	US	natural gas, high pressure, domestic supply with seasonal storage | natural gas, high pressure | Cutoff, U - US	ecoinvent	No
Natural Gas Combustion	RoW	heat production, natural gas, at industrial furnace >100kW | heat, district or industrial, natural gas | Cutoff, U - RoW	ecoinvent	No
Diesel	GLO	diesel, burned in building machine | diesel, burned in building machine | Cutoff, U - GLO	ecoinvent	No
Gasoline	GLO	petrol, unleaded, burned in machinery | petrol, unleaded, burned in machinery | Cutoff, U - GLO	ecoinvent	No
Propane	GLO	propane, burned in building machine | propane, burned in building machine | Cutoff, U - GLO	ecoinvent	No
Acetylene	RoW	acetylene production | acetylene | Cutoff, U - RoW	ecoinvent	No
Municipal Water	RoW	tap water production, conventional treatment | tap water | Cutoff, U - RoW	ecoinvent	No
Ground Water	N/A	Elementary flow, resource, in ground, water, unspecified natural origin	ecoinvent	No
Surface Water	N/A	Elementary flow, resource, in water, water (fresh water)	ecoinvent	No
Silicomanganese	RoW	ferromanganese production, high-coal, 74.5% Mn | ferromanganese, high-coal, 74.5% Mn | Cutoff, U - RoW	ecoinvent	No
Ferro Silicon	RoW	ferrosilicon production | ferrosilicon | Cutoff, U - RoW	ecoinvent	No
Ferromanganese	RoW	ferromanganese production, high-coal, 74.5% Mn | ferromanganese, high-coal, 74.5% Mn | Cutoff, U - RoW	ecoinvent	No
Iron Silicide	RoW	ferrosilicon production | ferrosilicon | Cutoff, U - RoW	ecoinvent	No
Vanadium	GLO	titanium production | titanium | Cutoff, U - GLO	ecoinvent	No
Ferro Chromium	RoW	ferrochromium production, high-carbon, 55% Cr | ferrochromium, high-carbon, 55% Cr | Cutoff, U - RoW	ecoinvent	No
Nickel	GLO	smelting and refining of nickel concentrate, 16% Ni | nickel, class 1 | Cutoff, U - GLO	ecoinvent	No
Calcium Silicate	RoW	silica sand production | silica sand | Cutoff, U - RoW	ecoinvent	No
Ferroniobium	RoW	ferroniobium production, from pyrochlore concentrate, 66% Nb | ferroniobium, 66% Nb | Cutoff, U - RoW	ecoinvent	No
Chromium	RoW	ferrochromium production, high-carbon, 55% Cr | ferrochromium, high-carbon, 55% Cr | Cutoff, U - RoW	ecoinvent	No
Aluminum	RNA	Aluminum, primary ingot, at plant, RNA	USLCI, matched to ecoinvent.	No
Aluminum Oxide	RoW	market for aluminium oxide, metallurgical | aluminium oxide, metallurgical | Cutoff, U - RoW	ecoinvent	No
Molybdenum Oxide	GLO	molybdenum trioxide production | molybdenum trioxide | Cutoff, U - GLO	ecoinvent	No
Ferromolybdenum	RoW	molybdenum production | molybdenum | Cutoff, U - RoW	ecoinvent	No
Vanadium Nitrate	GLO	titanium production | titanium | Cutoff, U - GLO	ecoinvent	No
Copper	GLO	copper, anode to generic market for copper-rich materials | copper-rich materials | Cutoff, U - GLO	ecoinvent	No
Sulfur	RoW	sulfur production, petroleum refinery operation | sulfur | Cutoff, U - RoW	ecoinvent	No
Phosphorous	RoW	phosphorus production, white, liquid | phosphorus, white, liquid | Cutoff, U - RoW	ecoinvent	No
Silicon Carbide	RoW	silicon carbide production | silicon carbide | Cutoff, U - RoW	ecoinvent	No
Iron Phosphide	RoW RoW	iron ore beneficiation | iron ore concentrate | Cutoff, U – RoW phosphorous chloride production | phosphorous chloride | Cutoff, U - RoW	ecoinvent	No
Ferrochrome	RoW	ferrochromium production, high-carbon, 55% Cr | ferrochromium, high-carbon, 55% Cr | Cutoff, U - RoW	ecoinvent	No

Material	Geographic Region	Dataset	Provider	Proxy*
Titanium	GLO	titanium production | titanium | Cutoff, U - GLO	ecoinvent	No
Ferroboron	GLO	boron carbide production | boron carbide | Cutoff, U - GLO	ecoinvent	No
Graphite	RoW	graphite production | graphite | Cutoff, U - RoW	ecoinvent	No
Anthracite	RNA	hard coal mine operation and hard coal preparation | hard coal | Cutoff, U - RNA	ecoinvent	No
Ladle Carbon	RoW	market for hard coal | hard coal | Cutoff, U - RoW	ecoinvent	No
Ca Wire	RoW RoW	calcium carbonate production, precipitated | calcium carbonate, precipitated | Cutoff, U – RoW wire drawing, copper | wire drawing, copper | Cutoff, U - RoW	ecoinvent	No
Al Wire	RoW RoW	aluminium production, primary, ingot | aluminium, primary, ingot | Cutoff, U – RoW wire drawing, steel | wire drawing, steel | Cutoff, U - RoW	ecoinvent	No
CASi Wire	RoW RoW RoW	calcium carbonate production, precipitated | calcium carbonate, precipitated | Cutoff, U – RoW silicone product production | silicone product | Cutoff, U – RoW wire drawing, steel | wire drawing, steel | Cutoff, U - RoW	ecoinvent	No
C wire	GLO RoW	carbon black production | carbon black | Cutoff, U – GLO wire drawing, steel | wire drawing, steel | Cutoff, U - RoW	ecoinvent	No
Calcium Carbide	RoW	calcium carbide production, technical grade | calcium carbide, technical grade | Cutoff, U - RoW	ecoinvent	No
CaSI Cored Wire	RoW RoW RoW	calcium carbonate production, precipitated | calcium carbonate, precipitated | Cutoff, U – RoW silicone product production | silicone product | Cutoff, U – RoW wire drawing, steel | wire drawing, steel | Cutoff, U - RoW	ecoinvent	No
Charge Carbon	RoW	market for hard coal | hard coal | Cutoff, U - RoW	ecoinvent	No
Coke	RoW	coke production | coke | Cutoff, U - RoW	ecoinvent	No
Dolomite	RoW	dolomite production | dolomite | Cutoff, U - RoW	ecoinvent	No
Graphite Electrodes	RoW	graphite production | graphite | Cutoff, U - RoW	ecoinvent	No
Injection Carbon	RoW	market for hard coal | hard coal | Cutoff, U - RoW	ecoinvent	No
Lime	RoW	lime production, milled, loose | lime | Cutoff, U - RoW	ecoinvent	No
Quick Lime	RNA	Quicklime, at plant	USLCI, matched to ecoinvent.	No
Oils	RoW	lubricating oil production | lubricating oil | Cutoff, U - RoW	ecoinvent	No
Refractory	RoW	refractory production, basic, packed | refractory, basic, packed | Cutoff, U - RoW	ecoinvent	No
Sand	N/A	Elementary flow, resource, in ground, sand, quartz	ecoinvent	No
Oxygen Gas	RoW	industrial gases production, cryogenic air separation | oxygen, liquid | Cutoff, U - RoW	ecoinvent	No
Nitrogen Gas	RoW	industrial gases production, cryogenic air separation | nitrogen, liquid | Cutoff, U - RoW	ecoinvent	No
Argon Gas	RoW	industrial gases production, cryogenic air separation | argon, crude, liquid | Cutoff, U - RoW	ecoinvent	No
Calcium	RoW	calcium carbide production, technical grade | calcium carbide, technical grade | Cutoff, U - RoW	ecoinvent	No
Samplers	RoW	cast iron production | cast iron | Cutoff, U - RoW	ecoinvent	No
Purchased Electricity	US – subregion specific	electricity production, wind, >3MW turbine, onshore | electricity, high voltage | Cutoff, U - US electricity production, hard coal | electricity, high voltage | Cutoff, U - US heat and power co-generation, biogas, gas engine | electricity, high voltage | Cutoff, U - US electricity production, deep geothermal | electricity, high voltage | Cutoff, U - US electricity production, natural gas, conventional power plant | electricity, high voltage | Cutoff, U - US	ecoinvent	No

<table>
<tr><th>Material</th><th>Geographic Region</th><th>Dataset</th><th>Provider</th><th>Proxy*</th></tr>
<tr><td></td><td></td><td>electricity production, oil | electricity, high voltage | Cutoff, U - US
electricity production, nuclear, boiling water reactor | electricity, high voltage | Cutoff, U - US
electricity production, hydro, run-of-river | electricity, high voltage | Cutoff, U - US
electricity production, lignite | electricity, high voltage | Cutoff, U - US
electricity production, wind, <1MW turbine, onshore | electricity, high voltage | Cutoff, U - US
electricity production, photovoltaic, 570kWp open ground installation, multi-Si | electricity, low voltage | Cutoff, U - US</td><td></td><td></td></tr>
<tr><td>PPA – Solar</td><td>US-SERC</td><td>electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel, mounted | electricity, low voltage | Cutoff, U - US-SERC</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Inbound Ship</td><td>GLO</td><td>Transport, ocean freighter, average fuel mix</td><td>USLCI, matched to ecoinvent..</td><td>No</td></tr>
<tr><td>Inbound Barge</td><td>US</td><td>Transport, barge, average fuel mix</td><td>USLCI, matched to ecoinvent.</td><td>No</td></tr>
<tr><td>Inbound Truck</td><td>RNA</td><td>Transport, combination truck, diesel powered</td><td>USLCI, matched to ecoinvent.</td><td>No</td></tr>
<tr><td>Inbound Rail</td><td>US</td><td>Transport, train, diesel powered</td><td>USLCI, matched to ecoinvent.</td><td>No</td></tr>
<tr><td>Wastewater to POTW</td><td>RoW</td><td>treatment of wastewater, average, wastewater treatment | wastewater, average | Cutoff, U - RoW</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Mercury to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, mercury compounds</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Nitrogen Dioxide to Air</td><td></td><td>Elementary flow, emission to air, unspecified, nitrogen dioxide</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Lead to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, lead II</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Arsenic to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, arsenic</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Cadmium to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, cadmium compounds</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Chromium to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, chromium compounds</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Manganese to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, manganese II</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Nickel to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, nickel compounds</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Suspended Solids to Water</td><td>N/A</td><td>Elementary flow, emission to water, unspecified, suspended solids, unspecified</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Iron to Water</td><td>N/A</td><td>Elementary flow, emission to water, unspecified, iron ion</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Fluorine to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, fluorine</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Beryllium to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, beryllium compounds</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Aluminum Oxide to Air</td><td>RoW</td><td>market for aluminium oxide, metallurgical | aluminium oxide, metallurgical | Cutoff, U - RoW</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Calcium Oxide to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, calcium II</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Copper Oxide to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, copper oxide</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Iron Oxide to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, iron II</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Lead Oxide to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, lead compounds</td><td>ecoinvent</td><td>No</td></tr>
<tr><td>Magnesium Oxide to Air</td><td>N/A</td><td>Elementary flow, emission to air, unspecified, magnesium</td><td>ecoinvent</td><td>No</td></tr>
</table>

Material	Geographic Region	Dataset	Provider	Proxy*
Manganese Oxide to Air	N/A	Elementary flow, emission to air, unspecified, manganese II	ecoinvent	No
Zinc Oxide to Air	N/A	Elementary flow, emission to air, unspecified, zinc oxide	ecoinvent	No
Antimony to Air	N/A	Elementary flow, emission to air, unspecified, antimony oxide	ecoinvent	No
Barium to Water	N/A	Elementary flow, emission to water, unspecified, barium compounds	ecoinvent	No
Chromium to Water	N/A	Elementary flow, emission to water, unspecified, chromium compounds	ecoinvent	No
Water to Water	N/A	Elementary flow, emission to water, lake, water, US	ecoinvent	No
PAH to Air	N/A	Elementary flow, emission to air, unspecified, PAH, polycyclic aromatic hydrocarbons	ecoinvent	No
Methane to Air	N/A	Elementary flow, emission to air, unspecified, methane	ecoinvent	No
Water to Air	N/A	Elementary flow, emission to air, unspecified, water	ecoinvent	No
Carbon Monoxide to Air	N/A	Elementary flow, emission to air, unspecified, carbon monoxide	ecoinvent	No
HAPs to Air	N/A	Elementary flow, emission to air, unspecified, mercury compounds	ecoinvent	No
Nitrous Oxide to Air	N/A	Elementary flow, emission to air, unspecified, nitrogen oxides	ecoinvent	No
PM10 to Air	N/A	Elementary flow, emission to air, unspecified, particulate matter, >2.5um and <10um	ecoinvent	No
PM2.5 to Air	N/A	Elementary flow, emission to air, unspecified, particulate matter, <2.5um	ecoinvent	No
Sulfur Dioxide to Air	N/A	Elementary flow, emission to air, unspecified, sulfur dioxide	ecoinvent	No
VOCs to Air	N/A	Elementary flow, emission to air, unspecified, VOC, volatile organic compounds	ecoinvent	No
CO_2 to Air	N/A	Elementary flow, emission to air, unspecified, carbon dioxide, fossil	ecoinvent	No
Non Haz Landfill	RoW	treatment of inert waste, sanitary landfill | inert waste | Cutoff, U - RoW	ecoinvent	No
Haz Waste Incineration	RoW	treatment of municipal solid waste, municipal incineration | municipal solid waste | Cutoff, U - RoW	ecoinvent	No
General Trash	RoW	treatment of inert waste, sanitary landfill | inert waste | Cutoff, U - RoW	ecoinvent	No
Sludge Solidification	RoW	treatment of sludge from steel rolling, residual material landfill | sludge from steel rolling | Cutoff, U - RoW	ecoinvent	No
Shredder Fluff Landfill	RoW	treatment of inert waste, sanitary landfill | inert waste | Cutoff, U - RoW	ecoinvent	No
Haz Waste Landfill	RoW	treatment of hazardous waste, underground deposit | hazardous waste, for underground deposit | Cutoff, U - RoW	ecoinvent	No
Outbound Truck	RNA	Transport, combination truck, diesel powered	USLCI, matched to ecoinvent.	No
Outbound Rail	US	Transport, train, diesel powered	USLCI, matched to ecoinvent.	No

** Geo. = Geographical proxy, Tech. = Technological proxy*

Table 36: A1 background data – Section Rolling (ecoinvent v3.10, cutoff unit process models)

Material	Geographic Region	Dataset	Provider	Proxy*
Oil	RoW	lubricating oil production | lubricating oil | Cutoff, U - RoW	ecoinvent	No
Refractory	RoW	refractory production, basic, packed | refractory, basic, packed | Cutoff, U - RoW	ecoinvent	No
Purchased Electricity	US – subregion specific	electricity production, wind, >3MW turbine, onshore | electricity, high voltage | Cutoff, U - US electricity production, hard coal | electricity, high voltage | Cutoff, U - US heat and power co-generation, biogas, gas engine | electricity, high voltage | Cutoff, U - US electricity production, deep geothermal | electricity, high voltage | Cutoff, U - US electricity production, natural gas, conventional power plant | electricity, high voltage | Cutoff, U - US electricity production, oil | electricity, high voltage | Cutoff, U - US electricity production, nuclear, boiling water reactor | electricity, high voltage | Cutoff, U - US electricity production, hydro, run-of-river | electricity, high voltage | Cutoff, U - US electricity production, lignite | electricity, high voltage | Cutoff, U - US electricity production, wind, <1MW turbine, onshore | electricity, high voltage | Cutoff, U - US electricity production, photovoltaic, 570kWp open ground installation, multi-Si | electricity, low voltage | Cutoff, U - US	ecoinvent	No
PPA – Solar	US-SERC	electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel, mounted | electricity, low voltage | Cutoff, U - US-SERC	ecoinvent	No
Natural Gas Production	US	natural gas, high pressure, domestic supply with seasonal storage | natural gas, high pressure | Cutoff, U - US	ecoinvent	No
Natural Gas Combustion	RoW	heat production, natural gas, at industrial furnace >100kW | heat, district or industrial, natural gas | Cutoff, U - RoW	ecoinvent	No
Gasoline	GLO	petrol, unleaded, burned in machinery | petrol, unleaded, burned in machinery | Cutoff, U - GLO	ecoinvent	No
Propane	GLO	propane, burned in building machine | propane, burned in building machine | Cutoff, U - GLO	ecoinvent	No
Diesel	GLO	diesel, burned in building machine | diesel, burned in building machine | Cutoff, U - GLO	ecoinvent	No
Municipal Water	RoW	tap water production, conventional treatment | tap water | Cutoff, U - RoW	ecoinvent	No
Ground Water	N/A	Elementary flow, resource, in ground, water, unspecified natural origin	ecoinvent	No
Surface Water	N/A	Elementary flow, resource, in water, water (fresh water)	ecoinvent	No
Dunnage Packaging	RoW	beam, hardwood, raw, kiln drying to u=20% | sawnwood, beam, hardwood, raw, dried (u=20%) | Cutoff, U - RoW	ecoinvent	No
Steel Banding	RoW	steel production, chromium steel 18/8, hot rolled | steel, chromium steel 18/8, hot rolled | Cutoff, U - RoW	ecoinvent	No
VCI Bag	RoW	packaging film production, low density polyethylene | packaging film, low density polyethylene | Cutoff, U - RoW	ecoinvent	No
Inbound Rail	US	Transport, train, diesel powered	USLCI, matched to ecoinvent.	No
Inbound Truck	RNA	Transport, combination truck, diesel powered	USLCI, matched to ecoinvent.	No
Methane to Air	N/A	Elementary flow, emission to air, unspecified, methane	ecoinvent	No

Material	Geographic Region	Dataset	Provider	Proxy*
Wastewater to POTW	RoW	treatment of wastewater, average, wastewater treatment | wastewater, average | Cutoff, U - RoW	ecoinvent	No
CO_2 to Air	N/A	Elementary flow, emission to air, unspecified, carbon dioxide, fossil	ecoinvent	No
Nitrous Oxide to Air	N/A	Elementary flow, emission to air, unspecified, nitrogen oxides	ecoinvent	No
Carbon Monoxide to Air	N/A	Elementary flow, emission to air, unspecified, carbon monoxide	ecoinvent	No
PM10 to Air	N/A	Elementary flow, emission to air, unspecified, particulate matter, >2.5um and <10um	ecoinvent	No
PM2.5 to Air	N/A	Elementary flow, emission to air, unspecified, particulate matter, <2.5um	ecoinvent	No
Sulfur Dioxide to Air	N/A	Elementary flow, emission to air, unspecified, sulfur dioxide	ecoinvent	No
VOC to Air	N/A	Elementary flow, emission to air, unspecified, VOC, volatile organic compounds	ecoinvent	No
Suspended Solids to Water	N/A	Elementary flow, emission to water, unspecified, suspended solids, unspecified	ecoinvent	No
Iron to Water	N/A	Elementary flow, emission to water, unspecified, iron ion	ecoinvent	No
Lead Oxide to Air	N/A	Elementary flow, emission to air, unspecified, lead compounds	ecoinvent	No
Barium to Water	N/A	Elementary flow, emission to water, unspecified, barium compounds	ecoinvent	No
Chromium to Water	N/A	Elementary flow, emission to water, unspecified, chromium compounds	ecoinvent	No
Copper to Water	N/A	Elementary flow, emission to water, unspecified, copper compounds	ecoinvent	No
Lead to Water	N/A	Elementary flow, emission to water, unspecified, lead compounds	ecoinvent	No
Manganese to Water	N/A	Elementary flow, emission to water, unspecified, manganese	ecoinvent	No
Nickel to Water	N/A	Elementary flow, emission to water, unspecified, nickel compounds	ecoinvent	No
Zinc to Water	N/A	Elementary flow, emission to water, unspecified, zinc compounds	ecoinvent	No
Water to Water	N/A	Elementary flow, emission to water, lake, water, US	ecoinvent	No
Lithium Carbonate to Water	N/A	Elementary flow, emission to water, unspecified, lithium carbonate	ecoinvent	No
Water to Air	N/A	Elementary flow, emission to air, unspecified, water	ecoinvent	No
2-Methylnaphthalene to Air	N/A	Elementary flow, emission to air, unspecified, methyl naphthalenes	ecoinvent	No
Ammonia to Air	N/A	Elementary flow, emission to air, unspecified, ammonia	ecoinvent	No
Ethane to Air	N/A	Elementary flow, emission to air, unspecified, ethane	ecoinvent	No
Fluorides to Air	N/A	Elementary flow, emission to air, unspecified, fluoride	ecoinvent	No
Sulfuric Acid to Air	N/A	Elementary flow, emission to air, unspecified, sulfuric acid	ecoinvent	No
1,3-Butadiene to Air	N/A	Elementary flow, emission to air, unspecified, 2,3-Dimethyl-1,3-butadiene	ecoinvent	No
1,4-Dichlorobenzene to Air	N/A	Elementary flow, emission to air, unspecified, 1,4-dichlorobenzene	ecoinvent	No
Acetaldehyde to Air	N/A	Elementary flow, emission to air, unspecified, acetaldehyde	ecoinvent	No
Acrolein to Air	N/A	Elementary flow, emission to air, unspecified, acrolein	ecoinvent	No
Benzene to Air	N/A	Elementary flow, emission to air, unspecified, benzene	ecoinvent	No
Carbon Disulfide to Air	N/A	Elementary flow, emission to air, unspecified, carbon disulfide	ecoinvent	No
Carbon Tetrachloride to Air	N/A	Elementary flow, emission to air, low population density, carbon tetrachloride	ecoinvent	No
Chlorine to Air	N/A	Elementary flow, emission to air, unspecified, chlorine	ecoinvent	No
Chloroform to Air	N/A	Elementary flow, emission to air, unspecified, chloroform	ecoinvent	No
Ethyl Benzene to Air	N/A	Elementary flow, emission to air, unspecified, ethyl benzene	ecoinvent	No
Formaldehyde to Air	N/A	Elementary flow, emission to air, unspecified, formaldehyde	ecoinvent	No
Hydrochloric Acid to Air	N/A	Elementary flow, emission to air, unspecified, hydrochloric acid	ecoinvent	No

Material	Geographic Region	Dataset	Provider	Proxy*
Hydrogen Fluoride to Air	N/A	Elementary flow, emission to air, unspecified, hydrogen fluoride	ecoinvent	No
Methanol to Air	N/A	Elementary flow, emission to air, unspecified, methanol	ecoinvent	No
Methyl Chloride to Air	N/A	Elementary flow, emission to air, unspecified, chloromethane	ecoinvent	No
Methyl Ethyl Ketone to Air	N/A	Elementary flow, emission to air, unspecified, methyl ethyl ketone	ecoinvent	No
Methyl Isobutyl Ketone to Air	N/A	Elementary flow, emission to air, unspecified, methyl-isopropylketone	ecoinvent	No
Naphthalene to Air	N/A	Elementary flow, emission to air, unspecified, naphthalene	ecoinvent	No
PAH to Air	N/A	Elementary flow, emission to air, unspecified, PAH, polycyclic aromatic hydrocarbons	ecoinvent	No
Styrene to Air	N/A	Elementary flow, emission to air, unspecified, styrene	ecoinvent	No
Toluene to Air	N/A	Elementary flow, emission to air, unspecified, toluene	ecoinvent	No
Trichloroethylene to Air	N/A	Elementary flow, emission to air, unspecified, trichloroethylene	ecoinvent	No
Non Haz Waste Landfill	RoW	treatment of inert waste, sanitary landfill | inert waste | Cutoff, U - RoW	ecoinvent	No
Haz Waste Incineration	RoW	treatment of municipal solid waste, municipal incineration | municipal solid waste | Cutoff, U - RoW	ecoinvent	No
General Trash	RoW	treatment of inert waste, sanitary landfill | inert waste | Cutoff, U - RoW	ecoinvent	No
Sludge Solidification	RoW	treatment of sludge from steel rolling, residual material landfill | sludge from steel rolling | Cutoff, U - RoW	ecoinvent	No
Haz Waste Landfill	RoW	treatment of hazardous waste, underground deposit | hazardous waste, for underground deposit | Cutoff, U - RoW	ecoinvent	No
Outbound Truck	RNA	Transport, combination truck, diesel powered	USLCI, matched to ecoinvent.	RNA

** Geo. = Geographical proxy, Tech. = Technological proxy*

Table 37: A2 background data (ecoinvent v3.10, cutoff unit process models)

Material	Geographic region	Dataset	Provider	Proxy?*
Truck transport	RNA	Transport, combination truck, diesel powered	USLCI, matched to ecoinvent..	No
Rail transport	US	Transport, train, diesel powered	USLCI, matched to ecoinvent..	No

**Geo. – Geographical proxy, Tech. = Technical proxy*

Table 38: A3 background data (ecoinvent v3.10, cutoff unit process models)

Material	Geographic region	Dataset	Provider	Proxy?*
Fluids & oil	RoW	lubricating oil production | lubricating oil | Cutoff, U	ecoinvent	No
Stick welding electrodes	GLO RoW RoW RoW GLO RoW RoW RoW RoW RoW	Steel cold rolled coil calcium carbonate production, precipitated | calcium carbonate, precipitated | Cutoff, U titanium dioxide production, sulfate process | titanium dioxide | Cutoff, U ferromanganese production, high-coal, 74.5% Mn | ferromanganese, high-coal, 74.5% Mn | Cutoff, U market for zircon | zircon | Cutoff, U cellulose fibre production | cellulose fibre | Cutoff, U	The World Steel Association (CRC) ecoinvent (all others)	Tech

Material	Geographic region	Dataset	Provider	Proxy?*
	RoW	silica sand production | silica sand | Cutoff, U sodium silicate production, furnace process, solid product | sodium silicate, solid | Cutoff, U kaolin production | kaolin | Cutoff, U titanium dioxide production, sulfate process | titanium dioxide | Cutoff, U zirconium oxide production | zirconium oxide | Cutoff, U		
Flux core electrodes	GLO RoW RoW RoW RoW RoW RNA RoW	Steel cold rolled coil calcium carbonate production, precipitated | calcium carbonate, precipitated | Cutoff, U titanium dioxide production, sulfate process | titanium dioxide | Cutoff, U ferromanganese production, high-coal, 74.5% Mn | ferromanganese, high-coal, 74.5% Mn | Cutoff, U silicon production, metallurgical grade | silicon, metallurgical grade | Cutoff, U sodium silicate production, furnace process, solid product | sodium silicate, solid | Cutoff, U Aluminum – primary extruded aluminum titanium dioxide production, sulfate process | titanium dioxide | Cutoff, U	The World Steel Association (CRC) The Aluminum Association (Aluminum) ecoinvent (all others)	Tech
Submerged arc electrodes	GLO RoW UN-Oceania RoW RoW RoW RoW	Steel wire rod silica sand production | silica sand | Cutoff, U aluminium oxide production | aluminium oxide, non-metallurgical | Cutoff, U Barium Fluoride (chlor-alkali electrolysis, membrane cell | sodium hydroxide, without water, in 50% solution state | Cutoff, U & water production, deionised | water, deionised | Cutoff, U) ferromanganese production, high-coal, 74.5% Mn | ferromanganese, high-coal, 74.5% Mn | Cutoff, U magnesium production, electrolysis | magnesium | Cutoff, U	The World Steel Association (Steel wire rod) ecoinvent (all others)	Tech
Metal core electrodes	GLO RoW RoW	Steel cold rolled coil calcium carbonate production, precipitated | calcium carbonate, precipitated | Cutoff, U ferromanganese production, high-coal, 74.5% Mn | ferromanganese, high-coal, 74.5% Mn | Cutoff, U	The World Steel Association (CRC) ecoinvent (all others)	Tech
Gas metal Arc Electrodes	GLO RoW	Steel cold rolled coil ferromanganese production, high-coal, 74.5% Mn | ferromanganese, high-coal, 74.5% Mn | Cutoff, U	The World Steel Association (CRC) ecoinvent	Tech
Steel wire	GLO	Steel wire rod	The World Steel Association	No
Welding flux	RNA RoW RoW GLO GLO RoW RoW RoW RoW	Aluminum – primary extruded aluminum Barium Fluoride (chlor-alkali electrolysis, membrane cell | sodium hydroxide, without water, in 50% solution state | Cutoff, U & water production, deionised | water, deionised | Cutoff, U) fluorspar production, 97% purity | fluorspar, 97% purity | Cutoff, U Steel wire rod magnesium production, electrolysis | magnesium | Cutoff, U ferromanganese production, high-coal, 74.5% Mn | ferromanganese, high-coal, 74.5% Mn | Cutoff, U silica sand production | silica sand | Cutoff, U	The Aluminum Association (Aluminum) The World Steel Association (steel wire rod) ecoinvent (all others)	Tech

Material	Geographic region	Dataset	Provider	Proxy?*
		titanium dioxide production, sulfate process | titanium dioxide | Cutoff, U		
Acetylene, compressed	RoW	acetylene production | acetylene | Cutoff, U	ecoinvent	No
Argon, compressed	RoW	industrial gases production, cryogenic air separation | argon, crude, liquid | Cutoff, U	ecoinvent	No
Argon, liquid	RoW	argon production, liquid | argon, liquid | Cutoff, U	ecoinvent	No
Carbon dioxide, compressed	RoW	carbon dioxide production, liquid | carbon dioxide, liquid | Cutoff, S	ecoinvent	No
Carbon dioxide, liquid	RoW	carbon dioxide production, liquid | carbon dioxide, liquid | Cutoff, S	ecoinvent	No
Helium, compressed	GLO	natural gas liquids production | helium, crude | Cutoff, U	ecoinvent	No
Natural gas, compressed	GLO	natural gas liquids production | natural gas liquids | Cutoff, U	ecoinvent	No
Nitrogen, compressed	RoW	industrial gases production, cryogenic air separation | nitrogen, liquid | Cutoff, U	ecoinvent	No
Nitrogen, liquid	RoW	industrial gases production, cryogenic air separation | nitrogen, liquid | Cutoff, U	ecoinvent	No
Oxygen, compressed	RoW	industrial gases production, cryogenic air separation | oxygen, liquid | Cutoff, U	ecoinvent	No
Oxygen, liquid	RoW	industrial gases production, cryogenic air separation | oxygen, liquid | Cutoff, U	ecoinvent	No
Propane, compressed	GLO	natural gas liquids fractionation | propane | Cutoff, U	ecoinvent	No
Propane, liquid	GLO	natural gas liquids fractionation | propane | Cutoff, U	ecoinvent	No
Propylene, compressed	US	propylene production, from propane dehydrogenation | propylene | Cutoff, U	ecoinvent	No
Propylene, liquid	US	propylene production, from propane dehydrogenation | propylene | Cutoff, U	ecoinvent	No
Electricity	US – SERC US – WECC US – NPCC US – RFC US – HICC US – MRO US – PR US – TRE	market for electricity, medium voltage | electricity, medium voltage | Cutoff, U	ecoinvent	No
Propane, internal transport	GLO	natural gas liquids fractionation | propane | Cutoff, U	ecoinvent	No
Gasoline, internal transport	GLO	petrol, unleaded, burned in machinery | petrol, unleaded, burned in machinery | Cutoff, U	ecoinvent	No
Diesel, internal transport	RoW	diesel production, petroleum refinery operation | diesel | Cutoff, U	ecoinvent	No
Kerosene, internal transport	RoW	kerosene production, petroleum refinery operation | kerosene | Cutoff, U	ecoinvent	No
Thermal energy from natural gas	RoW	heat production, natural gas, at industrial furnace >100kW | heat, district or industrial, natural gas | Cutoff, U	ecoinvent	No
Inbound truck transport	RNA	Transport, combination truck, diesel powered	USLCI, matched to ecoinvent..	No
Shop waste	GLO	treatment of waste glass, sanitary landfill | waste glass | Cutoff, U	ecoinvent	No
Used oil	RoW	treatment of waste mineral oil, hazardous waste incineration | waste mineral oil | Cutoff, U	ecoinvent	No

Material	Geographic region	Dataset	Provider	Proxy?*
Argon emissions to air	N/A	Elementary flow, emission to air, unspecified, argon	ecoinvent	No
Carbon dioxide emissions to air	N/A	Elementary flow, emission to air, unspecified, carbon dioxide, fossil	ecoinvent	No
Helium emissions to air	N/A	Elementary flow, emission to air, unspecified, helium	ecoinvent	No
Nitrogen emissions to air	N/A	Elementary flow, emission to air, unspecified, nitrogen	ecoinvent	No
Oxygen emissions to air	N/A	Elementary flow, emission to air, unspecified, oxygen	ecoinvent	No
Water emissions to air	N/A	Elementary flow, emission to air, unspecified, water	ecoinvent	No

[Critical Review Placeholder]