Life Cycle Inventory of Steel

for the Canadian Raw Materials Database Project

DRAFT: Notes Prepared for the CRMD Peer Review Committee

THIS REPORT IS NOT TO BE CITED

revised: August 3, 1999
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1.0 GOAL DEFINITION

The goal of the study is to prepare a life cycle inventory of two steel products; hot rolled coil produced using the basic oxygen furnace steelmaking technology and bars produced using the electric arc furnace steelmaking technology. The data is intended for use within the Canadian Raw Materials Database project, a joint initiative of Canadian industry and government to make life cycle data of raw materials publicly available. The intended audience for the steel data includes steel customers and consumers of steel as well as steel researchers.

2.0 SCOPE DEFINITION

The scope defines the breadth, depth, and the detail of the study in such a way as to be compatible and sufficient to address the stated goal. Generally, the scope considers the following items:

- function and functional unit of the system,
- the product system to be studied,
- the product system boundaries,
- allocation procedures,
- type of impact assessment employed,
- data requirements,
- assumptions,
- limitations,
- data quality,
- critical review, and the
- study report.

In the case of the steel LCI prepared for the CRMD, impact assessment is not included within the scope definition and the work is limited to an inventory analysis. Considering the type and format of the report required for the study, the methodology report was developed in conjunction with Canadian raw materials industries, Environment Canada and CSA International. The final methodology report is available from CSA International. This report contains information regarding the application of the methodology to the steel sector and the results obtained.

2.1 Function and Functional Unit

The product system function is defined as the production of steel products at the factory gate. The steel products are later used in the manufacture of many types of goods, such as automobiles, food packaging, bridges, and housing, though these uses of steel are beyond the scope of this work.

The function unit, the unit by which the product inputs and outputs are referenced, is one kilogram of steel product.

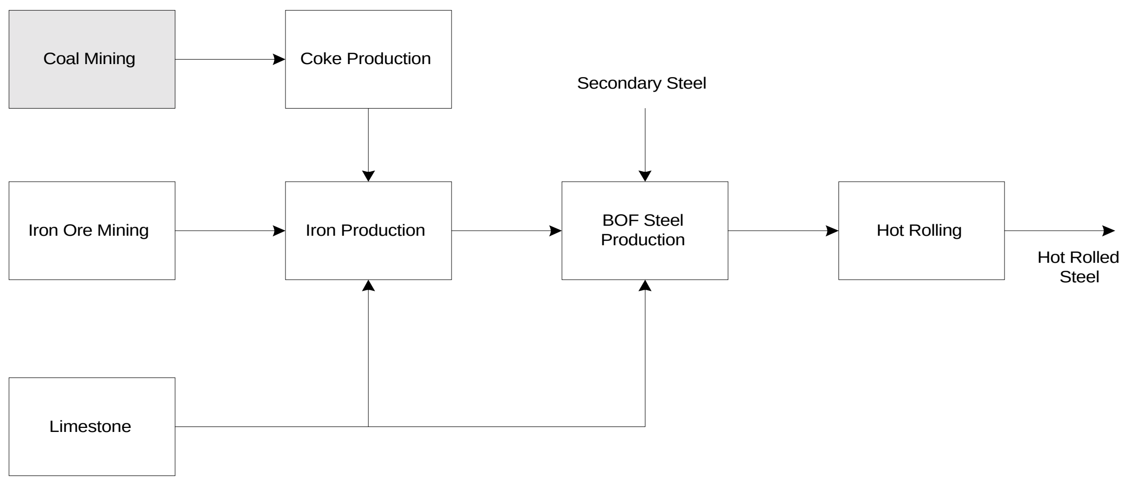
2.2 System Boundaries

Two steel products were modeled in the study; hot rolled steel and bar steel. The simplified process flow diagrams for these products are given in Figure 1 and Figure 2.

The product system for the four steel products is cradle to gate. That is, unit processes from acquisition of raw materials through production of the steel are included. Primary data was collected for the following unit processes:

- iron ore mining,
- limestone quarrying,

- coke production,
- iron production,
- BOF steel production,
- hot rolling,
- EAF steel production, and
- bar production.



Note: Shaded box indicates use of secondary data.

Figure 1. Outline of BOF steel product system.

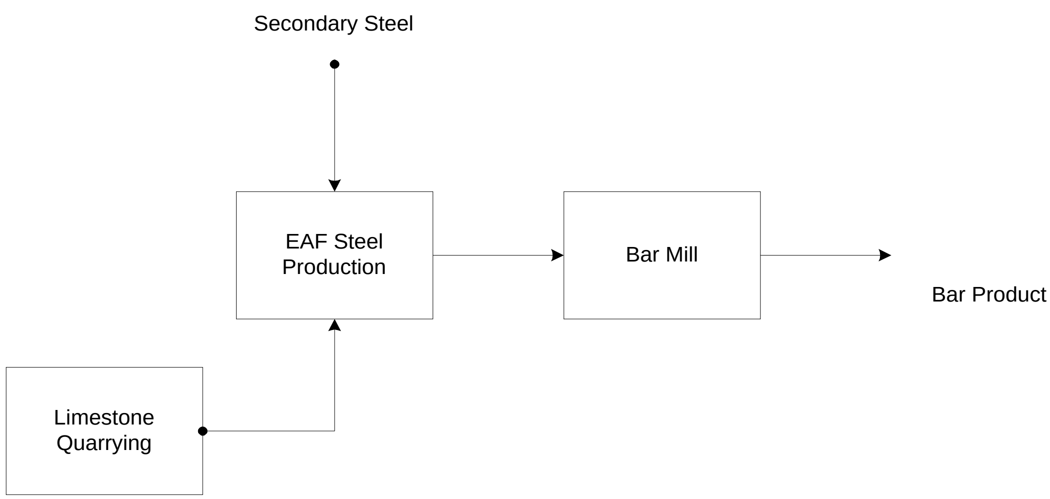


Figure 2. Outline of EAF steel product system.

2.2.1 Process Flow Diagrams for Steel Manufacturing Unit Processes

Process flow diagrams for steel manufacturing unit processes are presented in the following diagrams, Figures 3 to 8. The unit processes presented are coke production, iron production, BOF steel production, hot rolling, EAF steel production, and bar rolling.

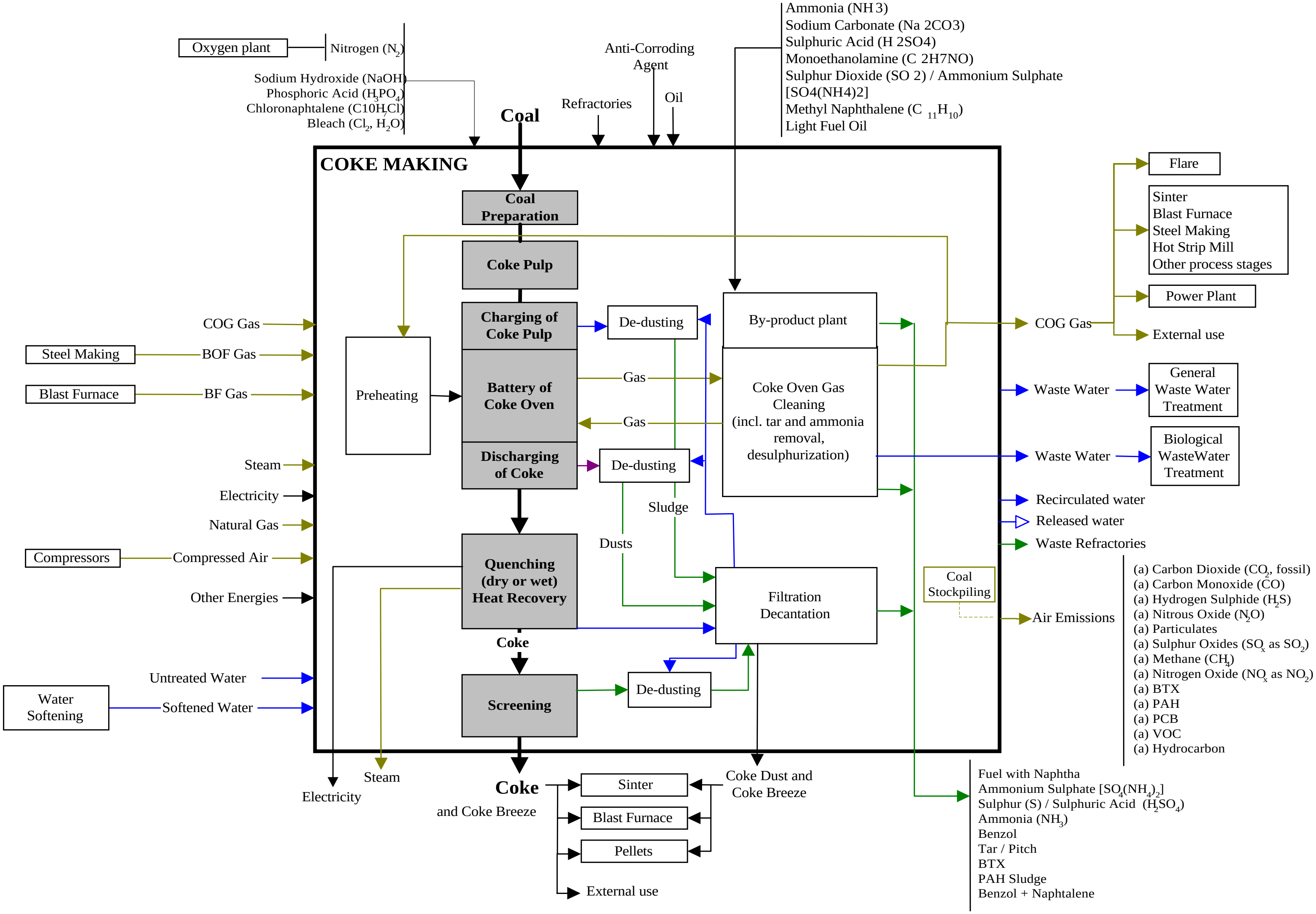


Figure 3. Coke production unit process.

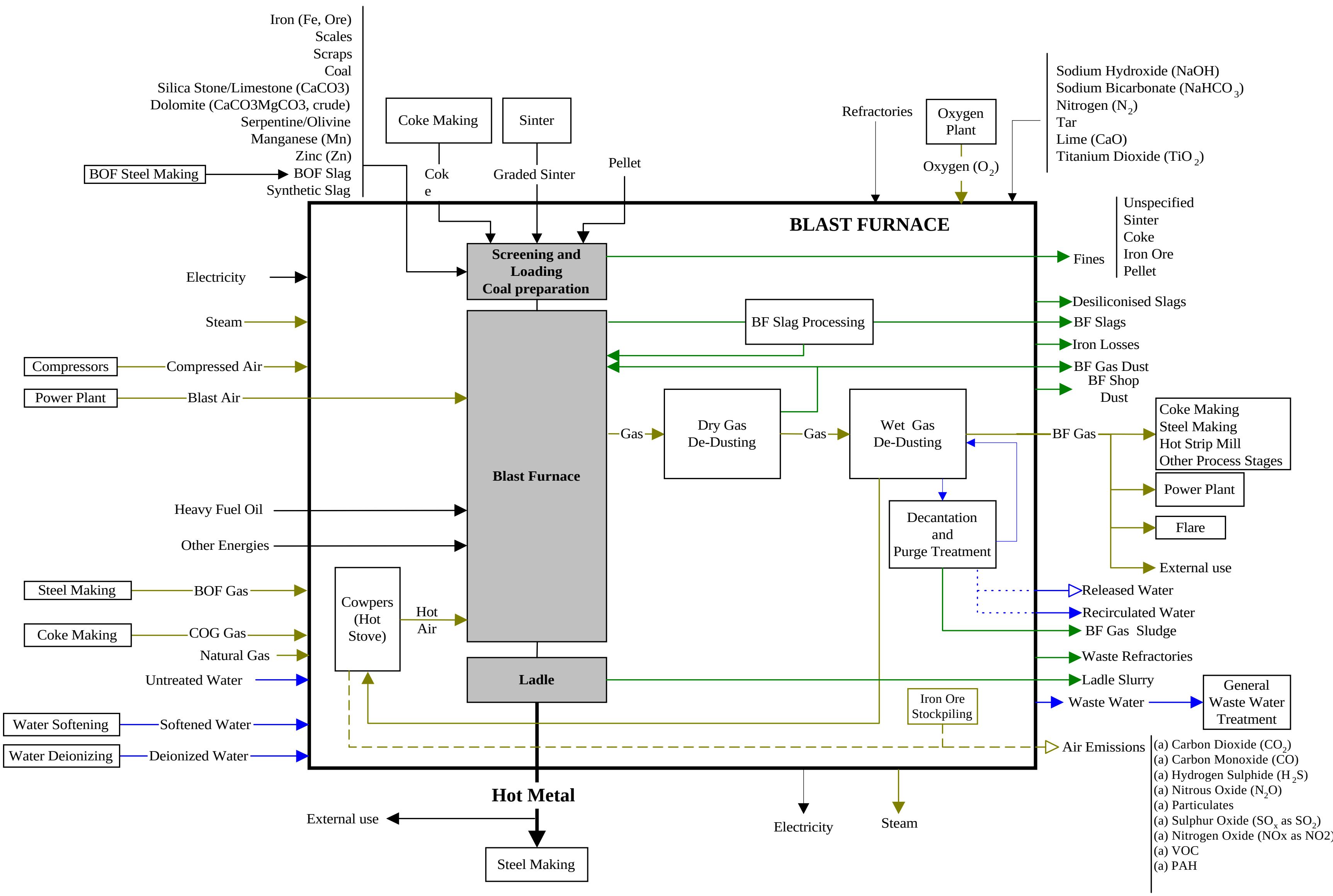


Figure 4. Iron production unit process.

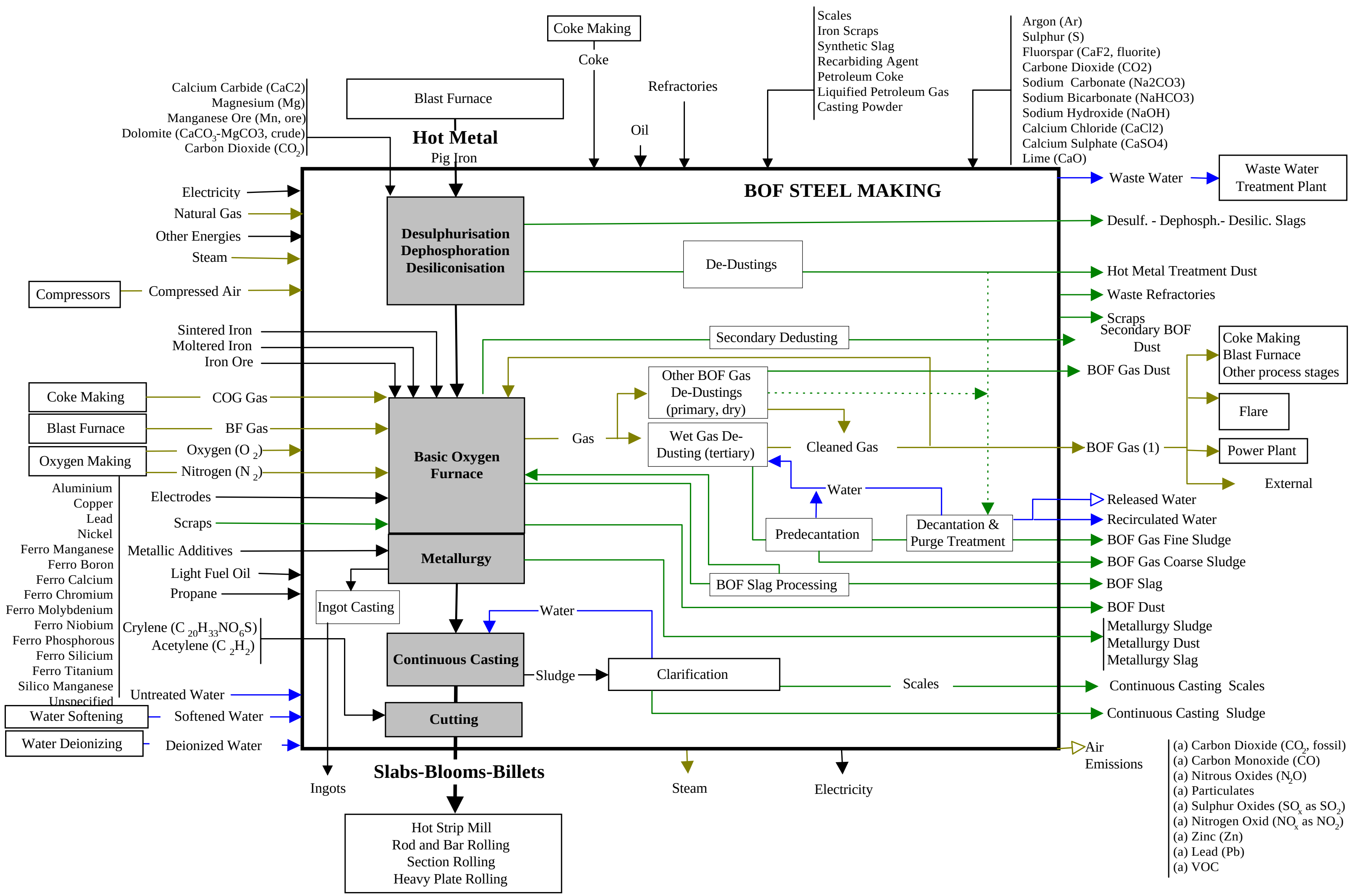


Figure 5. BOF steelmaking unit process.

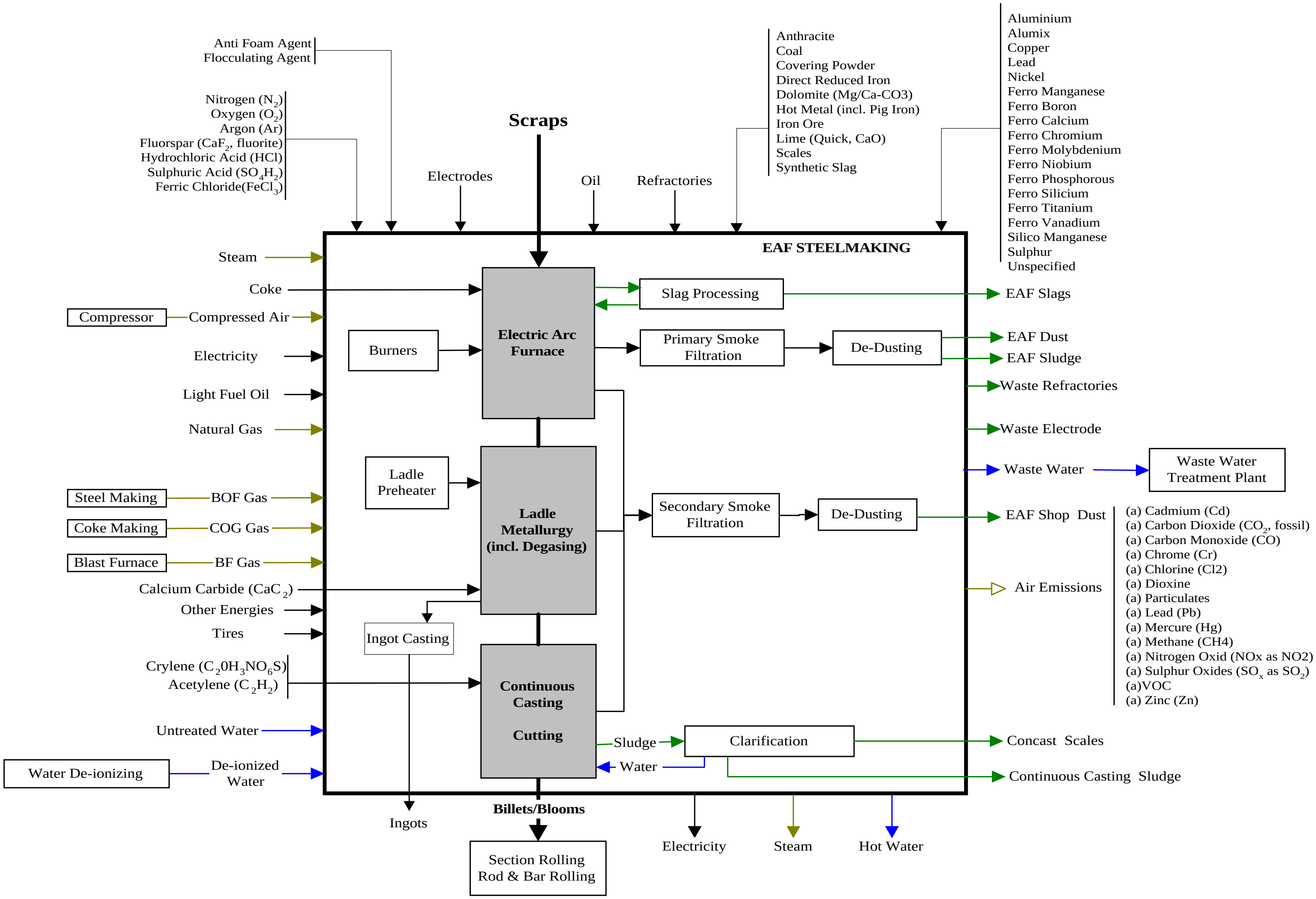


Figure 6. EAF steelmaking unit process.

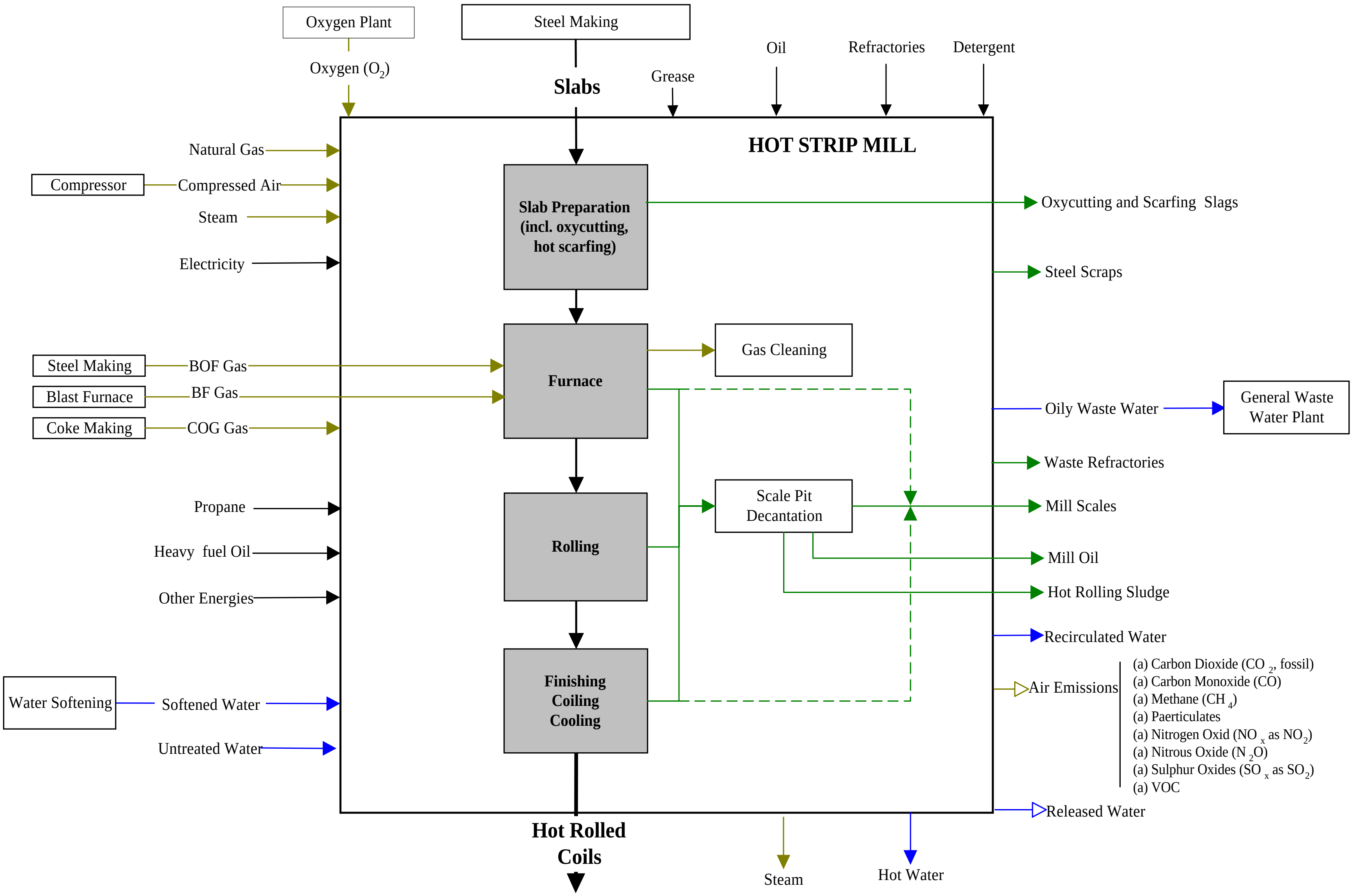


Figure 7. Hot rolling unit process.

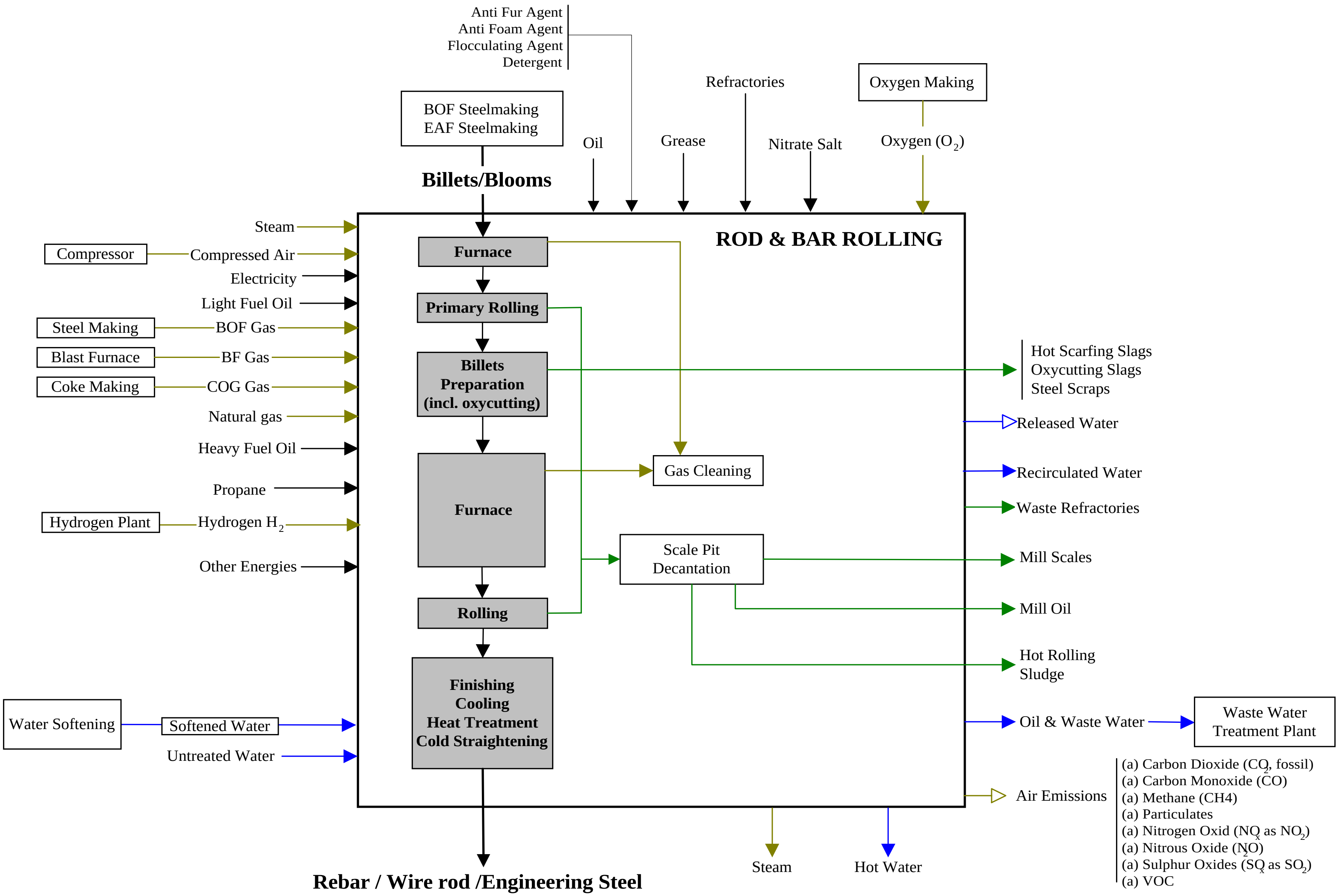


Figure 8. Bar rolling unit process.

2.3 Data Quality

Every attempt was made to collect high quality primary data. Where primary data was not available, secondary or surrogate data was employed. For each process, information regarding the source, nature, and quality of the data was reported by the respondent. In addition to the data quality aspects of geographic coverage, temporal coverage, technology coverage, and data sources, data quality was reported using the following four data quality indicators (DQI's):

Precision: A measure of the spread of variability of data set values about the mean of the data set. For each data category, the mean and standard deviation of reported values is calculated and reported for each unit process in the product system. These precision measures were used to assess the uncertainty of the reported values and aid in the sensitivity analysis of the study results.

Completeness: A measure of the primary data values used in the analysis divided by the number of possible data points associated with each data category for each unit operation. An agreed target is generally defined before data collection begins in a comparative study, with the goal that each product system have the equivalent level of completeness. Targets are typically set a 70% or better. As with the precision measure, completeness is also used to assess the uncertainty of the reported values.

Representativeness: A measure of the degree to which the data values used in the study present a true and accurate measurement of the population of interest. The degree of representativeness is normally judged by the comparison of values determined in the study with existing reported values in other analyses or published data sources dealing with the subject matter. Major variances identified are examined and explained.

Consistency: A qualitative understanding of how uniformly the study methodology is applied to the various components of the study. This quality measure is one of the most important to manage in the inventory process. There are a number of steps that must be taken to ensure consistency. The most significant of these is communication. In a study that involves a number of different companies, which in turn collect data from different sites in different countries and continents, there must be a clear understanding of which data is being requested, how it is measured, how it is reported, and how it is used.

2.3.1 Geographic Coverage

The Canadian and American steel data was derived from a world-wide LCI study commissioned by the International Iron and Steel Institute. The geographic regions that participated in the world-wide study are shown in Figure 9.

For North America, the geographic coverage of steel production and its associated supply chain includes Canada and the United States. More specifically, the steel production occurs in the Canadian provinces of Ontario and Quebec and the American states of Maryland, Ohio, and Pennsylvania. Figure 10 indicates the location of the contributing sites while Table 1 summarizes the domain and geographical coverage for steel production.

There were a few exceptions to this geographic coverage. In the case of steel bar, a European steel production site was added to the North American database to increase the sample size and protect confidentiality of company data. This European site data was generated in the same life cycle inventory exercise as the North American site data, so the methodology applied is consistent. In addition, the European site data was coupled with energy and ancillary materials data common to this study to make it more consistent with the North American sites. Iron ore mining data was collected from a site in Minnesota. Iron ore used in the North American steel industry comes from Minnesota, Michigan, Quebec, and Labrador. Primary data from the iron ore regions other than Minnesota were not available for inclusion in the steel LCI at the time of this study. Instead, the Minnesota data was augmented with primary data from an iron ore mining site in Sweden. The data from the Swedish site was collected as part of the international steel life cycle inventory exercise and the data quality was deemed superior to secondary data sources. The Swedish mine is similar to the Minnesota site except the Swedish site is an underground mine. The particulate emissions of the Swedish site were increased to approximate those of an open pit mine, such as the site in Minnesota. Primary data for limestone quarrying is based on a site in the United Kingdom. This data was also collected as part of the international steel LCI study. For the two instances where company-specific coke production data was not available, global coke production data collected by the International Iron and Steel Institute was used. The global coke production data is the average of 23 coke plants located in Europe, Japan, and Canada, representing production in 1994/95. This global data for the coke production unit process was updated by using the agreed method of co-production allocation and employing energy and ancillary materials data common to this study.

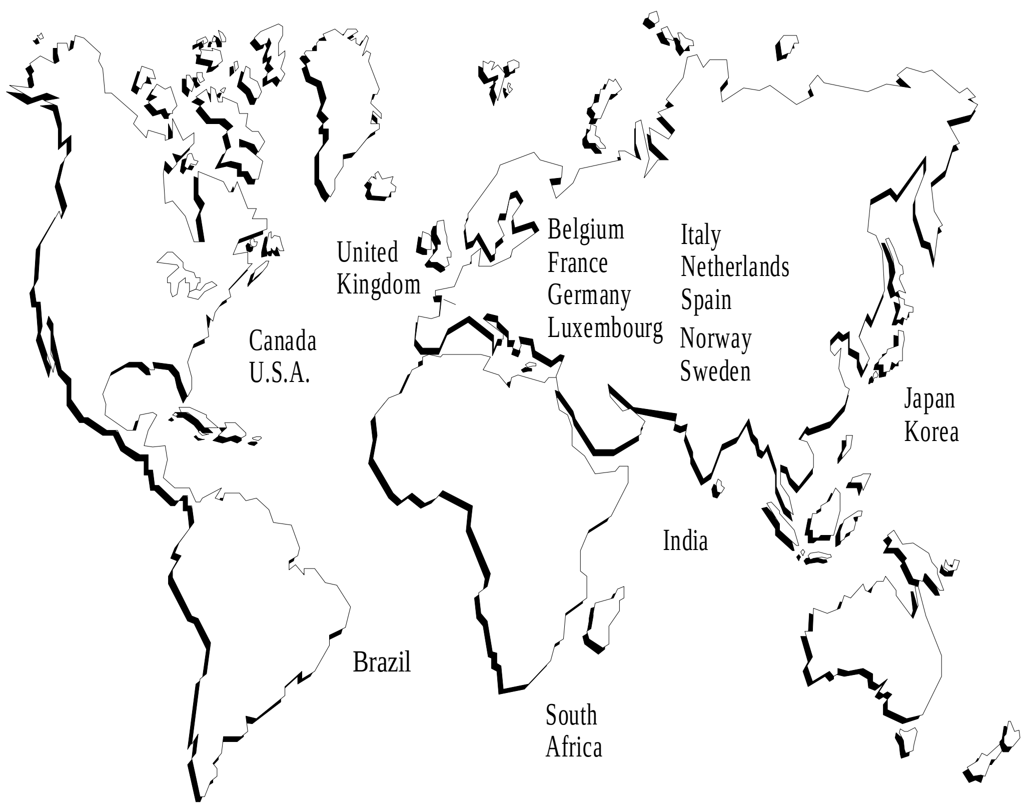


Figure 9. Contributing countries to the world-wide LCI.

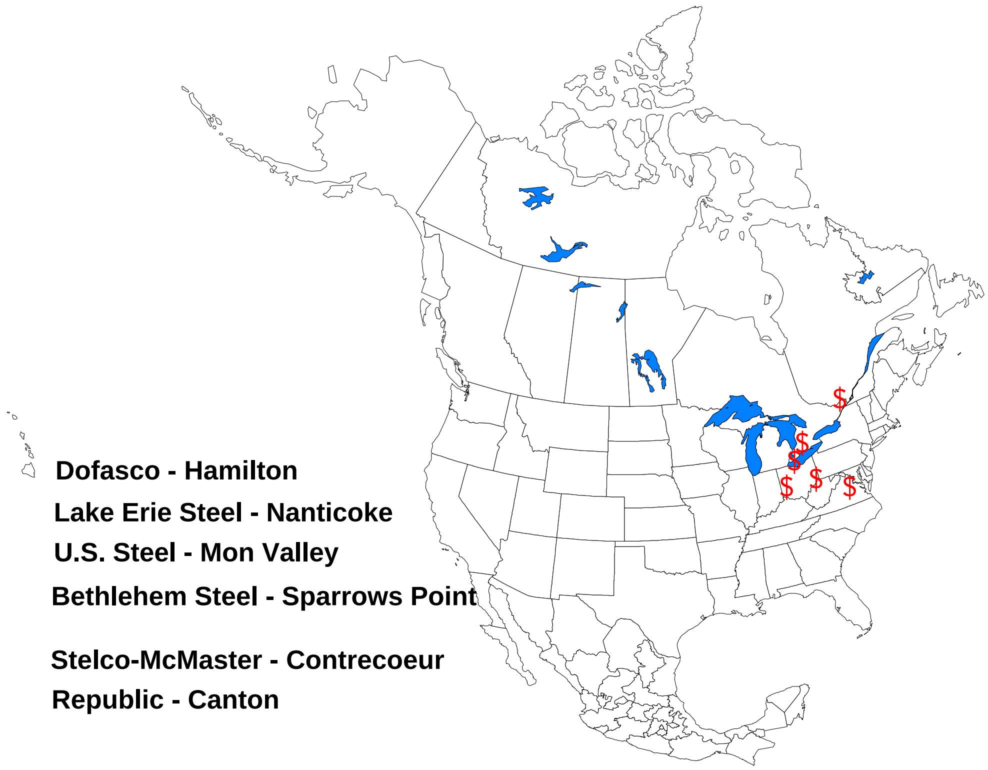


Figure 10. Contributing steel manufacturing sites in Canada and the United States.

TABLE 1. DOMAIN AND GEOGRAPHICAL COVERAGE FOR STEEL PRODUCTION

Steel Technology	Unit Process	Geographical Region	Total
BOF Steel Production	Iron ore pellet production	North America, Sweden	2
	Limestone Quarrying	United Kingdom	1
	Coke Production	North America (Global Avg.)	2 (23)
	Iron Production	North America	4
	BOF Steel Production	North America	4
	Hot Rolling	North America	4
Sub-Total			17 (40)
EAF Steel Production	Limestone Quarrying	United Kingdom	1
	EAF Steel Production	North America, Europe	3
	Bar Production	North America, Europe	3
Sub-Total			7
TOTAL			24 (47)

2.3.2 Time Period Covered

The primary data used for steel production is based on annual production in either 1994 or 1995. Secondary data is based on sources from no later than 1990, though constituent data within the secondary sources may be older than 1990. Best efforts were made to obtain the most up-to-date and representative secondary data.

2.3.3 Technology Coverage

Two steelmaking technologies are covered in the steel LCI. The products hot rolled coil, cold rolled coil, and galvanized coil are produced using basic oxygen furnace (BOF) steelmaking technology. Bar product included in this study is made using electric arc furnace (EAF) steelmaking technology. BOF steelmaking combines molten iron sourced from a blast furnace, recycled steel, limestone, and alloying additives. Oxygen is injected into the steelmaking vessel to remove carbon from the molten iron. In comparison, EAF steelmaking uses electricity to melt recycled steel for the casting of new products. Two technologies for the casting of steel are included in the steel LCI. Virtually all of the steel produced in North America utilizes continuous casting technology. This casting method involves the direct pouring of liquid steel from a steelmaking vessel into a casting machine that cools the steel while forming a steel slab or billet. All of the steel production facilities in this study use continuous casting except for one facility that produces bar steel from an EAF shop. This site uses ingot casting. Ingot casting involves pouring liquid steel into a mold, allowing it to cool over time, and then removing the mold to arrive at the steel product.

There are four producers of hot rolled coil from BOF plants in Canada. These plants are Algoma, Dofasco, Lake Erie Steel, and Stelco. For information, there are two producers of hot rolled coil from EAF plants in Canada, that being IPSCO and Dofasco, though the Dofasco plant started only in 1996 and is a hybrid technology as it may also consume hot metal.

There are 10 producers of bars from EAF plants in Canada. These producers are AltaSteel (Edmonton), Gerdau MRM Steel (Selkirk), Gerdau Courtice Steel (Cambridge), Union Drawn Steel (Hamilton), Atlas Specialty Steels (Welland), Co-Steel Lasco (Whitby), Slater Steels (Hamilton), Ispat Sidbec (Contrecoeur), Stelco-McMaster (Contrecoeur), and Ispat Sidbec (Longueuil).

2.3.4 Data Sources

Data was acquired from a combination of primary and secondary sources. Four North American steel companies provided primary data for the production of hot rolled coil, while data was sourced from three sites for cold rolled steel and hot dip galvanized steel. Two North American sites and one European site provided primary data for bar steel. Additional primary coke production data was obtained from 21 sites in Europe and Japan and used, along with the 2 North American sites, in the calculation of a global average value. This average value was used in two cases where data was not available from two BOF steel producers. Further primary data was collected for some upstream processes, such as iron ore mining and lime production. Secondary data was obtained from LCI databases and literature.

Sources of primary and secondary data:

- Primary data from participating steel and mining companies.
- BOF steelmaking: 2 in Canada, 2 in the U.S.A.
- Coke production: 2 in Canada, 21 in Europe and Japan.
- EAF steelmaking: 1 in Canada, 1 in the U.S.A., 1 in Europe
- Iron ore mining: 1 in Minnesota, 1 in Sweden.

- Limestone quarrying: 1 in the United Kingdom.
- Secondary data from Ecobalance database and literature sources (Table 2).

TABLE 2. SECONDARY DATA SOURCES AND THEIR DESCRIPTION.

Material	Source	Data Quality
Aluminum (Al)	Swiss Federal Office of Environment, Forests, and Landscape (FOEFL or BUWAL) Environment Series No. 132. Bern. February 1991.	Model based on aluminum slab production, 25% aluminum scrap & 75% primary aluminum.
Cast Iron	Confidential source	▪ Technology: Primary data from an iron casting plant supplying parts to the North American automotive industry. Averaged with North American secondary data on iron casting to preserve confidentiality. ▪ Temporal: Primary data collected for the year 1995. Secondary data is unknown. ▪ Geographical: North American data
Chromium (Cr)	Swiss Federal Institute of Technology (ETH), Zurich, Ecoprofiles for Energy Systems, 1996. Page 58	▪ Technology: Production of 1 kg chromium including mining, concentration, and reduction by electrolysis. Transport is not included. 99% in mass of ETH sources are taken into account. Chromium "ore" is reported as pure chromium, therefore, 1 kg of "ore" is used to produce 1 kg of material. ▪ Temporal: 1995 ▪ Geographical: Average of European sites.
Coal	BUWAL 132 (1991) A11	Adapted by Ecobilan. Adaption covers CO2 emissions added for what BUWAL calls precombustion for fuels production models; cross loop treatment for fuels production models; recalcuation from process data when provided in BUWAL; waste changed to 0.05 kg/kg representing greater dominance of open-pit mining.
Copper (Cu)	Swiss Federal Institute of Technology (ETH), Zurich, Ecoprofiles for Energy Systems, 1996. Page 60-69	▪ Technology: Production of 1 kg Cu (ingot) with 60 % primary copper + 40% secondary copper. Inputs of Copper ore are 1 kg (for 1 kg Cu produced) because all flows are calculated up to the cradle (or grave) in ETH data (including Cu ore present in the secondary material). Also, Cu "ore" is reported as pure copper, therefore, 1 kg of "ore" is used to produce 1 kg of material. Transport is included for secondary copper (200 km rail, 100 km truck). 99% in mass of ETH sources are taken into account. ▪ Temporal: 1995 ▪ Geographical: Average of European sites.

Material	Source	Data Quality
Dolomite ($CaCO_3.MgCO_3$)	Swiss Federal Office of Environment, Forests, and Landscape (FOEFL or BUWAL) Environment Series No. 132. Bern. February 1991.	Particulate emissions changed from 72 g/kg of dolomite to 0.11 g/kg due to primary data from one European limestone quarry.
Ferrite (Fe)	Confidential source	▪ Technology: Production of Ferrite. Only 85% of input are accounted for. Site data has been aggregated with upstream processes in order to ensure confidentiality ▪ Temporal: data collected in 1992. ▪ Geographical: European data
Lead (Pb)	Swiss Federal Institute of Technology (ETH), Zurich, Ecoprofiles for Energy Systems, 1996. Page 91	▪ Technology: Production of lead including mining. Lead "ore" is reported as pure lead, therefore, 1 kg of "ore" is used to produce 1 kg of material. ▪ Temporal: 1995 ▪ Geographical: Average of European sites.
Tin (Sn)	1) Metal resources and energy, Chapman, London 1983. 2) Metals and Minerals Yearbook, section Minerals 1989.	▪ Technology: Production of 1 kg of tin. Both mining and recycling are taken into account. Tin "ore" is reported as pure tin, therefore, 1 kg of "ore" is used to produce 1 kg of material. ▪ Temporal: 1989 ▪ Geographical: Worldwide tin production. Important producers are: Brazil (23%), Malaysia (14%), Indonesia (14%), and China (12%).
Zinc (Zn)	Swiss Federal Institute of Technology (ETH), Zurich, Ecoprofiles for Energy Systems, 1996. Page 107-108.	▪ Technology: Mining, concentration, and refining. Transport included for 1 t.km rail and 36 t.km sea (per kg of Zn). Zinc ore is reported as pure zinc, therefore, 1 kg of ore is used to produce 1 kg of material. 99% in mass of ETH sources are taken into account. ▪ Temporal: 1995 ▪ Geographical Average of several European sites.

2.3.5 Precision

In the steel study, for each of the unit processes where primary data was collected, the mean, minimum, maximum, and standard deviation values were calculated for each data category. Secondary data used in the study generally consisted of a single value.

2.3.6 Completeness

Completeness is the measure of primary data values used in the analysis divided by the number of possible data points for each data category within the sample domain. The steel life cycle inventory completeness for each data category was derived from the questionnaires submitted by each participating site. Where a site submitted a questionnaire that contained a missing value for a data category, the procedures for the treatment of missing data were employed. On a unit process level, each of the sites that agreed to contribute to the sample domain reported data. For the purposes of this study, this represents a completeness of 100%.

2.3.7 Representativeness

The plants contributing Canadian BOF data represent 2 of 4 coke plants, 2 of 4 blast furnace sites, and 2 of 4 BOF sites. These sites contribute 56%, 41%, and 505 of annual production in Canada respectively (based on 1995 data). For EAF data, 1 of 16 EAF plants provided data, representing 7.5% of 1995 production. However, based just on those EAF plants that produce bar product, 1 in 10 EAF plants provided data, representing 9.6% of 1995 production in Canada (total includes a site that produces bar product from a BOF plant).

The life cycle inventory used for steel products was calculated using a small sample size. It would be natural to question whether the small sample size fairly represents the production of steel used in the generic automobile. The representativeness of primary steel data is presented in Table 3 as the percent of Canadian and U.S. production. Table 3 shows the number of sites where primary data was gathered and the percent of Canada and American production that these sites represent. One explanation why the percent production is relatively high given the sample size is that the two largest steel producers in each of Canada and the United States chose to take part in the life cycle inventory of steel products. In addition, the largest iron ore mine in North America was included in the study. The participating steel companies represent about 26% of annual steel production in Canada and the United States.

TABLE 3. UNIT PROCESS SAMPLE SIZE AND PERCENT OF PRODUCTION.

Unit Process	Sample Size	Percent of Canada and U.S. Production
Iron Ore Mining	2	13.6 [c]
Coke Production	2	8.8 [b,c]
Iron Production	4	14.4 [a]
BOF Steel Production	4	15.5 [a]
Hot Rolling	4	18.7 [b]
EAF Steel Production	3	3.2 [a,c]
Bar Mill	3	5.8 [b,c]

[a] based on 1995 AISI production data.
[b] estimated from 1993 AISI production data.
[c] figure does not include primary data from global steel study used to complement North American data.

Another way to address representativeness is to compare North American data to global data collected by the International Iron and Steel Institute (IISI) for key data categories. Table 4 presents the comparison of North American and global data for hot rolled steel product produced using basic oxygen furnace steelmaking technology. The inventory methodology used in the IISI work differs slightly from that used in the USAMP project, so the percentage difference between the North American average and the global average is shown in the table as opposed to absolute values. It can be seen that for each steel product the difference between the North American and global data sets is less than 10% for each of the key data categories. Based on this result and the knowledge that steelmaking technology is similar among integrated steel producers in North America, it can be expected that expanding the North American sample size would have relatively little effect on the inventory results for hot rolled steel, cold rolled steel, and galvanized steel.

TABLE 4. DIFFERENCE OF NORTH AMERICAN HOT ROLLED STEEL COMPARED TO GLOBAL AVERAGE.

Data Category	Hot Rolled Steel
Iron Ore (raw material)	-8.4
Coal (raw material)	-8.8
Carbon Dioxide (air)	9.8
Total Energy (energy)	3.2

A similar analysis for steel bars produced by electric arc furnace steelmaking technology is not as easy. There was insufficient data to prepare a North American average for steel bars in the IISI study. As the inventory methodology is different for the IISI and USAMP studies, a direct comparison for most data categories would not give insight to the impact of the small sample size on reported results. However, one data category unaffected by the different inventory methodologies is the consumption of recycled steel. In Table 5, it can be seen that the North American average for recycled steel consumption is within 3.8% of the global average.

TABLE 5. DIFFERENCE OF NORTH AMERICAN BARS COMPARED TO GLOBAL AVERAGE.

Data Category	Bars
Recycled Steel (raw material)	3.8

Another way to look at the inventory for steel bars is to compare the casting technology employed. One electric are furnace site in the inventory uses ingot casting while the other sites employ the more modern continuous casting technology. Again, looking at key indicators, the difference in recycled steel consumed is very small, with the ingot casting facility consuming 3.5% more recycled steel than the North American average. However, the indicators for total energy used and carbon dioxide emissions are more significant. The ingot casting facility consumes about 25% more energy than the average and has about 40% more carbon dioxide emissions. The higher energy and carbon dioxide emissions may be attributed to the older facilities and technology employed at the site using ingot casting. Consequently, the steel bar inventory may be said to overstate the North American average that would be expected if the sample size were increased. To further assess the representativeness of the primary data, each site indicated whether each data value supplied was measured, calculated, or estimated. This information allows the industry to make a qualitative judgement regarding the level of confidence in the results. For the global steel study, from which the North American average was derived, about 60% of the primary data values were measured, 25% were calculated, and about 15% were estimated.

2.3.8 Consistency and Reproducability

Effort was undertaken to ensure the consistent application of the LCI methodology for the steel study. Experts from steel companies around the world worked with the project consultant to produce process flow diagrams with common nomenclature. A training session was held for all those people who were collecting data at the unit process level. These people received comprehensive manuals that provided guidance on the unit processes, including the process flow diagrams with the common nomenclature, to further aid their data collection efforts. Each of these people could also call the project consultant to ask questions about data collection. The data collection used Excel spreadsheets with data verification based on initial data gathering from 3 sites. If a data value was entered into the spreadsheet that lay outside the initial data range, a warning to check data validity issued. The person then was instructed to check the validity of the data point, keeping the data if it was valid or correcting the value if it was an error. Additionally, the spreadsheets calculated carbon and iron balances to give the user another check on the validity of the data entered. The data contained in the spreadsheets was electronically downloaded into the LCI modeling software. This procedure eliminated the chance of making a data transcription error. The data entered into the LCI modeling software was again checked by the project consultant. If an error was noted, the consultant contacted the data source for correction. In addition to this, the industry experts reviewed the model results to check for inconsistencies.

2.4 Data Collection

2.4.1 Data Categories

The scope of the project is limited to the life cycle inventory of two steel products; hot rolled coil and EAF bars. Table 6 lists the inventory items that were tracked throughout this study. These data categories are the same as those used in the United States Automotive Materials Partnership (USAMP) LCI study of a generic car, the study from which the steel data is generated.

TABLE 6. DATA CATEGORY LIST.

Data Category	Components
Energy [1]	- Fossil - Non-Fossil - Process (Electrical and Non-electrical) - Feedstock - Transportation - Total
Water Consumption	- Groundwater - Surface Water
Air Emissions	- Dust & Particulates (Including metals) - Carbon Dioxide - Carbon Monoxide - Sulfur Oxides - Nitrogen Oxides - NMHC [2] - Methane - Hydrogen Chloride - Hydrogen Fluoride - Pb

Data Category	Components
Water Emissions	- Dissolved Solids - Suspended Solids - Heavy Metals 3 - Oils and Greases - Other Organics - Phosphate - Ammonia
Solid Wastes	- Sanitary and Municipal Waste - Total Solid Waste
Raw Materials Consumed	- All significant inputs as defined by the decision rules.
1 All energies will include pre-combustion contributions. 2 All organics other than methane are reported in the aggregate here. 3 This includes As, Cd, Cr, Co, Cu, Pb, Hg, Ni, and Zn.	

These data categories are felt to be consistent with the goal and scope of this study and are adequate to make overview statements pertaining to the environmental performance of the generic vehicle. The purpose of the USAMP/LCI Generic Vehicle Study is to identify a suitable set of metrics to benchmark the environmental performance of the generic vehicle from a global and regional perspective. The data category list is consistent with this objective. Local effects, such as toxicity, are assumed to be managed at the various sites and hence, are not a focus of this study.

Note: Only two categories of waste are tracked in the general USAMP methodology: Sanitary and Municipal Waste, and Total Waste. In the software model, when records used as primary sources indicated “hazardous waste”, the amount has been recorded as such. However, due to inconsistencies in the ways that hazardous waste is defined by different government agencies (RCRA, Superfund, etc.) as well as by the three different OEMs, it has not been possible to show more detailed waste categories in the final results.

All flows (inputs and outputs) in the life cycle of the vehicle are reported in metric units:

- kilogram (kg) for material consumption and waste production;
- gram (g) for emissions to water and air;
- Megajoule (MJ) for energy; and
- liter (l) for liquid volumes (water consumption).

Information on the inventory flows listed in Table 6 were gathered for primary LCI data collection. However, secondary sources of LCI did not always consistently track the same list of flows.

2.4.2 Ancillary Material Inputs

In order to establish the consistent identification of ancillary material flows that will be modeled in the inventory, the USAMP/LCI partners agreed that best efforts will be made to apply the following decisions rules:

- First, the identification of all potential ancillary material flows for a unit process is established by listing all ancillary materials that are greater than 1% by mass of the output for the unit process. Once the ancillaries have been identified, a mass balance for the subsystems being analyzed is performed and normalized to the output from the subsystem.

- Ancillary materials that will be included in the scope of the analysis are then classified as either primary, secondary, and negligible ancillaries on the basis of an analysis of their contribution to the total mass of the system, total energy of the system and their environmental relevance.
- All ancillary materials of a ranked ancillary list that have a cumulative mass contribution of up to 99.9% of the system are considered as primary ancillaries and will require primary data sources within the data collection activities. The additional ancillary materials that bring the total cumulative mass of the system to at least 95% of the total would be considered as secondary ancillaries for which secondary data sources may be used to quantify their life cycle contribution.
- A further decision rule is used to classify energy contribution. All ancillary materials that have a cumulative contribution of 95% of the total system energy are considered primary ancillaries, regardless of their mass ranking. The additional ancillary materials that bring the cumulative systems energy to at least 99% are considered as secondary ancillaries.
- In addition, any input, regardless of mass or energy contribution, is considered as a primary ancillary if any of the environmental releases during its extraction, manufacturing or use contributes more that 15% to an environmental release data category.
- All remaining ancillary materials should be considered negligible and need not be included in the scope of the study.

The steel industry identified an extensive list of ancillary materials for each of the products included in this study. A team of industry experts identified the materials used for each of the unit processes included in the steel sub-systems and verified this list by doing preliminary data collection at three sites. The criteria used for inclusion of ancillary materials was to include all those materials for which data was available, regardless of its contribution to mass, energy, or environmental relevance to the sub-system. Ancillary material data was sourced from the Ecobalance database. The ancillary materials for each steel product that were included in the study are presented in Table 7. The mass % of the total ancillary materials included in the study is 94.4% for hot rolled steel, 94.8% for cold rolled steel, and 95.2% for hot dip galvanized steel. These figures compare to the criteria set for the study, which was 95%. For bar products from an EAF mill, 91.2% of the total ancillary mass was included in the study. While this figure is less than the 95% set for the study, the consequences on the inventory profile are thought to be inconsequential as ancillary materials accounted for less than 0.01 kg per kg of bar product. The energy % of the total ancillary materials included in the study can not be determined. As all ancillary materials for which data was available were included in the study, the energy associated with ancillary materials for which there is no data is unknown. The energy associated with all ancillary materials for which data exists was included in the analysis. It is felt that the percent of included energy of ancillary materials should follow roughly the included mass percent. Given that all ancillary materials for which there was data were included, the high mass % of ancillary materials included, and the low relevance of ancillary materials for bar product, it seems likely that the life cycle profile of steel products is not significantly affected by ancillary materials for which there was no data. A similar case is made for the inclusion of ancillary materials on the basis of environmental relevance.

TABLE 7. SUMMARY OF STEEL ANCILLARY MATERIALS

Product System	***Secondary Ancillary Material Burden Included***	***Amount of Ancillary Materials Included***	
		(mass % of total ancillary materials)	***(kg ancillary materials/kg product)***
Hot Rolled Steel	Limestone (and Dolomite and Quick Lime), Oxygen, Nitrogen, Hydrogen, Argon, Metal Alloys, Zinc, Aluminum, Refractories, Oil (lubricating), Sulfuric Acid, Hydrochloric Acid, Olivine, Electrode, Sulfur Dioxide	94.4	0.26
EAF Bars	Refractories, Oxygen, Oil (lubricating), Metal Alloys, Limestone (and Dolomite and Quick Lime), Aluminum, Electrode, Sulfur, Nitrogen, Argon, Hydrochloric Acid, Sulfuric Acid	91.2	<0.01

2.4.3 Energy

2.4.3.1 Process Energy

The following table outlines the heats of combustion for the different fuels modeled in this project:

TABLE 8. COMBUSTION HEATS OF FUELS.

Fuel Type	Lower Heating Value (MJ/kg)	Higher Heating Value (MJ/kg)
Coal	29	30
Natural Gas	52	56
Diesel Oil	43.5	45
Gasoline	45	47
Heavy Fuel Oil	42	43

Higher heating value is the total amount of heat released when a fuel is burned. Some of the energy released in burning goes into transforming the water into steam and is usually lost. The amount of heat spent in transforming the water into steam is counted as part of the gross heat content (higher heating value) but is not counted as part of the net heat content (lower heating value). For this project, when a process reported using a certain amount of fuel in terms of energy units, the lower heating value was used to determine the amount of fuel needed. This is based on the fact that most industrial operations do not recover the heat in the water vapor of the combustion gas. The lower heating value is the amount of usable heat energy released under normal operating conditions. However, higher heating value was used when reporting the energy values in the inventory results as per the methodology report.

Table 9 shows the combustion emissions associated with the use of different fuels modeled in this project. The values in Table 9 were based largely on emissions factors from the U.S. EPA document AP-42.

TABLE 9. COMBUSTION EMISSION FACTORS (G/KG FUEL BURNED)

Emission	Combustion Type			
	Coal Industrial Boiler	Natural Gas Industrial Boiler	Heavy Fuel Oil Industrial Boiler	Diesel Industrial Boiler
Particulate Matter	1.3	0.060	2.6	1.1
CO	6.7	0.81	0.71	15
CO_2	2,637	2,390	3,467	3,213
SO_x	15	0.012	44	0.85
NO_x	7.6	11	7.5	55
Non-Methane Hydrocarbons	0.79	0.029	0.039	1.7
Methane	0.50	0.0060	0.14	0.18

2.4.3.2 Precombustion Energy

The following sections outline the precombustion modeling of the different fuels used throughout the generic vehicle modeling.

A.0 Coal Pre-combustion
Coal pre-combustion includes extraction of coal from the ground, then cleaning and preparation of the coal for use. Transportation to the point of use is not included at this stage.

A.1 Coal Mining
Materials and energy consumed in mining and cleaning of coal comes from 1987 Census Bureau data [25]. Emissions due to mining coal are from the combustion of diesel oil by mining equipment (except methane which is released directly from the mine). All emissions factors come from AP-42 Mobile Sources Volume II, January 1991. In terms of water effluents, DOE states that water effluents due to mining are unquantifiable, however water effluents from this type of operation generally do not cause global impacts.

A.2 Cleaning and Preparation
Cleaning and preparing coal may involve many processes, including beneficiation, which removes sulfur and mineral matter so that stringent Federal emissions limits during combustion are met. However,

- there are not enough specific data as to the percentage of coal that goes through these processes; and
- the amount of energy consumed in these processes is negligible compared to the amount of energy that is generated from coal combustion.

Therefore, coal cleaning and preparation steps are omitted from the model. Water effluents coming from coal pre-combustion processes are considered negligible for this study. In general, the only water effluents coming from coal pre-combustion are those from mining (and refining) the fuels that are used to transport materials.

B.0 Refined Petroleum Products Pre-Combustion
This section includes pre-combustion data for the refined petroleum products heavy fuel oil, diesel oil, and gasoline. The pre-combustion steps include extraction of crude oil from the ground, transportation of the crude oil to a refinery, and refining the crude oil into finished

refinery products. Transportation of the finished refinery products to the point of use is also included at this stage.

B.1 Geographical Boundaries

The modeling of refined petroleum products production includes worldwide crude oil extraction and U.S. refinery operations. Foreign crude oil extraction and transportation to the United States is modeled because half of the U.S. supply of crude oil is imported. The transport of finished refinery products into the U.S. is not studied because foreign refinery products only accounts for a small percent of the total finished refinery products used in the U.S. in 1994, and may be accounted for under domestic refinery production. In addition, domestic refinery data are more accurate and reliable.

B.2 Crude Oil Extraction

There are three separate methods for crude oil extraction and recovery: onshore production, offshore production, and thermal enhanced recovery, which entails the underground injection of carbon dioxide or steam produced by natural gas boilers. All of these methods are modeled. Heater treater separators are used to separate the crude oil, natural gas, and water mixture that is extracted. As natural gas is produced as a co-product of crude oil production, emissions will be allocated between gross natural gas and crude oil production on a mass based method. The emissions associated with the venting and flaring of some of the natural gas extracted from the well will also be accounted for. The inflows associated with the three different methods of crude oil extraction include electricity used in pumping, and natural gas used as fuel to run the heater treater systems. Outflows include air emissions, water effluents, and solid waste.

B.3 Transportation

The United States is broken up into Petroleum Administration for Defense Districts (PADDs) in order to insure that each region or PADD is supplied with enough petroleum for strategic defense reasons. The transportation distances used in this report will be averaged across all of the PADDs. The amount of foreign and domestic crude oil transported into each PADD will be estimated from refinery receipts of crude oil which is known for each PADD. Distances used to model transportation of crude oil are based on national averages, obtained from the following types of data and methods of calculation:

Domestic Tanker and Domestic Barge: Army report lists tons and ton-miles of crude oil transported by tanker and barge on all United States waterways. Average miles are calculated by dividing total ton-miles traveled by total tons transported. This is done separately for both tanker and barge.

Domestic Pipeline : Association of Oil Pipelines lists total ton-miles of crude oil carried in domestic pipelines. Average miles are calculated by dividing total ton-miles of crude oil, carried in domestic pipelines, by tons of crude oil received at refineries via pipeline. Foreign pipeline is calculated the same way.

Domestic Rail: Association of Oil Pipelines lists total ton-miles of crude oil carried by rail in the United States. Average miles are calculated by dividing total ton-miles of crude oil, carried by rail, by tons of crude oil received at refineries via railroad tank cars.

Domestic Truck: Association of Oil Pipelines lists estimated total ton-miles of crude oil transported by motor carriers in the United States. Average miles are calculated by dividing total ton-miles of crude oil, transported by motor carriers, by tons of crude oil received at refineries via truck.

Foreign Tanker: The Petroleum Supply Annual lists imports of crude oil by country for each PADD (in barrels). PADD I crude oil is assumed to all arrive at New York. PADD II and III oil is assumed to arrive at Houston. PADD V oil is assumed to arrive at Los Angeles. PADD IV does not receive any foreign oil other than Canada. Nautical miles between ports of origin and United States ports (New York, Houston, and Los Angeles) are given in DeLuchi's study, based on information from the Defense Mapping Agency. From this information a weighted average is calculated, for each PADD, by multiplying barrels imported from each country by the distance from that country to the specified United States port of entry. These results, in barrel-miles for each PADD, are added together and then divided by the total number of barrels imported to get an average distance in miles traveled by the foreign tankers.

B.4 Crude Oil Refining

The inflows associated with refining include crude oil, natural gas, LPG, steam, electricity, and coal. Outflows for this process include air emissions, water effluents, and solid waste. Allocation of refining processes must be addressed. Petroleum refineries produce a number of different products from the amount of crude oil that they receive. Additional complexity is introduced by the fact that the refinery product mix is variable, both among refineries and even with time for a given integrated refinery.

B.5 Capital Equipment

Life cycle environmental flows associated with the production of the capital equipment and facilities used in the extraction, transportation and refining of crude oil are excluded from the fuel model since the energy used in the construction of large energy facilities and other equipment used in fuel cycles (including electric power plants, oil wells, oil tankers and hydroelectric plants) is negligible (less than 1%) compared with the energy produced or carried by that equipment over its useful life.

C.0 Natural Gas Pre-Combustion

Natural gas pre-combustion includes extraction of natural gas from the ground, then processing of the natural gas for use. Transportation to the point of use is not included at this stage.

C.1 Natural Gas Extraction

Raw natural gas is a mixture of hydrocarbons, N_2, CO_2, sulfur compounds, and water. It may have any range of compounds from mostly methane to inert gases, such as nitrogen, carbon dioxide, and helium, and smaller amounts of ethane, propane, and butane. Natural gas may be produced onshore, offshore, and in conjunction with petroleum processes. The energy used to produce natural gas is provided by EIA Natural Gas Annual[39] and U.S. Bureau of Census. The process energy is allocated among petroleum, natural gas, and natural gas liquids based on the following assumptions:

- Almost all the of natural gas consumed that the Census Bureau reports goes toward field operations—natural gas lifting and re-injecting. This data corresponds with data provided by EIA;
- Any energy used to re-inject natural gas into wells is excluded from the natural gas pre-combustion processes, since re-injection is mainly used in oil wells; and
- The amount of electricity used for field equipment and processing plants is little relative to the amount of gas they produce[41].

Thus, energy in this model excludes gas re-injection energy requirements.

C.2 Natural Gas Processing (Sweetening)

The amine process, or gas sweetening removes and recovers H_2S. The recovered hydrogen sulfide gas is either (1) vented, (2) flared in waste gas flares or modern smokeless flares, (3) incinerated, or (4) utilized for the production of elemental sulfur or sulfuric acid. Emissions due to only venting the gas into the environment are covered in the model. Vented gas is usually passed to a tail gas incinerator in which the H_2S is oxidized to SO_2 and is then passed to the atmosphere out a stack. Emissions are mostly SO_2 due to the 100% conversion of H_2S to SO_2. Very little particulate and NOx emissions are generated from this process. Emissions factors for the amine process come from AP-42 (1995). The following table shows the LCI associated with the precombustion of the different types of fuel used in this project.

TABLE 10. PRECOMBUSTION LCI FOR PRODUCING 1 KG OF FUELS.

Environmental Flow	Units	Natural Gas	Heavy Fuel Oil	Diesel Fuel	Gasoline	Coal
Inflow						
(r) Coal (in ground)	kg	1.8 E-06	0.039	0.039	0.053	1.0
(r) Limestone ($CaCO_3$, in ground)	kg	3.4 E-07	0.0074	0.0075	0.010	4.4 E-04
(r) Natural Gas (in ground)	kg	1.0	0.037	0.037	0.072	0.0003
(r) Oil (in ground)	kg	2.4 E-06	1.1	1.1	1.1	0.003
(r) Uranium (U, in ground)	kg	4.4 E-11	9.4 E-07	9.4 E-07	1.3 E-06	5.6 E-08
Water Used (total)	liter	2.9 E-07	0.12	0.12	0.14	3.5 E-04
Outflows						
(a) Dust & Particulates	g	1.8 E-03	0.72	0.72	1.1	0.041
(a) Carbon Dioxide (CO_2, fossil)	g	91	389	390	703	16
(a) Carbon Monoxide (CO)	g	0.025	0.19	0.19	0.41	0.13
(a) Sulfur Oxides (SOx as SO_2)	g	23	3.5	3.5	5.8	0.067
(a) Nitrogen Oxides (NO_x as NO_2)	g	0.33	0.90	0.91	1.7	0.12
(a) Non-Methane Hydrocarbons	g	9.0 E-04	1.0	1.0	1.9	0.017
(a) Methane (CH_4)	g	5.0	1.7	1.7	2.0	6.9
(a) Hydrogen Chloride (HCl)	g	9.8 E-07	0.021	0.021	0.028	0.0013
(a) Hydrogen Fluoride (HF)	g	1.2 E-07	0.0026	0.0026	0.0035	1.6 E-04
(a) Lead	g	2.6 E-09	5.7 E-05	5.7 E-05	7.6 E-05	3.3 E-06
(w) Dissolved Solids	g	1.1 E-04	0.069	0.069	0.069	0.13
(w) Suspended Solids	g	5.6 E-06	1.8	1.8	4.8	0.0053
(w) Heavy Metals (total)	g	6.0 E-08	0.026	0.026	0.034	6.9 E-04
(w) Oils and Greases	g	6.5 E-07	0.23	0.23	0.49	6.6 E-04
(w) Other Organics	g	-	-	-	-	-
(w) Phosphates (as P)	g	-	-	-	-	-
(w) Ammonia (as N)	g	1.8 E-07	0.060	0.060	0.16	1.7 E-04
Waste (total)	kg	4.4 E-06	0.011	0.011	0.011	0.24
Energy Reminder						
E (HHV) Total Energy	MJ	58	49	51	58	30

E (HHV) Fossil Energy	MJ	58	49	51	58	30
E (HHV) Non-Fossil Energy	MJ	2.6 E-06	0.059	0.060	0.080	0.0034
E (HHV) Process Energy	MJ	1.7	5.8	5.9	11	0.22
E (HHV) Feedstock Energy	MJ	56	43	45	47	30
E (HHV) Transportation Energy	MJ	4.8 E-07	0.45	0.46	0.46	7.2 E-04

2.4.3.3 Electricity Grid Profiles
The conversion of the electrical power mix into primary energy units (Joules) takes into account the combustion efficiencies of the various fuels and the conversion efficiencies of the generating facilities. In addition, the pre-combustion energies for the various fuel types and line losses from the transmission of electricity are also added. The modeling of electricity production by different methods is explained in the following sections:

A.0 Coal Electricity Production
Production of electricity from coal includes coal pre-combustion, transportation of the coal to the utility, coal combustion (including control technologies) and coal ash management. Data on coal pre-combustion is listed separately, therefore, this section only describes the coal transport, combustion, and ash management.

A.1 Transportation of Coal from Site of Extraction to Power Plant
Coal may be transported by different transportation means, including rail, road, pipeline, and river. The expression used to describe the energy intensity of transporting coal (or any other material) is Btu per ton-mile.
This is calculated as:

E / T*M

where:
E is total Btu used by the mode of transport and the energy used for the backhaul (assuming the return trip is empty);
T is total tonnage of the transported material; and
M is the distance the material was carried.

It is safe to assume that for the most part, the carrier returns empty. For example, 91% of the unit train cars that carry coal return empty to the mine, and trucks return empty unless they can find a similar product to transport back. Therefore, all transportation data will assume a one-way haul.

Rail: The 1987 national average length of haul for coal by means of rail is 490 miles. It is assumed that diesel fuel is used for rail transportation. DeLuchi (1993) presents energy consumed in coal transportation by rail from a few sources (U.S. Department of Energy (1983), U.S. Congressional Research Service (CRS) (1977), and Argonne National Laboratory (ANL) (1982)). The energy consumed is averaged out to be 589 Btu per ton-mile.

Truck: DeLuchi (1993) is in accordance with the DOE *Energy Technology Characterizations Handbook* (1983) on an average haul distance of 60 miles for a round trip of coal delivery. It is assumed that diesel fuel is used for truck transportation. DeLuchi (1993) estimates energy consumed in coal transportation by truck from a few sources (U.S. Department of Energy (1983), U.S. Congressional Research Service (CRS) (1977), and Argonne National Laboratory (ANL) (1982), and Rose (1979)). The energy consumed is averaged out to be 2349 Btu per ton-mile.

Ship: The national average length of haul for coal by means of water is 450 miles[45]. DeLuchi (1993) estimates energy consumed in coal transportation by ship from a few sources (U.S. Department of Energy (1983), U.S. Congressional Research Service (CRS) (1977), and Argonne National Laboratory (ANL) (1982), and Rose (1979)). The energy consumed is averaged 539 Btu per ton-mile.

Slurry Pipeline: In general, coal slurry pipeline is a highly reliable (99%) source of transportation, and can last longer than 20 or 30 years. It is the cleanest and safest coal delivery system to power plants. Data for energy consumed in coal transportation by slurry pipeline was presented in *Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity* (1993) over a few sources: U.S. Department of Energy (1983), Banks (1977) and Argonne National Laboratory (ANL) (1982). The energy consumed for this mode of transport is averaged out to be 668 Btu per ton-mile. Included in this average is energy used for slurry preparation, pipeline pumping, dewatering facilities, and specifically, energy used in the Black Mesa Pipeline, which runs 273 miles from the Black Mesa Coal Mine in Arizona to the Mohave Power Plant in Laughlin, Nevada. DeLuchi (1993) estimates that the average length of haul for a pipeline is 300 miles, including the pipeline itself, tramway transportation, and conveyor belts. Emissions from all of the different types of transportation methods are included in the model. The emission factors for the different transportation methods are shown elsewhere.

A.2 Coal Combustion

Energy consumed and emissions associated with combustion of coal in utility boilers comes from a variety of sources. Emissions and total coal burned were obtained from the 1994 Interim Inventory based on the Form EIA-767 data (the Interim Inventory 1994). Emissions factors for pollutants not provided in the Interim Inventory (1994) are obtained from AP-42 (1995). Emissions are presented for each individual firing configuration. Because firing configurations have varying combustion requirements (coal burning temperatures, firing methods, and emissions control equipment, etc.), they emit varying amounts of pollutants. The firing configurations included in the model are:

- pulverized coal fired, dry bottom and wall fired;
- pulverized coal fired, dry bottom and tangentially-fired;
- pulverized coal-fired and wet bottom;
- spreader stoker;
- fluidized bed combustor; and
- cyclone furnace.

The Interim Inventory (1994) provides actual air emissions (VOC’s, NOx, CO, SOx, and PM-10) by specific type of coal (bituminous, subbituminous, and lignite) and by furnace type. The firing types provided are also identified by a Source Classification Code (SCC). Each firing type was placed into a broader category of firing configurations (identified in AP-42), using SCC numbers. The following table presents the firing types provided by the Interim Inventory (1994), and how they were placed in the firing configuration category, based on SCC numbers.

TABLE 11. COAL FURNACE FIRING TYPES.

Firing Configuration (AP-42, 1995)	Firing Types (Interim Inventory, 1994)
Pulveized coal fired, dry bottom, wall fired	Front Furnace Arch Furnace (50%)48 Rear Furnace Spreader Stoker (80%)49 Opposed Furnace Vertical Furnace
Pulverized coal fired, dry bottom and tangentially fired	Tangential Furnace
Pulverized coal fired, wet bottom	Arch Furnace (50%)
Spreader Stoker	Spreader Stoker (20%)
Fluidized bed combustor	Fluidized Bed
Cyclone furnace	Cyclone

Several steps were made to obtain actual emissions in pounds per ton of each type of coal. The tonnage for each emission provided by the Interim Inventory (1994) database was summed for each firing configuration. This number was divided by the total amount of coal consumed for each firing configuration, to obtain actual emissions per firing configuration, per type of coal. Where actual emissions data were not available, such as methane, and trace elements, emissions factors were obtained from AP-42 (1995) and a weighted average was used for each firing configuration. The model also takes into account all carbon dioxide emissions, which are calculated by multiplying 36.7 by the percent weight of carbon content in coal. Fixed carbon content percentages of different coal samples are provided by Babcock and Wilcox for anthracite, bituminous coal, subbituminous coal, and lignite. Averaged values, and CO_2 emissions factors (in g/kg coal) are provided in the table below:

TABLE 12. CARBON CONTENT AND CO_2 EMISSION FACTORS FOR COAL TYPES.

Coal	Fixed Carbon Content %	CO2 Emission Factor (g/kg)
Anthracite	see footnote 51	2,840
Bituminous	85	3,120
Subbituminous	75	2,753
Lignite	70	2,569

Finally, the model takes the weighted average of each of the firing configurations for each type of coal. For example, the emissions from the spreader stoker for bituminous coal combustion are omitted from the model, since bituminous coal combusted in the spreader stoker is a negligible representation of all of the bituminous coal fed into the firing configurations.

Emissions Control Technology:
Because there is actual plant data for VOCs, NOx, CO, SO2, and particulate matter, emission control technologies for some of the major pollutants of concern, such as NOx and SOx, are already taken into account.

Lime and limestone, used for flue gas desulfurization (FGD), are modeled. Coal utility plants use different methods for scrubbing, such as limestone slurries and dry spraying, and use as the primary FGD materials lime and limestone. Quantities of lime and limestone vary, depending on the type of coal, the molar ratio needed to scrub the SOx, and the percentage of S (by weight) in the coal. Each type of coal was modeled according to the general scrubbing material for that type of coal and based on its percentage by weight of S. Data on scrubbing, molar ratios, and technologies were collected from a source at a coal utility plant in North America (1996), a source at American Electric Power Company (1997) and from the DOE Energy Information Administration *Electric Power Annual* 1994, Vol. II, November 1995.

Water Effluents:
Coal combustors use water for boiler makeup, treatment of fumes, and slag cooling. However, it is assumed that most of the water is recycled in the facility. Therefore, water effluents generated as a result of combustion of coal are negligible in this model.

A.3 Post-Combustion of Coal
The coal combustion process produces waste that must be disposed of off-site, including coal ash, resulting from coal combustion, and sludge, resulting from flue gas desulfurization (FGD). In 1984, 69 x 10^6 tons and 16 x 10^6 tons of coal ash and FGD sludge, respectively, were generated from electrical facilities [52]. Energy and emissions to remove coal ash and FDG sludge are modeled. Since the quantity of FDG sludge is approximately 25% the amount of coal ash, all energy and emissions to remove and dispose of FDG sludge are considered to be about 25% of those found for the disposal of coal ash. Energy to transport FDG sludge and coal ash from the plant to their respective storage locations is modeled. The moisture content of coal ash (in % weight of ash) at the point it is removed from the silo is assumed to be approximately 17% (moisture content may be anywhere from 8% to 25%). The average energy consumed to place ash from the silo into the truck, 0.143 kilowatt hours per ton, is very minimal, as most of the work is due to gravitational force (ash falling from the shoot). The distance from the power plant to the coal ash and FGD sludge landfills is assumed to be one mile[55]. The trucks used to transport the materials are tandem trucks, filled based on weight of the material. The tandem truck carries an actual payload of about 27.6 short tons, and consumes 0.038 gallons of diesel fuel per short ton[56] of material.

B Heavy Fuel Oil Electricity Production
Production of electricity from heavy fuel oil includes heavy fuel oil pre-combustion, transportation of the heavy fuel oil to the utility and heavy fuel oil combustion (including control technologies). Data on heavy fuel oil pre-combustion is listed separately; therefore, this section only describes the heavy fuel oil transport and combustion.

B.1 Transportation of Heavy Fuel Oil from Refinery to Power Plant
The transportation of heavy fuel oil from the refinery to a utility plant is assumed to be through the use of pipelines and road transport. Of all the heavy fuel oil transported, 85% is assumed to be transported by pipeline an average distance of 800 miles. The remaining 15% is assumed to be transported by diesel truck an average one-way distance of 75 miles. Emissions from the two different types of transportation methods are included in the model. The emission factors for the different transportation methods are shown elsewhere.

B.2 Heavy Fuel Oil Combustion
The major source of data for the combustion of fuel oil is EPA AP-42. As described in detail for coal combustion, different technologies of fuel oil combustion have been averaged, according to

their relative use. Lime and limestone, used for flue gas desulfurization (FDG), are modeled. The average heavy fuel oil utility plants use different methods for scrubbing, such as limestone slurries and dry spraying, and use as the primary FGD materials lime and limestone. The quantities of lime and limestone needed are based on, the molar ratio needed to scrub the SOx, and the percentage of S (by weight) in the heavy fuel oil [58]. About 1.01 moles of FDG material are used to scrub 1 mole of SO_2.

C.0 Natural Gas Electricity Production

Production of electricity from natural gas includes natural gas pre-combustion, transportation of the natural gas to the utility, and natural gas combustion. Data on natural gas pre-combustion is listed separately, therefore, this section only describes the natural gas transport, and combustion.

C.1 Transportation of Natural Gas from Site of Extraction to Power Plant

Natural gas is transported by way of high-pressure transmission lines. Compressors along these lines may be powered from different sources: gas-fueled reciprocating engines and gas turbines, and electric motors. Emissions are all different due to the different sources of power in the compressors: the turbines, the engines, and the electric motors, so all of these sources will be modeled. The total amount of gas that is consumed in the compressors is averaged over the different sources of power. It is known that most pipeline compressor units are reciprocating engines. Since reciprocating engines are more efficient when they operate under a large load, and since many of the pipeline compressors do operate under a large load, it follows that there are more reciprocating engines in the compressors than turbines (DeLuchi, 1993). To obtain a breakdown of energy sources for compressors in transmission pipelines, actual pipeline company data was used. Averaging out the percent horsepower for each type of power source for the pipeline, the horsepower type can be seen in Table 13.

TABLE 13. HORSEPOWER TYPE.

% Horsepower in 1989[60]	
Turbines	24.2
Engines	73.4
Electric	2.5

Horsepower hours by type of compressor and the associated fuel combustion per horsepower-hour is used to obtain a weighted percent of energy and emissions due to each type of compressor in transmission pipelines. Since electric power is so little relative to the other compressors (2.5%), it is neglected. AP-42 (1995) provides emissions data for gas turbines and reciprocating engines. Emission factors for controlled emissions (i.e., with NOx reduction technologies in place) for NOx, CO, TOC, total non-methane organic compounds, CH4, and PM-10 were used. The control technology is assumed to be in place due to increasingly stricter NOx control standards. For gas turbines, uncontrolled emissions factors are provided for NOx, CO, TOC, total non-methane organic compounds, CH4, and PM-10 in AP-42 (1995).

C.2 Natural Gas Combustion

Natural gas is combusted in gas boilers. Emissions from combustion of natural gas are mainly due to improper operating conditions, such as inefficient mixing of fuel and air in the boiler, or an insufficient amount of air, etc. Emissions vary by the type and size of combustor and operating conditions. Emissions factors for gas boilers were obtained from EPA AP-42 (1995) for NOx, CO, SOx, particulate matter, CO, and TOC's. NOx control technologies are required for many boilers to comply with strict NOx emissions standards, so it is assumed that most boilers have NOx control technologies. Therefore, emissions factors for NOx in AP-42 (1995) use the factors for boilers with NOx control technologies.

D.0 Nuclear Energy Electricity Production

Uranium contains two different isotopes, of uranium—238U and 235U. 235U is used as a fuel for nuclear reactors because it is fissionable, so the atoms can be split, releasing large amounts of heat. However, natural uranium consists of more than 99 percent 238U and less than 1 percent 235U. To be used as a fuel, its 235U content must be enriched to 3-5 percent. The data included in the model is uranium hexafluoride (UF6) manufacturing, enrichment of 235U, and fuel rods manufacturing[61]. There is no available data on disposal of waste, plant construction, or emissions of radionucleides.

E.0 Hydro Power Electricity Production

Hydroelectric power generation refers to water used to generate electricity at plants in which turbine generators are driven by falling water. Included in the hydroelectric power production model are greenhouse gas emissions (CO_2 and CH_4) from operation of a hydroelectric plant (flooded biomass decomposition). The Federal Energy Regulatory Commission[62]provides US hydroelectric plant information such as average annual generation, plant capacity, and reservoir area and depth. Construction of the facility (steel and concrete production and transportation to the reservoir plus construction energy) is excluded from the model. Capital equipment in hydroelectric power production has been raised to be a potential source of burdens for hydroelectricity[63] (it has been shown that capital equipment was negligible for fossil fuel combustion). However, in order to be consistent with the other energy production methods, capital equipment is excluded. The data obtained on greenhouse gases emissions does not distinguish flooded biomass decomposition from new biomass decomposition and is assumed to refer only to flooded biomass.

F.0 Electricity Production per Geographical Zone

The following tables show the electricity *production* percentages for the different North American Electric Reliability Council (NERC) regions in the North America.

TABLE 14. ELECTRICITY PRODUCTION BY NERC REGION.

Fuel Type	NERC Region (values given as %)				
	NPCC	ECAR	WSCC	ERCOT	SERC
HFO	10.7	0.3	0.1	0.1	3.4
Hydro	15.4	0.5	40.6	0.3	4.6
Natural Gas	18.3	0.5	10.2	37.4	5.9
Nuclear	35.1	10.4	12.8	17.1	29.5
Coal	20.5	88.3	36.3	45.2	56.6
Fuel Type	**NERC Region (values given as %)**				
	MAAC	**MAPP**	**MAIN**	**SPP**	**U.S. Average**
HFO	3.1	0.5	0.5	0.3	2
Hydro	0.8	8.4	1.4	2.9	9.8
Natural Gas	5.3	0.9	1.7	28.3	10.2
Nuclear	40.8	15.9	42.4	15.7	23

Coal	50	74.3	54	52.8	55

Note that the percentages are given for the United States portion of the region listed. Some regions are split between Canada and the United States (WSCC for example), however, the electricity production percentages are given for only the United States portion as that was all the data available. The following table shows the LCI for the U.S. average electricity production grid.

TABLE 15. LCI FOR PRODUCING 1 MJ OF ELECTRICITY.

Environmental Flow	Units	U.S. Grid Average
Inflow		
(r) Coal (in ground)	kg	0.069
(r) Limestone ($CaCO_3$, in ground)	kg	0.013
(r) Natural Gas (in ground)	kg	0.0076
(r) Oil (in ground)	kg	0.0024
(r) Uranium (U, in ground)	kg	1.7 E-06
Water Used (total)	liter	0.0021
Outflows		
(a) Dust & Particulates	g	0.97
(a) Carbon Dioxide (CO_2, fossil)	g	213
(a) Carbon Monoxide (CO)	g	0.047
(a) Sulfur Oxides (SOx as SO_2)	g	1.2
(a) Nitrogen Oxides (NO_x as NO_2)	g	0.66
(a) Non-Methane Hydrocarbons	g	0.0045
(a) Methane (CH_4)	g	0.52
(a) Hydrogen Chloride (HCl)	g	0.037
(a) Hydrogen Fluoride (HF)	g	0.0046
(a) Lead	g	1.0 E-04
(w) Dissolved Solids	g	0.11
(w) Suspended Solids	g	0.0040
(w) Heavy Metals (total)	g	5.6 E-05
(w) Oils and Greases	g	0.00051
(w) Other Organics	g	-
(w) Phosphates (as P)	g	-
(w) Ammonia (as N)	g	0.00022
Waste (total)	kg	0.031
Energy Reminder		
E (HHV) Total Energy	MJ	3.5
E (HHV) Fossil Energy	MJ	3.4
E (HHV) Non-Fossil Energy	MJ	0.11
E (HHV) Process Energy	MJ	3.5
E (HHV) Feedstock Energy	MJ	-

Environmental Flow	Units	U.S. Grid Average
E (HHV) Transportation Energy	MJ	0.019

2.4.3.4 Transportation Energy

The following section describes the modeling of transportation energy used by the generic modes of transportation in this study.

A.0 Transportation Emissions

A.1 Diesel Barge

The barge was assumed to be a ship transporting generic goods, with a Btu/ton-mile of 402 (source –*Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricit*y, M. DeLuchi) Emission factors for CO, NOx and HC are for a 2500 hp diesel engine cruising speed (source - *AP-4*2, US EPA). The deadweight tons for the ship are assumed to be under 15,000. The diesel fuel consumed is assumed to have 0.2% sulfur, converted completely to SO_2 during combustion. The fuel density for the diesel fuel is assumed to be 3173.83 grams/gallon (source -*Ecobalance of Packaging Materials State of 199*0, BUWAL)

A.2 Diesel Truck

The truck is assumed to be an 18-ton heavy-duty truck, fully loaded; 5.5 miles/gallon is assumed. The emission factors are for 1991-1997 trucks operated at low altitude (source - *AP-4*2, US EPA). CO_2 and SOx emissions are calculated using the diesel fuel's carbon content and sulfur content respectively. Diesel fuel is assumed to be 0.2% sulfur and 85.8% carbon.

A.3 Diesel Train

Data for average annual freight ton miles and gallons of diesel fuel consumed come from the Bureau of Transportation Statistics. The values are an average of six years worth of data (1990-1995). Emission factors are for Class I railroads (source - *Procedures for Emission Inventory Preparation - Vol.IV: Mobile Source*s, Bureau of Transportation Statistics). CO_2 emissions are calculated using the assumption of 85.8% carbon in diesel fuel. Diesel fuel density is given as 3173.83 grams/gallon (source -*Ecobalance of Packaging Materials State of 199*0, BUWAL).

A.4 Heavy Fuel Oil Ocean Tanker

The tanker is assumed to be an international oil tanker averaged over different deadweight ton sizes, transporting crude oil or petroleum products. The fuel oil density is given as 3575 grams/gallon and the btu/ton mile is calculated as 114 (source -*Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricit*y, M. DeLuchi). CO_2 and SO_x emissions are calculated using the heavy fuel oil's carbon content and sulfur content respectively. Heavy fuel oil is assumed to be 2.2% sulfur and 85.8% carbon.

2.5 Environmental Emissions

2.5.1 Air Emissions

In some data sources (e.g., European secondary sources on plastics production), the breakdown of hydrocarbons between methane and non-methane hydrocarbons was not available. Therefore, assumptions were made to the split between methane and non-methane hydrocarbons. This was done as follows:

- For European secondary sources on plastics production, the split was made based on new data from APME that does break out NMHC and methane.

- For combustion sources, data was compared to sources that do list NMHC and methane and checked with new data from AP-42.
- For sources where there was no indication of the breakdown, a 50/50 split was used.

2.5.2 Water Effluents

For primary data, individual metals have been separately recorded into the software model, and heavy metals have been captured in an aggregated category “(w) Heavy Metals (total). However, some secondary sources are not consistent in this matter and report a category called “(w) Metals”, the content of which is unspecified: these metals can either be heavy metals or non-heavy metals. Only values that were explicitly specified as heavy metals were included in the final inventory. Therefore, the final life cycle inventory value for heavy metals is underestimated by the amount of heavy metals present in the unspecified metal category of the secondary sources used in this study.

Steel sector water emissions related to the products being studied were measured on a weight basis for each of the water emission categories set out in the methodology. Values reported represent actual discharges or estimates based on samples and commonly accepted methods of calculation from surface points after passing through water treatment points or designated release points. Accidental releases are captured in these discharge points.

2.5.3 Solid Waste

Steel sector solid waste related to the products being studied was measured on a dry weight basis of a material that is deposited in a solid waste landfill.

Some of the secondary data for the production of metals have been derived from a Swiss database, ETH (Laboratorium fur Energiesysteme ETD, Zurich, 1996). In this database, waste streams are not recorded as such, the emissions of the landfill are accounted for instead. This is not consistent with the way waste is managed in all the other sources used for the project. The consequences are that the total waste quantity is underestimated. The emissions of the landfill are yet recorded in the model, with an additional family of categories, the name of which starts with a (s), for emissions to soil. They are not displayed in this report.

2.6 Allocation Procedures

Allocation procedures are used to partition inputs and/or outputs within a specific product system. An allocation procedure is required when a unit process within a system shares a common pollution treatment infrastructure or where multiple products or co-products are produced in a common unit process. There are several allocation techniques that may be used.

For allocation of utilities and services common to several processes, allocations should reflect relative use of the service. For example, in allocating effluent treatment facilities, allocation is determined by the percent of treatment load generated by the subject process (indicate if measured or calculated). A co-product is defined as a material/energy flow for which there is a market and the share of the material/energy entering the market is greater than 30% of the material/energy that is generated in the unit process. In addition, the market price for the material/energy must be sufficient to sustain its production on a profitable basis. If a co-product does not meet these requirements, it will not be eligible for allocation. Special conditions apply where a single process produces both product(s) and energy. In this case, in general, the input materials are partitioned between making the chemical products and producing energy. This methodology avoids allocating inappropriate emissions from chemical products to energy production, etc. All allocation procedures used are documented in the following sections.

Allocation has been defined in several publications and is not described in detail here. Following the ISO definition, allocation is the partitioning of input and output flows of a unit process to the product system under study. The need for co-product allocation arises when a unit process generates more than one product and one or more of these products leave the system boundary. Allocation to co-products is one of the more controversial issues in life cycle inventory studies. One reason for the controversy is allocation may be used to unfairly reduce the inputs and outputs assigned to the functional unit. The result will be less environmental burdens associated with the product system under study. Not allocating to co-products will have the effect of overstating the environmental burdens associated with the product system. The steel LCI study includes consideration of several approaches to co-product allocation. Steel products can be modeled by allocating inputs and outputs based on a mass, energy, or economics basis. Two other options are available, these being no allocation and avoiding allocation by using system expansion. The last option is not allocation, but is included here for convenience. AISI decided to pursue multiple approaches to co-product allocation because it is an issue of some debate and flexibility was a part of the study goals. For the USAMP LCI study, AISI used allocation for five co-products. Four co-products are generated in the coke production unit process: coal tar, ammonia, ammonium sulfate, and light oil. These co-products were allocated on the basis of mass. One co-product is generated in the iron production unit process: blast furnace slag. This co-product was allocated based on economic value. Within the system boundary, allocation was based on a physical parameter or, if more appropriate, economic value. An example of a physical allocation is water flow into a common wastewater treatment plant that has multiple inputs. The inputs and outputs of the wastewater treatment plant were allocated to a product based on the water flow from the unit process associated with the product. The only exception to allocation based on a physical parameter was economic allocation used for blast furnace gas. The blast furnace gas was allocated at the iron production unit process.

TABLE 16. ECONOMIC ALLOCATION FACTORS FOR THE IRON PRODUCTION UNIT PROCESS.

Material	Value	Comment
Hot Metal (iron from blast furnace)	$154.36/tonne	Company Data
Blast Furnace Slag	$8.74/tonne	USGS
Blast Furnace Gas	$0.00215/MJ	Based on Natural Gas

2.7 Deliberate Omissions

The steel LCI study did not include capital infrastructure or the environmental inputs and outputs associated with people who work in the unit processes. For example, the study did not include the inputs and outputs associated with building a coke oven or of a person travelling to work at the plant site.

The manufacturing and post consumer scrap is assumed to be ready for transport at the shipping location. Estimates for selective handling and processing (e.g., component dismantling) have not been included. These aspects are considered to be minor.

2.8 Treatment of Anomalies/Missing Data

For all stages of the generic vehicle life cycle, it was difficult to classify the origin of water use in all cases between surface and ground water. Therefore, water use is recorded in this model in terms of total water used only. This can not be used to determine any impact of water use in terms of disruption of natural water cycles. However, water depletion impact on the environment is a site or regional specific concern, as for instance, water use in Texas implies a different impact on the natural water cycle then water use in the Northeast United States. Life cycle assessment is not the best tool to understand nor represent this type of site specific concern, because the final water use number combines water use across many different temporal and spatial boundaries. Treatment of anomalies and missing data for specific portions of the generic vehicle model are expressed in the following sections.

The systematic application of the data collection procedures and verification of data was a key aspect of the steel study. The aim of the data validation procedures was to reduce the likelihood of using incorrect data, errors during transfer of data to the LCI database, and identify missing data. A spreadsheet-based questionnaire was used for primary data collection. The questionnaire included a built-in check of most data entries. This checking system used the results of preliminary data collection from a sample of steel manufacturing sites. If a person tried to enter values that fell outside the range of preliminary data, a warning was generated to indicate an error might have been made and the offending value should be reviewed. The completed questionnaires were downloaded into the LCI database, with the automated data validation augmented by manual auditing by the study consultant. A further review of the data was undertaken by industry experts to check for data anomalies and missing data. Data anomalies were corrected through further investigation or removed if no explanation could be found. Data was based on a reported value, a valid zero value where applicable, or a value calculated based on the average of values reported from similar unit processes.

3.0 RESULTS

3.1 Steel LCI Data

The LCI results for hot rolled coil are presented in Table 17. The LCI results for EAF bars are presented in Table 18.

TABLE 17. LCI RESULTS FOR 1 KG HOT ROLLED COIL.

InFlows:	(r) Bentonite (Al2O3.4SiO2.H2O, in ground)	kg	2.07E-02
	(r) Coal (in ground)	kg	5.46E-01
	(r) Dolomite (CaCO3.MgCO3, in ground)	kg	8.66E-02
	(r) Ilmenite (FeO.TiO2, ore)	kg	2.00E-04
	(r) Iron (Fe, ore)	kg	1.29E+00
	(r) Limestone (CaCO3, in ground)	kg	8.41E-02
	(r) Manganese (Mn, ore)	kg	1.62E-02
	(r) Natural Gas (in ground)	kg	7.16E-02
	(r) Oil (in ground)	kg	5.64E-02
	(r) Olivine (in ground)	kg	6.52E-03
	(r) Sand (in ground)	kg	7.11E-04
	(r) Sodium Chloride (NaCl, in ground or in sea)	kg	1.53E-03
	(r) Uranium (U, ore)	kg	3.88E-06
	(r) Zinc (Zn, ore)	kg	1.69E-08
	Steel Scrap	kg	2.08E-01
	Water Used (total)	litre	2.39E+01
OutFlows:	(a) Carbon Dioxide (CO2, fossil and mineral)	g	1.82E+03
	(a) Carbon Monoxide (CO)	g	1.86E+01
	(a) Hydrocarbons (except methane)	g	6.01E+00
	(a) Hydrocarbons (unspecified)	g	8.79E-02
	(a) Hydrogen Chloride (HCl)	g	6.80E-02
	(a) Hydrogen Fluoride (HF)	g	1.77E-02
	(a) Lead (Pb)	g	1.13E-04
	(a) Methane (CH4)	g	2.31E+00
	(a) Nitrogen Oxides (NOx as NO2)	g	2.76E+00
	(a) Particulates (unspecified)	g	1.31E+01
	(a) Sulphur Oxides (SOx as SO2)	g	5.11E+00
	(w) Ammonia (NH4+, NH3, as N)	g	6.17E-02
	(w) Dissolved Matter (unspecified)	g	8.67E-01
	(w) Heavy Metals	g	1.16E-03
	(w) Metals (unspecified)	g	9.93E-03
	(w) Oils (unspecified)	g	1.05E-02
	(w) Organic Dissolved Matter (unspecified)	g	2.79E-04
	(w) Phosphates (as P)	g	6.29E-04
	(w) Suspended Matter (unspecified)	g	3.27E-01
	Product ()	kg	1.00E+00
	Waste (total)	kg	4.35E-01
Reminders:	E Feedstock Energy	MJ	0.00E+00
	E Fossil Energy	MJ	2.47E+01
	E Non-Fossil Energy	MJ	4.28E-01
	E Process Energy	MJ	2.46E+01
	E Total Energy	MJ	2.52E+01
	E Transportation Energy	MJ	5.68E-01

TABLE 18. LCI RESULTS FOR 1 KG EAF BARS.

InFlows:	(r) Bentonite (Al2O3.4SiO2.H2O, in ground)	kg	1.00E-06
	(r) Coal (in ground)	kg	1.77E-01
	(r) Dolomite (CaCO3.MgCO3, in ground)	kg	1.66E-03
	(r) Iron (Fe, ore)	kg	9.90E-03
	(r) Limestone (CaCO3, in ground)	kg	9.60E-02
	(r) Manganese (Mn, ore)	kg	1.66E-02
	(r) Natural Gas (in ground)	kg	2.04E-02
	(r) Oil (in ground)	kg	1.79E-02
	(r) Sand (in ground)	kg	6.08E-03
	(r) Sodium Chloride (NaCl, in ground or in sea)	kg	1.03E-04
	(r) Uranium (U, ore)	kg	2.48E-06
	Steel Scrap	kg	1.10E+00
	Water Used (total)	litre	8.48E+00
OutFlows:	(a) Carbon Dioxide (CO2, fossil and mineral)	g	5.95E+02
	(a) Carbon Monoxide (CO)	g	3.97E+00
	(a) Hydrocarbons (except methane)	g	1.82E-01
	(a) Hydrocarbons (unspecified)	g	1.06E-01
	(a) Hydrogen Chloride (HCl)	g	8.96E-02
	(a) Hydrogen Fluoride (HF)	g	1.14E-02
	(a) Lead (Pb)	g	9.34E-04
	(a) Methane (CH4)	g	1.29E+00
	(a) Nitrogen Oxides (NOx as NO2)	g	1.77E+00
	(a) Particulates (unspecified)	g	7.22E+00
	(a) Sulphur Oxides (SOx as SO2)	g	2.98E+00
	(w) Ammonia (NH4+, NH3, as N)	g	1.04E-03
	(w) Dissolved Matter (unspecified)	g	1.69E-01
	(w) Heavy Metals	g	1.33E-03
	(w) Metals (unspecified)	g	3.90E-02
	(w) Oils (unspecified)	g	4.37E-03
	(w) Organic Dissolved Matter (unspecified)	g	6.60E-05
	(w) Phosphates (as P)	g	3.78E-03
	(w) Suspended Matter (unspecified)	g	6.19E-02
	Product	kg	1.00E+00
	Waste (total)	kg	1.33E-01
Reminders:	E (HHV) Feedstock Energy	MJ	0.00E+00
	E (HHV) Fossil Energy	MJ	8.44E+00
	E (HHV) Non-Fossil Energy	MJ	9.90E-01
	E (HHV) Process Energy	MJ	9.30E+00
	E (HHV) Total Energy	MJ	9.43E+00
	E (HHV) Transportation Energy	MJ	1.33E-01

3.2 Sensitivity of Results

Table 19 shows that the steel LCI results are increased when no allocation choice is used but not more than 6% for any flow and energy values did not increase by more than 4%.

TABLE 19. SENSITIVITY OF LCI RESULTS TO USE OF ALLOCATION.

Environmental Flow	Hot Rolled Coil (% difference from no allocation basis)
Inflow	
(r) Bentonite ($Al_2O_3.4SiO_2.H_2O$, in ground)	2.2%
(r) Coal (in ground)	4.8%
(r) Dolomite ($CaCO_3.MgCO_3$, in ground)	1.2%
(r) Ilmenite ($FeO.TiO_2$, ore)	1.2%
(r) Iron (Fe, ore)	1.9%
(r) Natural Gas (in ground)	1.5%
(r) Oil (in ground)	2.6%
(r) Sodium Chloride (NaCl, in ground)	2.5%
(r) Uranium (U, ore)*	1.1%
Iron Scrap (total)	1.3%
Water Used (total)	2.1%
Outflow	
(a) Dust and Particulates	0.9%
(a) Carbon Dioxide (CO_2, fossil)	2.0%
(a) Carbon Monoxide (CO)	0.9%
(a) Sulfur Oxides (SOx as SO_2)	2.0%
(a) Nitrogen Oxides (NOx as NO_2)	2.0%
(a) Non-Methane Hydrocarbons	2.0%
(a) Methane (CH_4)	4.5%
(a) Hydrogen Chloride (HCl)	1.5%
(a) Hydrogen Fluoride (HF)	1.7%
(a) Lead (Pb)	1.4%
(w) Dissolved Solids	2.3%
(w) Suspended Solids	1.1%
(w) Oils and Greases	2.7%
(w) Other Organics	3.1%
(w) Phosphates (as P)	5.5%
(w) Ammonia (as N)	3.0%
Waste (total)	2.3%
Waste (municipal and industrial)	2.4%
Energy Reminder	
E (HHV) Total Energy	2.1%

Environmental Flow	Hot Rolled Coil (% difference from no allocation basis)
E (HHV) Fossil Energy	3.7%
E (HHV) Non-Fossil Energy	1.3%
E (HHV) Process Energy	3.7%
E (HHV) Transportation Energy	3.7%
* Uranium use is for electricity production	

Another issue for sensitivity is the quality of the upstream data. Iron ore mining is a key upstream process so its effect on the overall results was checked. Changing the LCI profile for iron ore mining by +25% had the following results on the hot rolled coil LCI:

- total energy changed <0.05%,
- iron consumption changed <4.1%,
- coal consumption changed < 0.002%,
- carbon dioxide emissions changed <0.02%, and
- nitrogen oxides to air <0.07%