2.6 IRON AND STEEL SECTOR (NAICS 3311, 3312)

2.6.1. Overview of the Iron and Steel Manufacturing Sector

The iron and steel sector is an essential part of the U.S. manufacturing sector, providing the necessary raw material for the extensive industrial supply chain. U.S. infrastructure is heavily reliant on the U.S. iron and steel sector, as it provides the foundation for construction (bridges, buildings), transportation systems (railroads, cars, trucks), utility systems (municipal water systems, power systems), as well as other diverse applications including military equipment, food storage, appliances, and tools.

Steel is typically produced through one of two manufacturing methods, each of which is relatively energy-intensive. An integrated steel mill produces molten iron in blast furnaces using a form of coal known as coke, which is either produced onsite or purchased. This iron is used as a charge to produce steel in a basic oxygen furnace (BOF). Alternatively, an electric arc furnace (EAF) steel producer, also known as a mini-mill, uses EAFs to produce steel from steel scrap and other iron-bearing materials. Table 2.6-1 shows the NAICS code subsectors in iron and steel manufacturing with data reported in MECS.

Table 2.6-1. Iron and steel subsectors with data reported in MECS

NAICS code	Iron and steel subsector
3311	Iron and steel mills and ferroalloy manufacturing
331111	Iron and steel mills
331112	Electrometallurgical ferroalloy product manufacturing
3312	Steel product manufacturing from purchased steel

2.6.2. Energy Use Profile for the Iron and Steel Sector

Steel is the fifth largest consumer of fuels among U.S. manufacturing sectors. The efficiency of the processes and equipment used to produce iron and steel is constrained by severe operating conditions (high temperatures, corrosive environments) and thermodynamic, kinetic, or transport limitations. These factors collectively contribute to proportionally high energy use per ton of product produced.

A snapshot of where the iron and steel sector ranks in terms of energy use and losses within manufacturing is shown in Table 2.6-2. Energy losses are shown in red font. All values are based on the most currently available complete set of manufacturing energy use statistics, representing annual energy use and loss values for calendar year 2006. The sector ranks among the top five in U.S. manufacturing in most energy end use categories.

Table 2.6-2. Snapshot of the iron and steel sector: Energy use and rank within U.S. manufacturing

Category	Rank	Energy (TBtu)
Total primary energy	5	1,481
Offsite losses	4	439
Onsite energy	5	1,043
Onsite losses	5	550
Steam generation and distribution	5	78
Electricity generation	4	8
Process energy	5	431
Nonprocess energy	9	33
Feedstock energy	3	448
Total primary and feedstock energy*	5	1,557
GHG combustion emissions		**MMT CO_2e**
Total	5	62
Onsite	6	23

*When total primary energy and feedstock energy are summed, the energy value of byproduct fuels derived from feedstock energy sources is excluded to avoid double counting of feedstock energy

Although outside the scope of the footprint analysis, a substantial amount of energy in the iron and steel sector is consumed as non-fuel feedstocks in this sector. As shown in Fig. 2.6-1, the total feedstock energy consumed by the sector is 448 TBtu. The only two manufacturing sectors with greater feedstock energy use are the petroleum refining sector (NAICS 324110, feedstock energy consumption equal to 3.4 quads) and the chemicals sector (NAICS 325, feedstock energy consumption equal to 2.8 quads).

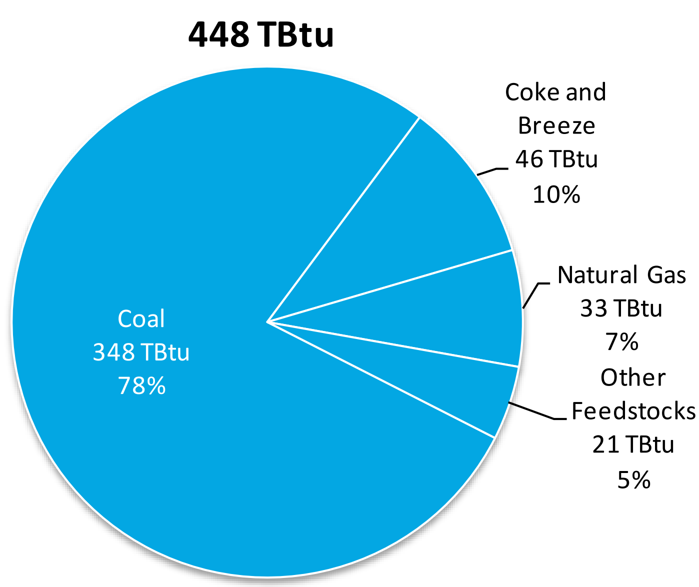


Fig. 2.6-1. Feedstock energy use in the iron and steel sector

2.6.2.1. Energy and carbon footprint

The *Manufacturing Energy and Carbon Footprint* for the iron and steel sector is shown in Fig. 2.6-2 and Fig. 2.6-3. The footprint serves as the basis for characterizing the offsite and onsite flow of energy, as well as carbon emissions from generation through end use in this sector.

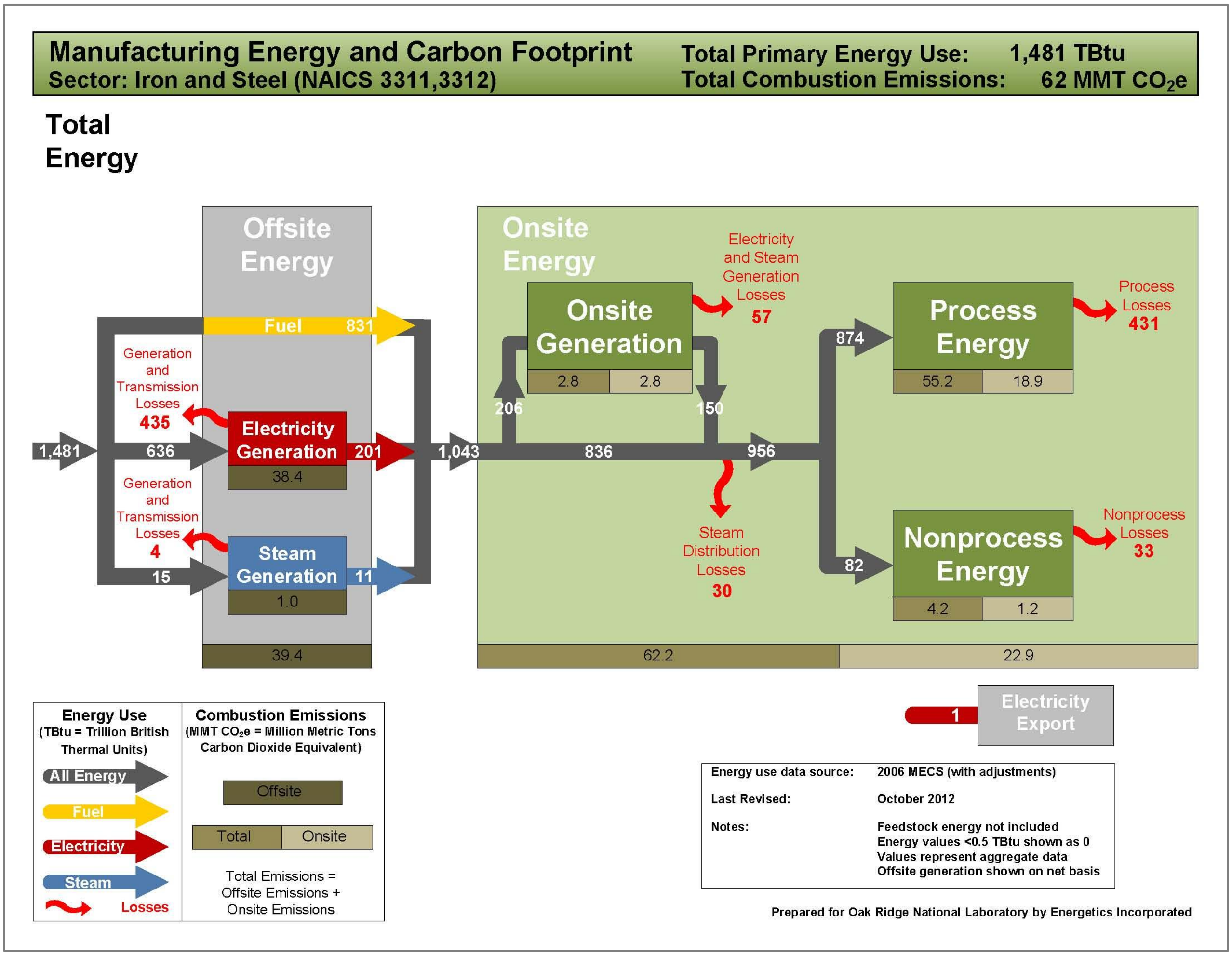


Fig. 2.6-2. Total energy and carbon footprint for the iron and steel sector

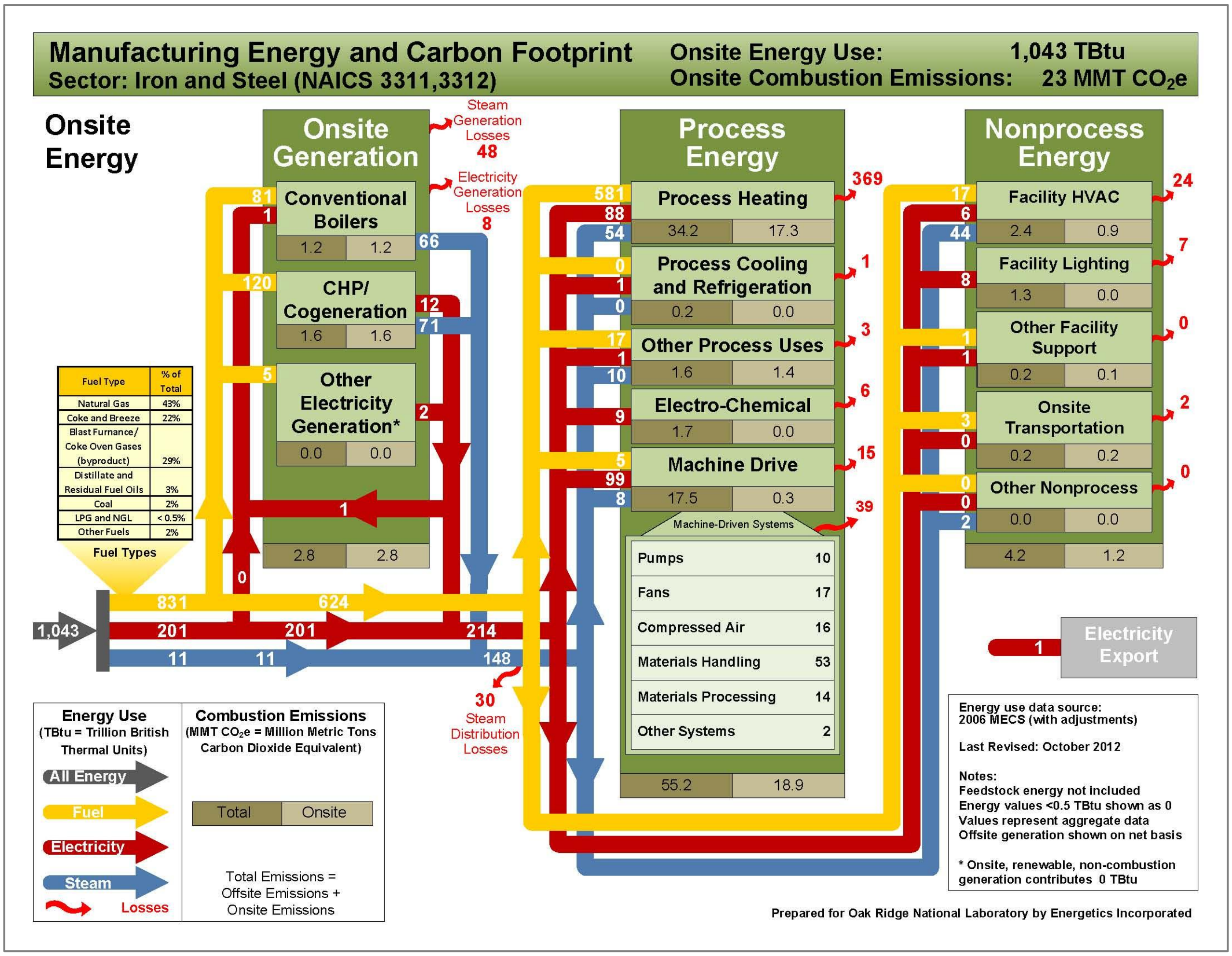


Fig. 2.6-3. Onsite energy and carbon footprint for the iron and steel sector

2.6.2.2. Primary energy

Primary energy use includes fuels, electricity, and steam consumed in manufacturing, including the generation and distribution/transmission losses associated with offsite and onsite electricity and steam generation. The primary energy use by energy type for the iron and steel sector is depicted in Fig. 2.6-4. Consistent with the footprints, blue represents steam energy, red represents electric energy, and yellow represents fuel energy.

The iron and steel sector consumes 1,481 TBtu of primary energy. Electricity generation accounts for the largest portion of this total—657 TBtu (44%). Offsite electricity generation and transmission losses account for two-thirds of electricity generation energy consumption (435 TBtu) while 201 TBtu of offsite electricity enters the plant boundary. Onsite electricity generation accounts for only 13 TBtu and onsite electricity losses account for a further 8 TBtu of energy.

Direct fuel use is the next largest category of primary energy, consuming 624 TBtu (42%) of total primary energy consumption. Natural gas is the most used fuel, accounting for nearly half of direct fuel consumption at 322 TBtu, while coke and breeze is the next largest fraction of direct fuel at 181 TBtu. Blast furnace gas (a byproduct fuel of coke and breeze) and coke oven gas (also a byproduct fuel) together consume 90 TBtu for direct fuel uses. Other fuels including coal, residual fuel oil, and distillate fuel oil consume the remaining 32 TBtu of direct fuel energy.

Steam is the smallest category of primary energy—consuming 200 TBtu (14%) of total primary energy. Onsite generation of steam accounts for 109 TBtu of this total, while losses from onsite steam generation and distribution account for an additional 78 TBtu. In contrast with electricity generation, only 6% of steam generation energy is offsite.

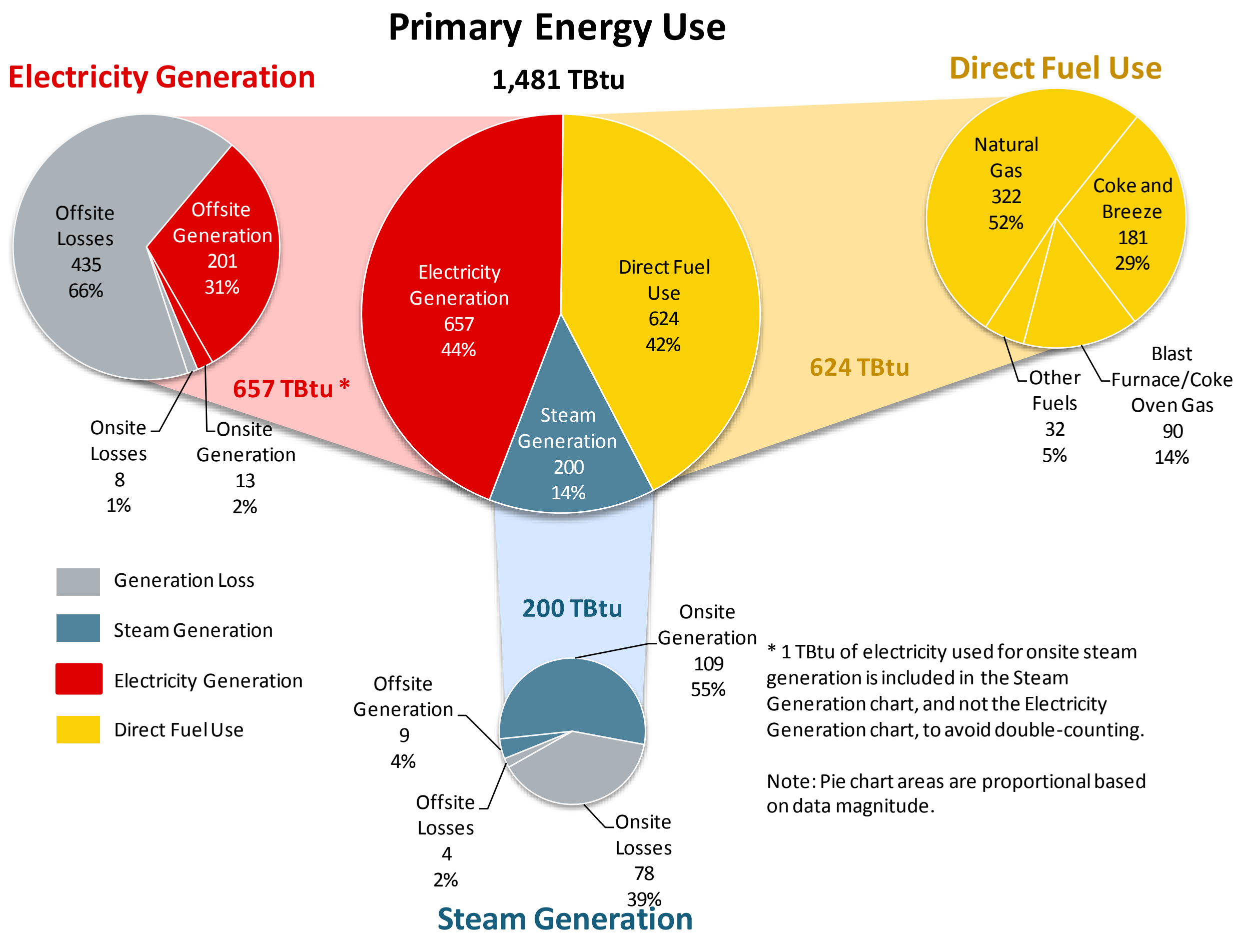


Fig. 2.6-4. Primary energy by energy type in the iron and steel sector

2.6.2.3. Onsite energy

Onsite energy enters the plant boundary in the form of three offsite energy types: fuel, steam, and electricity. The onsite energy consumed in iron and steel manufacturing in 2006 was 1,043 TBtu, or 70% of primary energy. As shown in Fig. 2.6-5, the onsite energy supply consists mainly of fuel. Offsite electricity accounts for 19%, and offsite steam only 1%, of the offsite energy supply. The largest fuel type supplied to the iron and steel sector is natural gas, at 34%, followed by byproduct waste gases including blast furnace and coke oven gases which account for a further 23% of the total. Compared to other sectors, the iron and steel sector is unique for its heavy reliance on coke and breeze purchased from offsite sources, which contributes 181 TBtu or 17% of onsite energy use. It should be noted that this value of coke and breeze fuel use has been adjusted downward to avoid the double counting of fuel use with blast furnace gas.

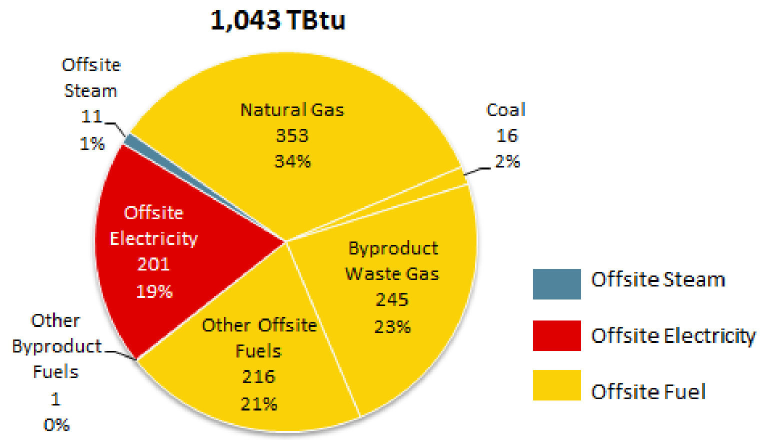


Fig. 2.6-5. Offsite energy supply in the iron and steel sector

Figure 2.6-6 illustrates the energy use patterns across major iron and steel subsectors. The vast majority (94%) of energy use within the sector occurs in iron and steel mills (NAICS 331111) subsector. The other two NAICS-based subsectors with data shown in MECS, electrometallurgical ferroalloy products and steel products from purchased steel, consume less than 5% of sector fuel and electricity use.

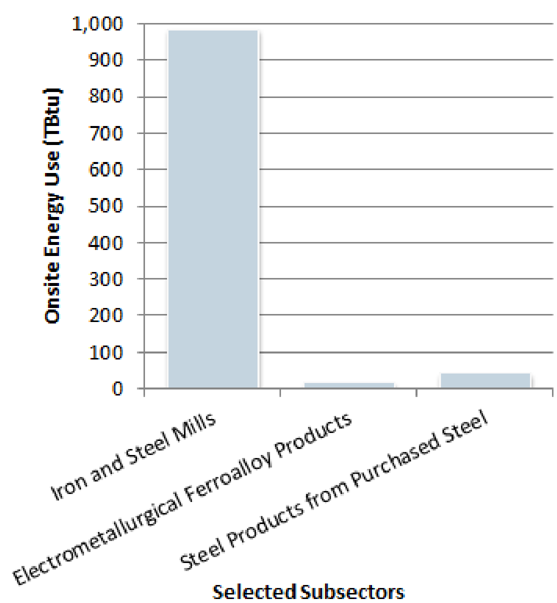


Fig. 2.6-6. Onsite energy use in selected iron and steel subsectors

2.6.2.4. Fuel energy

Onsite fuel use in the iron and steel sector was 831 TBtu in 2006. Natural gas is the largest source of fuel in the sector, supplying 43% of onsite fuel. The iron and steel sector is also reliant on coke and breeze and utilizes byproduct fuels including coke oven gases and blast furnace gases.

EIA MECS data assumes for purposes of estimation that all energy sources used for fuel are completely consumed in the process. However, in the case of iron making processes using blast furnaces, incomplete consumption of blast furnace fuel inputs may be a significant cause of duplication. Following a literature reviews and consultation with iron and steel industry experts, it was determined that the majority of blast furnace gas formation results from the input fuel use of coke. To address this issue, MECS suggests adjusting the fuel use of coal coke downward by the heat content of the blast furnace gas consumed in the sector, which is approximately two-thirds.[17] As a result, this analysis has adjusted the reported MECS coke and breeze value downward to avoid double-counting between coke consumed in a blast furnace and blast furnace gases. About two-thirds of byproduct waste gases are assumed to be blast furnace gases; thus, coke and breeze energy consumption was adjusted down by two-thirds of 245 TBtu (163 TBtu).

2.6.2.5. Electrical energy

The iron and steel sector is ranked fourth in the use of onsite direct electricity. A large portion of primary use is associated with generation, transmission and distribution (T&D) losses, taking place mostly offsite. On average, the efficiency of utility electricity generation and transmission is assumed to be 31.6%, resulting in over 419 TBtu of energy losses in order to produce 201 TBtu of electricity that is used in the sector. A profile of electricity generation, use, and loss is shown in Fig. 2.6-7.

The sector does meet a small portion of its electricity demand through onsite generation. About 13 TBtu of energy use is associated with onsite electricity generation. Most of the electricity produced onsite in the steel sector comes from CHP units; less than 20% of onsite generation is produced using other generation methods, such as the generators running on combustible energy sources or renewable resources.

Nearly half (46%) of electricity use in the iron and steel sector is consumed by machine-driven systems such as compressors, fans, motors, and pumps. Process heating end uses is the next largest category of electricity consumption within the sector, consuming 41% of electricity use. Electric arc furnaces, which use electric power to melt scrap steel and produce new steel, is the major process heating user of electricity. Other heating methods such as induction heaters also consume large amounts of electricity. Less than 15% of sector electricity use is consumed by other process uses such as process cooling and refrigeration, electrochemical processes, and nonprocess uses such as facility HVAC and lighting.

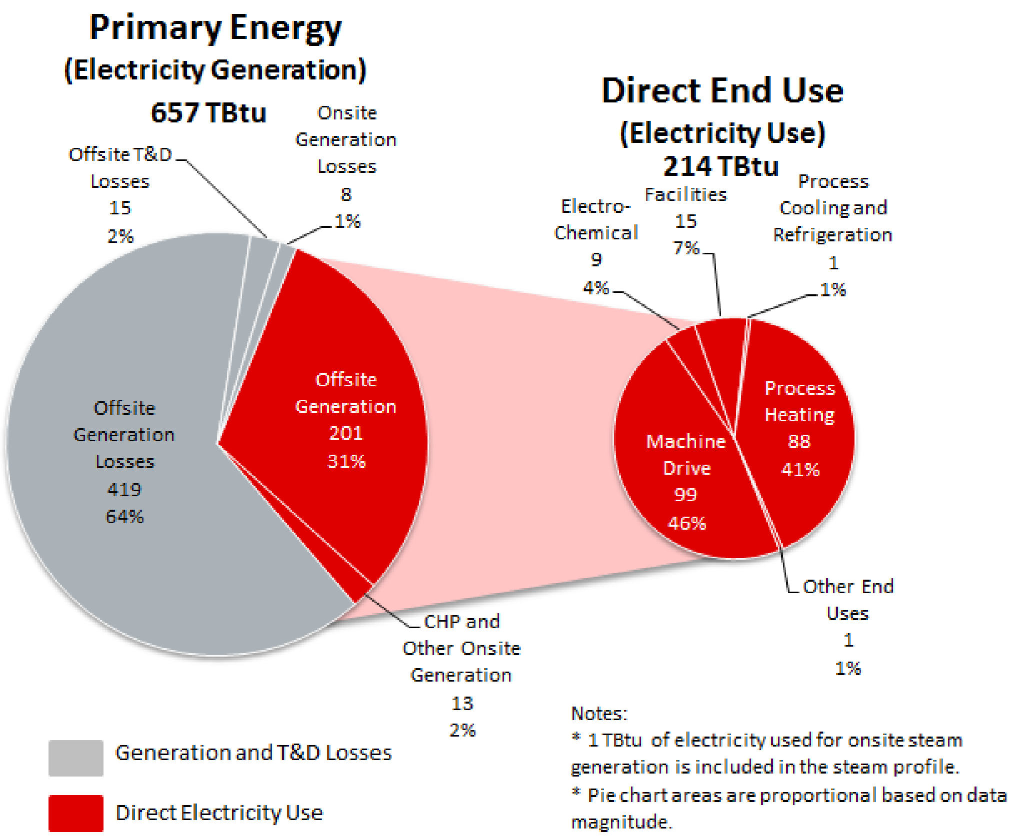


Fig. 2.6-7. Electricity generation and *direct* end use in the iron and steel sector

[17] [2002 Manufacturing Energy Consumption Survey (MECS) Methodology, http://www.eia.doe.gov/emeu/mecs/mecs2002/methodology_02/meth_02.html]

2.6.2.6. Steam energy

A profile of iron and steel sector steam generation, use, and associated losses is shown in Fig. 2.6-8. Steam is produced through one of three methods: offsite steam that is transferred into plants or purchased through the local utility or other sources (9 TBtu), steam generated using CHP units (57 TBtu), and steam generated using conventional boilers (52 TBtu). Less than half of produced steam is lost through offsite generation and transmission losses (1 TBtu), onsite generation losses (48 TBtu), or onsite steam distribution losses (30 TBtu). Process heating applications use 46% of steam, with 38% used in facility HVAC, 8% used in other process uses, 7% used in machine-driven applications, and 1% used in other nonprocess uses.

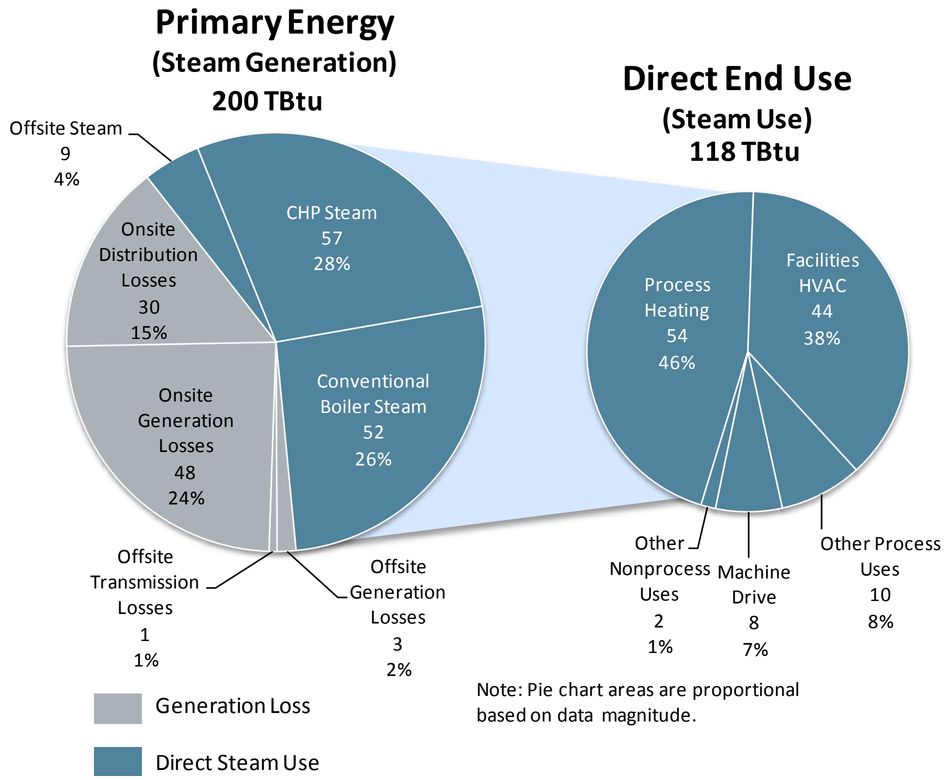


Fig. 2.6-8. Steam generation and *direct* end use in the iron and steel sector

2.6.2.7. Combined heat and power energy

Combined heat and power systems produce the majority of steam for iron and steel plants and also generate the majority of onsite electricity production. Blast furnace or coke oven gas is the main fuel used for CHP applications, followed by natural gas and other fuels including residual fuel oil and coal. CHP systems produce more steam than electricity, with CHP-generated steam production nearly six times greater than CHP-generated electricity. Nearly one-third of CHP fuel input results in losses. CHP fuel use and output is shown in Fig. 2.6-9.

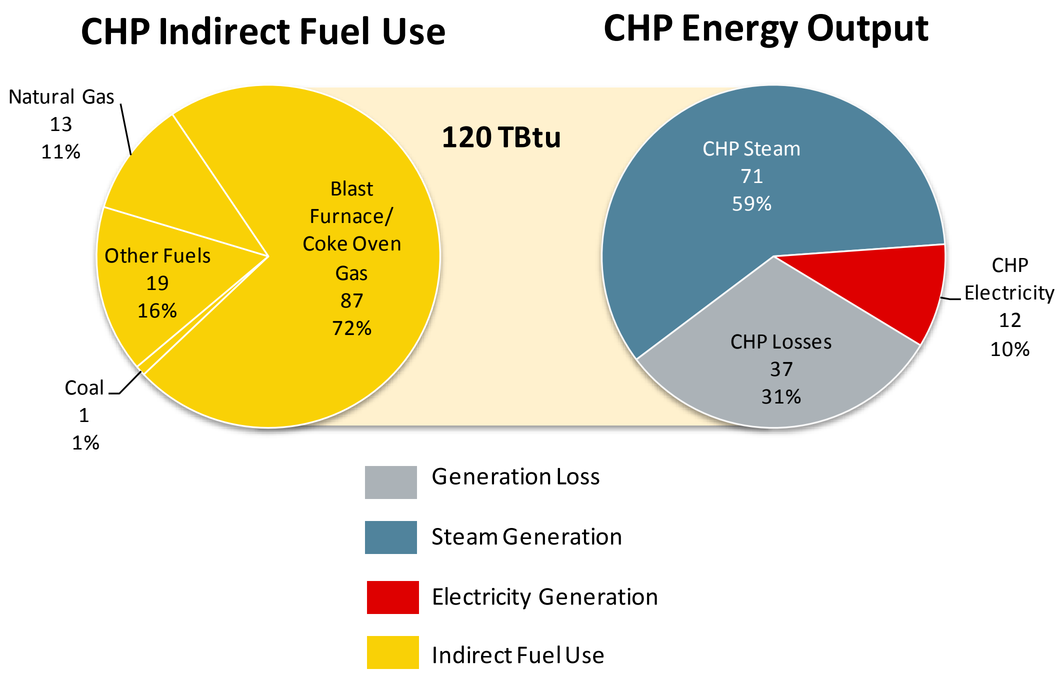


Fig. 2.6-9. CHP fuel consumption and energy output in the iron and steel sector

2.6.2.8. Direct end use energy

Figure 2.6-10 shows a simple breakdown of primary energy by type at direct end use. Direct fuel use is the largest share of direct energy use, while generation and distribution losses (including both electricity and steam generation losses) account for 36% of primary energy.

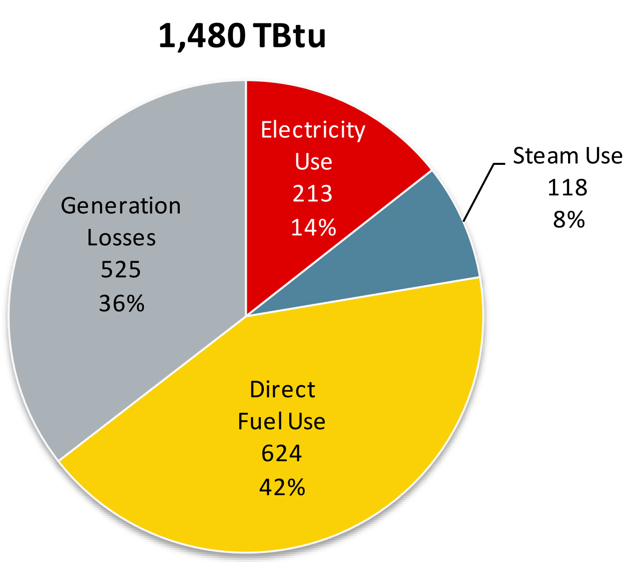


Fig. 2.6-10. Primary energy by type at *direct* end use in the iron and steel sector

The direct end uses of energy are shown in Fig. 2.6-11. The majority of energy is used directly for process use. Nonprocess uses account for only 6% of energy use in the sector.

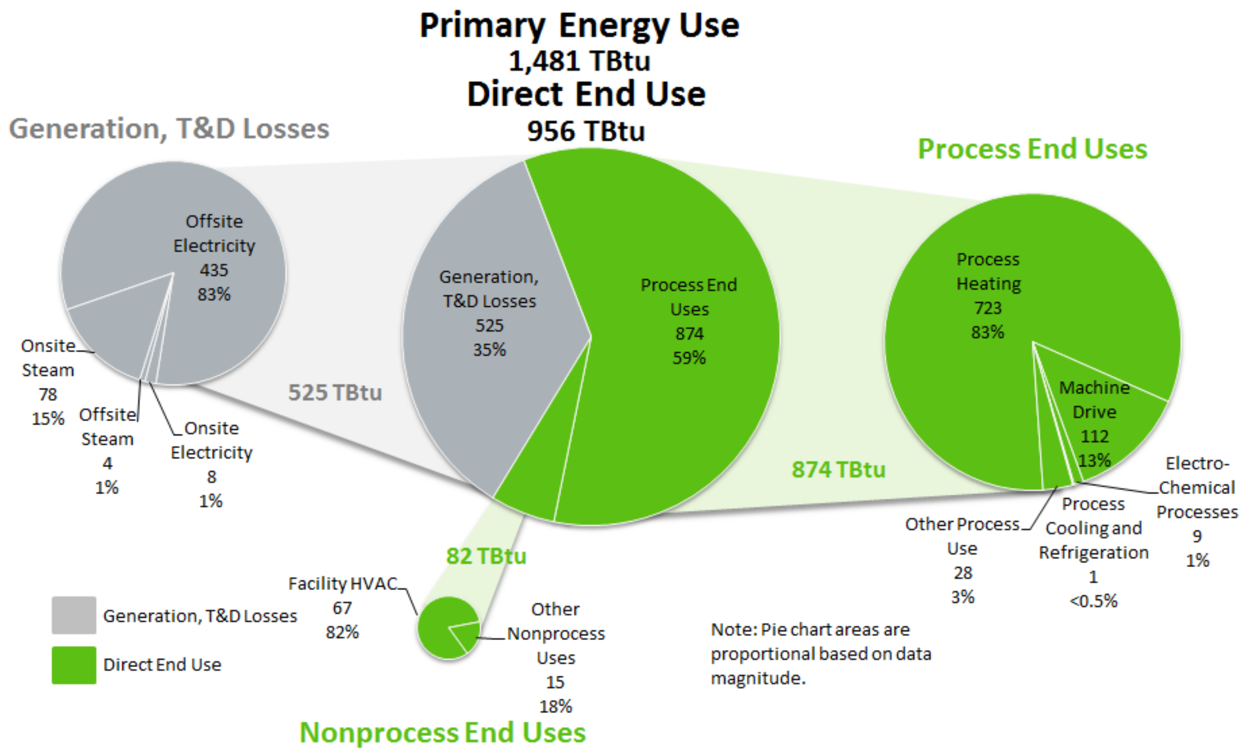


Fig. 2.6-11. Primary energy by *direct* end use in the iron and steel sector

Process heating is the single largest end use of energy, consuming 723 TBtu out of 874 TBtu (83%) total delivered to process end uses. Natural gas, waste gas, and coke and breeze are the three major fuels for process heating, used largely for combustion-based furnaces in the iron and steel sector. Electricity is also a large source of energy for process heating, largely utilized by electric arc furnaces and induction heaters. Machine-driven systems are the next largest users of process energy, followed by electrochemical processes. Electricity is the principal source of energy for these processes, which are predominantly electric-based. Facility HVAC is the largest user of nonprocess energy, followed by facility lighting, and other nonprocess energy uses such as onsite transportation and other facility support.

2.6.2.9. Applied end use energy

In addition to the energy generation losses identified above, the direct end use losses have also been calculated in the energy footprint model. When both generation and end use losses are accounted for, the energy that remains is the *applied energy*. Applied energy can be illustrated by re-examining Fig. 2.6-4, which shows primary energy by energy type for U.S. manufacturing. Each of the energy types (i.e., fuel, electricity, or steam) shown in this figure have associated onsite and offsite generation losses (shown with onsite and offsite losses combined in light gray) that are incurred during energy generation (and transmission and distribution). While the majority of electricity generation losses take place offsite (as shown in Fig. 2.6-7), the majority of steam generation losses are onsite (as shown in Fig. 2.6-8), and direct fuel use is assumed to have no associated generation losses. The non-gray areas of each of the satellite pie charts show the energy that remains after generation losses. After taking into account these generation losses, a further portion of the remaining energy is lost at direct end uses, due to process and nonprocess system and equipment inefficiencies, shown in dark gray. The remaining energy is applied to end uses, shown in light green as “Applied Energy” in Fig. 2.6-12.

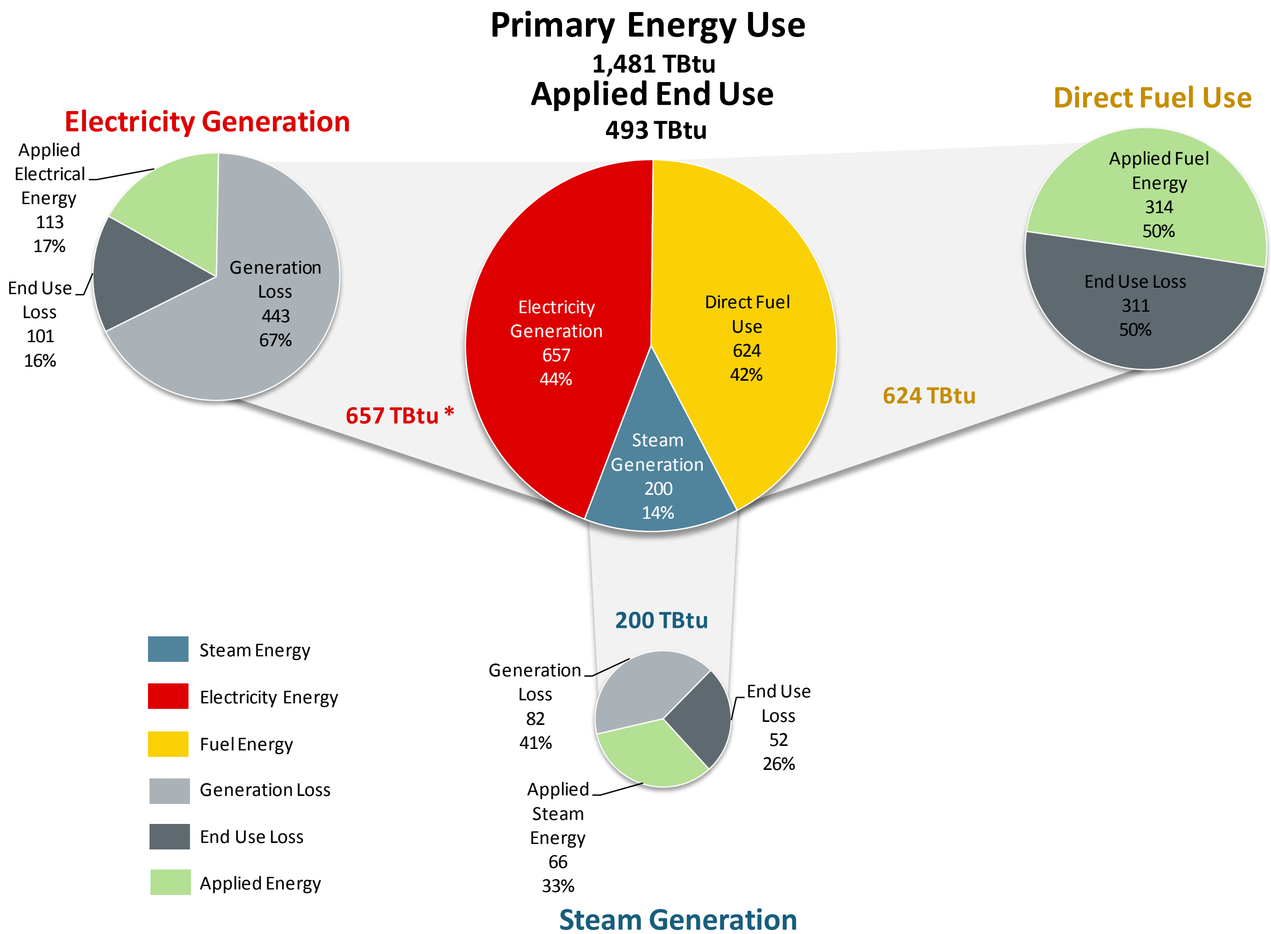


Fig. 2.6-12. Primary energy and applied energy by energy type in the iron and steel sector

Figure 2.6-13 shows the breakdown of primary energy by energy loss and applied energy. In this sector, 33% of primary energy input is applied to process and nonprocess end uses. Generation losses account for 36% of primary energy input and end use losses account for the remaining 31% of primary energy input

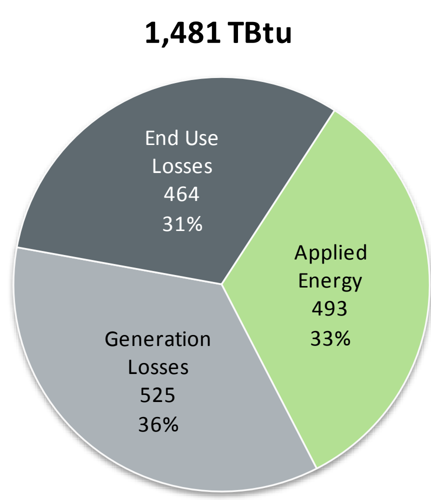
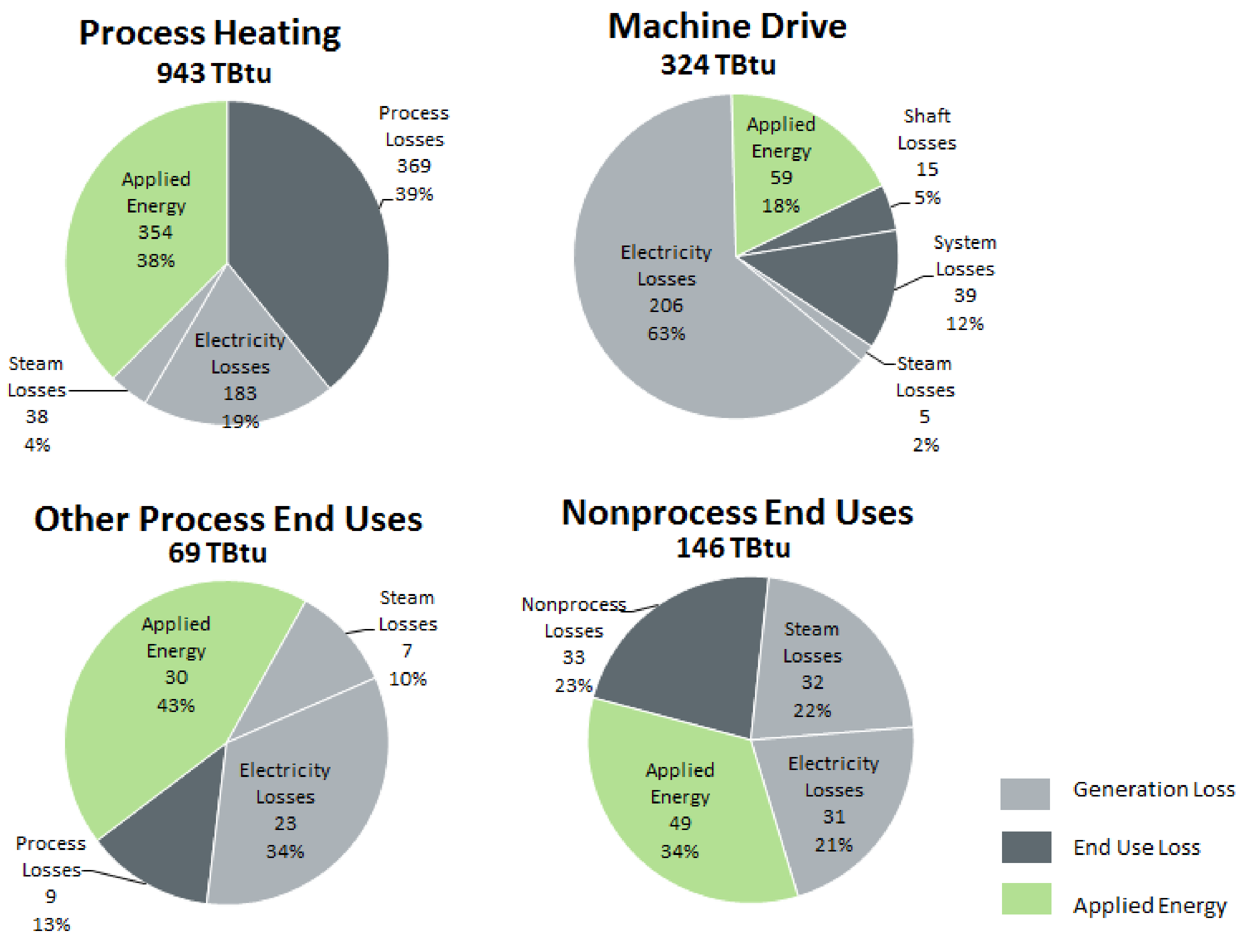


Fig. 2.6-13. Primary energy by loss and applied energy in the iron and steel sector

Applied energy can also be calculated for specific end uses, as shown in Fig. 2.6-14. This figure shows generation losses labeled as either steam or electricity losses. End use losses are labeled as process or nonprocess losses; in the case of machine drive end use, process losses are further defined as machine drive, or machine driven system losses. For process heating, 38% of primary energy is applied to the process (detail of the methodology to estimate process heating losses are shown in Appendix F). In machine-driven systems, only 18% of primary energy is applied, primarily because of the inefficiency in electricity generation.



Note: Pie chart areas are not proportional to magnitude of energy consumption

Fig. 2.6-14. Primary applied energy by *direct* end use in the iron and steel sector

2.6.3. Greenhouse Gas Combustion Emissions Profile for the Iron and Steel Sector

Emissions from the iron and steel sector totaled 62 MMT CO_2e in 2006, emitting the fifth-highest amount compared to other manufacturing sectors. Greenhouse gas emissions[18] by offsite energy supply type are shown in Fig. 2.6-15. Emissions released during offsite production of electricity contribute 60% of sector emissions, while only 2% of emissions are attributed to the production of offsite steam. There is a comparatively small amount of offsite and onsite steam generation emissions in the iron and steel sector compared to other energy-intensive sectors. The onsite consumption of fuels (shown in yellow), including natural gas, byproduct fuels, coal, and other fuels accounts for 36% of total emissions. These fuels are used for both direct (e.g., process or nonprocess) and indirect (e.g., fuel for CHP units or boilers) end uses. Table D.5 shows fuel GHG combustion emission factors associated with fuel combustion, as well as electricity and steam generation.

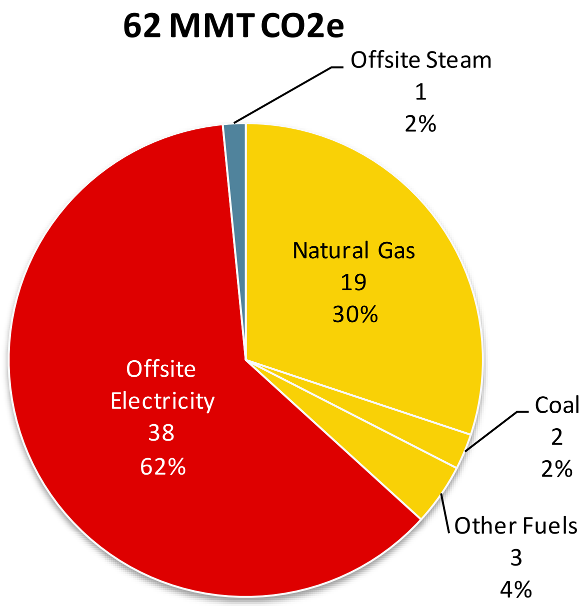


Fig. 2.6-15. Total GHG combustion emissions in the iron and steel sector (shown by energy supply type)

An alternative view of emissions is shown in Fig. 2.6-16, which also shows total emissions by energy type, but this figure assigns emissions to onsite electricity and steam production (as opposed to assigning emissions strictly to offsite supplied fuels). All emissions associated with electricity production are shown in red, including emissions released during offsite electricity generation and emissions released during onsite generation of electricity. All emissions associated with steam production are shown in blue, including emissions released during offsite steam generation and emissions released to generate steam onsite in boilers and CHP systems. Lastly, all emissions associated with fuel combustion at process and nonprocess end uses are shown in yellow. Electricity generation is the largest source of emissions; onsite electricity generation emissions are negligible, however offsite electricity contributes 62% of total emissions. Combined offsite and onsite steam emissions contribute an additional 6% of emissions, while the remaining 32% of emissions are released during fuel combustion for process and nonprocess end uses.

[18] Iron and steel production is an energy-intensive activity that also generates significant process-related emissions. In the iron and steel sector, carbon serves a dual purpose – as a reducing agent to convert iron oxides to iron, and also as an energy source. Methodologies for accounting between energy and process carbon emissions can vary in this sector, and are dependent on processes employed at individual facilities. For example, the IPCC indicates that all carbon used in blast and EAF furnaces should be considered as process emissions. As a detailed analysis of carbon emissions for this sector was beyond the scope of this report, it is assumed that all carbon emissions for blast furnace gas, coke oven gas, and coke and breeze in this sector are process emissions. Other reports such as the EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010 provide a more thorough analysis of the uncertainties and nuances involved in measuring and reporting GHG emissions for this sector.

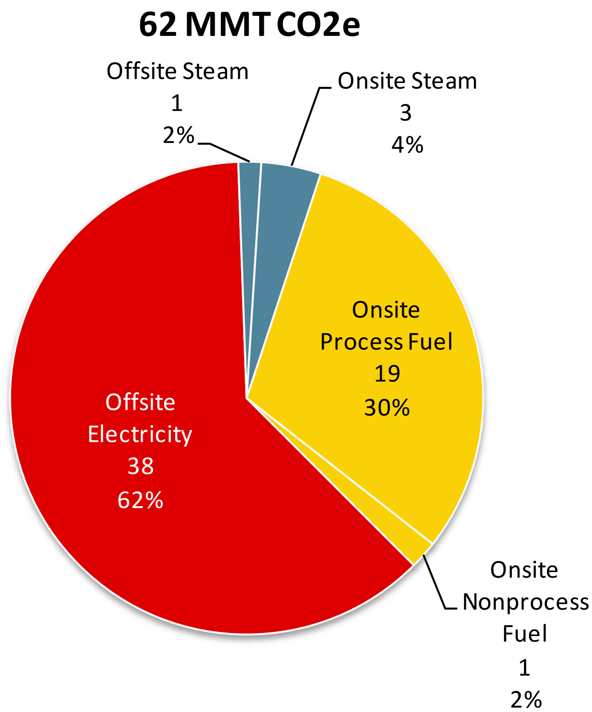


Fig. 2.6-16. Total GHG combustion emissions in the iron and steel sector (shown by energy end use type)

Emissions can also be associated with the direct end uses of energy, as is shown in Fig. 2.6-17. In this figure, the emissions released from offsite both offsite and onsite electricity and steam generation are distributed to direct end uses, along with emissions resulting from fuel consumed at the direct end uses. This pie chart allows for a direct comparison of the emissions resulting from individual direct process and nonprocess end uses. Process heating accounts for 57% of emissions, while machine driven end uses account for 29% of emissions. The emissions associated other process and nonprocess uses are also shown in the figure.

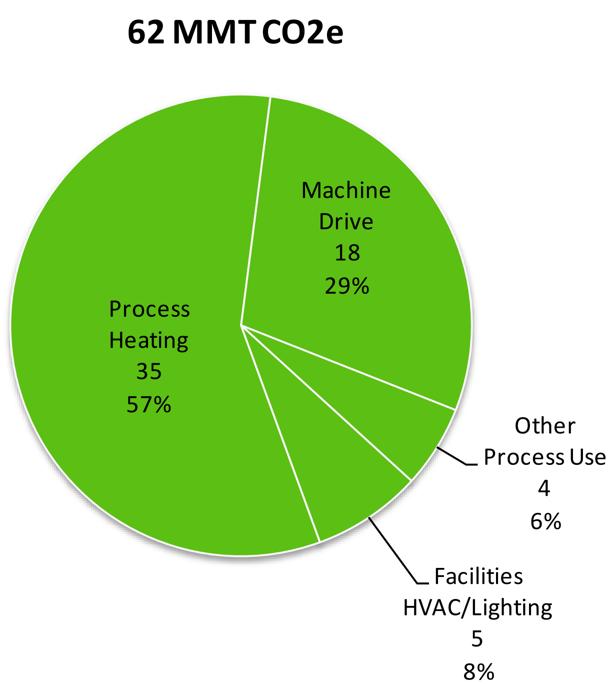


Fig. 2.6-17. Total GHG combustion emissions in the iron and steel sector (shown by direct energy end use)

2.6.4. Energy and Emissions Profile Summary Table

The energy and emissions profiles for the iron and steel sector discussed above are summarized in Table 2.6-3 below. Offsite and onsite contributions to energy supply, use and loss are shown separately in this table, along with GHG combustion emissions. "Applied energy" is calculated for each direct energy use area by subtracting associated offsite and onsite energy losses. For GHG combustion emissions, emissions from the point of use, whether offsite or onsite, are depicted in the first emissions column; offsite emissions are combined with onsite emissions in the total emissions columns. The values in this table correspond to the energy and carbon footprints, which show two carbon values associated with each onsite end use: at point of use and the total based on onsite use.

Table 2.6-3. Energy use, loss, and GHG combustion emissions in the iron and steel sector

Iron and steel			Energy (TBtu)			GHG combustion emissions (MMT CO_2e)		
			Energy use	**Energy loss**	**Applied energy**	**At point of use**	**Total based on onsite use***	**Total based on direct end use****
Offsite		Fuel supply (831 TBtu)	-	-	N/A	-	Distributed to onsite	Distributed to onsite direct
		Electricity generation/transmission	636	435		38.4		
		Steam generation/transmission	15	4		1.0		
		Total offsite (including fuel supply)	**1,481**	**439**		**39.4**		
Onsite	**Indirect**	Conventional boilers	82	16	N/A	1.2	1.2	Distributed to onsite direct
		CHP/cogeneration	120	37		1.6	1.6	
		Other electricity generation	5	3		0.0	0.0	
		Steam distribution	-	30		0.0	0.0	
		Total onsite generation	**207**	**86**		**2.8**	**2.8**	
	Direct	Process heating	723	369	354	17.3	34.2	35.4
		Process cooling and refrigeration	1	1	1	0.0	0.2	0.2
		Machine drive	112	53	59	0.3	17.5	17.8
		Electro-chemical	9	5	4	0.0	1.7	1.7
		Other process uses	28	3	25	1.3	1.6	1.8
		Nonprocess energy	82	33	49	1.2	4.2	5.2
		Total process and nonprocess	**956**	**464**	**493**	**20.1**	**59.4**	**62.2**

* These values are referenced as "Total" emissions in the footprints, Total emissions = onsite emissions + offsite emissions (i.e., emissions associated with offsite generation are distributed to indirect and direct onsite end uses)
** These values represent direct end use carbon emissions only (i.e., emissions associated with offsite and onsite generation are distributed to direct (and final) end use)