TECHNICAL SUPPORT DOCUMENT FOR THE IRON AND STEEL SECTOR: PROPOSED RULE FOR MANDATORY REPORTING OF GREENHOUSE GASES

Office of Air and Radiation
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INTRODUCTION

The iron and steel industry in the United States is the third largest in the world (after China and Japan), accounting for about 8 percent of the world's raw iron and steel production [1] and supplying several industrial sectors, such as construction (building and bridge skeletons and supports), vehicle bodies, appliances, tools, and heavy equipment. Currently, there are 18 integrated iron and steel steelmaking facilities that make iron from iron ore and coke in a blast furnace (BF) and refine the molten iron (and some ferrous scrap) in a basic oxygen furnace (BOF) to make steel. In addition, there are over 90 electric arc furnace (EAF) steelmaking facilities that produce steel primarily from recycled ferrous scrap. In 2007, integrated mills produced 40 million metric tons (mt) of raw steel and minimills produced 58 million mt. [2] The iron and steel source category also includes taconite (iron ore) processing facilities, cokemaking facilities, and direct reduced ironmaking (DRI) facilities. There are eight taconite iron ore processing facilities that produced 52 million mt of pellets in 2007[3], primarily for use in blast furnaces to make iron. There are 18 cokemaking facilities that produced 15.8 million mt of coke in 2007, [4] also primarily for use in blast furnaces, and 7 of these coke plants are co-located with integrated iron and steel facilities. There is one operating DRI plant located at an EAF steelmaking facility that produced 0.2 million mt of iron in 2007. [5]

GHG emissions from the source category are estimated at about 85 million metric tons of carbon dioxide equivalents per year (MMTCO$_2$e/yr) or just over 1 percent of total U.S. GHG emissions. Emissions from both process units (47 MMTCO$_2$e/yr) and miscellaneous combustion units (38 MMTCO$_2$e/yr) are significant.[a] Small amounts of N$_2$O and CH$_4$ are also emitted during the combustion of different types of fuels. The primary process units that emit GHG emissions are BF stoves (24 MMTCO$_2$e/yr), taconite indurating furnaces, BOFs, EAFs (about 5 MMTCO$_2$e/yr each), coke oven battery combustion stacks (6 MMTCO$_2$e/yr), and sinter plants (3 MMTCO$_2$e/yr). Smaller amounts of GHG emissions are produced by coke pushing (0.16 MMTCO$_2$e/yr) and DRI furnaces (0.14 MMTCO$_2$e/yr).

In addition to the blast furnace stoves and byproduct coke battery underfiring systems, the other combustion units where fuel is the only source of GHG emissions include boilers, process heaters, reheat and annealing furnaces, flares, flame suppression systems, ladle reheaters, and other miscellaneous sources. Emissions from these other combustion sources are estimated at 16.8 MMTCO$_2$e/yr for integrated iron and steel facilities, 18.6 MMTCO$_2$e/yr for EAF steelmaking facilities, and 2.7 MMTCO$_2$e/yr for coke facilities not located at integrated iron and steel facilities.

This document describes the various processes in the iron and steel industry that generate greenhouse gas emissions and provides information on the locations and sizes of facilities that may be impacted by the proposed mandatory reporting rule. The impact of potential thresholds on the number of facilities reporting and the emissions coverage is also discussed. Options for monitoring greenhouse gases to determine the level of emissions are also presented and discussed. Other sections of this document address procedures for estimating missing data, quality assurance/quality control (QA/QC) requirements, and reporting procedures.

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[a] These are preliminary estimates and are documented in the following sections of this Technical Support Document.

1. INDUSTRY DESCRIPTION

This section summarizes the processes and major emission points of greenhouse gases for taconite iron ore processing, coke plants, sinter plants, blast furnaces, basic oxygen furnaces, electric arc furnaces, and plants producing iron by direct reduction. Other processes associated with steelmaking, such as ladle metallurgy, argon-oxygen decarburization, and casting are also discussed.

The focus of this document is on process sources of GHG emissions because the methodologies for determining GHG emissions from combustion units are discussed in the technical support document that applies to all types of general stationary fuel combustion sources.[b] However, there are several types of combustion units unique to the iron and steel industry, and they are important parts of the different processes. A description of these processes is given in this section to provide background on combustion units at iron and steel facilities. In addition, the information on combustion units at iron and steel facilities needs to be presented to develop and describe preliminary estimates of total GHG emissions from all sources in the source category, including estimates of both process emissions and combustion unit emissions.

The combustion units at iron and steel facilities where GHGs are formed solely from burning fuels include:

- Byproduct recovery coke oven battery combustion stacks,
- Blast furnace stoves,
- Boilers,
- Process heaters,
- Reheat furnaces,
- Flame suppression systems,
- Annealing furnaces,
- Flares,
- Ladle reheaters, and
- Other miscellaneous combustion sources.

The major process units at iron and steel facilities where raw materials, usually in combination with fuel combustion, contribute to the emission of GHGs include:

- Taconite indurating furnaces,
- Nonrecovery coke oven battery combustion stacks,
- Coke pushing,
- BOFs,
- EAFs,
- DRI furnaces, and
- Sinter plants.

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[b] Process emissions of GHGs include emissions from processes where raw materials, usually in addition to the combustion of fuels, contribute to the formation of GHGs. Combustion units are those in which the GHGs are generated solely from the combustion of fuel.

1.1 Integrated Iron and Steel Facilities

This section discusses the processes at integrated iron and steel facilities that are the major sources of GHG emissions: blast furnaces, BOFs, sinter plants, and miscellaneous combustion units. A few integrated facilities also have co-located coke plants. However, coke production is discussed in a separate section because there are many independent (stand-alone) coke plants, and the complex production processes are best described in a separate section.

1.1.1 Blast Furnaces

There are 35 blast furnaces at 17 plant locations shown in Table 1.

Table 1. Blast Furnace (BF) Locations and Capacity [6]

No.	Plants with Blast Furnaces (BF)	Location	Number of BFs	BF Capacity (tpy)[c]
1	Mittal (formerly Ispat-Inland)	East Chicago, IN	5	6,500,000
2	US Steel	Gary, IN	4	5,560,000
3	Mittal (formerly ISG, Bethlehem)	Burns Harbor, IN	2	5,100,000
4	Mittal (formerly LTV)	Cleveland, OH	2	4,100,000
5	Severstal (formerly ISG, Bethlehem)	Sparrows Point, MD	1	3,500,000
6	Mittal (formerly LTV)	East Chicago, IN	2	3,100,000
7	US Steel (formerly National Steel)	Ecorse, MI	3	2,781,000
8	Mittal (formerly Weirton Steel)	Weirton, WV	2	2,700,000
9	Severstal (formerly Rouge Steel)	Dearborn, MI	2	2,700,000
10	US Steel Edgar Thomson Works	Braddock, PA	2	2,500,000
11	US Steel (formerly National Steel)	Granite City, IL	2	2,400,000
12	Republic Engineered Products	Lorain, OH	2	2,300,000
13	Severstal (formerly Wheeling Pittsburgh)	Mingo Junction, OH	2	2,300,000
14	AK Steel	Middletown, OH	1	2,200,000
15	US Steel	Fairfield, AL	1	2,000,000
16	AK Steel	Ashland, KY	1	1,900,000
17	Severstal (formerly WCI Steel)	Warren, OH	1	1,400,000
	Total		**35**	**53,041,000**

tpy = short tons per year

Iron Production [6, 7]

Iron is produced in blast furnaces by the reduction of iron-bearing materials with a hot gas. The large, refractory-lined blast furnace is charged through its top with iron ore pellets, sinter, flux (limestone and dolomite), and coke, which provides fuel and forms a reducing atmosphere in the furnace. Many modern blast furnaces also inject pulverized coal or other sources of carbon to reduce the quantity of coke required. Iron oxides, coke, coal, and fluxes react with the heated blast air injected near the bottom of the furnace to form molten reduced iron, carbon monoxide (CO), and slag (a molten liquid solution of silicates and oxides that solidifies upon cooling). The molten iron and slag collect in the hearth at the base of the furnace. The by-product gas is collected at the top of the furnace and is recovered for use as fuel.

The production of one ton of iron requires approximately 1.4 tons of ore or other iron-bearing material; 0.5 to 0.65 ton of coke and coal; 0.25 ton of limestone or dolomite; and 1.8 to 2

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[c] Note: Throughout this document the terms "ton" and "tons per year (tpy)" refer to short tons (2,000 lbs), which is consistent with the way the U.S. industry reports production and capacity. The abbreviation "mt" is used for metric tons (also known as "tonne" or 2,205 lbs) and is used for emissions, which are conventionally expressed in metric units.

tons of air. By-products consist of 0.2 to 0.4 ton of slag and 2.5 to 3.5 tons of blast furnace gas containing up to 100 pounds of dust.

The molten iron and slag are removed from the furnace periodically (this is called "tapping" or "casting"). The casting process begins with drilling a taphole into the clay-filled iron notch at the base of the hearth. During casting, molten iron flows into runners that lead to transport ladles. Slag also flows from the furnace and is directed through separate runners to a slag pit adjacent to the casthouse or into slag pots for transport to a remote slag pit. At the conclusion of the cast, the taphole is replugged with clay. The area around the base of the furnace, including all iron and slag runners, is enclosed by a casthouse. The molten iron is transferred to a refractory-lined rail car (called a "torpedo" car because of it shape) and sent to the BOF shop. The hot metal is then poured from the torpedo cars into the BOF shop ladle; this is referred to as hot metal transfer (also known as "reladling"). Hot metal transfer generally takes place under a hood to capture emissions of PM including kish (flakes of carbon), which is formed during the process.

Blast Furnace Gas [6, 7]

The blast furnace by-product gas, which is collected from the furnace top, has a low heating value (about 90 Btu/ft^3) and is composed of nitrogen (about 60 percent), carbon monoxide (28 percent) and carbon dioxide (12 percent). A portion of this gas is fired in the blast furnace stoves to preheat the blast air, and the rest is used in other plant operations.

There are generally three to four stoves per blast furnace. Before the blast air is delivered to the blast furnace, it is preheated by passing it through a regenerator (heat exchanger). In this way, some of the energy of the off-gas that would otherwise have been lost is returned to the process. The additional thermal energy returned to the blast furnace as heat decreases the amount of fuel that has to be burned for each unit of hot metal and improves the efficiency of the process. In many furnaces, the off-gas is enriched by the addition of a fuel with much higher calorific value, such as natural gas or coke oven gas, to obtain even higher hot blast temperatures. This decreases the fuel requirements and increases the hot metal production rate to a greater extent than is possible when burning blast furnace gas alone to heat the stoves.

Desulfurization [6, 7]

Desulfurization of the hot metal is accomplished by adding reagents such as soda ash, lime, and magnesium. Injection of the reagents is accomplished pneumatically with either dry air or nitrogen. Desulfurization may take place at various locations within the iron and steel making facility; however, if the location is the BOF shop, then it is most often accomplished at the hot metal transfer (reladling) station to take advantage of the fume collection system at that location.

Emissions

The vast majority of GHGs (CO_2) are emitted from the blast furnaces stove stacks where the combustion gases from the stoves are discharged. A small amount of emissions may also occur from flares, leaks in the ductwork for conveying the gas, and from blast furnace "slips." A slip occurs when the burden material hangs or bridges in the furnace rather than continuing its downward movement. When this happens, the solid material below the "hang" continues to move downward and forms a void below the hang that is filled with hot gas at very high

pressure. When the hang finally collapses, the sudden downward thrust of the burden material forces the hot gas upward with the force of an explosion. To prevent damage to the furnace, the pressure is relieved through bleeder stacks on top of the furnace that discharge the particle-laden gas directly to the atmosphere.

Emissions of CO_2 are also generated from the combustion of natural gas using flame suppression to reduce emissions of particulate matter. Flame suppression maintains a flame over the surface of the molten metal (for example, during tapping) to consume oxygen and to inhibit the formation of metal oxides that become airborne. Emissions also occur from the flaring of blast furnace gas.

The IPCC guidelines also note that a small amount of CH_4 may be emitted from blast furnace stoves. The blast furnace gas, which is mostly nitrogen, carbon monoxide, and CO_2, is usually supplemented with natural gas, which is mostly CH_4, and a small amount of methane may be emitted because of incomplete combustion.

Title V operating permits were reviewed to obtain data on the design energy input of blast furnace stoves and to relate the energy input to capacity. [8] The results are given in Table 2 and show an average of 2.2 million Btu per short ton of iron (0.00255 TJ/mt of iron). The IPCC guidelines provide an emission factor of 260 $mtCO_2e$ /TJ for the combustion of blast furnace gas. [9] Based on the production of 36.1 million mt of pig iron on 2007,[2] CO_2 emissions from blast furnace stoves would be about 24 $MMTCO_2e$/yr.

Table 2. Energy Consumption by Blast Furnace Stoves [8]

Capacity (million short tons per year)	Million Btu/hr	Million Btu per short ton of iron
5.5	1,320	2.10
4.0	586	1.28
2.5	953	3.34
1.6	441	2.41
2.0	486	2.13
3.4	1,025	2.64
2.7	700	2.27
1.2	309.1	2.31
1.0	298.4	2.68
1.4	309.9	1.97
1.3	319.2	2.12
1.6	301.5	1.68
0.9	192.9	1.88
Average		**2.22**

1.1.2 Basic Oxygen Furnace (BOF)

As shown in Table 3, there are 18 plants that operate 46 BOFs at 21 BOF shops. A "shop" consists of at least two furnaces (sometimes three) that may be operated alternately or together with each furnace in a different stage of the operating cycle.

Table 3. Basic Oxygen Furnace Locations and Capacity [6]

No.	Plants with BOFs	Location	Number of BOFs	BOF Capacity (short tons per year)
1	Mittal (formerly Ispat-Inland)	East Chicago, IN	4	10,000,000
2	US Steel	Gary, IN	6	7,500,000
3	Mittal (formerly ISG, Bethlehem)	Burns Harbor, IN	3	4,700,000
4	Severstal (formerly ISG, Bethlehem)	Sparrows Point, MD	2	3,900,000
5	Mittal (formerly LTV)	Cleveland, OH	4	3,800,000
6	Mittal (formerly LTV)	East Chicago, IN	2	3,800,000
7	US Steel (formerly National Steel)	Ecorse, MI	2	3,800,000
8	Severstal (formerly Rouge Steel)	Dearborn, MI	2	3,309,000
9	Mittal (formerly Weirton Steel)	Weirton, WV	2	3,000,000
10	US Steel Edgar Thomson Works	Braddock, PA	2	2,900,000
11	US Steel (formerly National Steel)	Granite City, IL	2	2,800,000
12	AK Steel	Middletown, OH	2	2,716,000
13	Republic Engineered Products	Lorain, OH	2	2,700,000
14	Severstal (formerlyWheeling Pittsburgh)	Mingo Junction, OH	2	2,600,000
15	US Steel	Fairfield, AL	3	2,200,000
16	AK Steel	Ashland, KY	2	2,200,000
17	Severstal (formerly WCI Steel)	Warren, OH	2	1,900,000
18	Mittal (formerly Acme Steel)	Riverdale, IL	2	750,000
	Total		**46**	**64,575,000**

BOF Steelmaking [6, 7]

The BOF is a large, open-mouthed vessel lined with a basic refractory material (the term "basic" refers to the chemical characteristic of the lining) that refines iron into steel. The BOF receives a charge composed of molten iron from the blast furnace and ferrous scrap. A jet of high-purity oxygen is injected into the BOF and oxidizes carbon and silicon in the molten iron in order to remove these constituents and to provide heat for melting the scrap. After the oxygen jet is started, lime is added to the top of the bath to provide a slag of the desired basicity. Fluorspar and mill scale are also added in order to achieve the desired slag fluidity. The oxygen combines with the unwanted elements (with the exception of sulfur) to form oxides, which leave the bath as gases or enter the slag. As refining continues and the carbon content decreases, the melting point of the bath increases. Sufficient heat must be generated from the oxidation reactions to keep the bath molten.

There are currently three methods that are used to supply the oxidizing gas: (1) top blown, (2) bottom blown, and (3) combination blowing. Most bottom blown furnaces use tuyeres consisting of two concentric pipes, where oxygen is blown through the center of the inner pipe and a hydrocarbon coolant (such as methane) is injected between the two pipes. The hydrocarbon decomposes at the temperature of liquid steel, absorbing heat as it exits and protecting the oxygen tuyere from overheating and burn back.

The distinct operations in the BOF process are the following:

- Charging – the addition of molten iron and metal scrap to the furnace
- Oxygen blow – introducing oxygen into the furnace to refine the iron

- Turndown – tilting the vessel to obtain a sample and check temperature
- Reblow – introducing additional oxygen, if needed
- Tapping – pouring the molten steel into a ladle
- Deslagging – pouring residual slag out of the vessel.

The basic oxygen steelmaking process is a thermochemical process; computations are made to determine the necessary percentage of molten iron, scrap, flux materials, and alloy additions. Various steelmaking fluxes are added during the refining process to reduce the sulfur and phosphorus content of the metal to the prescribed level. The oxidation of silicon, carbon, manganese, phosphorus, and iron provide the energy required to melt the scrap, form the slag, and raise the temperature of the bath to the desired temperature.

Process Emissions

The major emission point for CO_2 from the BOF is the furnace exhaust gas that is discharged through a stack after gas cleaning. The carbon is removed as carbon monoxide and CO_2 during the oxygen blow. Carbon may also be introduced to a much smaller extent from fluxing materials and other process additives that are charged to the furnace. Using the default values in the IPCC guidelines for iron (0.04) and steel (0.01) for the fraction of carbon [10] gives an emission factor of 0.11 mtCO_2e/mt steel for carbon removed from the iron as CO_2. Applying the emission factor to the production of 40 million mt of steel in BOFs in 2007 [2] yields an estimate of 4.4 MMTCO$_2$e/yr.

1.1.3 Sintering

Sintering is a process that recovers the raw material value of many waste materials generated at iron and steel plants that would otherwise be landfilled or stockpiled. An important function of the sinter plant is to return waste iron-bearing materials to the blast furnace to produce iron. Another function is to provide part or all of the flux material (e.g., limestone, dolomite) for the ironmaking process. As shown in Table 4, there are currently 5 plants with sintering operations, and all of the sinter plants are part of an integrated iron and steel plant. [6]

Table 4. Sinter Plants [6]

No.	Plant	Location	Sinter Capacity (short tons per year)
1	US Steel	Gary, IN	4,400,000
2	Severstal (formerly ISG, Bethlehem)	Sparrows Point, MD	4,000,000
3	Mittal (formerly ISG, Bethlehem)	Burns Harbor, IN	2,900,000
4	Mittal (formerly LTV)	East Chicago, IN	1,900,000
5	Mittal (formerly Ispat-Inland)	East Chicago, IN	1,400,000
Total			**14,600,000**

Sinter Process [6]

Feed material to the sintering process includes ore fines, coke, reverts (including blast furnace dust, mill scale, and other by-products of steelmaking), recycled hot and cold fines from the sintering process, and trim materials (calcite fines, and other supplemental materials needed

to produce a sinter product with prescribed chemistry and tonnage). The materials are proportioned and mixed to prepare a chemically uniform feed to the sinter strand, so that the sinter will have qualities desired for satisfactory operation of the blast furnace. The chemical quality of the sinter is often assessed in terms of its basicity, which is the percent total basic oxides divided by the percent total acid oxides ($(CaO+MgO)/(SiO_2+Al_2O_3)$); sinter basicity is generally 1.0 to 3.0. The relative amounts of each material are determined based on the desired basicity, the rate of consumption of material at the sinter strand, the amount of sinter fines that must be recycled, and the total carbon content needed for proper ignition of the feed material.

The sintering machine accepts feed material and conveys it down the length of the moving strand. Near the feed end of the grate, the bed is ignited on the surface by gas burners and, as the mixture moves along on the traveling grate, air is pulled down through the mixture to burn the fuel by downdraft combustion; either coke oven gas or natural gas may be used for fuel to ignite the undersize coke or coal in the feed.

Process Emissions

The primary emission point of interest for the sinter plant is the stack that discharges the windbox exhaust gases after gas cleaning. The CO_2 is formed from the fuel combustion (natural gas or coke oven gas) and from carbon in the feed materials, including coke fines and other carbonaceous materials. Based on the IPCC emission factor of 0.2 mtCO$_2$e/mt of sinter [10] and the production of 13.3 million mt of sinter,[6] CO_2 emissions are estimated as 2.7 MMTCO$_2$e/yr. However, greenhouse gas emissions from sinter plants may vary widely over time as a consequence of variations in the fuel inputs and other feedstock, especially in the types and quantities of iron-bearing materials that are recycled. Both natural gas and coke oven gas contain CH_4, and when the gases are burned, a small amount of the CH_4 is emitted with the exhaust gases due to incomplete combustion. Consequently, sinter plants (and any other process that burns fuels that contain CH_4) also emit a small amount of CH_4.

1.1.4 Miscellaneous Combustion Sources

There are many different types of combustion processes at iron and steel facilities not directly related to the major production processes discussed in previous section. These include boilers, process heaters, flares, dryout heaters, and several types of furnaces (more detailed examples are given in Appendix B). For example, soaking pits and reheat furnaces are used to raise the temperature of the steel until it is sufficiently hot to be plastic enough for economic reduction by rolling of forging. Annealing furnaces are used to heat the steel to relieve cooling stresses induced by cold or hot working and to soften the steel to improve machinability and formability. Ladle reheating using natural gas to keep the ladle hot while waiting for molten steel. Natural gas is the most commonly used fuel; however, coke oven gas and blast furnace gas are also used in the combustion processes.

Table 5 provides the results from reviewing the operating permits of 6 integrated iron and steel plants to extract information on the sizes of their combustion units. The facilities average 3.12 MM Btu/ton of steel for combustion units burning natural gas, coke oven gas, and blast furnace gas. At 90 percent utilization of combustion capacity, the average is 2.91 MM Btu/ton

of steel (0.00338 TJ/mt steel). Table 6 illustrates the development of an emission factor of 0.42 $mtCO_2e$/mt of steel for combustion units based on the energy distribution of these gases for fuel, 90 percent utilization of combustion capacity, and the IPCC emission factors for the three gases. For a production rate of steel of 40 million mt in 2007, emissions from combustion units at integrated iron and steel plants would be 16.8 MMTCO2e.

Table 5. Design Capacity of Combustion Units at Integrated Iron and Steel Facilities [8]

Steel capacity (short tons per year)	MM Btu/hr	MM Btu/short ton
3,800,000	1,088	2.51
2,800,000	1,113	3.48
2,716,000	844	2.72
2,700,000	1,055	3.42
2,600,000	1,033	3.48
2,200,000	952	3.79
Average		3.23
At 90%		**2.91**

Table 6. Development of an Emission Factor for Combustion Units

Fuel	% of energy [11]	IPCC emission factor $(mtCO_2/TJ)$ [9]	TJ/mt of steel[a]	$mtCO_2$/mt of steel[b]
Natural gas	51	56.1	0.0017	0.097
Coke oven gas	14	44	0.00047	0.021
Blast furnace gas	34	260	0.0011	0.30
Total				**0.42**

[a] (% of energy/100) * (0.00338 TJ/mt of steel)
[b] (IPCC emission factor in $mtCO_2/TJ$)*(TJ/mt of steel)

1.2 Coke Production

As shown in Table 7, there are 18 coke plants in the U.S. that produce coke from coal primarily for use in blast furnaces to make iron, but also for use at iron foundries and other industrial processes. In 2007, coke plants produced 15.8 million mt of coke and coke breeze (undersize coke).[4] Most coke is produced in by-product recovery coke oven batteries. However, there are three non-recovery coke oven batteries, including the two newest coke plants, and both of the newest nonrecovery plants use the waste heat from combustion to generate electricity. The recovery of waste heat to generate electricity reduces the purchase of electricity, the need to purchase additional fuel to generate electricity onsite, or when supplied to the grid, reduces the amount of electricity that must be produced from fossil fuel combustion.

Table 7. U.S. Coke Plants[12, 14]

No.	Company	City	State	Number of batteries	Coke capacity (short tons per year)
1	Indiana Harbor Coke[a]	East Chicago	IN	4	1,300,000
2	Haverhill Coke[a]	Haverhill	OH	4	1,100,000
3	US Steel	Clairton	PA	12	5,573,185
4	Jewell Coke and Coal[a]	Vansant	VA	6	649,000
5	US Steel	Gary	IN	4	2,249,860
6	Mittal Steel	Burns Harbor	IN	2	1,877,000
7	Mountain State Carbon	Follansbee	WV	4	1,247,000
8	AK Steel	Ashland	KY	2	1,000,000
9	EES Coke	Ecorse	MI	1	1,000,000
10	ABC Coke	Tarrant	AL	3	699,967
11	US Steel	Granite City	IL	2	601,862
12	Mittal Steel	Warren	OH	1	550,000
13	Shenango	Neville Island	PA	1	514,779
14	Sloss Industries	Birmingham	AL	3	451,948
15	AK Steel	Middletown	OH	1	429,901
16	Koppers	Monessen	PA	2	372,581
17	Tonawanda	Tonawanda	NY	1	268,964
18	Erie Coke	Erie	PA	2	214,951
Total				**55**	**20,099,998**

[a] These are nonrecovery coke plants.

By-product Recovery Coke Oven Batteries [12, 13]

Coke ovens use thermal distillation to remove volatile non-carbon elements from coal to produce coke. Thermal distillation takes place in groups of ovens called batteries. A by-product coke oven battery consists of 20 to 100 adjacent ovens with common side walls made of high quality silica and other types of refractory brick. The wall separating adjacent ovens, as well as each end wall, is made up of a series of heating flues. At any one time, half of the flues in a given wall will be burning gas while the other half will be conveying waste heat from the combustion flues to a heat exchanger and then to the combustion stack. Every 20 to 30 minutes the battery "reverses," and the former waste heat flues become combustion flues while the former combustion flues become waste heat flues. This process avoids melting the battery brick work (the flame temperature is above the melting point of the brick) and provides more uniform heating of the coal mass. Process heat comes from the combustion of coke oven gas, sometimes supplemented with blast furnace gas. The flue gas is introduced from piping in the basement of the battery and combusted in flues. The gas flow to each flue is metered and controlled. Waste gases from combustion, including GHGs, exit through the battery stack.

Each oven holds between 15 and 25 short tons of coal. Offtake flues remove gases evolved from the destructive distillation process. Process heat comes from the combustion of gases between or beneath the coking chambers. The operation of each oven in the battery is cyclic, but the batteries usually contain a sufficiently large number of ovens so that the yield of by-products is essentially continuous. Coking continues for 15 to 18 hours to produce blast furnace coke and 25 to 30 hours to produce foundry coke. The coking time is determined by the coal mixture, moisture content, rate of underfiring, and the desired properties of the coke. Coking temperatures generally range from 900 to 1,100°C and are kept on the higher side of the range to produce blast furnace coke.

Pulverized coal is mixed and blended, and sometimes water and oil are added to control the bulk density of the mixture. The prepared coal mixture is transported to the coal storage bunkers on the coke oven battery. A specific volume of coal is discharged from the bunker into a larry car—a charging vehicle that moves along the top of the battery. The larry car is positioned over an empty, hot oven; the lids on the charging ports are removed; and the coal is discharged from the hoppers of the larry car into the oven. To minimize the escape of gases from the oven during charging, steam aspiration is used to draw gases from the space above the charged coal into a collecting main. After charging, the aspiration is turned off, and the gases are directed through an offtake system into a gas collecting main.

The maximum temperature attained at the center of the coke mass is usually 1100°C to 1500°C. At this temperature, almost all volatile matter from the coal mass volatilizes and leaves a high quality metallurgical coke. Air is prevented from leaking into the ovens by maintaining a positive back pressure of about 10 mm of water. The gases and hydrocarbons, including GHGs, that evolve during thermal distillation are removed through the offtake system and sent to the by-product plant for recovery.

Near the end of the coking cycle, each oven is dampered off the collection main. Once an oven is dampered off, the standpipe cap is opened to relieve pressure. Volatile gases exiting through the open standpipe are ignited if they fail to self-ignite and are allowed to burn until the oven has been pushed. At the end of the coking cycle, doors at both ends of the oven are removed, and the hot coke is pushed out the coke side of the oven by a ram that is extended from a pusher machine. The coke is pushed through a coke guide into a special rail car, called a quench car, which traverses the coke side of the battery. The quench car carries the coke to a quench tower where the hot coke is deluged with water. The quenched coke is discharged onto an inclined "coke wharf" to allow excess water to drain and to cool the coke to a reasonable temperature. Gates along the lower edge of the wharf control the rate that the coke falls on the conveyor belt that carries it to a crushing and screening system.

Gases evolved during coking leave the coke oven through standpipes, pass into goosenecks, and travel through a damper valve to the gas collection main that directs the gases to the by-product plant. These gases account for 20 to 35 percent by weight of the initial coal charge and are composed of water vapor, tar, light oils, heavy hydrocarbons, and other chemical compounds.

At the by-product recovery plant, tar and tar derivatives, ammonia, and light oil are extracted from the raw coke oven gas. After tar, ammonia, and light oil removal, the gas undergoes a final desulfurization process at most coke plants to remove hydrogen sulfide before being used as fuel. Approximately 35 to 40 percent of cleaned coke oven gas (after the removal

of economically valuable by-products) is used to heat the coke ovens, and the remainder is used in other operations related to steel production, in boilers, or is flared. Coke oven gas has a heating value of 500 to 600 Btu/ft^{3} and is composed of hydrogen (about 47 percent), methane (32 percent), carbon monoxide (6 percent), and CO_2 (2 percent).

Nonrecovery Coke Oven Batteries [12, 13]

As the name implies, the nonrecovery cokemaking process does not recover the numerous chemical by-products as discussed above. All of the coke oven gas is burned, and instead of recovery of chemicals, this process offers the potential for heat recovery and cogeneration of electricity. Non-recovery ovens are of a horizontal design (as opposed to the vertical slot oven used in the by-product process) with a typical range of 30 to 60 ovens per battery. The oven is generally between 9 and 14 m (30 and 45 ft) long and 1.8 to 3.7 m (6 to 12 ft) wide. The internal oven chamber is usually semicylindrical in shape with the apex of the arch 1.5 to 3.7 m (5 to 12 ft) above the oven floor. Each oven is equipped with two doors, one on each side of the horizontal oven, but there are no lids or offtakes as found on by-product ovens. The oven is charged through the oven doorway with a coal conveyor rather than from the top through charging ports.

After an oven is charged with coal, carbonization begins as a result of the hot oven brick work from the previous charge. Combustion products and volatiles that evolve from the coal mass are burned in the chamber above the coal, in the gas pathway through the walls, and beneath the oven in sole flues. Each oven chamber has two to six downcomers in each oven wall, and the sole flue may be subdivided into separate flues that are supplied by the downcomers. The sole flue is designed to heat the bottom of the coal charge by conduction while radiant and convective heat flow is produced above the coal charge.

Primary combustion air is introduced into the oven chamber above the coal through one of several dampered ports in the door. The dampers are adjusted to maintain the proper temperature in the oven crown. Outside air may also be introduced into the sole flues; however, additional air usually is required in the sole flue only for the first hour or two after charging. All of the ovens are maintained under a negative pressure. Consequently, the ovens do not leak under normal operating conditions as do the by-product ovens which are maintained under a positive pressure. The combustion gases are removed from the ovens and directed to the stack through a waste heat tunnel that is located on top of the battery centerline and extends the length of the battery.

Emissions

The primary emission point of gases is the battery's combustion stack. Test data were obtained for 53 emission tests (generally 3 runs per tests) for CO_2 emissions from the combustion stacks at by-product recovery coke plants for development of an emission factor for EPA's 2008 revision to AP-42. [13] These tests averaged 0.143 mtCO$_2$e/mt coal (0.21 mtCO$_2$e/mt coke). Test results for a nonrecovery battery were obtained and analyzed. The average of three runs at Haverhill Coke resulted in an emission factor of 1.23 mtCO$_2$e/mt coke, [15] approximately six times higher than the factor for the combustion stack at by-product recovery batteries. The emission factor for nonrecovery combustion stacks is much higher because all of the coke oven gas and all of the by-products are burned. In comparison, organic liquids (such as tar and light oil) are recovered at by-product recovery coke plants, and only about one third of the gas is consumed in underfiring the ovens. Emissions from combustion stacks based on the 2007

production rate are estimated as 3 MMTCO2e from nonrecovery battery stacks and 2.8 $MMTCO_2e/mt$ from byproduct recovery battery stacks.

A small amount of CO_2 is emitted from the pushing operation when the incandescent coke is pushed from the oven and transported to the quench tower where it is quenched with water. The 2008 revisions to EPA's AP-42 compilation of emission factors provides an emission factor of 0.008 $mtCO_2e/mt$ coal (0.01 $mtCO_2e/mt$ coke).[13] Using the 2007 production rate for coke (15.8 million mt),[4] the emissions from pushing are estimated as 0.16 MMTCO2e/yr.

Fugitive emissions occur during the coking process from leaks of raw coke oven gas that contains methane. The leaks occur from doors, lids, offtakes, and collecting mains and are almost impossible to quantify because they change in location, frequency, and duration during the coking cycle, and they are not captured in a conveyance. However, the number, size, and frequency of these leaks have decreased significantly over the past 20 years as a result of stringent regulations, including national standards, consent decrees, and State regulations.

Many by-product recovery coke plants also have other combustion sources, primarily boilers and flares. These units use excess coke oven gas that is not used for underfiring the battery or shipped offsite for use as fuel in other processes. The IPCC guidelines [10] provide an emission factor of 0.56 $mtCO_2e/mt$ coke (assuming all of the coke oven gas is burned). Emissions from the combustion of coke oven gas in units other than the coke battery underfiring system are estimated as 0.35 $mtCO_2e/mt$ coke (0.56 - 0.21 $mtCO_2e/mt$ coke). For the production of 7.6 million mt of coke in stand alone byproduct coke plants (i.e., coke plants not located at iron and steel facilities), emissions from other combustion units would be 2.7 MMTCO2e/yr. (Emissions from the combustion of coke oven gas from coke plants co-located with integrated iron and steel facilities are included in the estimates for integrated iron and steel facilities.)

1.3 Taconite Iron Ore Processing [16]

There are eight taconite or pellet production facilities that mine taconite ore from the Mesabi Iron Ore Range with six facilties in Minnesota and two in Michigan (Table 8). Taconite ore is transported from the mine to primary crushers, and after crushing, the ore is conveyed to large storage bins at the concentrator building. In the concentrator building, water is typically added to the ore as it is conveyed into rod and ball mills, which further grind the taconite ore to the consistency of coarse beach sand. In a subsequent process step, taconite ore in the slurry is separated from the waste rock material using a magnetic separation process. The concentrated taconite slurry then enters the agglomerating process where water is removed from the taconite slurry using vacuum disk filters or similar equipment. Next, the taconite is mixed with various binding agents such as bentonite and dolomite in a balling drum that tumbles and rolls the taconite into unfired pellets. When the unfired pellets exit the balling drum, they are transferred to a metal grate that conveys them to the indurating furnace. During the indurating process, the unfired taconite pellets are hardened and oxidized in the indurating furnace at a fusion temperature between 2,290° to 2,550°F.

Table 8. Taconite or Pellet Production Facilities [17, 18]

No.	Facility	City	State	Number of furnaces	Pellet capacity (tpy)	Coal usage (tpy)	Natural gas (MMCF/yr)
1	USS Keetac	Kewatin	MN	2	6,160,000	146,000	292
2	USS Mintac	Mountain Iron	MN	3	16,352,000	105,833	7,231
3	Empire	Palmer	MI	2	9,408,000	191,067	2,781
4	Tilden	Ishpeming	MI	1	8,802,000	166,589	2,120
5	United Taconite	Forbes	MN	2	6,608,000	97,100	476
6	Hibbing	Hibbing	MN	2	9,632,000	--	3,000
7	Northshore	Silver Bay	MN	2	5,376,000	--	3,591
8	Ispat-Inland	Virginia	MN	2	3,248,000	--	1,540
Totals				16	65,586,000	706,589	21,031

tpy = short tons per year
MMCF/yr = millions of cubic feet per year

Process Emissions

The primary source of greenhouse gas emissions is the exhaust from the indurating furnaces. These furnaces are considered to be process sources of GHG emissions rather than exclusively combustion sources because a significant amount of the CO_2 emissions originate from carbon in the raw materials (dolomite, bentonite, iron ore). The indurating furnaces have historically been fired with natural gas; however, several plants converted to coal after natural gas prices surged over the past several years. None of the plants can burn 100 percent coal, and three of the plants are not permitted to burn coal. Data on fuel type and consumption along with pellet production rates were obtained for the 2004 to 2005 time period from personal communications with plant representatives and are shown in Table 9. The fuel consumption data were scaled up from production rates to capacity to estimate fuel consumption when operating at capacity.

Test data for CO_2 were obtained from a plant burning coal as fuel and from the same plant when burning natural gas as fuel. [19, 20] As shown in Table 9, the CO_2 emissions were 0.11 $mtCO_2e$/mt pellet when burning coal and 0.072 $mtCO_2e$/mt pellet when burning natural gas. The IPCC default emission factor is 0.03 $mtCO_2e$/mt pellet; however, this is apparently based on carbon in the fuel (natural gas) and does not include the carbon in the feed materials or the use of coal as fuel. For the CO_2 emission estimate, the emission factors from the tests were used for coal and natural gas, and coal and natural gas consumption was scaled to the 2007 production rate of 52 million mt of pellets to provide an estimate of 5.6 $MMTCO_2e$ for 2007.

Although the indurating furnace is by far the primary source of CO_2 emissions, the taconite facilities also have other combustion units. A review of operating permits indicated that most of the plants have boilers. Other combustion devices reported include space heaters and

emergency diesel generators. One company also operates a power plant at the site to supply electricity for taconite processing and to supply the electricity grid. [8]

Table 9. Test Results for a Taconite Plant

Tilden – natural gas as fuel (March 13, 1995)[19]		Tilden – coal as fuel (July 13, 2000)[20]	
pellets (tph)	779	pellets (tph)	609
natural gas (MCF/hr)	289.5	coal (tph)	15.85
CO_2 emissions (tph)	56.3	CO_2 emissions (tph)	65.8
CO_2 emissions (ton/ton pellets)	0.072	CO_2 emissions (ton/ton pellets)	0.11
CO_2 emissions (ton/MCF)	0.194	CO_2 (ton/ton coal)	4.15

tph = short tons per hour
MCF/hr = thousands of cubic feet per hour

1.4 Electric Arc Furnace (EAF) Steelmaking [24]

The production of steel in EAFs (minimills) has increased dramatically over the past 30 years. Minimills accounted for 10 percent of the national steel production in 1970, 30 to 40 percent in the 1980s, 40 to 50 percent in the 1990s, and 59 percent in 2007. The growth has been attributed in part to an expansion in the types and quality of steel products that minimills can produce, including heavy structurals, rail, plate, specialty bar, hot rolled, cold rolled, galvanized, and stainless flat rolled products. Most of the steel produced in EAFs is carbon steel used in the manufacture of construction materials, automobiles, appliances, and other applications. Approximately 4 percent (about 2 million tons) is specialty and stainless steel, which are high value steel products. The types of steel are defined by their composition of alloying elements. Stainless and alloy steels contain less carbon and zinc and more chromium, manganese, and nickel than carbon steels. Some stainless steel grades contain 12 to 28 percent chromium and 4 to 25 percent nickel. Table 10 lists 91 EAF minimills, their location, and capacity.

Table 10. Electric Arc Furnace Locations and Capacity [22, 23]

No.	Company	City	State	Capacity (short tons per year)	Cumulative percent of capacity
1	Nucor Corporation	Berkeley Co.	SC	3,300,000	4.6
2	Nucor-Yamato Steel	Blytheville	AR	3,277,000	9.1
3	Nucor Corporation	Hickman	AR	2,400,000	12.4
4	Steel Dynamics Inc.	Butler	IN	2,200,000	15.4
5	Sterling Steel	Sterling	IL	2,070,000	18.3
6	Nucor Corporation	Decatur	AL	2,000,000	21.0
7	TXI Chaparral Steel	Midlothian	TX	2,000,000	23.8
8	Nucor Corporation	Crawfordsville	IN	1,900,000	26.4
9	CMC Steel/SMI Steel.	Birmingham	AL	1,855,000	29.0
10	North Star Steel - Blue Scope Steel	Delta	OH	1,800,000	31.5
11	Steel Dynamics Inc.	Whitley Co.	IN	1,600,000	33.7
12	Gerdau Ameristeel (Gallatin Steel)	Ghent	KY	1,500,000	35.7
13	Evraz Rocky Mountain Steel	Pueblo	CO	1,200,000	37.4

Table 10. Electric Arc Furnace Locations and Capacity [22, 23]

No.	Company	City	State	Capacity (short tons per year)	Cumulative percent of capacity
14	TXI Chaparral Steel	Dinwiddie	VA	1,200,000	39.0
15	Nucor Corporation	Plymouth	UT	1,111,000	40.6
16	Nucor Corporation	Norfolk	NE	1,103,000	42.1
17	Ipsco Inc.	Axis	AL	1,100,000	43.6
18	Ipsco Inc.	Muscatine	IA	1,100,000	45.1
19	Mittal Steel	Steelton	PA	1,100,000	46.7
20	CMC Steel Group/SMI Steel	Cayce	SC	1,089,000	48.2
21	Republic Engineered Steels, Inc.	Canton	OH	1,050,000	49.6
22	Gerdau Ameristeel	Beaumont	TX	1,002,000	51.0
23	Keystone Steel & Wire	Peoria	IL	1,000,000	52.4
24	Mittal Steel	Georgetown	SC	1,000,000	53.7
25	Nucor Corporation	Cofield	NC	1,000,000	55.1
26	AK Steel Corporation	Butler	PA	960,000	56.4
27	Gerdau Ameristeel	Wilton	IA	917,000	57.7
28	CMC Steel Group/SMI Steel.	Seguin	TX	900,000	59.0
29	Gerdau Ameristeel	Jackson	TN	892,000	60.2
30	Mittal Steel	Coatsville	PA	880,000	61.4
31	Nucor Corporation	Darlington	SC	872,000	62.6
32	Corus Tuscaloosa	Tuscaloosa	AL	870,000	63.8
33	Timken Co.	Canton	OH	870,000	65.0
34	Gerdau Ameristeel	St. Paul	MN	843,000	66.2
35	Nucor Corporation	Seattle	WA	840,000	67.3
36	Gerdau Ameristeel	Perth Amboy	NJ	800,000	68.4
37	North American Stainless	Ghent	KY	800,000	69.5
38	Nucor Corporation	Kankakee	IL	800,000	70.6
39	Gerdau Ameristeel	Sayreville	NJ	750,000	71.7
40	TAMCO	Rancho Cucamonga	CA	750,000	72.7
41	Gerdau Macsteel	Jackson	MI	725,000	73.7
42	Nucor Corporation	Jewett	TX	725,000	74.7
43	Steel Dynamics	Roanoke	VA	710,000	75.7
44	AK Steel Corporation	Mansfield	OH	700,000	76.6
45	Cascade Steel Rolling Mills, Inc	McMinnville	OR	700,000	77.6
46	Bayou Steel Corp	LaPlace	LA	683,000	78.6
47	Gerdau Ameristeel	Cartersville	GA	658,000	79.5
48	V&M Star	Youngstown	OH	650,000	80.4
49	Gerdau Ameristeel	Charlotte	NC	622,000	81.2
50	Gerdau Ameristeel	Baldwin	FL	607,000	82.1
51	Gerdau Macsteel	Fort Smith	AR	607,000	82.9
52	Gerdau Ameristeel (formerly Sheffield Steel)	Sand Springs	OK	600,000	83.7
53	Gerdau Macsteel	Monroe	MI	600,000	84.5
54	NS Group Inc./Koppel Steel Corp.	Beaver Falls	PA	550,000	85.3

Table 10. Electric Arc Furnace Locations and Capacity [22, 23]

No.	Company	City	State	Capacity (short tons per year)	Cumulative percent of capacity
55	Nucor Corporation	Auburn	NY	550,000	86.1
56	Charter Manufacturing	Saukville	WI	515,000	86.8
57	Gerdau Ameristeel	Knoxville	TN	515,000	87.5
58	BetaSteel Corporation	Portage	IN	500,000	88.2
59	Hoeganeas Corp.	Gallatin	TN	500,000	88.9
60	Mittal Steel (Ispat Inland)	East Chicago	IN	500,000	89.6
61	Nucor Corporation	Birmingham	AL	500,000	90.2
62	Nucor Corporation	Jackson	MS	500,000	90.9
63	Severstal	Mingo Junction	OH	500,000	91.6
64	Oregon Steel Mills, Inc.	Portland	OR	499,000	92.3
65	Allegheny Technologies Inc.	Brackenridge	PA	496,000	93.0
66	Carpenter Technology	Reading	PA	450,000	93.6
67	Ellwood Quality Steels	New Castle	PA	410,000	94.2
68	Allegheny Technologies Inc.	Midland	PA	400,000	94.7
69	Evraz Claymont	Claymont	DE	400,000	95.3
70	Marion Steel Co.	Marion	OH	400,000	95.8
71	Mittal Steel	Cleveland	OH	396,000	96.4
72	Erie Forge and Steel	Erie	PA	385,000	96.9
73	Timken Co.	Canton	OH	358,000	97.4
74	Lone Star Steel Inc.	Lone Star	TX	265,000	97.8
75	Border Steel Mills, Inc.	El Paso	TX	250,000	98.1
76	Standard Steel	Burnham	PA	231,000	98.4
77	Arkansas Steel	Newport	AR	130,000	98.6
78	LeTourneau Inc.	Longview	TX	124,000	98.8
79	Hoeganeas Corp.	Riverton	NJ	112,000	98.9
80	Universal Stainless & Alloy Products, Inc.	Bridgeville	PA	105,000	99.1
81	Steel of West Virginia	Huntington	WV	100,000	99.2
82	Electralloy	Oil City	PA	90,000	99.4
83	Finkl, A., & Sons	Chicago	IL	90,000	99.5
84	Kobelco Metal Powder of America	Seymore	IN	63,000	99.6
85	Timken Co.	Latrobe	PA	60,000	99.6
86	Standard Steel	Latrobe	PA	59,000	99.7
87	National Forge Co.	Irvine	PA	58,000	99.8
88	Crucible Materials	Syracuse	NY	50,000	99.9
89	Union Electric Steel	Carnegie	PA	35,000	99.9
90	Haynes International	Kokomo	IN	20,000	99.99
91	Champion Steel Co.	Orwell	OH	6,000	100.0
Total				**72,460,000**	

     U.S. minimills are the largest recyclers of metal scrap in the world. Recycled iron and steel scrap nationwide includes approximately 25 percent "home scrap" (from current operations at the plant), 26 percent "prompt scrap" (from plants manufacturing steel products), and 49 percent post-consumer scrap. The primary source of post-consumer scrap is the automobile, and

in 2004, the steel industry recycled 14.2 million tons of iron and steel scrap from 14 million vehicles. [21]

EAF Steelmaking [21, 24]

EAFs are operated as a batch process that includes charging scrap and other raw materials (loading these materials into the EAF), melting, slagging (removing slag), and tapping (pouring the molten steel into a ladle). The length of the operating cycle is referred to as the tap-to-tap time, and each batch of steel produced is known as a "heat." Tap-to-tap times range from 35 to over 200 minutes with generally higher tap-to-tap times for stainless and specialty steel. Newer EAFs are designed to achieve a tap-to-tap time of less than 60 minutes.

After ferrous scrap is charged to the EAF, the melting phase begins when electrical energy is supplied to the carbon electrodes. Oxy-fuel burners and oxygen lances may also be used to supply chemical energy. Oxy-fuel burners, which burn natural gas and oxygen, use convection and flame radiation to transfer heat to the scrap metal. During oxygen lancing, oxygen is injected directly into the molten steel; exothermic reactions with the iron and other components provide additional energy to assist in the melting of the scrap and removal of excess carbon. Alloying elements may be added to achieve the desired composition.

Refining of the molten steel can occur simultaneously with melting, especially in EAF operations where oxygen is introduced throughout the batch. During the refining process, substances that are incompatible with iron and steel are separated out by forming a layer of slag on top of the molten metal. After completion of the melting and refining steps, the slag door is opened, and the furnace is tipped backward so the slag pours out ("slagging"). The furnace is righted, and the tap hole is opened. The furnace is then tipped forward and the steel is poured ("tapped") into a ladle (a refractory-lined vessel designed to hold the molten steel) for transfer to the ladle metallurgy station. Bulk alloy additions are made during or after tapping based on the desired steel grade.

Process Emissions

CO_2 emissions are generated during the melting and refining process when carbon is removed from the charge material and carbon electrodes as carbon monoxide and CO_2. These emissions are captured and sent to a baghouse for removal of particulate matter before discharge to the atmosphere. The CO_2 emission estimate of 4.6 MMTCO$_2$e for EAFs is based on the IPCC emission factor of 0.08 mtCO$_2$e/mt of steel [7] and the production of 58 million mt of steel in 2007. [2]

Combustion Emissions

EAF facilities have the same miscellaneous combustion units found at integrated iron and steel facilities: boilers, process heaters, flares, dryout heaters, soaking pits, reheat furnaces, annealing furnaces, and ladle reheating. A difference is that the EAF facilities burn natural gas exclusively in these unit, and integrated facilities burn a combination of fuels (natural gas, coke oven gas, and blast furnace gas).

Operating permits were reviewed for several EAF facilities, including both small stainless and specialty steel producers as well as large carbon steel producers, to obtain

information on combustion units.   As shown in Table 11, the average capacity of the combustion processes was 5,400 CF of natural gas per ton of steel. CO_2 emissions were estimated based on the processes operating at 90 percent of their rated capacity, 1,000 Btu/CF for natural gas, and an IPCC emission factor of 56.1 $mtCO_2$/TJ. [9] The calculation is shown below and results in an emission factor of 0.32 $mtCO_2$e/mt steel from combustion units at EAF facilities:

(5,400 CF/ton)* (0.9)*(56.1 $mtCO_2$/TJ)*(1,000 Btu/CF)*(1.1 ton/mt)/(947.8 E6 Btu/TJ)= 0.32 $mtCO_2$e/mt steel.

The production of 58 million mt of steel in EAFs in 2007 results in an emission estimate of 18.6 $MMTCO_2$e from combustion units burning natural gas

Table 11. Natural Gas Usage from EAF Operating Permits [8]

EAF steel capacity (short tons per year)	Capacity of combustion units (MMCF/yr)	Natural gas per short ton of steel (CF/short ton)
105,000	584	5,562
385,000	1,839	4,777
410,000	1,564	3,815
500,000	5,600	11,200
607,000	2,847	4,690
960,000	5,718	5,956
3,300,000	6,079	1,842
Average		**5,406**

1.5 Direct reduced iron (DRI) production

As of December 2006, there were two DRI plants in the U.S., one operating and one shut down. [25] Both are located at EAF steelmaking facilities. The DRI process operates below the melting point of iron; consequently, the iron from the furnace is in solid form whereas blast furnaces produce molten iron. The operating plant is owned by Steel Dynamics in Butler, IN and began operation in 1998. The process feeds iron ore and coal to a rotary hearth furnace fired by natural gas at 376 million (MM) Btu/hr. [26] The non-operating DRI plant is located at Mittal Steel's EAF shop in Georgetown, SC. It was built in 1971 with a capacity of 500,000 mt/yr and was subsequently idled. [25]

Emission of CO_2 are generated in the DRI furnace from the combustion of natural gas in the furnace and from the carbonaceous materials (coal, coke) used to reduce the iron ore into iron. The IPCC guidelines also note that a small amount of CH_4 is emitted from the DRI process. [10] The CH_4 is the primary component of the natural gas used as fuel, and for any type of process or combustion unit burning natural gas, a small amount of CH_4 may be emitted because of incomplete combustion.

The plant produced about 200,000 mt of iron in 2006 (less than 0.5 percent of the U.S. total), and this represents about 50 percent of the plant's capacity. Using the IPCC emission

factor of 0.7 mtCO$_2$e/mt iron for DRI, [10] CO$_2$ emissions are about 0.14 MMTCO$_2$e /yr based on actual production and about twice that operating at capacity.

1.6 Other Steelmaking Processes

This section discusses miscellaneous processes at iron and steel facilities, and in general, these processes are not significant emitters of GHGs based on review of test reports that show CO$_2$ levels that are not distinguishable from background. An exception discussed below is argon-oxygen decarburization, which uses oxygen to remove carbon from steel to make low-carbon and specialty steels.

Ladle Metallurgy

The molten steel from BOFs and EAFs is transferred to a ladle metallurgy facility (LMF) for further alloy additions to achieve the desired specifications. The purpose of ladle metallurgy (also referred to as secondary steelmaking) is to produce steel that satisfies stringent requirements of surface, internal, and microcleanliness quality and mechanical properties. Ladle metallurgy is a secondary step of the steelmaking process and is performed in a ladle after the initial refining process in the primary BOF or EAF is completed. This secondary step enables plants to exercise control over many processing conditions contributing to a higher quality of steel including the following:

- Temperature, especially for continuous casting operations
- Deoxidation
- Decarburization (ease of producing steels to carbon levels of less than 0.03 percent)
- Addition of alloys to adjust chemical composition.

This step also increases production rates by decreasing refining times in the furnace. Several LMF processes are commonly used, including vacuum degassing, ladle refining, and lance powder injection.

Argon Oxygen Decarburization [6,24]

Argon oxygen decarburization (AOD) is a process used to further refine the steel outside the EAF during the production of certain stainless and specialty steels. In the AOD process, steel from the EAF is transferred into an AOD vessel and gaseous mixtures containing argon and oxygen or nitrogen are blown into the vessel to reduce the carbon content of the steel. Argon assists the carbon removal by increasing the affinity of carbon for oxygen. The carbon is removed from the steel and emitted as CO and CO$_2$, which makes AODs a source of GHG emissions.

Casting [6]

At most plants, the molten steel is transferred from ladle metallurgy to the continuous caster, which casts the steel into semi-finished shapes (slabs, blooms, billets, rounds, and other special sections). Although continuous casting is a relatively recent development, it has essentially replaced the ingot casting method because it increases process yield from 80 percent to over 95 percent, and it offers significant quality benefits.

Another finishing route, which is not used as frequently as continuous casting, is ingot casting. Molten steel is poured from the ladle into an ingot mold, where it cools and begins to

solidify. The molds are stripped away, and the ingots are transported to a soaking pit or reheat furnace where they are heated to a uniform temperature. The ingots are shaped by rolling into semi-finished products, usually blooms, billets, slabs, or by forging. Ingot casting is typically used for small specialty batches and certain applications for producing steel plates.

Rolling Mills [6]

Steel from the continuous caster is processed in rolling mills to produce steel shapes that are classified according to general appearance, overall size, proportions of the three dimensions, and intended use. Slabs are always oblong and are mostly 2 to 9 inches thick and 24 to 60 inches wide. Blooms are square or slightly oblong and mostly in the range of 6 inches by 6 inches to 12 inches by 12 inches. Billets are mostly square and range from 2 inches by 2 inches to 5 inches by 5 inches. Rolling mills are used to produce the final steel shapes that are sold by the steel mill, including coiled strips, rails and other structural shapes, sheets, bars, etc.

Other Steel Finishing Processes [6]

The semi-finished products may be further processed by a number of different steps, such as annealing, hot forming, cold rolling, pickling, galvanizing, coating, or painting. Some of these steps require additional heating or reheating. The additional heating or reheating is accomplished using furnaces usually fired with natural gas. The furnaces are custom designed for the type of steel, the dimensions of the semi-finished steel pieces, and the desired temperature.

1.7 Miscellaneous Emissions Sources

There are dozens of emission points and various types of fugitive emissions at integrated iron and steel facilities. These emissions from iron and steel plants have been of environmental interest primarily because of the particulate matter in the emissions. Examples include ladle metallurgy operations, desulfurization, hot metal transfer, sinter coolers, and the charging and tapping of furnaces. The information EPA has examined to date indicates that fugitive emissions contribute very little to the overall GHG emissions from the iron and steel sector (probably on the order of one percent or less). For example, fugitive emissions of blast furnace gas may be emitted during infrequent process upsets (called "slips") when gas is vented for a short period or from leaks in the ductwork that handles the gas. However, the mass of GHG emissions is expected to be small because most of the carbon in blast furnace gas is from carbon monoxide, which is not a greenhouse gas. [27]

Fugitive emissions and emissions from control device stacks may also occur from blast furnace tapping, the charging and tapping of BOFs and EAFs, ladle metallurgy, desulfurization, etc. However, EPA has no information that indicates CO_2 is generated from these operations, and a review of test reports from systems that capture these emissions show that CO_2 concentrations are very low (at ambient air levels).

Fugitive emissions containing methane may occur from leaks of raw coke oven gas from the coke oven battery during the coking cycle. However, the mass of these emissions is expected to be small based on the small number of leaks that are now allowed under existing Federal and State standards that regulate these emissions. In addition, since these emissions are not captured in a conveyance, there is no practical way to measure them.

2. TOTAL EMISSIONS

Table 12 summarizes the emission estimates developed in the previous section for each type of plant and for the major GHG emitting units.

Table 12. Summary of Emission Estimates

Type of facility	Number of facilities	Emissions (mtCO$_2$e/yr)[a]		
		Process units	Miscellaneous combustion units	Total
Taconite indurating furnaces	8	5,600,000	(b)	5,600,000
Byproduct coke stand alone:	9	1,592,640[c]	2,654,400	4,247,040
Nonrecovery coke	3	2,953,968[c]	(b)	2,953,968
EAF facilities	92	4,780,000	18,560,000	23,340,000
Integrated plants:				
Byproduct coke co-located	6	1,221,024	--	1,221,024
Blast furnaces	17	23,934,300[d]	--	23,934,300
BOFs	18	4,400,000	--	4,400,000
Sinter plants	5	2,654,545	--	2,654,545
Total integrated	18	32,209,869	16,800,000	49,009,869
Total for all facilities	**130**	**47,136,477**	**38,014,400**	**85,150,877**

[a] Emission estimates are provided for the predominant GHG (CO$_2$). Small amounts of methane (CH$_4$) may also be emitted because combustion is not complete (i.e., some of the CH$_4$ in fuel may not be combusted), and some CH$_4$ may be emitted from leaks in the equipment that handles the fuels (compressors, valves, flanges). Small amounts of N$_2$O may be emitted as a by-product of combustion. There is not enough data available to develop a credible estimate of the emissions of CH$_4$ and N$_2$O for this preliminary analysis.

[b] No information on combustion units at these plants, but emissions are expected to be small compared to those from the production processes.

[c] From the battery combustion stack.

[d] From the blast furnace stoves.

3. REVIEW OF EXISTING PROGRAMS AND METHODOLOGIES

This section presents a review and summary of methodologies for measuring or estimating greenhouse gas emissions for the iron and steel sector that have been developed by different international groups, U.S. agencies, and others. The following resources are examined and their approaches are summarized:

1. 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. *Chapter 4.2 Iron & Steel and Metallurgical Coke Production.*

2. U.S. Environmental Protection Agency (EPA). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006.* USEPA #430-R-08-005. April 2008. http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

3. World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD). *Calculating Greenhouse Gas Emissions from Iron and Steel Production.* January 2008. Available at: http://www.ghgprotocol.org/calculation-tools/iron-and-steel-sector.

4. European Union (EU) Emissions Trading System. *2007/589/EC: Commission Decision of 18 July 2007 Establishing Guidelines for the Monitoring and Reporting of Greenhouse Gas Emissions Pursuant to Directive 2003/87/EC of the European Parliament and of the Council.* Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32007D0589:EN:NOT. July 2007.

5. U.S. Department of Energy (DOE). Technical Guidelines: Voluntary Reporting Of Greenhouse Gases (1605(B)) Program. *Section 1.E.4.1.6. Iron and Steel Production.* January 2007.

6. American Iron and Steel Institute (AISI) protocol presented through the Climate Vision Program. *Principles for a Steel Industry Methodology for Reporting Carbon-Related Energy Sources and Raw Materials.*

7. Environment Canada. Guidance Manual for Estimating Greenhouse Gas Emissions. *Primary Iron and Steel Production.* http://www.ec.gc.ca/pdb/ghg/guidance_e.cfm. 2008.

3.1 2006 IPCC Guidelines [10]

The IPCC Guidelines present three tiers for estimating CO_2 emissions. The Tier 1 method uses production-based emission factors in which default emission factors are multiplied by the quantity of material produced (coke, iron, steel iron ore pellets). For Tier 1, the only site-specific input that is needed for the emission estimate is the production for the year of interest for coke, steel, pig iron, direct reduced iron (DRI), sinter, and iron ore pellets.

The Tier 2 approach for estimating CO_2 emissions uses a carbon balance in which carbon in the process outputs inputs is subtracted from carbon in process inputs, and the difference is assumed to be converted to CO_2. The guidelines provide typical or default values of the carbon content of process inputs and outputs (e.g., blast furnace gas, coke oven gas, limestone, dolomite, iron, ferrous scrap, steel). For Tier 2, the site-specific information is needed for the quantity of process inputs and outputs for each process for the year of interest. The carbon balances are performed around each process: the coke plant, sinter plant, iron and steel processes combined, DRI plant, and pellet production.

The Tier 3 approach for CO_2 emissions uses plant-specific emissions data to estimate national emissions and describes actual site-specific emission measurements as the preference. If emission measurements are not available, the next choice is to use site-specific data in the Tier 2 approach and then sum the results across plants to determine national totals.

The Guidelines provide two Tiers for estimating methane (CH_4) emissions for coke, iron, and sinter production. The Tier 1 approach uses a default emission factor, and Tier 3 is based on plant-specific emissions data. There is no Tier 2 approach for methane.

3.2 U.S. EPA GHG Inventory [28]

The current U.S. Inventory methodology for iron and steel and metallurgical coke production uses a mass balance approach based on an estimate of the amount of carbon contained in the steel produced, metallurgical coke oven byproducts produced, and pig iron produced and used for non-steel purposes. This amount of carbon is deducted from the carbon introduced into the iron and steel production process from metallurgical coke produced from coking coal, metallurgical coke consumed for pig iron production, and scrap steel consumed at steel plants. In addition, the amount of carbon generated from carbon anode consumption for steel produced in an electric arc furnace is estimated. The difference between the carbon inputs to metallurgical coke and iron and steel production and carbon outputs from these processes constitutes the CO_2 emissions from these processes.

The U.S. Inventory methodology does not account for certain other carbon inputs to the process including natural gas, limestone, etc. The GHG emissions from these other carbon inputs are included (but not separately identified) elsewhere in the U.S. Inventory (e.g., Energy, Lime, Limestone, and Dolomite use, etc.). The U.S. Inventory methodology also does not include consumption of raw materials for sinter, pellet, and direct reduced iron production; the GHG emissions from these other processes are included (but not separately identified) in the "Energy" section of the Inventory. Methane emissions from metallurgical coke production and pig iron production are estimated using emission factors and activity data. Emissions of CO_2 and CH_4 associated with metallurgical coke production and iron and steel production are attributed to the Industrial Processes chapter of the U.S. Inventory.

3.3 WRI/WBCSD Calculation Procedure [29]

The WRI/WBCSD protocol presents two procedures for estimating CO_2 emissions from the production of coke, sinter, DRI, and iron and steel, and both use a carbon balance approach.

The preferred approach is Tier 3, which uses facility-specific data for carbon content of all process inputs and outputs and the mass rate of all process inputs and outputs. In the absence of facility-specific data, Tier 1 default factors for carbon contents of inputs and outputs are provided. CO_2 emissions from flaring are based on the volume of gas flared, the carbon content of the gas, and a combustion efficiency of 98 percent. CH_4 emissions from flaring are estimated by assuming 2 percent of the CH_4 in the gas is not burned. The WRI/WBCSD provides equations for estimating CH_4 emissions from the production of coke, sinter, pig iron, and DRI; CH_4 emissions from steelmaking are assumed to be negligible. In the absence of facility-specific data that would allow the derivation of Tier 3 emission factors, equations and default emission factors (Tier 1) are provided for CH_4 emissions for all of these processes except for pig iron production.

3.4 European Union (EU) Emissions Trading System [30]

Source streams are defined as: (1) "de-minimus" sources that collectively contribute less than 1,000 mt CO_2/yr or that contribute less than 2% of total emissions up to 20,000 mt/yr); (2) "minor" sources that collectively contribute less than 5,000 mt CO_2/yr or that contribute less than 10% of total emissions up to 100,000 mt/yr); and (3) "major" sources that include all other streams. The highest tier must be used for major source streams unless it is not technically feasible. Tier 1 can be used for minor source streams, and a facility may use their own no-tier method for de-minimius streams.

Annex V addresses sinter and iron ore pellets plants, and Annex VI addresses pig iron and steel manufacture, including continuous casting. If the process is part of a larger integrated iron and steel plant, the operator is given the choice of a carbon balance approach around either the entire plant or around each process. The tiers relate to the quality of the input data:

Tier	Uncertainty in mass flow of inputs and outputs must be less than	Carbon content
1	±7.5%	Default (typical) values
2	±5.0%	Country-specific values
3	±2.5%	Analysis of representative samples
4	±1.5%	--

This approach is similar to the IPCC Tier 2/3 methods.

3.5 DOE Technical Guidelines [31]

The DOE guidelines provide 3 general approaches for the production of iron and steel that are given a rating of A, B, or C. A rating of "A" is for approaches that use a carbon balance around the process with site-specific data for process inputs, outputs, and carbon content. Default values are given for carbon content, and if the default values are used, the approach is given a rating of "B". The "C" rating is assigned when emissions are simply estimated as 1.75 MT CO_2/ton of steel. The approach focuses on the streams that contain the most carbon: limestone, dolomite, coke/coal, iron, steel, and graphite electrodes. The approach does not consider slag or air pollution control residues (dusts and sludges) that are not likely to contain much carbon.

3.6 AISI Methodology [32]

The AISI methodology is based on a net carbon balance within the fence line of the facility. Their approach states that:

> *...if all of the carbon in metallurgical coal is accounted for by the total quantity of coal entering a plant, it is not necessary to determine if that carbon is ultimately emitted as CO_2 emissions from coke battery stacks, blast furnace stoves, flares, boilers, BOF off-gas, or other sources of byproduct fuel combustion. It is only important to make adjustments for carbon that may leave the plant boundary in a form other than CO_2 (e.g., sold or transferred coke, tar, byproducts, or byproduct fuels such as blast furnace gas or coke oven gas). Adjustments can also be made for carbon contained in steel products if deemed to be significant.*

The carbon balance focuses on the streams contributing the most carbon and do not include minor contributors, such as iron ore, scrap, semi-finished steel, or ferroalloys. However, raw materials with intrinsic carbon content (e.g., iron carbide, carbon electrodes, charge carbon, limestone) should be reported if they are significant. In addition, adjustment (subtraction) should be made for offsite transfer of process gases, slag, scrap, or coke by-products if they are significant. They suggest emissions less than 1% of the facility's total should be considered de minimus.

The methodology includes a simple reporting form that requests the quantity of all fuels by type, all carbon-containing materials consumed onsite, and the amount of steel produced by BOFs and by EAFs. The form also requests information on the amount of electricity and steam that was purchased. The methodology also provides factors that convert fuel and raw material quantities to CO_2 emissions (e.g., 5,540 lb CO_2/ton of coking coal).

3.7 Environment Canada Guidance Manual [33]

The guidance for mandatory reporting in Canada primarily references the IPCC guidelines. However, the guidance also contains a section on developing a site-specific emission factor rather than using default emissions factors with these observations:

- A facility-specific emission factor is preferred over general or industry-averaged factors because they provide a better representation of emissions from a facility's specific operations. It may be necessary to update facility-specific emission factors on a periodic basis to account for changes in facility conditions.

- Obtaining emissions data by continuous emissions monitoring system (CEMS) is the preferred method when data on emissions are needed over an extended period. There are various types of monitoring systems available for installation, which use different instrumentation equipment. It is necessary for the facility to ensure the proper operation and calibration of the monitoring equipment used.

- Stack sampling and analysis can be used to obtain direct data on emissions over a short period (during the period of the test). Details on the sampling method and lab techniques used should be provided if you choose to collect facility data through this method. Standardized sampling and lab analysis protocols should be used when available.

3.8   Current Practices for Estimating Greenhouse Gas Emissions

The current practice of many U.S. iron and steel companies as well as international iron and steel facilities is to voluntarily report GHG emission intensity (e.g., in terms of MMTCO2e/mt steel produced). Many of these facilities are using the methodologies described in the WRI/WBCSD protocol.

4. TYPES OF INFORMATION TO BE REPORTED

Based on the review of existing programs and the emission sources at iron and steel facilities, the major GHG (by far) to be reported is CO_2. However, CH_4 is emitted due to incomplete combustion, and N_2O is emitted as a byproduct of combustion. These are the three major GHGs to be reported for the iron and steel industry.

The type of information to be reported will depend in large part on the option chosen for determining GHG emissions. However, in order to check the reported GHG emissions for reasonableness and for other data quality considerations, certain types of typical information about the emission sources is needed. The following items are recommended for reporting to assist in checks for reasonableness and for other data quality considerations:

1. Annual emission estimates for CO_2 presented by calendar quarters for coke oven battery combustion stacks, coke pushing, blast furnace stoves, taconite indurating furnaces, BOFs, EAFs, DRI furnaces, and sinter plants;

2. Annual emission estimates for CH_4 and N_2O presented by calendar quarters for each type of fuel that is burned;

3. Total for all process inputs and outputs when the carbon balance is used for specific processes by calendar quarters;

4. Site-specific emission factor for all processes for which the site-specific emission factor approach is used;

5. Annual production quantity for taconite pellets, coke, sinter, iron, raw steel by calendar quarters (in metric tons);

6. Annual production capacity for taconite pellets, coke, sinter, iron, raw steel; and

7. Annual operating hours for taconite furnaces, coke oven batteries, sinter production, blast furnaces, DRI furnaces, EAFs, and BOFs.

5. OPTIONS FOR REPORTING THRESHOLDS

In evaluating potential thresholds for iron and steel production, EPA considered emissions-based thresholds of 1,000 $mtCO_2e$, 10,000 $mtCO_2e$, 25,000 $mtCO_2e$, and 100,000 $mtCO_2e$. Table 14 summarizes the emission estimates developed in the previous sections and shows that the average emission level for each type of plant is well above the thresholds. However, there are several small EAF facilities that would fall below some of the thresholds.

Table 15 illustrates the various thresholds and their estimated effect on the amount of emissions that would be covered (reported). All integrated iron and steel facilities and taconite facilities exceed the highest emissions threshold considered. Most EAF facilities (with the possible exception of about 11 facilities) are estimated to exceed the 25,000 $mtCO_2e$ emissions threshold. Table 15 also provides an estimate of the production level that corresponds to the emission thresholds. The production thresholds are estimated from the emission factors developed earlier for EAF processes (0.08 $mtCO_2e$/mt steel) and combustion sources (0.32 $mtCO_2e$/mt steel).

Table 14. Summary of Emission Estimates

Facility	Number of plants	Production (mt/yr)	Type of production	Total emissions ($mtCO_2e$)	Average per plant ($mtCO_2e$)
Taconite	8	52,000,000	pellets	5,600,000	700,000
Byproduct coke stand alone	9	7,056,000	coke	4,247,040	471,893
Nonrecovery coke	3	2,234,400	coke	2,953,968	984,656
Integrated plants	18	40,000,000	steel	49,009,869	2,722,771
EAF	92	58,000,000	steel	23,340,000	253,696
Total facilities	**130**	**159,290,400**	**products**	**85,150,877**	**655,007**

Table 15. Reporting Thresholds

Threshold level $mtCO_2e$	Production threshold (mt/yr)	Total national emissions ($mtCO_2e$)	Total number of U.S. facilities	Emissions covered		Facilities covered	
				$mtCO_2e$/yr	Percent	Number	Percent
all in	0	85,150,877	130	85,150,877	100.0	130	100
1,000	2,500	85,150,877	130	85,150,877	100.0	130	100
10,000	25,000	85,150,877	130	85,141,423	99.99	128	98
25,000	62,500	85,150,877	130	85,013,059	99.8	121	93
100,000	250,000	85,150,877	130	84,468,696	99.2	111	85

6. OPTIONS FOR MONITORING METHODS

6.1 CO$_2$ Emissions from Process Sources

The monitoring methods for the iron and steel sector include emissions from stationary combustion sources and from process sources. The methods for combustion sources, where the only source of CO$_2$ emissions is the carbon in the fuel, are addressed separately for stationary combustion sources in general. (See the technical support document for general stationary fuel combustion sources for more details EPA-HQ-OAR-2008-0508-004.) This section summarizes the monitoring methods for process sources, which are defined as sources in which the process feed materials, usually in addition to the fuel, contribute the carbon for CO$_2$ emissions. The affected processes are each indurating furnace, BOF, nonrecovery coke oven battery, coke pushing operation, sinter plant, direct reduction furnace, and EAF.

The approach to develop the monitoring options was to consider accuracy, uncertainty, completeness, and comparability in the estimates; whether they were technically feasible, reasonably easy to implement, and cost effective; and if they provided adequate flexibility to the owner or operator. The five options that were developed from the review of existing methods for monitoring CO$_2$ emissions from the process sources are described below:

1. Option 1: Apply a default emission factor based on the type of process and an annual activity rate (e.g. quantity of raw steel, sinter, or direct reduced iron produced).   This option is the same as the IPCC Tier 1 approach.

2. Option 2: Perform a carbon balance of all inputs and outputs using default or typical values for the carbon content of inputs and outputs. Use facility production and other records to determine the annual quantity of process inputs and outputs. Calculate CO$_2$ emissions from the difference of carbon-in minus carbon-out assuming all is converted to CO$_2$. This option is the same as the IPCC Tier 2 approach, the WRI default approach, and the DOE 1605(b) approach that is rated "B." It is similar to the approach recommended by AISI except that the carbon balance for Option 2 is based on the individual processes rather than the entire plant.

3. Option 3: Perform a monthly carbon balance of all inputs and outputs using measurements of the carbon content of specific process inputs and process outputs and measure the mass rate of process inputs and process outputs. Calculate CO$_2$ emissions from the difference of carbon-in minus carbon-out assuming all is converted to CO$_2$. This is the IPCC Tier 3 approach (if direct measurements are not available), the WRI preferred approach, the approach used in the EU Emissions Trading Scheme, and the DOE 1605(b) approach that is rated "A."

4. Option 4: Develop a site-specific emission factor based on simultaneous and accurate measurements of CO$_2$ emissions and production rate or process input rate during representative operating conditions. Multiply the site-specific factor by the annual production rate or appropriate periodic production rate (or process input rate, as

appropriate). This approach is included in Environment Canada's methodologies and might be considered a form of direct measurement as in the IPCC's Tier 3 approach.

5. Option 5: Direct and continuous measurement of CO_2 emissions using a continuous emission monitoring system (CEMS) for CO_2 concentration and stack gas volumetric flow rate based on the requirements in 40 CFR part 75. This is the IPCC Tier 3 approach (direct measurement).

Two characteristics of Options 1 and 2 are the use of default values and lack of direct measurements, which results in a very high level of uncertainty in the emission estimates. These default approaches will not provide site-specific estimates of emissions that will reflect differences in feedstocks, operating conditions, fuel combustion efficiency, variability in fuels and other differences among facilities. Methodologies based on default values have commonly been used more for sector wide or national total estimates from aggregated activity data than for determining emissions from a specific facility.

Options 3, 4, and 5 use approaches that provide good site-specific estimates of emissions that reflect differences in feedstocks, operating conditions, fuel combustion efficiency, and other differences among plants. These three options span the range of types of methodologies currently used that do not apply default or typical values. The options also provide flexibility. For example, a CO_2 CEM may be the most accurate measurement method: however, it may expensive except for the largest emission sources, it would certainly be expensive for sources with multiple stacks, and it is not feasible for certain sources, such as flares and other emission points where emissions are not captured in a conveyance (e.g., a stack). In those cases, one of the other two options would be more appropriate.

Several iron and steel companies in the U.S. and abroad have recommended and are using a carbon balance approach similar to or a variation of the one described in Option 3. Many of the measurements required for that approach, such as the amount of specific feedstocks consumed, production rates from each process, process gas (coke oven gas, blast furnace gas) production and consumption, and purchased fuel consumption, are already routinely measured and used for accounting purposes (e.g., determining the cost of production), process control, and yield calculations. In addition, most plants monitor the composition of blast furnace gas and coke oven gas for process control and to ensure gas quality for combustion, and the carbon content of steel is routinely determined because it is a quality specification. Consequently, Option 3 offers an advantage in that it would use a significant amount of information that is already readily available.

According to the IPCC's 2006 guidelines, the uncertainty associated with default emission factors for Options 1 and 2 is ±25 percent, and the uncertainty in the production data used with the default emission factor is ±10 percent,[10] which results in a combined overall uncertainty greater than ±25 percent. If process-specific carbon contents and actual mass rate data for the process inputs and outputs are used (i.e., Option 3) or if direct measurements are used (i.e., Options 4 and 5), the guidelines state that the uncertainty associated with the emission

estimates would be reduced. Options 3, 4, and 5 meet the requirements of the IPCC's highest tier methodology (Tier 3).[10]

6.2 Methane and Nitrous Oxide Emissions

A small amount of CH_4 is emitted when any fuel that contains CH_4 is burned, in either process units or combustion units, because combustion is not complete (i.e., a small amount of methane escapes unburned). A small amount of N_2O is produced as a combustion byproduct when fuel is burned. For coke oven gas and blast furnace gas that are used as fuels, the recommended approach for estimating emissions of CH_4 and N_2O is to use the same methodology as that used for combustion units and to apply the default emission factor presented for natural gas, which is the procedure used in the IPCC Guidelines for coke oven gas and blast furnace gas, [9] and the measured high heating value.

6.3 CO_2 Emissions from Coke Pushing Operations

Emissions may also occur when the incandescent coke is pushed from the coke oven and transported to the quench tower where it is cooled (quenched) with water. A small portion of the coke burns during this process prior to quenching. EPA updated the coke oven section of the AP-42 compilation of emission factors in May 2008, and the update included an emission factor for CO_2 emissions developed from 26 tests for particulate matter from pushing operations.[13] The emissions factor (0.008 mtCO$_2$e per metric ton of coal charged) was derived to account for emissions from the pushing emission control device and those escaping the capture system. The recommended approach is for coke facilities to use the AP-42 emission factor to estimate CO_2 emissions from coke pushing operations.

7. OPTIONS FOR ESTIMATING MISSING DATA

For process sources that use Option 3 (carbon balance) or Option 4 (site-specific emission factor), no missing data procedures are appropriate because 100 percent data availability would be required. (There are no valid reasons for missing data for these options because re-testing for the site-specific emission factor can be performed at any time, and for the carbon balance, only a weekly sample would be necessary). For process sources that use Option 5 (direct measurement by CEMS), the missing data procedures that are appropriate are the same as for units using Tier 4 in the general stationary fuel combustion source category.

8. QA/QC REQUIREMENTS

For the carbon balance approach, the following QA/QC procedures would better ensure the quality of the reported emissions:

- For each process input and output other than fuels, the carbon content could be analyzed by a third-party certified laboratory using the test methods (and their QA/QC procedures) in the General Provisions (subpart A) of the proposed rule.

- Facilities could keep records that include a detailed explanation of how company records of measurements are used to estimate all sources of carbon input and output. The owner or operator also could document the procedures used to ensure the accuracy of the measurements of fuel usage including, but not limited to, calibration of weighing equipment, fuel flow meters, and other measurement devices. The estimated accuracy of measurements made with these devices could also be recorded, and the technical basis for these estimates provided. The procedures and equations used to convert the fuel feed rates to units of mass also could be documented.

- Records could be made available for verification of the records and measurements upon request.

For the site-specific emission factor approach, the following QA/QC elements were identified:

- The QA/QC procedures in the EPA reference test methods could be followed.

- The results of a performance test could include the analysis of samples, determination of emissions, and raw data. The performance test report could contain all information and data used to derive the emission factor.

For each of the options, all QA/QC data from each facility in the iron and steel production source category should be available for inspection upon request.

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APPENDIX A. DEFINITIONS AND THEIR ORIGINS

<u>Argon-oxygen decarburization vessel</u> means any closed-bottom, refractory-lined converter vessel with submerged tuyeres through which gaseous mixtures containing argon and oxygen or nitrogen may be blown into molten steel for further refining to reduce the carbon content of the steel.[a]

<u>Basic oxygen furnace</u> means any refractory-lined vessel in which high-purity oxygen is blown under pressure through a bath of molten iron, scrap metal, and fluxes to produce steel.[b]

<u>Blast furnace</u> means a furnace that is located at an integrated iron and steel facility and is used for the production of molten iron from iron ore pellets and other iron bearing materials.[b]

<u>By-product coke oven battery</u> means a group of ovens connected by common walls, where coal undergoes destructive distillation under positive pressure to produce coke and coke oven gas from which by-products are recovered.[c]

<u>Cokemaking facility</u> means a facility that produces coke from coal in either a by-product coke oven battery or a non-recovery coke oven battery.[c]

<u>Direct reduction furnace</u> means a high temperature furnace typically fired with natural gas to produce solid iron from iron ore or iron ore pellets and coke, coal, or other carbonaceous materials.[d]

<u>Electric arc furnace (EAF)</u> means a furnace that produces molten steel and heats the charge materials with electric arcs from carbon electrodes. The charge materials in the electric arc furnace is primarily recycled ferrous scrap but also may include direct reduced iron or molten iron from the blast furnace.[a]

<u>Electric arc furnace (EAF) steelmaking facility</u> means a facility that produces carbon, alloy, or specialty steels using an EAF. This definition excludes EAFs at steel foundries and EAFs used to produce nonferrous metals.[a]

<u>Indurating furnace</u> means a furnace where unfired taconite pellets, called green balls, are hardened at high temperatures to produce fired pellets for use in a blast furnace. Types of indurating furnaces include straight gate and grate kiln furnaces.[e]

<u>Integrated iron and steel manufacturing facility</u> means a facility engaged in the production of steel from iron ore or iron ore pellets. At a minimum, an integrated iron and steel facility has a basic oxygen furnace for refining molten iron into steel.[b, f]

<u>Non-recovery coke oven battery</u> means a group of ovens connected by common walls and operated as a unit, where coal undergoes destructive distillation under negative pressure to produce coke, and which is designed for the combustion of the coke oven gas from which by-products are not recovered.[c]

Pushing means the process of removing the coke from the coke oven at the end of the coking cycle. Pushing begins when coke first begins to fall from the oven into the quench car and ends when the quench car enters the quench tower.[c]

Sinter process means a process that produces a fused aggregate of fine iron-bearing materials suited for use in a blast furnace. The sinter machine is composed of a continuous traveling grate that conveys a bed of ore fines and other finely divided iron-bearing material and fuel (typically coke breeze), a burner at the feed end of the grate for ignition, and a series of downdraft windboxes along the length of the strand to support downdraft combustion and heat sufficient to produce a fused sinter product.[b]

Taconite iron ore processing facility means a facility that separates and concentrates iron ore from taconite, a low grade iron ore, and heats the taconite in an indurating furnace to produce taconite pellets that are used as the primary feed material for the production of iron in blast furnaces at integrated iron and steel facilities.[e]

Origins:

[a] 40 CFR Part 63, Subpart YYYYY. National Emission Standards for Hazardous Air Pollutants for Area Sources: Electric Arc Furnace Steelmaking Facilities.

[b] 40 CFR Part 63, Subpart FFFFF. National Emission Standards for Integrated Iron and Steel Manufacturing.

[c] 40 CFR Part 63, Subpart CCCCC. National Emission Standards for Hazardous Air Pollutants for Coke Ovens: Pushing, Quenching, and Battery Stacks.

[d] The definition of "direct reduction furnace" was developed from the process description in *The Making, Shaping, and Treating of Steel* (Reference 7) because there is no definition codified in 40 CFR.

[e] 40 CFR Part 63, Subpart RRRRR. National Emission Standards for Taconite Iron Ore Processing.

[f] This definition in 40 CFR was modified by adding "and iron ore pellets" because most integrated plants use pellets in the blast furnace rather than iron ore. Also added "At a minimum, an integrated iron and steel facility has a basic oxygen furnace for refining molten iron into steel" because one integrated plant recently shut down the onsite blast furnace, but continues to operate the BOFs with molten iron supplied by a nearby plant.

APPENDIX B. EXAMPLES OF COMBUSTION UNITS

Table B-1. Examples of Combustion Unit at Minimills [8]

Plant Name	City	State	CO$_2$ source
Universal Stainless and Alloy Products	Bridgeville	PA	Ladle Reheat Furnace
			Vessel Reheat Furnace
			Electro-Slag Remelt Holding Furnace
			Annealing Furnaces
			Plate Warming Furnace
			Miscellaneous space heating units (75)
Erie Forge and Steel	Erie	PA	North American Steam Boiler
			Ladle preheaters
			Ladle refining furnace
			Heat treat furnaces
			Hood furnace
Ellwood Quality Steels Company	New Castle	PA	Boilers (4)
			Oxy-fuel burner (for EAF)
			Anneal furnaces
			Scrap torching
			Ladle preheaters
			EAF pre-heater
AK Steel Corporation	Butler	PA	Boilers
			Spaceheaters > 2.5 MMBtu/hr
			Electric furnace
			Slab heating furnaces
			Decarb furnace
			Silicon drying furnace
			AOD reactor
			Continuous caster
			Vacuum degas
			Anneal furnaces
			Drying furnace
			Carlite line dry furnace
			Ladle preheaters
Electroalloy	Oil City	PA	Miscellaneous NG (<2.5 MMBtu/hr)
			Anneal furnaces
			Granular metal process
			Ladle preheaters for melt shop
Nucor Steel	Blytheville	AR	Pickle line boilers
			Galvanizing line
			Alkali wash burners
			Chromate spray dryer
			Annealing furnaces
			Tunnel furnace
			Ladle preheaters
			Ladle dryouts
			Vertical holding stations
			Tundish preheaters
			Tundish dryers

Table B-1. Examples of Combustion Unit at Minimills [8]

Plant Name	City	State	CO_2 source
Oregon Steel Mills Rivergate Plant	Portland	OR	Oxide reformer furnace
			Vacuum Degasser Boiler
			Degasser stack flare
			Other natural gas sources
			Glass frit rotary dryer
			Low NO_x natural gas sources
			Heat treat facility
Quanex Corporation - MacSteel Division	Fort Smith	AR	Natural gas-fired boiler
			Tundish preheaters
			Three ladle preheaters
			One ladle dryout, six refractory dryers
			Reheat furnace
			Boiler
			Heat treating furnaces
			Car bottom furnace

Table B-2. Reported Fuel Usage at U.S. Steel's Integrated Plant in Michigan (2004) [28]

Source	Fuel	MMCF/yr
No. 2 Boilerhouse	Blast furnace gas	30,711
D blast furnace stove	Blast furnace gas	30,397
B blast furnace stove	Blast furnace gas	28,145
Blast furnace flares	Blast furnace gas	28,059
No. 1 Boilerhouse	Blast furnace gas	21,290
Mill furnace heaters	Coke oven gas	4,647
Mill furnace heaters	Natural Gas	3,163
No. 2 Boilerhouse	Coke oven gas	2,773
No. 1 Boilerhouse	Coke oven gas	1,917
No. 1 Boiler	Coke oven gas	987
Heaters	Natural Gas	590
Dryout Heaters	Natural Gas	580
Heaters	Natural Gas	428
Process Heaters	Natural Gas	393
Boiler	Natural Gas	268
Annealing Heaters	Natural Gas	228
No. 2 Boilerhouse	Natural Gas	208
No. 1 Boiler	Natural Gas	135
B blast furnace stove	Natural Gas	126
Annealing Heaters	Natural Gas	122
BOF operation	Natural Gas	121
No. 3 Boilerhouse	Natural Gas	107