Table 4-56: Approach 2 Quantitative Uncertainty Estimates for CO_2 Emissions from Phosphoric Acid Production (MMT CO_2 Eq. and Percent)

Source	Gas	2014 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Phosphoric Acid Production	CO_2	1.1	0.9	1.4	-19%	+20%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Methodological recalculations were applied to the entire time series to ensure consistency in emissions from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

Recalculations Discussion

Relative to the previous Inventory, the phosphate rock consumption data (sold or used and imports for consumption) for 2013 were revised based on updated data publicly available from USGS (USGS 2015). This revision caused a decrease in the 2013 emission estimate by approximately 2 percent.

Additionally, during the development of the current Inventory emission estimates, it was discovered that the phosphate rock CO_2 content had been incorrectly transcribed in the previous Inventory. This error was corrected in the current Inventory and resulted in a slight change of emissions over the entire time series.

Planned Improvements

EPA continues to evaluate potential improvements to the Inventory estimates for this source category, which include direct integration of EPA's Greenhouse Gas Reporting Program (GHGRP) data for 2010 through 2014 and the use of reported GHGRP data to update the inorganic C content of phosphate rock for prior years. Confidentiality of CBI is being assessed, in addition to the applicability of EPA's GHGRP data for the averaged inorganic C content data (by region) from 2010 through 2014 to inform estimates in prior years in the required time series (i.e., 1990 through 2009). In implementing improvements and integration of data from EPA's GHGRP, the latest guidance from the IPCC on the use of facility-level data in national inventories will be relied upon.[29]

4.16 Iron and Steel Production (IPCC Source Category 2C1) and Metallurgical Coke Production

Iron and steel production is a multi-step process that generates process-related emissions of carbon dioxide (CO_2) and methane (CH_4) as raw materials are refined into iron and then transformed into crude steel. Emissions from conventional fuels (e.g., natural gas, fuel oil) consumed for energy purposes during the production of iron and steel are accounted for in the Energy chapter.

Iron and steel production includes six distinct production processes: coke production, sinter production, direct reduced iron (DRI) production, pig iron production, electric arc furnace (EAF) steel production, and basic oxygen furnace (BOF) steel production. The number of production processes at a particular plant is dependent upon the specific plant configuration. In addition to the production processes mentioned above, CO_2 is also generated at iron

[29] See <http://www.ipcc-nggip.iges.or.jp/meeting/pdffiles/1008_Model_and_Facility_Level_Data_Report.pdf>.

and steel mills through the consumption of process byproducts (e.g., blast furnace gas, coke oven gas) used for various purposes including heating, annealing, and electricity generation. Process byproducts sold for use as synthetic natural gas are deducted and reported in the Energy chapter. In general, CO_2 emissions are generated in these production processes through the reduction and consumption of various carbon-containing inputs (e.g., ore, scrap, flux, coke byproducts). In addition, fugitive CH_4 emissions can also be generated from these processes but also sinter, direct iron and pellet production.

Currently, there are between 15 and 20 integrated iron and steel steelmaking facilities that utilize BOFs to refine and produce steel from iron and more than 100 steelmaking facilities that utilize EAFs to produce steel primarily from recycled ferrous scrap. In addition, there are 18 cokemaking facilities, of which 7 facilities are co-located with integrated iron and steel facilities. Slightly more than 62 percent of the raw steel produced in the United States is produced in one of seven states: Alabama, Arkansas, Indiana, Kentucky, Mississippi, Ohio, and Tennessee (AISI 2015a).

Total production of crude steel in the United States between 2000 and 2008 ranged from a low of 99,320,000 tons to a high of 109,880,000 tons (2001 and 2004, respectively). Due to the decrease in demand caused by the global economic downturn (particularly from the automotive industry), crude steel production in the United States sharply decreased to 65,459,000 tons in 2009. In 2010, crude steel production rebounded to 88,731,000 tons as economic conditions improved and then continued to increase to 95,237,000 tons in 2011 and 97,770,000 tons in 2012; crude steel production slightly decreased to 95,766,000 tons in 2013 and then slightly increased to 97,195,000 tons in 2014 (AISI 2015a). The United States was the third largest producer of raw steel in the world, behind China and Japan, accounting for approximately 5.3 percent of world production in 2013 (AISI 2015a).

The majority of CO_2 emissions from the iron and steel production process come from the use of coke in the production of pig iron and from the consumption of other process byproducts, with lesser amounts emitted from the use of flux and from the removal of carbon from pig iron used to produce steel.

According to the *2006 IPCC Guidelines* (IPCC 2006), the production of metallurgical coke from coking coal is considered to be an energy use of fossil fuel and the use of coke in iron and steel production is considered to be an industrial process source. Therefore, the *2006 IPCC Guidelines* suggest that emissions from the production of metallurgical coke should be reported separately in the Energy sector, while emissions from coke consumption in iron and steel production should be reported in the Industrial Processes and Product Use sector. However, the approaches and emission estimates for both metallurgical coke production and iron and steel production are both presented here because much of the relevant activity data is used to estimate emissions from both metallurgical coke production and iron and steel production. For example, some byproducts (e.g., coke oven gas) of the metallurgical coke production process are consumed during iron and steel production, and some byproducts of the iron and steel production process (e.g., blast furnace gas) are consumed during metallurgical coke production. Emissions associated with the consumption of these byproducts are attributed at the point of consumption. Emissions associated with the use of conventional fuels (e.g., natural gas, fuel oil) for electricity generation, heating and annealing, or other miscellaneous purposes downstream of the iron and steelmaking furnaces are reported in the Energy chapter.

Metallurgical Coke Production

Emissions of CO_2 from metallurgical coke production in 2014 were 1.9 MMT CO_2 Eq. (1,938 kt CO_2) (see Table 4-57 and Table 4-58). Emissions increased in 2014 from 2013 levels, but have decreased overall since 1990. Domestic coke production data for 2014 are not yet published and so 2013 data were used as proxy for 2014. Coke production in 2014 was 26 percent lower than in 2000 and 45 percent below 1990. Overall, emissions from metallurgical coke production have declined by 23 percent (0.6 MMT CO_2 Eq.) from 1990 to 2014.

Table 4-57: CO_2 Emissions from Metallurgical Coke Production (MMT CO_2 Eq.)

Gas	1990	2005	2010	2011	2012	2013	2014
CO_2	2.5	2.0	2.1	1.4	0.5	1.8	1.9
Total	**2.5**	**2.0**	**2.1**	**1.4**	**0.5**	**1.8**	**1.9**

Table 4-58: CO_2 Emissions from Metallurgical Coke Production (kt)

Gas	1990	2005	2010	2011	2012	2013	2014
CO_2	2,503	2,044	2,085	1,426	543	1,824	1,938

Iron and Steel Production

Emissions of CO_2 and CH_4 from iron and steel production in 2014 were 53.4 MMT CO_2 Eq. (53,417 kt) and 0.0094 MMT CO_2 Eq. (0.4 kt), respectively (see Table 4-59 through Table 4-62), totaling approximately 53.4 MMT CO_2 Eq. Emissions decreased in 2014 and have decreased overall since 1990 due to restructuring of the industry, technological improvements, and increased scrap steel utilization. Carbon dioxide emission estimates include emissions from the consumption of carbonaceous materials in the blast furnace, EAF, and BOF, as well as blast furnace gas and coke oven gas consumption for other activities at the steel mill.

In 2014, domestic production of pig iron decreased by 3 percent from 2013 levels. Overall, domestic pig iron production has declined since the 1990s. Pig iron production in 2014 was 39 percent lower than in 2000 and 41 percent below 1990. Carbon dioxide emissions from steel production have decreased by 4 percent (0.3 MMT CO_2 Eq.) since 1990, while overall CO_2 emissions from iron and steel production have declined by 45 percent (43.7 MMT CO_2 Eq.) from 1990 to 2014.

Table 4-59: CO_2 Emissions from Iron and Steel Production (MMT CO_2 Eq.)

Source/Activity Data	1990	2005	2010	2011	2012	2013	2014
Sinter Production	2.4	1.7	1.0	1.2	1.2	1.1	1.1
Iron Production	45.6	17.5	17.8	18.4	10.9	11.9	16.8
Steel Production	7.9	9.4	9.2	9.3	9.9	8.6	7.6
Other Activities[a]	41.2	35.9	25.5	29.7	31.7	28.7	27.9
Total	**97.2**	**64.5**	**53.6**	**58.5**	**53.7**	**50.4**	**53.4**

[a] Includes emissions from blast furnace gas and coke oven gas combustion for activities at the steel mill other than consumption in blast furnace, EAFs, or BOFs.
Note: Totals may not sum due to independent rounding.

Table 4-60: CO_2 Emissions from Iron and Steel Production (kt)

Source/Activity Data	1990	2005	2010	2011	2012	2013	2014
Sinter Production	2,448	1,663	1,045	1,188	1,159	1,117	1,104
Iron Production	45,592	17,545	17,802	18,375	10,917	11,934	16,754
Steel Production	7,933	9,356	9,235	9,255	9,860	8,617	7,648
Other Activities [a]	41,193	35,934	25,504	29,683	31,750	28,709	27,911
Total	**97,166**	**64,499**	**53,586**	**58,501**	**53,686**	**50,378**	**53,417**

[a] Includes emissions from blast furnace gas and coke oven gas combustion for activities at the steel mill other than consumption in blast furnace, EAFs, or BOFs.
Note: Totals may not sum due to independent rounding.

Table 4-61: CH_4 Emissions from Iron and Steel Production (MMT CO_2 Eq.)

Source/Activity Data	1990	2005	2010	2011	2012	2013	2014
Sinter Production	+	+	+	+	+	+	+
Total	+	+	+	+	+	+	+

+ Does not exceed 0.05 MMT CO_2 Eq.

Table 4-62: CH_4 Emissions from Iron and Steel Production (kt)

Source/Activity Data	1990	2005	2010	2011	2012	2013	2014
Sinter Production	0.9	0.6	0.4	0.4	0.4	0.4	0.4
Total	**0.9**	**0.6**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**

Methodology

Emission estimates presented in this chapter are largely based on Tier 2 methodologies provided by the *2006 IPCC Guidelines* (IPCC 2006). These Tier 2 methodologies call for a mass balance accounting of the carbonaceous inputs and outputs during the iron and steel production process and the metallurgical coke production process. Tier 1 methods are used for certain iron and steel production processes (i.e., sinter production and DRI production) for which available data are insufficient for utilizing a Tier 2 method.

The Tier 2 methodology equation is as follows:

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

where,

E_{CO2}	=	Emissions from coke, pig iron, EAF steel, or BOF steel production, metric tons
a	=	Input material *a*
b	=	Output material *b*
Q_a	=	Quantity of input material *a*, metric tons
C_a	=	Carbon content of input material *a*, metric tons C/metric ton material
Q_b	=	Quantity of output material *b*, metric tons
C_b	=	Carbon content of output material *b*, metric tons C/metric ton material
44/12	=	Stoichiometric ratio of CO_2 to C

The Tier 1 methodology equations are as follows:

$$E_{s,p} = Q_s \times EF_{s,p}$$

$$E_{d,CO2} = Q_d \times EF_{d,CO2}$$

where,

$E_{s,p}$	=	Emissions from sinter production process for pollutant *p* (CO_2 or CH_4), metric ton
Q_s	=	Quantity of sinter produced, metric tons
$EF_{s,p}$	=	Emission factor for pollutant *p* (CO_2 or CH_4), metric ton *p*/metric ton sinter
$E_{d,CO2}$	=	Emissions from DRI production process for CO_2, metric ton
Q_d	=	Quantity of DRI produced, metric tons
$EF_{d,CO2}$	=	Emission factor for CO_2, metric ton CO_2/metric ton DRI

Metallurgical Coke Production

Coking coal is used to manufacture metallurgical coke that is used primarily as a reducing agent in the production of iron and steel, but is also used in the production of other metals including zinc and lead (see Zinc Production and Lead Production sections of this chapter). Emissions associated with producing metallurgical coke from coking coal are estimated and reported separately from emissions that result from the iron and steel production process. To estimate emissions from metallurgical coke production, a Tier 2 method provided by the *2006 IPCC Guidelines* (IPCC 2006) was utilized. The amount of carbon contained in materials produced during the metallurgical coke production process (i.e., coke, coke breeze, coke oven gas, and coal tar) is deducted from the amount of carbon contained in materials consumed during the metallurgical coke production process (i.e., natural gas, blast furnace gas, and coking coal). Light oil, which is produced during the metallurgical coke production process, is excluded from the deductions due to data limitations. The amount of carbon contained in these materials is calculated by multiplying the material-specific carbon content by the amount of material consumed or produced (see Table 4-63). The amount of coal tar produced was approximated using a production factor of 0.03 tons of coal tar per ton of coking coal consumed. The amount of coke breeze produced was approximated using a production factor of 0.075 tons of coke breeze per ton of coking coal consumed (AISI 2008c; DOE 2000). Data on the consumption of carbonaceous materials (other than coking coal) as well as coke oven gas production were available for integrated steel mills only (i.e., steel mills with co-located coke plants). Therefore, carbonaceous material (other than coking coal) consumption and coke oven gas production were excluded from emission estimates for merchant coke plants. Carbon contained in coke oven gas used for coke-oven underfiring was not included in the deductions to avoid double-counting.

Table 4-63: Material Carbon Contents for Metallurgical Coke Production

Material	kg C/kg
Coal Tar	0.62
Coke	0.83
Coke Breeze	0.83
Coking Coal	0.73
Material	**kg C/GJ**
Coke Oven Gas	12.1
Blast Furnace Gas	70.8

Source: IPCC (2006), Table 4.3. Coke Oven Gas and Blast Furnace Gas, Table 1.3.

Although the *2006 IPCC Guidelines* provide a Tier 1 CH_4 emission factor for metallurgical coke production (i.e., 0.1 g CH_4 per metric ton of coke production), it is not appropriate to use because CO_2 emissions were estimated using the Tier 2 mass balance methodology. The mass balance methodology makes a basic assumption that all carbon that enters the metallurgical coke production process either exits the process as part of a C-containing output or as CO_2 emissions. This is consistent with a preliminary assessment of aggregated facility-level greenhouse gas CH_4 emissions reported by coke production facilities under EPA's Greenhouse Gas Reporting Program (GHGRP). The assessment indicates that CH_4 emissions from coke production are below 500 kt or 0.05 percent of total national emissions. Pending resources and significance, EPA may include these emissions in future reports to enhance completeness.

Data relating to the mass of coking coal consumed at metallurgical coke plants and the mass of metallurgical coke produced at coke plants were taken from the Energy Information Administration (EIA), *Quarterly Coal Report: October through December* (EIA 1998 through 2015a) (see Table 4-64). Data on the volume of natural gas consumption, blast furnace gas consumption, and coke oven gas production for metallurgical coke production at integrated steel mills were obtained from the American Iron and Steel Institute (AISI), *Annual Statistical Report* (AISI 2004 through 2015a) and through personal communications with AISI (2008c) (see Table 4-65). The factor for the quantity of coal tar produced per ton of coking coal consumed was provided by AISI (2008c). The factor for the quantity of coke breeze produced per ton of coking coal consumed was obtained through Table 2-1 of the report *Energy and Environmental Profile of the U.S. Iron and Steel Industry* (DOE 2000). Data on natural gas consumption and coke oven gas production at merchant coke plants were not available and were excluded from the emission estimate. Carbon contents for coking coal, metallurgical coke, coal tar, coke oven gas, and blast furnace gas were provided by the *2006 IPCC Guidelines* (IPCC 2006). The C content for coke breeze was assumed to equal the C content of coke.

Table 4-64: Production and Consumption Data for the Calculation of CO_2 and CH_4 Emissions from Metallurgical Coke Production (Thousand Metric Tons)

Source/Activity Data	1990	2005	2010	2011	2012	2013	2014[a]
Metallurgical Coke Production							
Coking Coal Consumption at Coke Plants	35,269	21,259	19,135	19,445	18,825	19,481	19,481
Coke Production at Coke Plants	25,054	15,167	13,628	13,989	13,764	13,898	13,898
Coal Breeze Production	2,645	1,594	1,435	1,458	1,412	1,461	1,461
Coal Tar Production	1,058	638	574	583	565	584	584

[a] 2013 data were used as a proxy because 2014 data are not yet published.

Table 4-65: Production and Consumption Data for the Calculation of CO_2 Emissions from Metallurgical Coke Production (Million ft^3)

Source/Activity Data	1990	2005	2010	2011	2012	2013	2014
Metallurgical Coke Production							
Coke Oven Gas Production	250,767	114,213	95,405	109,044	113,772	108,162	102,899
Natural Gas Consumption	599	2,996	3,108	3,175	3,267	3,247	3,039
Blast Furnace Gas Consumption	24,602	4,460	3,181	3,853	4,351	4,255	4,346

Iron and Steel Production

Emissions of CO_2 from sinter production and direct reduced iron production were estimated by multiplying total national sinter production and the total national direct reduced iron production by Tier 1 CO_2 emission factors (see Table 4-66). Because estimates of sinter production and direct reduced iron production were not available, production was assumed to equal consumption.

Table 4-66: CO_2 Emission Factors for Sinter Production and Direct Reduced Iron Production

Material Produced	Metric Ton CO_2/Metric Ton
Sinter	0.2
Direct Reduced Iron	0.7

Source: IPCC (2006), Table 4.1.

To estimate emissions from pig iron production in the blast furnace, the amount of carbon contained in the produced pig iron and blast furnace gas were deducted from the amount of carbon contained in inputs (i.e., metallurgical coke, sinter, natural ore, pellets, natural gas, fuel oil, coke oven gas, and direct coal injection). The carbon contained in the pig iron, blast furnace gas, and blast furnace inputs was estimated by multiplying the material-specific C content by each material type (see Table 4-67). Carbon in blast furnace gas used to pre-heat the blast furnace air is combusted to form CO_2 during this process. Carbon contained in blast furnace gas used as a blast furnace input was not included in the deductions to avoid double-counting.

Emissions from steel production in EAFs were estimated by deducting the carbon contained in the steel produced from the carbon contained in the EAF anode, charge carbon, and scrap steel added to the EAF. Small amounts of carbon from direct reduced iron, pig iron, and flux additions to the EAFs were also included in the EAF calculation. For BOFs, estimates of carbon contained in BOF steel were deducted from C contained in inputs such as natural gas, coke oven gas, fluxes, and pig iron. In each case, the carbon was calculated by multiplying material-specific carbon contents by each material type (see Table 4-67). For EAFs, the amount of EAF anode consumed was approximated by multiplying total EAF steel production by the amount of EAF anode consumed per metric ton of steel produced (0.002 metric tons EAF anode per metric ton steel produced [AISI 2008c]). The amount of flux (e.g., limestone and dolomite) used during steel manufacture was deducted from the Other Process Uses of Carbonates source category to avoid double-counting.

Carbon dioxide emissions from the consumption of blast furnace gas and coke oven gas for other activities occurring at the steel mill were estimated by multiplying the amount of these materials consumed for these purposes by the material-specific carbon content (see Table 4-67).

Carbon dioxide emissions associated with the sinter production, direct reduced iron production, pig iron production, steel production, and other steel mill activities were summed to calculate the total CO_2 emissions from iron and steel production (see Table 4-59 and Table 4-60).

Table 4-67: Material Carbon Contents for Iron and Steel Production

Material	kg C/kg
Coke	0.83
Direct Reduced Iron	0.02
Dolomite	0.13
EAF Carbon Electrodes	0.82

EAF Charge Carbon	0.83
Limestone	0.12
Pig Iron	0.04
Steel	0.01
Material	**kg C/GJ**
Coke Oven Gas	12.1
Blast Furnace Gas	70.8

Source: IPCC (2006), Table 4.3. Coke Oven Gas and Blast Furnace Gas, Table 1.3.

The production process for sinter results in fugitive emissions of CH_4, which are emitted via leaks in the production equipment, rather than through the emission stacks or vents of the production plants. The fugitive emissions were calculated by applying Tier 1 emission factors taken from the *2006 IPCC Guidelines* (IPCC 2006) for sinter production (see Table 4-68). Although the *1995 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1995) provide a Tier 1 CH_4 emission factor for pig iron production, it is not appropriate to use because CO_2 emissions were estimated using the Tier 2 mass balance methodology. The mass balance methodology makes a basic assumption that all carbon that enters the pig iron production process either exits the process as part of a carbon-containing output or as CO_2 emissions; the estimation of CH_4 emissions is precluded. A preliminary analysis of facility-level emissions reported during iron production further supports this assumption and indicates that CH_4 emissions are below 500 kt CO_2 Eq. and well below 0.05 percent of total national emissions. The production of direct reduced iron also results in emissions of CH_4 through the consumption of fossil fuels (e.g., natural gas, etc.); however, these emission estimates are excluded due to data limitations. Pending further analysis and resources, EPA may include these emissions in future reports to enhance completeness.

Table 4-68: CH_4 Emission Factors for Sinter and Pig Iron Production

Material Produced	Factor	Unit
Sinter	0.07	kg CH_4/metric ton

Source: IPCC (2006), Table 4.2.

Sinter consumption data for 1990 through 2014 were obtained from AISI's *Annual Statistical Report* (AISI 2004 through 2015a) and through personal communications with AISI (2008c) (see Table 4-69). In general, direct reduced iron (DRI) consumption data were obtained from the U.S. Geological Survey (USGS) *Minerals Yearbook – Iron and Steel Scrap* (USGS 1991 through 2014) and personal communication with the USGS Iron and Steel Commodity Specialist (Fenton 2015). However, data for DRI consumed in EAFs were not available for the years 1990 and 1991. EAF DRI consumption in 1990 and 1991 was calculated by multiplying the total DRI consumption for all furnaces by the EAF share of total DRI consumption in 1992. Also, data for DRI consumed in BOFs were not available for the years 1990 through 1993. BOF DRI consumption in 1990 through 1993 was calculated by multiplying the total DRI consumption for all furnaces (excluding EAFs and cupola) by the BOF share of total DRI consumption (excluding EAFs and cupola) in 1994.

The Tier 1 CO_2 emission factors for sinter production and direct reduced iron production were obtained through the *2006 IPCC Guidelines* (IPCC 2006). Time series data for pig iron production, coke, natural gas, fuel oil, sinter, and pellets consumed in the blast furnace; pig iron production; and blast furnace gas produced at the iron and steel mill and used in the metallurgical coke ovens and other steel mill activities were obtained from AISI's *Annual Statistical Report* (AISI 2004 through 2015a) and through personal communications with AISI (2008c) (see Table 4-69 and Table 4-70).

Data for EAF steel production, flux, EAF charge carbon, and natural gas consumption were obtained from AISI's *Annual Statistical Report* (AISI 2004 through 2015a) and through personal communications with AISI (2006 through 2015b and 2008c). The factor for the quantity of EAF anode consumed per ton of EAF steel produced was provided by AISI (2008c). Data for BOF steel production, flux, natural gas, natural ore, pellet, sinter consumption as well as BOF steel production were obtained from AISI's *Annual Statistical Report* (AISI 2004 through 2015a) and through personal communications with AISI (2008c). Data for EAF and BOF scrap steel, pig iron, and DRI consumption were obtained from the USGS *Minerals Yearbook – Iron and Steel Scrap* (USGS 1991 through 2014). Data on coke oven gas and blast furnace gas consumed at the iron and steel mill (other than in the EAF, BOF, or blast furnace) were obtained from AISI's *Annual Statistical Report* (AISI 2004 through 2015a) and through personal communications with AISI (2008c).

Data on blast furnace gas and coke oven gas sold for use as synthetic natural gas were obtained from EIA's *Natural Gas Annual* (EIA 2015a). Carbon contents for direct reduced iron, EAF carbon electrodes, EAF charge carbon, limestone, dolomite, pig iron, and steel were provided by the *2006 IPCC Guidelines* (IPCC 2006). The carbon contents for natural gas, fuel oil, and direct injection coal were obtained from EIA (2015b) and EPA (2010). Heat contents for fuel oil and direct injection coal were obtained from EIA (1992, 2011); natural gas heat content was obtained from Table 37 of AISI's *Annual Statistical Report* (AISI 2004 through 2015a). Heat contents for coke oven gas and blast furnace gas were provided in Table 37 of AISI's *Annual Statistical Report* (AISI 2004 through 2015a) and confirmed by AISI staff (Carroll 2015).

Table 4-69: Production and Consumption Data for the Calculation of CO_2 and CH_4 Emissions from Iron and Steel Production (Thousand Metric Tons)

Source/Activity Data	1990	2005	2010	2011	2012	2013	2014
Sinter Production							
Sinter Production	12,239	8,315	5,225	5,941	5,795	5,583	5,521
Direct Reduced Iron Production							
Direct Reduced Iron Production	516	1,303	1,441	1,582	3,530	3,350	2,113
Pig Iron Production							
Coke Consumption	24,946	13,832	10,883	11,962	9,571	9,308	11,136
Pig Iron Production	49,669	37,222	26,844	30,228	32,063	30,309	29,375
Direct Injection Coal Consumption	1,485	2,573	2,279	2,604	2,802	2,675	2,425
EAF Steel Production							
EAF Anode and Charge Carbon Consumption	67	1,127	1,189	1,257	1,318	1,122	1,127
Scrap Steel Consumption	42,691	46,600	47,500	50,500	50,900	47,300	48,873
Flux Consumption	319	695	640	726	748	771	771
EAF Steel Production	33,511	52,194	49,339	52,108	52,415	52,641	55,174
BOF Steel Production							
Pig Iron Consumption	47,307	34,400	31,200	31,300	31,500	29,600	23,755
Scrap Steel Consumption	14,713	11,400	9,860	8,800	8,350	7,890	5,917
Flux Consumption	576	582	431	454	476	454	454
BOF Steel Production	43,973	42,705	31,158	34,291	36,282	34,238	33,000

Table 4-70: Production and Consumption Data for the Calculation of CO_2 Emissions from Iron and Steel Production (Million ft^3 unless otherwise specified)

Source/Activity Data	1990	2005	2010	2011	2012	2013	2014
Pig Iron Production							
Natural Gas Consumption	56,273	59,844	47,814	59,132	62,469	48,812	47,734
Fuel Oil Consumption (thousand gallons)	163,397	16,170	27,505	21,378	19,240	17,468	16,674
Coke Oven Gas Consumption	22,033	16,557	14,233	17,772	18,608	17,710	16,896
Blast Furnace Gas Production	1,439,380	1,299,980	911,180	1,063,326	1,139,578	1,026,973	1,000,536
EAF Steel Production							
Natural Gas Consumption	15,905	19,985	10,403	6,263	11,145	10,514	9,622
BOF Steel Production							
Coke Oven Gas Consumption	3,851	524	546	554	568	568	524
Other Activities							
Coke Oven Gas Consumption	224,883	97,132	80,626	90,718	94,596	89,884	85,479
Blast Furnace Gas Consumption	1,414,778	1,295,520	907,999	1,059,473	1,135,227	1,022,718	996,190

Uncertainty and Time-Series Consistency

The estimates of CO_2 emissions from metallurgical coke production are based on material production and consumption data and average carbon contents. Uncertainty is associated with the total U.S. coking coal consumption, total U.S. coke production and materials consumed during this process. Data for coking coal consumption and metallurgical coke production are from different data sources (EIA) than data for other carbonaceous materials consumed at coke plants (AISI), which does not include data for merchant coke plants. There is uncertainty associated with the fact that coal tar and coke breeze production were estimated based on coke production because coal tar and coke breeze production data were not available. Since merchant coke plant data is not included in the estimate of other carbonaceous materials consumed at coke plants, the mass balance equation for CO_2 from metallurgical coke production cannot be reasonably completed. Therefore, for the purpose of this analysis, uncertainty parameters are applied to primary data inputs to the calculation (i.e., coking coal consumption and metallurgical coke production) only.

The estimates of CO_2 emissions from iron and steel production are based on material production and consumption data and average C contents. Current estimates include estimates from pellect consumption, but exclude emissions from pellet production. There is uncertainty associated with the assumption that direct reduced iron and sinter consumption are equal to production. There is uncertainty associated with the assumption that all coal used for purposes other than coking coal is for direct injection coal; some of this coal may be used for electricity generation. There is also uncertainty associated with the C contents for pellets, sinter, and natural ore, which are assumed to equal the C contents of direct reduced iron. For EAF steel production, there is uncertainty associated with the amount of EAF anode and charge carbon consumed due to inconsistent data throughout the time series. Also for EAF steel production, there is uncertainty associated with the assumption that 100 percent of the natural gas attributed to "steelmaking furnaces" by AISI is process-related and nothing is combusted for energy purposes. Uncertainty is also associated with the use of process gases such as blast furnace gas and coke oven gas. Data are not available to differentiate between the use of these gases for processes at the steel mill versus for energy generation (i.e., electricity and steam generation); therefore, all consumption is attributed to iron and steel production. These data and carbon contents produce a relatively accurate estimate of CO_2 emissions. However, there are uncertainties associated with each.

The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 4-71 for metallurgical coke production and iron and steel production. Total CO_2 emissions from metallurgical coke production and iron and steel production were estimated to be between 47.2 and 63.6 MMT CO_2 Eq. at the 95 percent confidence level. This indicates a range of approximately 15 percent below and 15 percent above the emission estimate of 55.4 MMT CO_2 Eq. Total CH_4 emissions from metallurgical coke production and iron and steel production were estimated to be between 0.008 and 0.01 MMT CO_2 Eq. at the 95 percent confidence level. This indicates a range of approximately 19 percent below and 19 percent above the emission estimate of 0.009 MMT CO_2 Eq.

Table 4-71: Approach 2 Quantitative Uncertainty Estimates for CO_2 and CH_4 Emissions from Iron and Steel Production and Metallurgical Coke Production (MMT CO_2 Eq. and Percent)

Source	Gas	2014 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Metallurgical Coke & Iron and Steel Production	CO_2	55.4	47.2	63.6	-15%	+15%
Metallurgical Coke & Iron and Steel Production	CH_4	+	+	+	-19%	+19%

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Methodological recalculations were applied to the entire time series to ensure consistency in emissions from 1990 through 2014. Details on the emission trends through time are described in more detail in the Methodology section, above.

Recalculations Discussion

Several adjustments were incorporated into the emission calculations for the Iron and Steel Production and Metallurgical Coke Production source categories. These adjustments applied to the entire time series from 1990 to 2014 and are briefly described below.

Previous Inventory reports included CH_4 emissions calculated using a Tier 1 CH_4 emission factor for two different production processes: metallurgical coke and pig iron. However, the use of a Tier 1 CH_4 emission factor was not applicable for the metallurgical coke and pig iron production processes in the United States, because the CO_2 emissions for these production processes were estimated using the Tier 2 mass balance methodology. The Tier 2 mass balance methodology makes a basic assumption that all carbon that enters the specific production process either exits the process as part of a carbon-containing output or as CO_2 emissions; the estimation of CH_4 emissions is necessarily precluded by definition. Because CO_2 emissions for the sinter production process were estimated using a Tier 1 CO_2 emission factor, it is still appropriate to use a Tier 1 CH_4 emission factor for the sinter production process. Due to exclusion of CH_4 emissions from the metallurgical coke and pig iron production processes, CH_4 emissions reported in the Inventory were significantly reduced. This assumption and the revisions are further supported by a preliminary analysis of annual facility-level CH_4 reported to EPA's GHGRP from the iron and coke production processes.

Previous Inventory reports have also relied significantly on activity data (i.e., production and input statistics) from AISI's *Annual Statistical Report* (AISI 2004 through 2015a); three key fuels used in the Tier 2 mass balance methodology were natural gas, coke oven gas, and blast furnace gas. For all three of these fuels, volumetric consumption was multiplied by a heat content to obtain the quantity of energy, which was then multiplied by carbon content to obtain the quantity of carbon. The heat content of natural gas was obtained from EIA's *Natural Gas Annual* (EIA 2015a) and varied from year to year with values ranging from 1,022 to 1,031 BTU/ft^3, while the heat contents of coke oven gas (500 BTU/ft^3) and blast furnace gas (90 BTU/ft^3) were obtained from the report, *Energy and Environmental Profile of the U.S. Iron and Steel Industry* (DOE 2000). However, close examination of Table 37 of the AISI's *Annual Statistical Report* (AISI 2004 through 2015a) indicates that the reported quantities of natural gas and blast furnace gas have different reporting bases based on heat contents (i.e., 1,000 BTU/ft^3 for natural gas and 95 BTU/ft^3 for blast furnace gas); the reporting basis for coke oven gas is identically 500 BTU/ft^3. AISI staff confirmed that the reporting bases included in Table 37 of the AISI's *Annual Statistical Report* (AISI 2004 through 2015a) have been used dating back to at least 1990. Therefore, the use of other heat contents with AISI's data is not appropriate. The heat content of natural gas was changed to 1,000 BTU/ft^3 for all years in the time series and the heat content of blast furnace gas was changed to 95 BTU/ft^3. Because blast furnace gas is used as both an input and an output in the Tier 2 mass balance methodology, the use of revised heat contents for natural gas and blast furnace gas only resulted in a slight decrease in estimated CO_2 emissions; however, the CO_2 emissions for individual production processes did change noticeably. For instance, across the entire time series, an increase in CO_2 emissions from heating, annealing, and other processes was essentially offset by a decrease in CO_2 emissions from the iron production process.

Planned Improvements

Future improvements involve improving completeness by including emissions from pellet production. The current version of the Inventory includes pellet consumption within the iron & steel sector, but does not include greenhouse gas emissions from pellet production. The EPA has identified a potential activity data source for national-level pellet production and will include this emission source in the future versions of the Inventory. EPA will also evaluate and analyze data reported under EPA's GHGRP by taconite indurating furnaces to improve the emission estimates for this and other Iron and Steel Production process categories. Particular attention will be made to ensure time series consistency of the emissions estimates presented in future Inventory reports, consistent with IPCC and UNFCCC guidelines. This is required as the facility-level reporting data from EPA's GHGRP, with the program's initial requirements for reporting of emissions in calendar year 2010, are not available for all inventory years (i.e., 1990 through 2009) as required for this Inventory. In implementing improvements and integration of data from EPA's GHGRP, the latest guidance from the IPCC on the use of facility-level data in national inventories will be relied upon.[30]

Additional improvements include accounting for emission estimates for the production of metallurgical coke to the Energy chapter as well as identifying the amount of carbonaceous materials, other than coking coal, consumed at merchant coke plants. Other potential improvements include identifying the amount of coal used for direct injection and the amount of coke breeze, coal tar, and light oil produced during coke production. Efforts will also be made to identify information to better characterize emissions from the use of process gases and fuels within the Energy and Industrial Processes and Product Use chapters.

4.17 Ferroalloy Production (IPCC Source Category 2C2)

Carbon dioxide (CO_2) and methane (CH_4) are emitted from the production of several ferroalloys. Ferroalloys are composites of iron (Fe) and other elements such as silicon (Si), manganese (Mn), and chromium (Cr). Emissions from fuels consumed for energy purposes during the production of ferroalloys are accounted for in the Energy chapter. Emissions from the production of two types of ferrosilicon (25 to 55 percent and 56 to 95 percent silicon), silicon metal (96 to 99 percent silicon), and miscellaneous alloys (32 to 65 percent silicon) have been calculated. Emissions from the production of ferrochromium and ferromanganese are not included here because of the small number of manufacturers of these materials in the United States, and therefore, government information disclosure rules prevent the publication of production data for these production facilities.

Similar to emissions from the production of iron and steel, CO_2 is emitted when metallurgical coke is oxidized during a high-temperature reaction with iron and the selected alloying element. Due to the strong reducing environment, CO is initially produced, and eventually oxidized to CO_2. A representative reaction equation for the production of 50 percent ferrosilicon (FeSi) is given below:

$$\mathrm{Fe_2O_3 + 2SiO_2 + 7C \rightarrow 2FeSi + 7CO}$$

While most of the carbon contained in the process materials is released to the atmosphere as CO_2, a percentage is also released as CH_4 and other volatiles. The amount of CH_4 that is released is dependent on furnace efficiency, operation technique, and control technology.

30 See <http://www.ipcc-nggip.iges.or.jp/meeting/pdffiles/1008_Model_and_Facility_Level_Data_Report.pdf>.