ANNEX 7 Uncertainty

The annual U.S. Inventory presents the best effort to produce estimates for greenhouse gas source and sink categories in the United States. These estimates were generated according to the UNFCCC reporting guidelines, following the recommendations set forth in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006), the *IPCC Good Practice Guidance* (IPCC 2000), the *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003), and the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2013). This Annex provides an overview of the uncertainty analysis conducted to support the U.S. Inventory, describes the sources of uncertainty characterized throughout the Inventory associated with various source categories (including emissions and sinks), and describes the methods through which uncertainty information was collected, quantified, and presented.

7.1. Overview

The current inventory emission estimates for some source categories, such as for CO_2 Emissions from Fossil Fuel Combustion, have relatively low level of uncertainty associated with them. However, for some other source categories, the inventory emission estimates are considered less certain. The two major types of uncertainty associated with these emission estimates are (1) model uncertainty, which arises when the emission and/or removal estimation models used in developing the inventory estimates do not fully and accurately characterize the respective emission and/or removal processes (due to a lack of technical details or other resources), resulting in the use of incorrect or incomplete estimation methodologies and (2) parameter uncertainty, which arises due to a lack of precise input data such as emission factors and activity data.

The model uncertainty can be partially analyzed by comparing the model results with those of other models developed to characterize the same emission (or removal) process, after taking into account the differences in their conceptual framework, capabilities, data and assumptions. However, it would be very difficult—if not impossible—to quantify the model uncertainty associated with the emission estimates (primarily because, in most cases, only a single model has been developed to estimate emissions from any one source). Therefore, model uncertainty was not quantified in this report. Nonetheless, it has been discussed qualitatively, where appropriate, along with the individual source category description and inventory estimation methodology.

Parameter uncertainty is, therefore, the principal type and source of uncertainty associated with the national inventory emission estimates and is the main focus of the quantitative uncertainty analyses in this report. Parameter uncertainty has been quantified for all of the emission sources and sinks in the U.S. Inventory, with the exception of one very small emission source category, CH_4 emissions from Incineration of Waste, which was included in the *1990-2008 National GHG Inventory* for the first time, and two other source categories (International Bunker Fuels and biomass energy consumption) whose emissions are not included in the Inventory totals.

The primary purpose of the uncertainty analysis conducted in support of the U.S. Inventory is (i) to determine the quantitative uncertainty associated with the emission (and removal) estimates presented in the main body of this report [based on the uncertainty associated with the input parameters used in the emission (and removal) estimation methodologies] and (ii) to evaluate the relative importance of the input parameters in contributing to uncertainty in the associated source category inventory estimate and in the overall inventory estimate. Thus, the U.S. Inventory uncertainty analysis provides a strong foundation for developing future improvements and revisions to the Inventory estimation process. For each source category, the analysis highlights opportunities for changes to data measurement, data collection, and calculation methodologies. These are presented in the "Planned Improvements" sections of each source category's discussion in the main body of the report.

7.2. Methodology and Results

The United States has developed a quality assurance and quality control (QA/QC) and uncertainty management plan (EPA 2002) in accordance with the IPCC *Good Practice Guidance* (IPCC 2000). Like the QA/QC plan, the uncertainty management plan is part of a continually evolving process. The uncertainty management plan provides for a quantitative assessment of the inventory analysis itself, thereby contributing to continuing efforts to understand both what causes uncertainty and how to improve inventory quality. Although the plan provides both general and specific guidelines for implementing quantitative uncertainty analysis, its components are intended to evolve over time, consistent with the inventory estimation process. The U.S. plan includes procedures and guidelines, and forms and templates, for developing quantitative assessments of uncertainty in the national Inventory estimates (EPA 2002). For the 1990-2013 Inventory, EPA has used the uncertainty management plan as well as the methodology presented in the *2006 IPCC Guidelines.*

The *2006 IPCC Guidelines* recommends two methods—Approach 1 and Approach 2—for developing quantitative estimates of uncertainty in the inventory estimate of individual source categories and the overall inventory. Of these, the Approach 2 method is both more flexible and reliable than Approach 1; both approaches are described in the next section. The United States is in the process of implementing a multi-year strategy to develop quantitative estimates of uncertainty for all source categories using the Approach 2. For the current Inventory, an Approach 2 method was implemented for all source categories with the exception of Composting and parts of Agricultural Soil Management source categories.

The current Inventory reflects significant improvements over the previous publication in the extent to which the Approach 2 method to uncertainty analysis was adopted. Each of the new Approach 2 analyses reflects additional detail and characterization of input parameters using statistical data collection, expert elicitation methods and more informed judgment. In following the UNFCCC requirement under Article 4.1, emissions from International Bunker Fuels and Indirect Greenhouse Gas Emissions are not included in the total emissions estimated for the U.S. Inventory; therefore, no quantitative uncertainty estimates have been developed for these source categories.[1] Emissions from biomass combustion are accounted for implicitly in the LULUCF chapter through the calculation of changes in carbon stocks. The Energy sector does provide an estimate of CO_2 emissions from bioenergy consumption provided as a memo item for informational purposes in line with the UNFCCC reporting requirements.

Approach 1 and Approach 2 Methods

The Approach 1 method for estimating uncertainty is based on the error propagation equation. This equation combines the uncertainty associated with the activity data and the uncertainty associated with the emission (or the other) factors. The Approach 1 method is applicable where emissions (or removals) are usually estimated as the product of an activity value and an emission factor or as the sum of individual sub-source category values. Inherent in employing the Approach 1 method are the assumptions that, for each source category, (i) both the activity data and the emission factor values are approximately normally distributed, (ii) the coefficient of variation (i.e., the ratio of the standard deviation to the mean) associated with each input variable is less than 30 percent, and (iii) the input variables within and across (sub-) source categories are not correlated (i.e., value of each variable is independent of the values of other variables).

The Approach 2 method is preferred (i) if the uncertainty associated with the input variables is significantly large, (ii) if the distributions underlying the input variables are not normal, (iii) if the estimates of uncertainty associated with the input variables are correlated, and/or (iv) if a sophisticated estimation methodology and/or several input variables are used to characterize the emission (or removal) process correctly. In practice, the Approach 2 is the preferred method of uncertainty analysis for all source categories where sufficient and reliable data are available to characterize the uncertainty of the input variables.

The Approach 2 method employs the Monte Carlo Stochastic Simulation technique (also referred to as the Monte Carlo method). Under this method, estimates of emissions (or removals) for a particular source category are generated many times (equal to the number of simulations specified) using an uncertainty model, which is an emission (or removal) estimation equation that imitates or is the same as the inventory estimation model for a particular source category. These estimates are generated using the respective, randomly-selected values for the constituent input variables using commercially available simulation software such as *@RISK* or *Crystal Ball*.

Characterization of Uncertainty in Input Variables

Both Approach 1 and Approach 2 uncertainty analyses require that all the input variables are well-characterized in terms of their Probability Density Functions (PDFs). In the absence of particularly convincing data measurements, sufficient data samples, or expert judgments that determined otherwise, the PDFs incorporated in the current source category uncertainty analyses were limited to normal, lognormal, uniform, triangular, and beta distributions. The choice among these five PDFs depended largely on the observed or measured data and expert judgment.

[1] However, because the input variables that determine the emissions from the Fossil Fuel Combustion and the International Bunker Fuels source categories are correlated, uncertainty associated with the activity variables in the International Bunker Fuels was taken into account in estimating the uncertainty associated with the Fossil Fuel Combustion.

Source Category Inventory Uncertainty Estimates

Discussion surrounding the input parameters and sources of uncertainty for each source category appears in the body of this report. Table A-289 summarizes results based on assessments of source category-level uncertainty. The table presents base year (1990 or 1995) and current year (2013) emissions for each source category. The combined uncertainty (at the 95 percent confidence interval) for each source category is expressed as the percentage deviation above and below the total 2013 emissions estimated for that source category. Source category trend uncertainty is described subsequently in this Appendix.

Table A-289: Summary Results of Source Category Uncertainty Analyses

Source Category	Base Year Emissions[i,a]	2013 Emissions[a]	2013 Uncertainty[b]	
	MMT CO_2 Eq.	MMT CO_2 Eq.	Low	High
CO_2	**5,123.3**	**5,504.8**	**-3%**	**4%**
Fossil Fuel Combustion[c]	4,740.3	5,157.3	-2%	5%
Non-Energy Use of Fuels	117.7	119.8	-26%	38%
Iron and Steel Production & Metallurgical Coke Production	99.8	52.3	-17%	17%
Natural Gas Systems	37.6	37.8	-19%	30%
Cement Production	33.3	36.1	-6%	6%
Petrochemical Production	21.6	26.5	-5%	5%
Lime Production	11.7	14.1	-3%	3%
Ammonia Production	13.0	10.2	-8%	8%
Incineration of Waste	8.0	10.1	-10%	13%
Petroleum Systems	4.4	6.0	-24%	149%
Liming of Agricultural Soils	4.7	5.9	-88%	103%
Urea Consumption for Non-Agricultural Purposes	3.8	4.7	-10%	10%
Other Process Uses of Carbonates	4.9	4.4	-8%	8%
Urea Fertilization	2.4	4.0	-42%	3%
Aluminum Production	6.8	3.3	-2%	2%
Soda Ash Production and Consumption	2.7	2.7	-7%	6%
Ferroalloy Production	2.2	1.8	-12%	12%
Titanium Dioxide Production	1.2	1.6	-13%	13%
Zinc Production	0.6	1.4	-16%	18%
Glass Production	1.5	1.2	-5%	4%
Phosphoric Acid Production	1.6	1.2	-18%	21%
Carbon Dioxide Consumption	1.5	0.9	-10%	16%
Peatlands Remaining Peatlands	1.1	0.8	-28%	31%
Lead Production	0.5	0.5	-14%	15%
Silicon Carbide Production and Consumption	0.4	0.2	-9%	9%
Magnesium Production and Processing	0.0	0.0	-20%	20%
Land Use, Land-Use Change, and Forestry (Sink)[d]	*(775.8)*	*(881.7)*	*18%*	*-15%*
Wood Biomass[e]	*215.2*	*208.6*	*NE*	*NE*
International Bunker Fuels[f]	*103.5*	*99.8*	*NE*	*NE*
Biomass – Ethanol[e]	*4.2*	*74.7*	*NE*	*NE*
CH_4	**745.5**	**636.3**	**-13%**	**14%**
Enteric Fermentation	164.2	164.5	-11%	18%
Natural Gas Systems	179.1	157.4	-19%	30%
Landfills	186.2	114.6	-56%	49%
Coal Mining	96.5	64.6	-12%	16%
Manure Management	37.2	61.4	-18%	20%
Petroleum Systems	31.5	25.2	-24%	149%
Wastewater Treatment	15.7	15.0	-39%	2%
Rice Cultivation	9.2	8.3	-50%	91%
Stationary Combustion	8.5	8.0	-42%	157%
Abandoned Underground Coal Mines	7.2	6.2	-20%	24%
Forest Fires	2.5	5.8	-81%	164%
Mobile Combustion	5.6	2.1	-13%	21%

Composting	0.4	2.0	-50%	50%
Iron and Steel Production & Metallurgical Coke Production	1.1	0.7	-21%	22%
Field Burning of Agricultural Residues	0.3	0.3	-41%	42%
Petrochemical Production	0.2	0.1	-61%	22%
Ferroalloy Production	0.0	0.0	-12%	12%
Silicon Carbide Production and Consumption	0.0	0.0	-9%	10%
Peatlands Remaining Peatlands	0.0	0.0	-60%	85%
Incineration of Waste	0.0	0.0	NE	NE
International Bunker Fuels[f]	*0.2*	*0.1*	*NE*	*NE*
N_2O	**329.9**	**355.2**	**-9%**	**41%**
Agricultural Soil Management	224.0	263.7	-18%	47%
Stationary Combustion	11.9	22.9	-27%	40%
Mobile Combustion	41.2	18.4	-10%	20%
Manure Management	13.8	17.3	-16%	24%
Nitric Acid Production	12.1	10.7	-5%	5%
Wastewater Treatment	3.4	4.9	-76%	107%
N_2O from Product Uses	4.2	4.2	-24%	24%
Adipic Acid Production	15.2	4.0	-4%	4%
Forest Fires	1.7	3.8	-72%	139%
Settlement Soils	1.4	2.4	-98%	268%
Composting	0.3	1.8	-50%	50%
Incineration of Waste	0.5	0.3	-52%	323%
Semiconductor Manufacture	0.0	0.2	-1%	1%
Field Burning of Agricultural Residues	0.1	0.1	-30%	31%
Peatlands Remaining Peatlands	0.0	0.0	-55%	63%
International Bunker Fuels[f]	*1.1*	*1.0*	*NE*	*NE*
HFCs, PFCs, SF_6, and NF_3	**136.7**	**171.0**	**-3%**	**9%**
Substitution of Ozone Depleting Substances[g]	35.0	153.3	0%	12%
Electrical Transmission and Distribution	25.4	5.1	-20%	19%
HCFC-22 Production	46.1	4.1	-7%	10%
Semiconductor Manufacture	3.6	4.0	-5%	5%
Aluminum Production	21.5	3.0	-5%	6%
Magnesium Production	5.2	1.5	-13%	18%
Total[h]	**6,335.4**	**6,667.2**	**-2%**	**5%**
Net Emissions (Sources and Sinks)[h]	**5,559.5**	**5,785.5**	**-3%**	**6%**

Note: Totals may not sum due to independent rounding.
NE: Not Estimated
+ Does not exceed 0.05 MMT CO_2 Eq.
[a] Emission estimates reported in this table correspond to emissions from only those source categories for which quantitative uncertainty was performed for the current Inventory. Thus the totals reported for 2013 in this table exclude approximately 5.7 MMT CO_2 Eq. of emissions for which quantitative uncertainty was not assessed. Hence, these emission estimates do not match the final total U.S. greenhouse gas emission estimates presented in this Inventory. All uncertainty estimates correspond only to the totals reported in this table.
[b] The uncertainty estimates correspond to a 95 percent confidence interval, with the lower bound corresponding to 2.5th percentile and the upper bound corresponding to 97.5th percentile.
[c] This source category's inventory estimates exclude CO_2 emissions from geothermal sources, as quantitative uncertainty analysis was not performed for that sub-source category. Hence, for this source category, the emissions reported in this table do not match the emission estimates presented in the Energy chapter of the Inventory.
[d] Sinks are only included in Net Emissions.
[e] Emissions from Wood Biomass and Ethanol Consumption are not included specifically in summing energy sector totals.
[f] Emissions from International Bunker Fuels are not included in the totals.
[g] This source category's estimate for 2013 excludes 5.3 MMT of CO_2 Eq. from several very small emission sources, as uncertainty associated with those sources was not assessed. Hence, for this source category, the emissions reported in this table do not match the emission estimates presented in the Industrial Processes and Product Use chapter of the Inventory.
[h] Totals exclude emissions for which uncertainty was not quantified.
[i] Base Year is 1990 for all sources except Substitution of Ozone Depleting Substances, for which the United States has chosen 1995.

Overall (Aggregate) Inventory Level Uncertainty Estimates

The overall level uncertainty estimate for the U.S. greenhouse gas emissions inventory was developed using the IPCC Approach 2 uncertainty estimation methodology. The uncertainty models of all the emission source categories could not be directly integrated to develop the overall uncertainty estimates due to software constraints in integrating multiple, large uncertainty models. Therefore, an alternative approach was adopted to develop the overall uncertainty estimates. The Monte Carlo simulation output data for each emission source category uncertainty analysis were combined by type of gas and the probability distributions were fitted to the combined simulation output data, where such simulated output data were available. If such detailed output data were not available for particular emissions sources, individual probability distributions were assigned to those source category emission estimates based on the most detailed data available from the quantitative uncertainty analysis performed.

For the Composting and for parts of Agricultural Soil Management source categories, Approach 1 uncertainty results were used in the overall uncertainty analysis estimation. However, for all other emission sources (excluding international bunker fuels, CO_2 from biomass combustion, and CH_4 from incineration of waste), Approach 2 uncertainty results were used in the overall uncertainty estimation.

The overall uncertainty model results indicate that the 2013 U.S. greenhouse gas emissions are estimated to be within the range of approximately 6,584 to 7,008 MMT CO_2 Eq., reflecting a relative 95 percent confidence interval uncertainty range of -1 percent to 5 percent with respect to the total U.S. greenhouse gas emission estimate of approximately 6,667 MMT CO_2 Eq. The uncertainty interval associated with total CO_2 emissions, which constitute about 83 percent of the total U.S. greenhouse gas emissions in 2013, ranges from -2 percent to 5 percent of total CO_2 emissions estimated. The results indicate that the uncertainty associated with the inventory estimate of the total CH_4 emissions ranges from -10 percent to 18 percent, uncertainty associated with the total inventory N_2O emission estimate ranges from -10 percent to 25 percent, and uncertainty associated with high GWP gas emissions ranges from -1 percent to 11 percent.

A summary of the overall quantitative uncertainty estimates is shown below.

Table A-290: Quantitative Uncertainty Assessment of Overall National Inventory Emissions (MMT CO_2 Eq. and Percent)

Gas	2013 Emission Estimate[a] (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[b] (MMT CO_2 Eq.)		(%)		Mean[c] (MMT CO_2 Eq.)	Standard Deviation[c] (MMT CO_2 Eq.)
		Lower Bound[d]	Upper Bound[d]	Lower Bound	Upper Bound		
CO_2	5,504.8	5,400	5,766	-2%	5%	5,584	95
CH_4[e]	636.3	573	751	-10%	18%	656	45
N_2O[e]	355.2	320	445	-10%	25%	376	32
PFC, HFC, SF_6, and NF_3[e]	171.0	170	190	-1%	11%	180	5
Total	**6,667.2**	**6,584**	**7,008**	**-1%**	**5%**	**6,795**	**110**
Net Emissions (Sources and Sinks)	**5,785.5**	**5,613**	**6,220**	**-3%**	**8%**	**5,916**	**154**

Notes:

[a] Emission estimates reported in this table correspond to emissions from only those source categories for which quantitative uncertainty was performed this year. Thus the totals reported in this table exclude approximately 5.7 MMT CO_2 Eq. of emissions for which quantitative uncertainty was not assessed. Hence, these emission estimates do not match the final total U.S. greenhouse gas emission estimates presented in this Inventory.

[b] The lower and upper bounds for emission estimates correspond to a 95 percent confidence interval, with the lower bound corresponding to 2.5th percentile and the upper bound corresponding to 97.5th percentile.

[c] Mean value indicates the arithmetic average of the simulated emission estimates; standard deviation indicates the extent of deviation of the simulated values from the mean.

[d] The lower and upper bound emission estimates for the sub-source categories do not sum to total emissions because the low and high estimates for total emissions were calculated separately through simulations.

[e] The overall uncertainty estimates did not take into account the uncertainty in the GWP values for CH_4, N_2O and high GWP gases used in the inventory emission calculations for 2013.

Trend Uncertainty

In addition to the estimates of uncertainty associated with the current year's emission estimates, this Annex also presents the estimates of trend uncertainty. The *2006 IPCC Guidelines* defines trend as the difference in emissions between the base year (i.e., 1990) and the current year (i.e., 2013) inventory estimates. However, for purposes of understanding the concept of trend uncertainty, the emission trend is defined in this Inventory as the percentage change in the emissions (or removal) estimated for the current year, relative to the emission (or removal) estimated for the base year. The uncertainty associated with this emission trend is referred to as trend uncertainty.

Under the Approach 1 method, the trend uncertainty for a source category is estimated using the sensitivity of the calculated difference between the base year and the current year (i.e., 2013) emissions to an incremental (i.e., 1 percent) increase in one or both of these values for that source category. The two sensitivities are expressed as percentages: Type A sensitivity highlights the effect on the difference between the base and the current year emissions caused by a 1 percent change in both, while Type B sensitivity highlights the effect caused by a change to only the current year's emissions. Both sensitivities are simplifications introduced in order to analyze the correlation between the base and the current year estimates. Once calculated, the two sensitivities are combined using the error propagation equation to estimate the overall trend uncertainty.

Under the Approach 2 method, the trend uncertainty is estimated using Monte Carlo Stochastic Simulation technique. The trend uncertainty analysis takes into account the fact that the base and the current year estimates often share input variables. For purposes of the current Inventory, a simple approach has been adopted, under which the base year source category emissions (or removals) are assumed to exhibit the same uncertainty characteristics as the current year emissions (or removals). Source category-specific PDFs for base year estimates were developed using current year (i.e., 2013) uncertainty output data. These were adjusted to account for differences in magnitude between the two years' inventory estimates. Then, for each source category, a trend uncertainty estimate was developed using the Monte Carlo method. The overall inventory trend uncertainty estimate was developed by combining all source category-specific trend uncertainty estimates. These trend uncertainty estimates present the range of likely change from base year to 2013, and are shown in Table A- 291.

Table A- 291: Quantitative Assessment of Trend Uncertainty (MMT CO_2 Eq. and Percent)

Gas/Source	Base Year Emissions[i,a]	2013 Emissions[a]	Emissions Trend[a]	Trend Range[a,b]	
	(MMT CO_2 Eq.)		(%)	(%)	
				Lower Bound	Upper Bound
CO_2	**5,123.3**	**5,504.8**	**7%**	**3%**	**13%**
Fossil Fuel Combustion[c]	4,740.3	5,157.3	9%	3%	14%
Non-Energy Use of Fuels	117.7	119.8	2%	-37%	67%
Iron and Steel Production & Metallurgical Coke Production	99.8	52.3	-48%	-59%	-33%
Natural Gas Systems	37.6	37.8	0%	-29%	42%
Cement Production	33.3	36.1	9%	-1%	19%
Petrochemical Production	21.6	26.5	23%	15%	31%
Lime Production	11.7	14.1	20%	16%	25%
Ammonia Production	13.0	10.2	-22%	-30%	-13%
Incineration of Waste	8.0	10.1	27%	8%	50%
Petroleum Systems	4.4	6.0	35%	-41%	217%
Liming of Agriculture Soils	4.7	5.9	27%	-103%	562%
Urea Consumption for Non-Agricultural Purposes	3.8	4.7	23%	7%	42%
Other Process Uses of Carbonates	4.9	4.4	-10%	-19%	1%
Urea Fertilization	2.4	4.0	66%	7%	152%
Aluminum Production	6.8	3.3	-52%	-54%	-51%
Soda Ash Production and Consumption	2.7	2.7	-1%	-10%	9%
Ferroalloy Production	2.2	1.8	-17%	-30%	-1%
Titanium Dioxide Production	1.2	1.6	35%	12%	61%
Zinc Production	0.6	1.4	126%	78%	188%
Phosphoric Acid Production	1.6	1.2	-26%	-45%	-1%
Glass Production	1.5	1.2	-24%	-29%	-19%
Carbon Dioxide Consumption	1.5	0.9	-39%	-48%	-26%
Wetlands Remaining Wetlands	1.1	0.8	-27%	-52%	13%
Lead Production	0.5	0.5	2%	-18%	25%
Silicon Carbide Production and Consumption	0.4	0.2	-55%	-60%	-49%
Magnesium Production and Processing	+	+	54%	-70%	61%
Land Use, Land-Use Change, and Forestry (Sink)[a]	*(775.8)*	*(881.7)*	*14%*	*-20%*	*61%*
Biomass – Wood[e]	*215.2*	*208.6*	*-3%*	*NE*	*NE*
International Bunker Fuels[f]	*103.5*	*99.8*	*-4%*	*NE*	*NE*
Biomass – Ethanol[e]	*4.2*	*74.7*	*1668%*	*NE*	*NE*

CH_4	**745.5**	**636.3**	**-15%**	**-32%**	**2%**
Enteric Fermentation	164.2	164.5	0%	-18%	24%
Landfills	186.2	114.6	-38%	-74%	50%
Coal Mining	96.5	64.6	-33%	-51%	-25%
Manure Management	37.2	61.4	65%	10%	132%
Iron and Steel Production & Metallurgical Coke Production	99.8	52.3	-48%	-56%	-17%
Natural Gas Systems	37.6	37.8	0%	-37%	24%
Petrochemical Production	21.6	26.5	23%	-84%	-14%
Wastewater Treatment	15.7	15.0	-4%	-68%	9%
Incineration of Waste	8.0	10.1	27%	NE	NE
Rice Cultivation	9.2	8.3	-9%	-65%	135%
Stationary Combustion	8.5	8.0	-6%	-70%	202%
Abandoned Underground Coal Mines	7.2	6.2	-14%	-45%	25%
Petroleum Systems	4.4	6.0	35%	-65%	89%
Forest Fires	2.5	5.8	131%	-66%	1,555%
Mobile Combustion	5.6	2.1	-62%	-70%	-51%
Composting	0.4	2.0	415%	130%	1,050%
Ferroalloy Production	2.2	1.8	-17%	-38%	-13%
Peatlands Remaining Peatlands	1.1	0.8	-27%	-30%	-30%
Field Burning of Agricultural Residues	0.3	0.3	-2%	-48%	84%
Silicon Carbide Production and Consumption	0.4	0.2	-55%	-71%	-62%
International Bunker Fuels[f]	*103.5*	*99.8*	*-4%*	*NE*	*NE*
N_2O	**329.9**	**355.2**	**8%**	**-25%**	**55%**
Agricultural Soil Management	224.0	263.7	18%	-28%	92%
Manure Management	37.2	61.4	65%	-5%	66%
Wastewater Treatment	15.7	15.0	-4%	-71%	521%
Nitric Acid Production	12.1	10.7	-12%	-18%	-5%
Incineration of Waste	8.0	10.1	27%	-85%	216%
Stationary Combustion	8.5	8.0	-6%	20%	202%
Forest Fires	2.5	5.8	131%	NE	NE
N_2O from Product Uses	4.2	4.2	0%	-32%	46%
Adipic Acid Production	15.2	4.0	-74%	-75%	-72%
Settlement Soils	1.4	2.4	77%	-96%	6,877%
Mobile Combustion	5.6	2.1	-62%	-64%	-45%
Composting	0.4	2.0	415%	131%	1,060%
Peatlands Remaining Peatlands	1.1	0.8	-27%	-72%	81%
Forest Soils	0.1	0.5	455%	NE	NE
Field Burning of Agricultural Residues	0.3	0.3	-2%	-32%	67%
International Bunker Fuels[f]	*103.5*	*99.8*	*-4%*	*NE*	*NE*
HFCs, PFCs, SF_6 and NF_3	**136.7**	**171.0**	**25%**	**21%**	**39%**
Substitution of Ozone Depleting Substances	35.0	153.3	338%	303%	376%
Electrical Transmission and Distribution	25.4	5.1	-80%	-85%	-73%
HCFC-22 Production	46.1	4.1	-91%	-92%	-90%
Aluminum Production	6.8	3.3	-52%	-87%	-85%
Semiconductor Manufacture	+	0.2	404%	4%	20%
Magnesium Production and Processing	+	+	54%	-75%	-65%
Total[h]	**6,335.4**	**6,667.2**	**5%**	**0%**	**11%**
Net Emission (Sources and Sinks)	**5,559.5**	**5,785.5**	**4%**	**-3%**	**11%**

Note: Totals may not sum due to independent rounding.

NE: Not Estimated

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Emission estimates reported in this table correspond to emissions from only those source categories for which quantitative uncertainty was performed for the current Inventory. Thus the totals reported for 2013 in this table exclude approximately 5.7 MMT CO_2 Eq. of emissions for which quantitative uncertainty was not assessed. Hence, these emission estimates do not match the final total U.S. greenhouse gas emission estimates presented in this Inventory. All uncertainty estimates correspond only to the totals reported in this table.

[b] The trend range represents a 95 percent confidence interval for the emission trend, with the lower bound corresponding to 2.5th percentile value and the upper bound corresponding to 97.5th percentile value.

[c] This source category's inventory estimates exclude CO_2 emissions from geothermal sources, as quantitative uncertainty analysis was not performed for that sub-source category. Hence, for this source category, the emissions reported in this table do not match the emission estimates presented in the Energy chapter of the Inventory.

[d] Sinks are only included in Net Emissions.

[e] Emissions from Wood Biomass and Ethanol Consumption are not included specifically in summing energy sector totals.

[f] Emissions from International Bunker Fuels are not included in the totals.

[g] This source category's estimate for 2013 excludes 5.3 MMT of CO_2 Eq. from several very small emission sources, as uncertainty associated with those sources was not assessed. Hence, for this source category, the emissions reported in this table do not match the emission estimates presented in the Industrial Processes and Product Use chapter of the Inventory.
[h] Totals exclude emissions for which uncertainty was not quantified. .
[i] Base Year is 1990 for all sources except Substitution of Ozone Depleting Substances, for which the United States has chosen 1995.

7.3. Planned Improvements

Identifying the sources of uncertainty in the emission and sink estimates of the Inventory and quantifying the magnitude of the associated uncertainty is the crucial first step towards improving those estimates. Quantitative assessment of the parameter uncertainty may also provide information about the relative importance of input parameters (such as activity data and emission factors), based on their relative contribution to the uncertainty within the source category estimates. Such information can be used to prioritize resources with a goal of reducing uncertainty over time within or among inventory source categories and their input parameters. In the current Inventory, potential sources of model uncertainty have been identified for some emission source categories, and uncertainty estimates based on their parameters' uncertainty have been developed for all the emission source categories, with the exception of CH_4 from incineration of waste, which is a minor emission source category newly added to the Inventory starting with the 2008 business year, and the international bunker fuels and wood biomass and ethanol combustion source categories, which are not included in the energy sector totals. Emissions from biomass and ethanol combustion however are accounted for implicitly in the LULUCF chapter through the calculation of changes in carbon stocks. The Energy sector does provide an estimate of CO_2 emissions from bioenergy consumption provided as a memo item for informational purposes.

Specific areas that require further research include:

- *Incorporating excluded emission sources.* Quantitative estimates for some of the sources and sinks of greenhouse gas emissions, such as from some land-use activities, industrial processes, and parts of mobile sources, could not be developed at this time either because data are incomplete or because methodologies do not exist for estimating emissions from these source categories. See Annex 5 of this report for a discussion of the sources of greenhouse gas emissions and sinks excluded from this report. In the future, efforts will focus on estimating emissions from excluded emission sources and developing uncertainty estimates for all source categories for which emissions are estimated.
- *Improving the accuracy of emission factors.* Further research is needed in some cases to improve the accuracy of emission factors used to calculate emissions from a variety of sources. For example, the accuracy of current emission factors applied to CH_4 and N_2O emissions from stationary and mobile combustion are highly uncertain.
- *Collecting detailed activity data.* Although methodologies exist for estimating emissions for some sources, problems arise in obtaining activity data at a level of detail in which aggregate emission factors can be applied. For example, the ability to estimate emissions of SF_6 from electrical transmission and distribution is limited due to a lack of activity data regarding national SF_6 consumption or average equipment leak rates.

In improving the quality of uncertainty estimates the following include areas that deserve further attention:

- *Refine Source Category and Overall Uncertainty Estimates.* For many individual source categories, further research is needed to more accurately characterize PDFs that surround emissions modeling input variables. This might involve using measured or published statistics or implementing rigorous elicitation protocol to elicit expert judgments, if published or measured data are not available.
- *Include GWP uncertainty in the estimation of Overall level and trend uncertainty.* The current year's Inventory does not include the uncertainty associated with the GWP values in the estimation of the overall uncertainty for the Inventory. Including this source would contribute to a better characterization of overall uncertainty and help assess the level of attention that this source of uncertainty warrants in the future.
- *Improve characterization of trend uncertainty associated with base year Inventory estimates.* The characterization of base year uncertainty estimates could be improved, by developing explicit uncertainty models for the base year. This would then improve the analysis of trend uncertainty. However, not all of the simplifying assumptions described in the "Trend Uncertainty" section above may be eliminated through this process due to a lack of availability of more appropriate data.

7.4. Additional Information on Uncertainty Analyses by Source

The quantitative uncertainty estimates associated with each emission and sink source category are reported in each chapter of this Inventory following the discussions of inventory estimates and their estimation methodology. This section provides additional descriptions of the uncertainty analyses performed for some of the sources, including the models and methods used to calculate the emission estimates and the potential sources of uncertainty surrounding them. These sources are organized below in the same order as the sources in each chapter of the main section of this Inventory. To avoid repetition, the following uncertainty analysis discussions of individual source categories do not include descriptions of these source categories. Hence, to better understand the details provided below, refer to the respective chapters and sections in the main section of this Inventory, as needed. All uncertainty estimates are reported relative to the 2013 Inventory estimates for the 95 percent confidence interval, unless otherwise specified.

Energy

The uncertainty analysis descriptions in this section correspond to source categories included in the Energy chapter of the Inventory.

CO_2 from Fossil Fuel Combustion

For estimates of CO_2 from fossil fuel combustion, There are uncertainties in the consumption data, carbon content of fuels and products, and carbon oxidation efficiencies.

Although statistics of total fossil fuel and other energy consumption are relatively accurate, the allocation of this consumption to individual end-use sectors (i.e., residential, commercial, industrial, and transportation) is less certain. For this uncertainty estimation, the inventory estimation model for CO_2 from fossil fuel combustion was integrated with the relevant variables from the inventory estimation model for International Bunker Fuels, to realistically characterize the interaction (or endogenous correlation) between the variables of these two models.

In developing the uncertainty estimation model, uniform distributions were assumed for all activity-related input variables and emission factors, based on the SAIC/EIA (2001) report.[2] Triangular distributions were assigned for the oxidization factors (or combustion efficiencies). The uncertainty ranges were assigned to the input variables based on the data reported in SAIC/EIA (2001) and on conversations with various agency personnel.[3]

The uncertainty ranges for the activity-related input variables were typically asymmetric around their inventory estimates; the uncertainty ranges for the emissions factors were symmetric. Bias (or systematic uncertainties) associated with these variables accounted for much of the uncertainties associated with these variables (SAIC/EIA 2001).[4] For purposes of this uncertainty analysis, each input variable was simulated 10,000 times through Monte Carlo sampling.

CH_4 and N_2O from Stationary Combustion

The uncertainty estimation model for this source category was developed by integrating the CH_4 and N_2O stationary source inventory estimation models with the model for CO_2 from fossil fuel combustion to realistically characterize the interaction (or endogenous correlation) between the variables of these three models. About 55 input variables were simulated for the uncertainty analysis of this source category (about 20 from the CO_2 emissions from fossil fuel combustion inventory estimation model and about 35 from the stationary source inventory models).

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[2] SAIC/EIA (2001) characterizes the underlying probability density function for the input variables as a combination of uniform and normal distributions (the former to represent the bias component and the latter to represent the random component). However, for purposes of the current uncertainty analysis, it was determined that uniform distribution was more appropriate to characterize the probability density function underlying each of these variables.

[3] In the SAIC/EIA (2001) report, the quantitative uncertainty estimates were developed for each of the three major fossil fuels used within each end-use sector; the variations within the sub-fuel types within each end-use sector were not modeled. However, for purposes of assigning uncertainty estimates to the sub-fuel type categories within each end-use sector in the current uncertainty analysis, SAIC/EIA (2001)-reported uncertainty estimates were extrapolated.

[4] Although, in general, random uncertainties are the main focus of statistical uncertainty analysis, when the uncertainty estimates are elicited from experts, their estimates include both random and systematic uncertainties. Hence, both these types of uncertainties are represented in this uncertainty analysis.

In developing the uncertainty estimation model, uniform distribution was assumed for all activity-related input variables and N_2O emission factors, based on the SAIC/EIA (2001) report.[5] For these variables, the uncertainty ranges were assigned to the input variables based on the data reported in SAIC/EIA (2001).[6] However, the CH_4 emission factors differ from those used by EIA. Since these factors were obtained from IPCC/UNEP/OECD/IEA (1997), uncertainty ranges were assigned based on IPCC default uncertainty estimates (IPCC 2000).

CH_4 and N_2O from Mobile Combustion

The uncertainty analysis was performed on 2013 estimates of CH_4 and N_2O emissions, incorporating probability distribution functions associated with the major input variables. For the purposes of this analysis, the uncertainty was modeled for the following four major sets of input variables: (1) VMT data, by on-road vehicle and fuel type and (2) emission factor data, by on-road vehicle, fuel, and control technology type, (3) fuel consumption, data, by non-road vehicle and equipment type, and (4) emission factor data, by non-road vehicle and equipment type.

Carbon Emitted from Non-Energy Uses of Fossil Fuels

An uncertainty analysis was conducted to quantify the uncertainty surrounding the estimates of emissions and storage factors from non-energy uses.

The non-energy use analysis is based on U.S.-specific storage factors for (1) feedstock materials (natural gas, LPG, pentanes plus, naphthas, other oils, still gas, special naphthas, and other industrial coal), (2) asphalt, (3) lubricants, and (4) waxes. To characterize uncertainty, five separate analyses were conducted, corresponding to each of the five categories. In all cases, statistical analyses or expert judgments of uncertainty were not available directly from the information sources for all the activity variables; thus, uncertainty estimates were determined using assumptions based on source category knowledge.

Incineration of Waste

The uncertainties in the waste incineration emission estimates arise from both the assumptions applied to the data and from the quality of the data. Key factors include MSW incineration rate; fraction oxidized; missing data on waste composition; average C content of waste components; assumptions on the synthetic/biogenic C ratio; and combustion conditions affecting N_2O emissions. The highest levels of uncertainty surround the variables that are based on assumptions (e.g., percent of clothing and footwear composed of synthetic rubber); the lowest levels of uncertainty surround variables that were determined by quantitative measurements (e.g., combustion efficiency, C content of C black).

Coal Mining

The uncertainty associated with emission estimates from underground ventilation systems can be attributed to the fact that the actual measurement data from MSHA or EPA's GHGRP used were not continuous but rather an average of quarterly instantaneous readings. Additionally, the measurement equipment used can be expected to have resulted in an average of 10 percent overestimation of annual CH_4 emissions (Mutmansky & Wang 2000). GHGRP data was used for a number of the mines beginning in 2013, however, the equipment uncertainty is applied to both MSHA and GHGRP data.

Estimates of CH_4 recovered by degasification systems are relatively certain for utilized CH_4 because of the availability of gas sales information. In addition, many coal mine operators provided information on mined-through dates for pre-drainage wells. Many of the recovery estimates use data on wells within 100 feet of a mined area. However, uncertainty exists concerning the radius of influence of each well. The number of wells counted, and thus the avoided emissions, may vary if the drainage area is found to be larger or smaller than estimated.

[5] SAIC/EIA (2001) characterizes the underlying probability density function for the input variables as a combination of uniform and normal distributions (the former distribution to represent the bias component and the latter to represent the random component). However, for purposes of the current uncertainty analysis, it was determined that uniform distribution was more appropriate to characterize the probability density function underlying each of these variables.

[6] In the SAIC/EIA (2001) report, the quantitative uncertainty estimates were developed for each of the three major fossil fuels used within each end-use sector; the variations within the sub-fuel types within each end-use sector were not modeled. However, for purposes of assigning uncertainty estimates to the sub-fuel type categories within each end-use sector in the current uncertainty analysis, SAIC/EIA (2001)-reported uncertainty estimates were extrapolated.

Abandoned Underground Coal Mines.

The parameters for which values must be estimated for each mine in order to predict its decline curve are: 1) the coal's adsorption isotherm; 2) CH_4 flow capacity as expressed by permeability; and 3) pressure at abandonment. Because these parameters are not available for each mine, a methodological approach to estimating emissions was used that generates a probability distribution of potential outcomes based on the most likely value and the probable range of values for each parameter. The range of values is not meant to capture the extreme values, but rather values that represent the highest and lowest quartile of the cumulative probability density function of each parameter. Once the low, mid, and high values are selected, they are applied to a probability density function.

Petroleum Systems

The uncertainty analysis conducted in 2010 has not yet been updated for the 1990 through 2013 Inventory years; instead, the uncertainty percentage ranges calculated previously were applied to 2013 emission estimates. The majority of sources in the current Inventory were calculated using the same emission factors and activity data for which probability density functions were developed in the 1990 through 2009 uncertainty analysis.

Natural Gas Systems

The uncertainty analysis conducted in 2010 has not yet been updated for the 1990 through 2013 Inventory years; instead, the uncertainty percentage ranges calculated previously were applied to 2013 emissions estimates. The majority of sources in the current Inventory were calculated using the same emission factors and activity data for which probability density functions were developed in the 1990 through 2009 uncertainty analysis.

International Bunker Fuels

Emission estimates related to the consumption of international bunker fuels are subject to the same uncertainties as those from domestic aviation and marine mobile combustion emissions; however, additional uncertainties result from the difficulty in collecting accurate fuel consumption activity data for international transport activities separate from domestic transport activities. Uncertainties exist with regard to the total fuel used by military aircraft and ships, and in the activity data on military operations and training that were used to estimate percentages of total fuel use reported as bunker fuel emissions. There are also uncertainties in fuel end-uses by fuel-type, emissions factors, fuel densities, diesel fuel sulfur content, aircraft and vessel engine characteristics and fuel efficiencies, and the methodology used to back-calculate the data set to 1990 using the original set from 1995.

Wood Biomass and Ethanol Consumption

It is assumed that the combustion efficiency for woody biomass is 100 percent, which is believed to be an overestimate of the efficiency of wood combustion processes in the United States. Decreasing the combustion efficiency would decrease emission estimates. Additionally, the heat content applied to the consumption of woody biomass in the residential, commercial, and electric power sectors is unlikely to be a completely accurate representation of the heat content for all the different types of woody biomass consumed within these sectors. Emission estimates from ethanol production are more certain than estimates from woody biomass consumption due to better activity data collection methods and uniform combustion techniques.

Industrial Processes and Product Use

The uncertainty analysis descriptions in this section correspond to source categories included in the Industrial Processes and Product Use chapter of the Inventory.

Cement Production

The uncertainties contained in these estimates are primarily due to uncertainties in the lime content of clinker and in the percentage of CKD recycled inside the cement kiln. Uncertainty is also associated with the assumption that all calcium-containing raw materials are $CaCO_3$, when a small percentage likely consists of other carbonate and non-carbonate raw materials.

Lime Production

The uncertainties contained in these estimates can be attributed to slight differences in the chemical composition of lime products and CO_2 recovery rates for on-site process use over the time series. Although the methodology accounts for various formulations of lime, it does not account for the trace impurities found in lime, such as iron oxide, alumina, and silica. In addition, a portion of the CO_2 emitted during lime production will actually be reabsorbed when the lime is consumed, especially at captive lime production facilities. Another uncertainty is the assumption that calcination emissions for LKD are around 2 percent. There is limited data publicly available on LKD generation rates and also quantities, types of other byproducts/wastes produced at lime facilities.

Glass Production

The uncertainty levels presented in this section arise in part due to variations in the chemical composition of limestone used in glass production. The uncertainty estimates also account for uncertainty associated with activity data. Large fluctuations in reported consumption exist, reflecting year-to-year changes in the number of survey responders. The accuracy of distribution by end use is also uncertain because this value is reported by the manufacturer of the input carbonates (limestone, dolomite & soda ash) and not the end user. Additionally, there is significant inherent uncertainty associated with estimating withheld data points for specific end uses of limestone and dolomite. Lastly, much of the limestone consumed in the United States is reported as "other unspecified uses;" therefore, it is difficult to accurately allocate this unspecified quantity to the correct end-uses.

Other Process Uses of Carbonates

The uncertainty levels presented in this section account for uncertainty associated with activity data. Data on limestone and dolomite consumption are collected by USGS through voluntary national surveys. Large fluctuations in reported consumption exist, reflecting year-to-year changes in the number of survey responders. The accuracy of distribution by end use is also uncertain because this value is reported by the producer/mines and not the end user. Additionally, there is significant inherent uncertainty associated with estimating withheld data points for specific end uses of limestone and dolomite. Lastly, much of the limestone consumed in the United States is reported as "other unspecified uses;" therefore, it is difficult to accurately allocate this unspecified quantity to the correct end-uses. Uncertainty in the estimates also arises in part due to variations in the chemical composition of limestone.

Ammonia Production

The uncertainties presented in this section are primarily due to how accurately the emission factor used represents an average across all ammonia plants using natural gas feedstock. Uncertainties are also associated with ammonia production estimates and the assumption that all ammonia production and subsequent urea production was from the same process. Uncertainty is also associated with the representativeness of the emission factor used for the petroleum coke-based ammonia process. It is also assumed that ammonia and urea are produced at collocated plants from the same natural gas raw material.

Urea Consumption for Non-Agricultural Purposes

The primary uncertainties associated with this source category are associated with the accuracy of the estimates of urea production, urea imports, urea exports, and the amount of urea used as fertilizer as well as the fact that each estimate is obtained from a different data source. Because urea production estimates are no longer available from the USGS, there is additional uncertainty associated with urea produced beginning in 2011. There is also uncertainty associated with the assumption that all of the carbon in urea is released into the environment as CO_2 during use.

Nitric Acid Production

Uncertainty associated with the parameters used to estimate N_2O emissions includes that of production data, the share of U.S. nitric acid production attributable to each emission abatement technology over the time series (especially prior to 2010), and the associated emission factors applied to each abatement technology type.

Adipic Acid Production

Uncertainty associated with N_2O emission estimates includes the methods used by companies to monitor and estimate emissions.

Silicon Carbide Production and Consumption

There is uncertainty associated with the emission factors used because they are based on stoichiometry as opposed to monitoring of actual SiC production plants. For CH_4, there is also uncertainty associated with the hydrogen-containing volatile compounds in the petroleum coke (IPCC 2006). There is also uncertainty associated with the use or destruction of methane generated from the process in addition to uncertainty associated with levels of production, net imports, consumption levels, and the percent of total consumption that is attributed to metallurgical and other non-abrasive uses.

Titanium Dioxide Production

As of 2004, the last remaining sulfate-process plant in the United States closed. Since annual TiO_2 production was not reported by USGS by the type of production process used (chloride or sulfate) prior to 2004 and only the percentage of total production capacity by process was reported, the percent of total TiO_2 production capacity that was attributed to the chloride process was multiplied by total TiO_2 production to estimate the amount of TiO_2 produced using the chloride process. Finally, the emission factor was applied uniformly to all chloride-process production, and no data were available to account for differences in production efficiency among chloride-process plants.

Soda Ash Production and Consumption

Emission estimates from soda ash production have relatively low associated uncertainty levels in that reliable and accurate data sources are available for the emission factor and activity data. Soda ash production data was collected by the USGS from voluntary surveys. One source of uncertainty is the purity of the trona ore used for manufacturing soda ash. The primary source of uncertainty, however, results from the fact that emissions from soda ash consumption are dependent upon the type of processing employed by each end-use.

Petrochemical Production

Sources of uncertainty on the CH_4 and CO_2 emission factors used for acrylonitrile and methanol production are derived from the use of default or average factors from a limited number of studies. There is some uncertainty in the applicability of the average emission factors for each petrochemical type across all prior years. While petrochemical production processes in the United States have not changed significantly since 1990, some operational efficiencies have been implemented at facilities over the time series.

HCFC-22 Production

The uncertainty analysis presented in this section was based on a plant-level Monte Carlo Stochastic Simulation for 2006. A normal probability density function was assumed for all measurements and biases except the equipment leak estimates for one plant; a log-normal probability density function was used for this plant's equipment leak estimates. The simulation for 2006 yielded a 95-percent confidence interval for U.S. emissions of 6.8 percent below to 9.6 percent above the reported total.

The relative errors yielded by the Monte Carlo Stochastic Simulation for 2006 were applied to the U.S. emission estimate for 2013. The resulting estimates of absolute uncertainty are likely to be reasonably accurate because (1) the methods used by the three plants to estimate their emissions are not believed to have changed significantly since 2006, and (2) although the distribution of emissions among the plants may have changed between 2006 and 2013 , the two plants that contribute significantly to emissions were estimated to have similar relative uncertainties in their 2006 (as well as 2005) emission estimates.

Carbon Dioxide Production

Uncertainty is associated with the number of facilities that are currently producing CO_2 from naturally occurring CO_2 reservoirs for commercial uses other than EOR, and for which the CO_2 emissions or recovery are not accounted for elsewhere.

Phosphoric Acid Production

Regional production for 2013 was estimated based on regional production data from previous years and multiplied by regionally-specific emission factors. There is uncertainty associated with the degree to which the estimated 2013 regional production data represents actual production in those regions.

An additional source of uncertainty is the carbonate composition of phosphate rock; the composition of phosphate rock varies depending upon where the material is mined, and may also vary over time. A third source of uncertainty is the assumption that all domestically-produced phosphate rock is used in phosphoric acid production and used without first being calcined. Iron and Steel Production and Metallurgical Coke Production

Uncertainty is associated with the total U.S. coking coal consumption, total U.S. coke production, and materials consumed during this process. 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.

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. For EAF steel production, there is uncertainty associated with the amount of EAF anode and charge C 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.

Ferroalloy Production

Uncertainty for this source is associated with the type and availability of annual ferroalloy production data, which have varied over the time series. Such production data may or may not include details such as ferroalloy content, production practices (e.g., biomass used as primary or secondary carbon source), amount of reducing agent used, and furnace specifics (e.g., type, operation technique, control technology).

Aluminum Production

Uncertainty was assigned to the CO_2, CF_4, and C_2F_6 emission values reported by each individual facility to EPA's GHGRP. Uncertainty surrounding the reported CO_2, CF_4, and C_2F_6 emission values were determined to have a normal distribution with uncertainty ranges of ±6, ±16, and ±20 percent, respectively.

Magnesium Production

Uncertainty surrounding the total estimated emissions in 2013 is attributed to the uncertainties around SF_6, HFC-134a and CO_2 emission estimates. To estimate the uncertainty surrounding the estimated 2013 SF_6 emissions from magnesium production and processing, the uncertainties associated with three variables were estimated: (1) emissions reported by magnesium producers and processors for 2013 through EPA's GHGRP, (2) emissions estimated for magnesium producers and processors that reported via the Partnership in prior years but did not report 2013 emissions through EPA's GHGRP, and (3) emissions estimated for magnesium producers and processors that did not participate in the Partnership or report through EPA's GHGRP. Additional uncertainties exist in these estimates that are not addressed in this methodology, such as the basic assumption that SF_6 neither reacts nor decomposes during use.

Lead Production

Uncertainty associated with lead production relates to the applicability of emission factors and the accuracy of primary and secondary production data provided by the USGS.

Zinc Production

There is uncertainty associated with the amount of EAF dust consumed in the United States to produce secondary zinc using emission-intensive Waelz kilns.

There are also uncertainties associated with the accuracy of the emission factors used to estimate CO_2 emissions from secondary zinc production processes.

Semiconductor Manufacture

The equation used to estimate uncertainty is:

$$\text{Total Emissions } (E_T) = \text{GHGRP Reported F-GHG Emissions } (E_{R,F\text{-}GHG}) + \text{Non-Reporters' Estimated F-GHG Emissions } (E_{NR,F\text{-}GHG}) + \text{GHGRP Reported } N_2O \text{ Emissions } (E_{R,N2O}) + \text{Non-Reporters' Estimated } N_2O \text{ Emissions } (E_{NR,N2O})$$

where E_R and E_{NR} denote totals for the indicated subcategories of emissions for F-GHG and N_2O, respectively.

The uncertainty estimate of $E_{R,\ F\text{-}GHG}$, or GHGRP reported F-GHG emissions, is developed based on gas-specific uncertainty estimates of emissions for two industry segments, one processing 200 mm wafers and one processing 300 mm wafers. These gas and wafer-specific uncertainty estimates are applied to the total emissions of the facilities that did not abate emissions as reported under EPA's GHGRP.

For those facilities reporting abatement of emissions under EPA's GHGRP, estimates of uncertainties for the no abatement industry segments are modified to reflect the use of full and partial abatement. For all facilities reporting gas abatement, a triangular distribution of destruction or removal efficiency is assumed for each gas. For facilities reporting partial abatement, the distribution of fraction of the gas fed through the abatement device, for each gas, is assumed to be triangularly distributed as well. Gas-specific emission uncertainties were estimated by convolving the distributions of unabated emissions with the appropriate distribution of abatement efficiency for fully and partially abated facilities using a Montel Carlo simulation.

The uncertainty in $E_{R,F\text{-}GHG}$ is obtained by allocating the estimates of uncertainties to the total GHGRP-reported emissions from each of the six industry segments. The uncertainty in $E_{R,N2O}$ is obtained by assuming that the uncertainty in the emissions reported by each of the GHGRP reporting facilities results from the uncertainty in quantity of N_2O consumed and the N_2O emission factor (or utilization). The quantity of N_2O utilized (the complement of the emission factor) was assumed to have a triangular distribution with a minimum value of 0 percent, mode of 20 percent and maximum value of 84 percent. The uncertainty for the total reported N_2O emissions was then estimated by combining the uncertainties of each of the facilities reported emissions using Monte Carlo simulation. The estimate of uncertainty in $E_{NR,F\text{-}GHG}$ and $E_{NR,N2O}$ entailed developing estimates of uncertainties for the emissions factors for each non-reporting sub-category and the corresponding estimates of TMLA.

The uncertainty in TMLA depends on the uncertainty of two variables – an estimate of the uncertainty in the average annual capacity utilization for each level of production of fabs (e.g., full scale or R&D production) and a corresponding estimate of the uncertainty in the number of layers manufactured. For both variables, the distributions of capacity utilizations and number of manufactured layers are assumed triangular for all categories of non-reporting fabs. To address the uncertainty in the capacity utilization for Inventory year 2013, the lower bound has been decreased by 10 percent, and the upper bound has been increased by 10 percent (or 100 percent if greater than 100 percent) compared to the bounds used in the 2012 Inventory year. For the triangular distributions that govern the number of possible layers manufactured, it is assumed the most probable value is one layer less than reported in the ITRS.

The uncertainty bounds for the average capacity utilization and the number of layers manufactured are used as inputs in a separate Monte Carlo simulation to estimate the uncertainty around the TMLA of both individual facilities as well as the total non-reporting TMLA of each sub-population. The uncertainty around the emission factors for each non-reporting category of facilities is dependent on the uncertainty of the total emissions (MMTCO_2e units) and the TMLA of each reporting facility in that category. For simplicity, the results of the Monte Carlo simulations on the bounds of the gas- and wafer size-specific emissions as well as the TMLA and emission factors are assumed to be normally distributed and the uncertainty bounds are assigned at 1.96 standard deviations around the estimated mean. The departures from normality were observed to be small. The final step in estimating the uncertainty in emissions of non-reporting facilities is convolving the distribution of emission factors with the distribution of TMLA using Monte Carlo simulation.

Substitution of Ozone Depleting Substances

Given that emissions of ODS substitutes occur from thousands of different kinds of equipment and from millions of point and mobile sources throughout the United States, significant uncertainties exist with regard to the levels of equipment sales, equipment characteristics, and end-use emissions profiles that were used to estimate annual emissions for the various compounds.

The uncertainty analysis quantifies the level of uncertainty associated with the aggregate emissions resulting from the top 21 end-uses (out of 60), comprising over 95 percent of the total emissions, and 6 other end-uses. These 27 end-uses comprise 97 percent of the total emissions, equivalent to 153.3 MMT CO_2 Eq.

In order to calculate uncertainty, functional forms were developed to simplify some of the complex "vintaging" aspects of some end-use sectors, especially with respect to refrigeration and air-conditioning, and to a lesser degree, fire extinguishing. The functional forms used variables that included. Uncertainty was estimated around each variable within the functional forms (e.g., growth rates, emission factors, transition from ODSs, change in charge size as a result of the transition, disposal quantities, disposal emission rates, and either stock for the current year or original ODS consumption) based on expert judgment. The most significant sources of uncertainty for this source category include the emission factors for residential unitary AC, as well as the percent of non-MDI aerosol propellant that is HFC-152a.

Electrical Transmission and Distribution

To estimate the uncertainty associated with emissions of SF_6 from Electrical Transmission and Distribution, uncertainties associated with four quantities were estimated: (1) emissions from Partners, (2) emissions from GHGRP-Only Reporters, (3) emissions from Non-Reporters, and (4) emissions from manufacturers of electrical equipment.Uncertainties were also estimated regarding (1) the quantity of SF_6 supplied with equipment by equipment manufacturers, which is projected from Partner provided nameplate capacity data and industry SF_6 nameplate capacity estimates, and (2) the manufacturers' SF_6 emissions rate.

Nitrous Oxide from Product Uses

The overall uncertainty associated with the 2013 N_2O emission estimate from N_2O product usage was calculated using the *2006 IPCC Guidelines* (IPCC 2006) Approach 2 methodology. Uncertainty associated with the parameters used to estimate N_2O emissions include production data, total market share of each end use, and the emission factors applied to each end use, respectively.

Agriculture

The uncertainty analysis descriptions in this section correspond to some source categories included in the Agriculture chapter of the Inventory.

Enteric Fermentation

Uncertainty estimates were developed for the 1990 through 2001 Inventory report (i.e., 2003 submission to the UNFCCC). There have been no significant changes to the methodology since that time; consequently, these uncertainty estimates were directly applied to the 2013 emission estimates in this Inventory report.

A total of 185 primary input variables were identified as key input variables for the uncertainty analysis. A normal distribution was assumed for almost all activity- and emission factor-related input variables. Triangular distributions were assigned to three input variables to ensure only positive values would be simulated.

Manure Management

An analysis (ERG 2003a) was conducted for the manure management emission estimates presented in the 1990 through 2001 Inventory report (i.e., 2003 submission to the UNFCCC) to determine the uncertainty associated with estimating CH_4 and N_2O emissions from livestock manure management. These uncertainty estimates were directly applied to the 2013 emission estimates as there have not been significant changes in the methodology since that time.

Rice Cultivation

The largest uncertainty in the calculation of CH_4 emissions from rice cultivation is associated with the emission factors. Seasonal emissions, derived from field measurements in the United States, vary by more than one order of magnitude.

Other sources of uncertainty include the primary rice-cropped area for each state, percent of rice-cropped area that is ratooned, the length of the growing season, and the extent to which flooding outside of the normal rice season is practiced. Expert judgment was used to estimate the uncertainty associated with primary rice-cropped area for each state at 1 to 5 percent, and a normal distribution was assumed.

Agricultural Soil Management

Uncertainty was estimated for each of the following five components of N_2O emissions from agricultural soil management: (1) direct emissions simulated by DAYCENT; (2) the components of indirect emissions (N volatilized and leached or runoff) simulated by DAYCENT; (3) direct emissions approximated with the IPCC (2006) Approach 1 method; (4) the components of indirect emissions (N volatilized and leached or runoff) approximated with the IPCC (2006) Approach 1 method; and (5) indirect emissions estimated with the IPCC (2006) Approach 1 method.

Field Burning of Agricultural Residues

Due to data limitations, uncertainty resulting from the fact that emissions from burning of Kentucky bluegrass and "other crop" residues are not included in the emissions estimates was not incorporated into the uncertainty analysis.

Land Use, Land-Use Change, and Forestry

The uncertainty analysis descriptions in this section correspond to source categories included in the Land Use, Land-Use Change, and Forestry chapter of the Inventory.

Forest Land Remaining Forest Land

The uncertainty analysis descriptions in this section correspond to source categories included in the Forest Land Remaining Forest Land sub-chapter of Land Use, Land-Use Change, and Forestry chapter of the Inventory.

Changes in Forest Carbon Stocks

A quantitative uncertainty analysis placed bounds on current flux for forest ecosystems as well as C in harvested wood products through Monte Carlo Stochastic Simulation of the Methods and probabilistic sampling of C conversion factors and inventory data.

Non-CO_2 Emissions from Forest Fires

Non-CO_2 gases emitted from forest fires depend on several variables, including: forest area for Alaska and the lower 48 states; average C densities for wildfires in Alaska, wildfires in the lower 48 states, and prescribed fires in the lower 48 states; emission ratios; and combustion factor values (proportion of biomass consumed by fire).

Direct N_2O fluxes from Forest Soils

The amount of N_2O emitted from forests depends not only on N inputs and fertilized area, but also on a large number of variables, including organic C availability, oxygen gas partial pressure, soil moisture content, pH, temperature, and tree planting/harvesting cycles. The effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain.

Uncertainties exist in the fertilization rates, annual area of forest lands receiving fertilizer, and the emission factors. The uncertainty ranges around the 2005 activity data and emission factor input variables were directly applied to the 2013 emissions estimates. IPCC (2006) provided estimates for the uncertainty associated with direct and indirect N_2O emission factor for synthetic N fertilizer application to soils.

Cropland Remaining Cropland

The uncertainty analysis descriptions in this section correspond to source categories included in the Cropland Remaining Cropland sub-chapter of Land Use, Land-Use Change, and Forestry chapter of the Inventory.

Agricultural Soil Carbon Stock Change

Uncertainty associated with the *Cropland Remaining Cropland* land-use category was addressed for changes in agricultural soil C stocks (including both mineral and organic soils).

CO_2 Emissions from Agricultural Liming

Uncertainty regarding limestone and dolomite activity data inputs was estimated at ±15 percent and assumed to be uniformly distributed around the inventory estimate (Tepordei 2003, Willett 2013b). Analysis of the uncertainty associated with the emission factors included the following: the fraction of agricultural lime dissolved by nitric acid versus the fraction that reacts with carbonic acid, and the portion of bicarbonate that leaches through the soil and is transported to the ocean. The uncertainties associated with the fraction of agricultural lime dissolved by nitric acid and the portion of bicarbonate that leaches through the soil were each modeled as a smoothed triangular distribution between ranges of zero percent to 100 percent.

CO_2 Emissions from Urea Fertilization

The largest source of uncertainty was the default emission factor, which assumes that 100 percent of the C in $CO(NH_2)_2$ applied to soils is ultimately emitted into the environment as CO_2. In addition, each urea consumption data point has an associated uncertainty. Lastly, there is uncertainty surrounding the assumptions behind the calculation that converts fertilizer years to calendar years.

Land Converted to Cropland

Uncertainty analysis for mineral soil C stock changes using the Approach 3 and Approach 2 approaches were based on the same method described for *Cropland Remaining Cropland*.

Uncertainty was estimated for each subsource (i.e., mineral soil C stocks and organic soil C stocks) and method that was used in the Inventory analysis (i.e., Approach 2 and Approach 3).

Grassland Remaining Grassland

Uncertainty was estimated for each subsource (i.e., mineral soil C stocks and organic soil C stocks) and disaggregated to the level of the inventory methodology employed (i.e., Approach 2 and Approach 3).

Land Converted to Grassland

Uncertainty was estimated for each subsource (i.e., mineral soil C stocks and organic soil C stocks) and disaggregated to the level of the inventory methodology employed (i.e., Approach 2 and Approach 3).

Wetlands Remaining Wetlands

The uncertainty analysis descriptions in this section correspond to source categories included in the Wetlands Remaining Wetlands sub-chapter of Land Use, Land-Use Change, and Forestry chapter of the Inventory.

Peatlands Remaining Peatlands

The uncertainty associated with peat production data was estimated to be ± 25 percent (Apodaca 2008), assumed to be normally distributed, and is attributed to the USGS receives data from the smaller peat producers but estimates production from some larger peat distributors. The uncertainty associated with the reported production data for Alaska was assumed to be the same as for the lower 48 states, or ± 25 percent with a normal distribution. The uncertainty associated with the average bulk density values was estimated to be ± 25 percent with a normal distribution (Apodaca 2008). The uncertainty associated with the emission factors was assumed to be triangularly distributed. The uncertainty values surrounding the C fractions were based on IPCC (2006) and the uncertainty was assumed to be uniformly distributed. The uncertainty values associated with the fraction of peatland covered by ditches was assumed to be ± 100 percent with a normal distribution based on the assumption that greater than 10 percent coverage, the upper uncertainty bound, is not typical of drained organic soils outside of The Netherlands (IPCC 2013).

Settlements Remaining Settlements

The uncertainty analysis descriptions in this section correspond to source categories included in the Settlements Remaining Settlements sub-chapter of Land Use, Land-Use Change, and Forestry chapter of the Inventory.

Changes in Carbon Stocks in Urban Trees

Uncertainty associated with changes in C stocks in urban trees includes the uncertainty associated with urban area, percent urban tree coverage, and estimates of gross and net C sequestration for each of the 50 states and the District of Columbia. Additional uncertainty is associated with the biomass equations, conversion factors, and decomposition assumptions used to calculate C sequestration and emission estimates (Nowak et al. 2002).

N_2O Fluxes from Settlement Soils

The amount of N_2O emitted from settlements depends not only on N inputs and fertilized area, but also on a large number of variables, including organic C availability, oxygen gas partial pressure, soil moisture content, pH, temperature, and irrigation/watering practices. The effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain.

Uncertainties exist in both the fertilizer N and sewage sludge application rates in addition to the emission factors. Uncertainty in the amounts of sewage sludge applied to non-agricultural lands and used in surface disposal was derived from variability in several factors. The uncertainty ranges around 2005 activity data and emission factor input variables were directly applied to the 2013 emission estimates.

Other

The uncertainty analysis descriptions in this section correspond to source categories included in the Other sub-chapter of Land Use, Land-Use Change, and Forestry chapter of the Inventory.

Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills

The uncertainty analysis for landfilled yard trimmings and food scraps includes an evaluation of the effects of uncertainty for the following data and factors: disposal in landfills per year (tons of C), initial C content, moisture content, decay rate, and proportion of C stored. The C storage landfill estimates are also a function of the composition of the yard trimmings (i.e., the proportions of grass, leaves and branches in the yard trimmings mixture). There are respective uncertainties associated with each of these factors.

Waste

The uncertainty analysis descriptions in this section correspond to source categories included in the Waste chapter of the Inventory.

Landfills

The primary uncertainty associated with the estimates of CH_4 emissions from MSW and industrial waste landfills concerns the characterization of landfills. There is also a high degree of uncertainty and variability associated with the first order decay model, particularly when a homogeneous waste composition and hypothetical decomposition rates are applied to heterogeneous landfills (IPCC 2006).

Additionally, there is a lack of landfill-specific information regarding the number and type of industrial waste landfills in the United States. Uncertainty also exists in the estimates of the landfill gas oxidized. Another significant source of uncertainty lies with the estimates of CH_4 that are recovered by flaring and gas-to-energy projects at MSW landfills. Industrial waste landfills are shown with a lower range of uncertainty due to the smaller number of data sources and associated uncertainty involved.

Wastewater Treatment

Uncertainty associated with the parameters used to estimate CH_4 emissions from wastewater treatment include that of numerous input variables used to model emissions from domestic wastewater, and wastewater from pulp and paper manufacture, meat and poultry processing, fruits and vegetable processing, ethanol production, and petroleum refining. Uncertainty associated with the parameters used to estimate N_2O emissions include that of sewage sludge disposal, total U.S. population, average protein consumed per person, fraction of N in protein, non-consumption nitrogen factor, emission factors per capita and per mass of sewage-N, and for the percentage of total population using centralized wastewater treatment plants.

Composting

The estimated uncertainty from the *2006 IPCC Guidelines* is ±50 percent for the Approach 1 methodology.

References

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