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). 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 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 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.

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. As noted, for all source categories, the inventory emission estimates include "Uncertainty and Time-Series Consistency" sections that consider both quantitative and qualitative assessments of uncertainty, considering factors consistent with those noted in Volume 1, Chapter 3 of the *2006 IPCC Guidelines* (i.e., completeness of data, representativeness of data and models, sampling errors, measurement errors, etc.). 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 encompasses several causes such as lack of completeness, lack of data or representative data, sampling error, random or systematic measurement error, misreporting or misclassification, or missing data. 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 included in the U.S. Inventory totals, with the exception of one very small emission source category, CH_4 emissions from Incineration of Waste, given the very low emissions for CH_4 from Incineration of Waste, no uncertainty estimate was derived. Uncertainty associated with three other source categories (International Bunker Fuels, Energy Sources of Indirect Greenhouse Gas Emissions, and CO_2 emissions from Wood Biomass and Biofuel Consumption) whose emissions are not included in the Inventory totals is discussed qualitatively in their respective sections 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). 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 through 2015 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. In following the UNFCCC requirement under Article 4.1, emissions from International Bunker Fuels, Wood Biomass and Biofuel Consumption, 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.[137] CO_2 Emissions from Biomass and Biofuel Consumption are accounted for implicitly in the Land Use, Land-Use Change and Forestry (LULUCF) chapter through the calculation of changes in carbon stocks. The Energy sector does provide an estimate of CO_2 emissions from Biomass and Biofuel Consumption provided as a memo item for informational purposes consistent 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.

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.

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-280 summarizes results based on assessments of source category-level uncertainty. The table presents base year (1990 or 1995) and current year (2015) 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

[137] 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.

the total 2015 emissions estimated for that source category. Source category trend uncertainty is described subsequently in this Appendix.

Table A-280: Summary Results of Source Category Uncertainty Analyses

Source Category	Base Year Emissions[h,a]	2015 Emissions[a]	2015 Uncertainty[b]	
	MMT CO_2 Eq.	MMT CO_2 Eq.	Low	High
CO_2	**5,122.6**	**5,411.0**	**-2%**	**4%**
Fossil Fuel Combustion[c]	4,739.9	5,049.4	-2%	5%
Non-Energy Use of Fuels	117.6	125.5	-25%	37%
Iron and Steel Production & Metallurgical Coke Production	101.5	48.9	-17%	17%
Natural Gas Systems	37.7	42.4	-19%	30%
Cement Production	33.5	39.9	-6%	6%
Petrochemical Production	21.3	28.1	-5%	5%
Lime Production	11.7	13.3	-3%	3%
Other Process Uses of Carbonates	4.9	11.2	-13%	16%
Ammonia Production	13.0	10.8	-8%	8%
Incineration of Waste	8.0	10.7	-10%	13%
Urea Fertilization	2.4	5.0	-43%	3%
Carbon Dioxide Consumption	1.5	4.3	-5%	5%
Liming	4.7	3.8	-111%	88%
Petroleum Systems	3.6	3.6	-24%	149%
Soda Ash Production and Consumption	2.8	2.8	-7%	6%
Aluminum Production	6.8	2.8	-2%	2%
Ferroalloy Production	2.2	2.0	-12%	12%
Titanium Dioxide Production	1.2	1.6	-12%	13%
Glass Production	1.5	1.3	-4%	5%
Urea Consumption for Non-Agricultural Purposes	3.8	1.1	-12%	12%
Phosphoric Acid Production	1.5	1.0	-19%	20%
Zinc Production	0.6	0.9	-19%	21%
Lead Production	0.5	0.5	-15%	16%
Silicon Carbide Production and Consumption	0.4	0.2	-9%	9%
Magnesium Production and Processing	+	+	-3%	4%
Wood Biomass and Biofuel Consumption[d]	*219.4*	*291.7*	*NE*	*NE*
International Bunker Fuels[e]	*103.5*	*110.8*	*NE*	*NE*
CH_4	**780.8**	**655.7**	**-9%**	**19%**
Enteric Fermentation	164.2	166.5	-11%	18%
Natural Gas Systems	194.1	162.4	-19%	30%
Landfills	179.6	115.7	-9%	9%
Manure Management	37.2	66.3	-18%	20%
Coal Mining	96.5	60.9	-12%	16%
Petroleum Systems	55.5	39.9	-24%	149%
Wastewater Treatment	15.7	14.8	-26%	22%
Rice Cultivation	16.0	11.2	-28%	28%
Stationary Combustion	8.5	7.0	-36%	136%
Abandoned Underground Coal Mines	7.2	6.4	-18%	24%
Composting	0.4	2.1	-50%	50%
Mobile Combustion	5.6	2.0	-18%	27%
Field Burning of Agricultural Residues	0.2	0.3	-40%	41%
Petrochemical Production	0.2	0.2	-57%	46%
Ferroalloy Production	+	+	-12%	12%
Silicon Carbide Production and Consumption	+	+	-9%	10%
Iron and Steel Production & Metallurgical Coke Production	+	+	-19%	19%
Incineration of Waste	+	+	NE	NE
International Bunker Fuels[e]	*0.2*	*0.1*	*NE*	*NE*
N_2O	**359.5**	**334.8**	**-10%**	**27%**
Agricultural Soil Management	256.6	251.3	-18%	47%
Direct	*212.0*	*213.3*	*-16%*	*26%*
Indirect	*44.6*	*38.0*	*-46%*	*155%*

Stationary Combustion	11.9	23.1	-22%	50%
Manure Management	14.0	17.7	-16%	24%
Mobile Combustion	41	15.1	-13%	19%
Nitric Acid Production	12.1	11.6	-5%	6%
Wastewater Treatment	3.4	5.0	-75%	107%
Adipic Acid Production	15.2	4.3	-4%	4%
N_2O from Product Uses	4.2	4.2	-24%	24%
Composting	0.3	1.9	-50%	50%
Incineration of Waste	0.5	0.3	-51%	330%
Semiconductor Manufacture	+	0.2	-13%	13%
Field Burning of Agricultural Residues	0.1	0.1	-29%	30%
International Bunker Fuels[e]	*0.9*	*0.9*	*NE*	*NE*
HFCs, PFCs, SF_6, and NF_3	**130.3**	**184.7**	**-1%**	**11%**
Substitution of Ozone Depleting Substances[f]	30.9	168.5	-1%	12%
Semiconductor Manufacture	3.6	4.8	-5%	5%
HCFC-22 Production	46.1	4.3	-7%	10%
Electrical Transmission and Distribution	23.1	4.2	-10%	11%
Aluminum Production	21.5	2.0	-6%	6%
Magnesium Production and Processing	5.2	1.0	-6%	6%
Total Emissions[g]	**6,393.3**	**6,586.2**	**-1%**	**5%**
LULUCF Emissions[i]	**10.6**	**19.7**	**-26%**	**94%**
LULUCF Carbon Stock Change[j]	**(830.2)**	**(778.7)**	**28%**	**-20%**
LULUCF Sector Net Total[k]	**(819.6)**	**(758.9)**	**28%**	**-21%**
Net Emissions (Sources and Sinks)[g]	**5,573.7**	**5,827.3**	**-3%**	**7%**

Notes: Total emissions (excluding emissions for which uncertainty was not quantified) is presented without LULUCF. Net emissions is presented with LULUCF.

\+ Does not exceed 0.05 MMT CO_2 Eq.

NE (Not Estimated)

[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 2015 in this table exclude approximately 0.4 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] Emissions from Wood Biomass and Biofuel Consumption are not included in summing energy sector totals.

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

[f] This source category's estimate for 2015 excludes 0.003 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.

[g] Totals exclude emissions for which uncertainty was not quantified.

[h] Base Year is 1990 for all sources except Substitution of Ozone Depleting Substances, for which the United States has chosen 1995.

[i] LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils.

[j] LULUCF Carbon Stock Change is the net C stock change from the following categories: *Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements*, and *Land Converted to Settlements*.

[k] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Overall (Aggregate) Inventory Level Uncertainty Estimates

The overall level uncertainty estimate for the U.S. 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 Composting and 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 and biofuel 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 2015 U.S. greenhouse gas emissions are estimated to be within the range of approximately 6,505.0 to 6,919.9 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 6,586.2 MMT CO_2 Eq. The uncertainty interval associated with total CO_2 emissions, which constitute about 82 percent of the total U.S. greenhouse gas emissions in 2015, ranges from -2 percent to 4 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 -9 percent to 19 percent, uncertainty associated with the total inventory N_2O emission estimate ranges from -10 percent to 27 percent, and uncertainty associated with Fluorinated GHG emissions ranges from -1 percent to 11 percent.

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

Table A-281: Quantitative Uncertainty Assessment of Overall National Inventory Emissions (MMT CO_2 Eq. and Percent)

Gas	2015 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	5,411.0	5,305.4	5,652.4	-2%	4%	5,474.3	90.2
CH_4[e]	655.7	599.9	779.2	-9%	19%	681.8	45.3
N_2O[e]	334.8	302.5	424.6	-10%	27%	357.0	30.7
PFC, HFC, SF_6, and NF_3[e]	184.7	183.1	204.4	-1%	11%	193.4	5.5
Total Emissions	**6,586.2**	**6,505.0**	**6,919.9**	**-1%**	**5%**	**6,706.6**	**106.0**
LULUCF Emissions[f]	**19.7**	**14.6**	**38.2**	**-26%**	**94%**	**23.3**	**6.3**
LULUCF Carbon Stock Change Flux[g]	**(778.7)**	**(993.1)**	**(620.7)**	**-20%**	**28%**	**(808.4)**	**94.7**
LULUCF Sector Net Total[h]	**(758.9)**	**(969.7)**	**(597.9)**	**-21%**	**28%**	**(785.1)**	**94.8**
Net Emissions (Sources and Sinks)	**5,827.3**	**5,643.8**	**6,207.4**	**-3%**	**7%**	**5,921.5**	**142.8**

Notes: Total emissions (excluding emissions for which uncertainty was not quantified) is presented without LULUCF. Net emissions is presented with LULUCF

[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 0.4 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 2015.

[f] LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils.

[g] LULUCF Carbon Stock Change is the net C stock change from the following categories: *Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements*, and *Land Converted to Settlements*.

[h] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

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., 2015) 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., 2015) 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 the 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., 2015) 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 2015, and are shown in Table A-282.

Table A-282: Quantitative Assessment of Trend Uncertainty (MMT CO_2 Eq. and Percent)

Gas/Source	Base Year Emissions[i,a]	2015 Emissions[a]	Emissions Trend[a]	Trend Range[a,b]	
	(MMT CO_2 Eq.)		(%)	(%)	
				Lower Bound	Upper Bound
CO_2	**5,122.6**	**5,411.0**	**6%**	**1%**	**11%**
Fossil Fuel Combustion[c]	4,739.9	5,049.4	7%	2%	12%
Non-Energy Use of Fuels	117.6	125.5	7%	-34%	71%
Iron and Steel Production & Metallurgical Coke Production	101.5	48.9	-52%	-62%	-39%
Natural Gas Systems	37.7	42.4	12%	-20%	59%
Cement Production	33.5	39.9	19%	9%	30%
Petrochemical Production	21.3	28.1	32%	23%	41%
Lime Production	11.7	13.3	14%	10%	18%
Other Process Uses of Carbonates	4.9	11.2	129%	88%	181%
Ammonia Production	13.0	10.8	-17%	-26%	-7%
Incineration of Waste	8.0	10.7	34%	14%	58%
Urea Fertilization	2.4	5.0	108%	36%	222%
Carbon Dioxide Consumption	1.5	4.3	192%	172%	213%
Liming	4.7	3.8	-18%	-99%	338%
Petroleum Systems	3.6	3.6	0%	-56%	133%
Soda Ash Production and Consumption	2.8	2.8	-1%	-10%	9%
Aluminum Production	6.8	2.8	-59%	-61%	-58%
Ferroalloy Production	2.2	2.0	-9%	-24%	9%
Titanium Dioxide Production	1.2	1.6	37%	14%	64%
Glass Production	1.5	1.3	-15%	-21%	-10%
Urea Consumption for Non-Agricultural Purposes	3.8	1.1	-70%	-75%	-65%
Phosphoric Acid Production	1.5	1.0	-35%	-51%	-13%
Zinc Production	0.6	0.9	48%	11%	97%
Lead Production	0.5	0.5	-8%	-27%	14%
Silicon Carbide Production and Consumption	0.4	0.2	-52%	-58%	-45%
Magnesium Production and Processing	+	+	90%	80%	99%
Wood Biomass and Biofuel Consumption[e]	*219.4*	*291.7*	*33%*	*NE*	*NE*
International Bunker Fuels[f]	*103.5*	*110.8*	*7%*	*NE*	*NE*
CH_4	780.8	655.7	-16%	-32%	1%
Enteric Fermentation	164.2	166.5	1%	-17%	25%
Natural Gas Systems	194.1	162.4	-16%	-41%	19%
Landfills	179.6	115.7	-36%	-74%	58%
Manure Management	37.2	66.3	78%	21%	147%
Coal Mining	96.5	60.9	-37%	-56%	-33%
Petroleum Systems	55.5	39.9	-28%	-68%	66%
Wastewater Treatment	15.7	14.8	-6%	-34%	33%
Rice Cultivation	16.0	11.2	-30%	-73%	89%

Stationary Combustion	8.5	7.0	-17%	-69%	129%
Abandoned Underground Coal Mines	7.2	6.4	-11%	-43%	28%
Composting	0.4	2.1	452%	142%	1139%
Mobile Combustion	5.6	2.0	-64%	-74%	-51%
Field Burning of Agricultural Residues	0.2	0.3	25%	-32%	132%
Petrochemical Production	0.2	0.2	-18%	-66%	95%
Ferroalloy Production	+	+	-19%	-32%	-4%
Silicon Carbide Production and Consumption	+	+	-67%	-71%	-62%
Iron and Steel Production & Metallurgical Coke Production	+	+	-60%	-70%	-46%
Incineration of Waste	+	+	-32%	NE	NE
International Bunker Fuels[f]	*0.2*	*0.1*	*-48%*	*NE*	*NE*
N_2O	**359.5**	**334.8**	**-7%**	**-34%**	**35%**
Agricultural Soil Management	256.6	251.3	-2%	-41%	58%
Stationary Combustion	11.9	23.1	94%	22%	212%
Manure Management	14.0	17.7	27%	-4%	66%
Mobile Combustion	41.2	15.1	-63%	-70%	-55%
Nitric Acid Production	12.1	11.6	-5%	-12%	3%
Wastewater Treatment	3.4	5.0	47%	-66%	553%
Adipic Acid Production	15.2	4.3	-72%	-73%	-70%
N_2O from Product Uses	4.2	4.2	0%	-32%	47%
Settlement Soils	1.4	2.5	77%	-96%	7073%
Composting	0.3	1.9	452%	147%	1143%
Incineration of Waste	0.5	0.3	-32%	-85%	197%
Semiconductor Manufacture	+	0.2	579%	471%	702%
Field Burning of Agricultural Residues	0.1	0.1	23%	-21%	93%
International Bunker Fuels[f]	*0.9*	*0.9*	*10%*	*NE*	*NE*
HFCs, PFCs, SF_6, and NF_3	**130.3**	**184.7**	**42%**	**36%**	**56%**
Substitution of Ozone Depleting Substances[g]	30.9	168.5	445%	399%	494%
Semiconductor Manufacture	3.6	4.8	34%	24%	45%
HCFC-22 Production	46.1	4.3	-91%	-92%	-90%
Electrical Transmission and Distribution	23.1	4.2	-82%	-85%	-79%
Aluminum Production	21.5	2.0	-91%	-91%	-90%
Magnesium Production and Processing	5.2	1.0	-80%	-84%	-80%
Total Emissions[h]	**6,393.3**	**6,586.2**	**3%**	**-2%**	**8%**
LULUCF Emissions[i]	10.6	19.7	85%	-2%	285%
LULUCF Carbon Stock Change[j]	(830.2)	(778.7)	-6%	-33%	30%
LULUCF Sector Net Total[k]	(819.6)	(758.9)	-7%	-34%	29%
Net Emissions (Sources and Sinks)	**5,573.7**	**5,827.3**	**5%**	**-3%**	**12%**

+ Does not exceed 0.05 MMT CO_2 Eq.

NE (Not Estimated)

[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 2015 in this table exclude approximately 0.4 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 Biofuel 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 2015 excludes 0.003 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.

[l] Base Year is 1990 for all sources except Substitution of Ozone Depleting Substances, for which the United States has chosen 1995.

[i] LULUCF emissions include the CH_4 and N_2O emissions reported for Peatlands Remaining Peatlands, Forest Fires, Drained Organic Soils, Grassland Fires, and Coastal Wetlands Remaining Coastal Wetlands; CH_4 emissions from Land Converted to Coastal Wetlands; and N_2O emissions from Forest Soils and Settlement Soils.

[j] LULUCF Carbon Stock Change is the net C stock change from the following categories: *Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements*, and *Land Converted to Settlements*.

[k] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Notes: Total emissions (excluding emissions for which uncertainty was not quantified) is presented without LULUCF. Net emissions is presented with LULUCF.

7.3. Reducing Uncertainty

There have been many improvements in reducing uncertainties across source categories over the last several years. These improvements are result of new data sources that provide more accurate data or more coverage, as well as methodological improvements. Several source categories now use the U.S. EPA's GHGRP reported data, which is an improvement over prior methods using default emission factors and provides more country-specific data for Inventory calculations. EPA's GHGRP relies on facility-level data which undergoes a multi-step verification process, including automated data checks to ensure consistency, comparison against expected ranges for similar facilities and industries, and statistical analysis.

For example, the use of EPA's GHGRP reported data to estimate CH_4 emissions from Coal Mining resulted in the uncertainty bounds of -12 to 16 percent in the 1990 to 2015 Inventory, which was an improvement over the uncertainty bounds in the 1990 to 2011 Inventory of -15 to 18 percent. Prior to 2012, Coal Mining emissions were estimated using an array of emission factor estimations with higher assumed uncertainty. Estimates of CH_4 emissions from MSW landfills were also revised with the availability of GHGRP reported data resulting in methodological and data quality improvements that reduced uncertainty. Previously, MSW landfill emissions estimates were calculated using a model and default factors with higher assumed uncertainty.

Due to the availability of GHGRP reported data, Semiconductor Manufacturing emissions methodology as well as the uncertainty model was revised for the 1990 to 2012 Inventory. The revised model to estimate uncertainty relies on analysis conducted during the development of the EPA's GHGRP Subpart I rulemaking to estimate uncertainty associated with facility-reported emissions. These results were applied to the GHGRP-reported data as well as to the non-reported emissions. An improved methodology to estimate non-reported emissions along with improved methodology to estimate uncertainty of these non-reported emissions led to a reduced overall uncertainty of -5 to 5 percent in the 1990 to 2015 Inventory compared against a range of -8 to 9 percent in the 1990 to 2011 Inventory for the emissions of F-GHGs from the Semiconductor Manufacturing source category.

7.4. 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, and the International Bunker Fuels, CO_2 from Wood Biomass and Biofuel Consumption, and Indirect Greenhouse Gas Emissions source categories, which are not included in the energy sector totals. CO_2 Emissions from Wood Biofuel and Ethanol Consumption however are accounted for implicitly in the Land Use, Land-Use Change and Forestry (LULUCF) chapter through the calculation of changes in carbon stocks. The Energy sector does provide an estimate of CO_2 emissions from Wood Biomass and Biofuel Consumption provided as a memo item for informational purposes.

Specific areas that require further research to reduce uncertainties and improve the quality of uncertainty estimates include:

- *Improving conceptualization*. Improving the inclusiveness of the structural assumptions chosen can reduce uncertainties. An example is better treatment of seasonality effects that leads to more accurate annual estimates of emissions or removals for the Agriculture, Forestry and Other Land Use (AFOLU) Sector.
- *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, consistent with IPCC good practice principles, 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, and research is underway to improve these emission factors.

- *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.
- *Improving models:* Improving model structure and parameterization can lead to better understanding and characterization of the systematic and random errors, as well as reductions in these causes of uncertainty.
- *Collecting more measured data and using more precise measurement methods.* Uncertainty associated with bias and random sampling error can be reducing by increasing the sample size and filling in data gaps. Measurement error can be reduced by using more precise measurement methods, avoiding simplifying assumption, and ensuring that measurement technologies are appropriately used and calibrated.
- *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. For example, activity data provided by EPA's GHGRP are used to develop estimates for several source categories—including but not limited to Magnesium Production and Processing, Semiconductor Manufacturing, and Electrical Transmission and Distribution—and could potentially be implemented for additional source categories to improve uncertainty results, where appropriate.
- *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.
- *Improving state of knowledge and eliminating known risk of bias.* Use expert judgment to improve the understanding of categories and processes leading to emissions and removals. Ensure methodologies, models, and estimation procedures are used appropriately and as advised by *2006 IPCC Guidelines*.

7.5. 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 current 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.[138] 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.[139]

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).[140] 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).

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.[141] For these variables, the uncertainty ranges were assigned to the input variables based on the data reported in SAIC/EIA (2001).[142] 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 2006).

CH_4 and N_2O from Mobile Combustion

The uncertainty analysis was performed on 2015 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, (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

[138] 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.

[139] 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.

[140] 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.

[141] 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.

[142] 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.

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 Greenhouse Gas Reporting Program (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. 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.

In 2015 a small level of uncertainty was introduced with using estimated rather than measured values of recovered methane from two of the mines with degasification systems. An increased level of uncertainty was applied to these two subsources, but the change had little impact on the overall uncertainty.

Abandoned Underground Coal Mines

A quantitative uncertainty analysis was conducted to estimate the uncertainty surrounding the estimates of emissions from abandoned underground coal mines using probability density functions for key variables within a computational structure that mirrors the calculation of the inventory estimate. The results provide the range within which, with 95 percent certainty, emissions from this source category are likely to fall.

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 for the 1990 through 2009 Inventory has not been updated for the 1990 through 2015 Inventory; instead, the uncertainty percentage ranges calculated previously were applied to 2015 emission estimates.

Natural Gas Systems

The uncertainty analysis conducted for the 1990 through 2009 Inventory has not been updated for the 1990 through 2015 Inventory; instead, the uncertainty percentage ranges calculated previously were applied to 2015 emission estimates.

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 Biofuel 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 and biodiesel consumption 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 (e.g., magnesium 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. Publicly available data on LKD generation rates, total quantities not used in cement production, and types of other byproducts/wastes produced at lime facilities is limited.

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. 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. 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. The uncertainty of total urea production activity data, collected through voluntary surveys, is a function of the reliability of reported production data and is influenced by the completeness of the survey responses.

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 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. The annual production reported by each nitric acid facility under EPA's GHGRP and then aggregated to estimate national N_2O emissions is assumed to have low uncertainty.

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

Uncertainty of activity data is also a function of the reliability of reported production data and is influenced by the completeness of the USGS survey responses; variability in response rates varies over the time series. 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. Additional uncertainty comes from the reported consumption and allocation of consumption within sectors that is collected on a quarterly basis by the USGS.

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 2015. 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 2015, 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 Consumption

Uncertainty is associated with the data reported through EPA's GHGRP, specifically the amount of CO_2 consumed for food and beverage applications given a threshold for reporting under EPA's GHGRP applicable to those reporting under Subpart PP, in addition to the exclusion of the amount of CO_2 transferred to all other end-use categories. Uncertainty is also associated with the exclusion of imports/exports data for CO_2 suppliers.

Phosphoric Acid Production

Regional production for 2015 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 2015 regional production data represents actual production in those regions. Total U.S. phosphate rock production data and data for imports and exports of phosphate rock are not considered to be a significant source of uncertainty.

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. Another source of uncertainty is the disposition of the organic carbon content of the phosphate rock. 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 pellet production, 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 electric arc furnace (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 2015 is attributed to the uncertainties around SF_6, HFC-134a and CO_2 emission estimates. To estimate the uncertainty surrounding the estimated 2015 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 2015 through EPA's GHGRP, (2) emissions estimated for magnesium producers and processors that reported via the Partnership in prior years but did not report 2015 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 which is collected via voluntary surveys; the uncertainty of the activity data is a function of the reliability of reported plant-level production data and the completeness of the survey response.

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 Manufacturing

The equation used to estimate uncertainty is:

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

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. For production fabs and for facilities that manufacture discrete devices, the most probable utilization is assumed to be 82 percent, with the highest and lowest utilization assumed to be 89 percent, and 70 percent, respectively. The most probable values for utilization for R&D facilities are assumed to be 20 percent, with the highest utilization at 30 percent, and the lowest utilization at 10 percent. 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 smallest number varied by technology generation between one and two layers less than given in the ITRS and largest number of layers corresponded to the figure given 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 (MMT CO_2 Eq.) 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 across the 65 end-uses in EPA's Vintaging Model. 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 2015 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 2015 emission estimates in the current 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 2003) 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 2015 emission estimates as there have not been significant changes in the methodology since that time.

Rice Cultivation

Sources of uncertainty in the Tier 3 method include management practices, uncertainties in model structure (i.e., algorithms and parameterization), and variance associated with the NRI sample. Sources of uncertainty in the IPCC (2006) Tier 1 method include the emission factors, management practices, and variance associated with the NRI sample. A Monte Carlo analysis was used to propagate uncertainties in the Tier 1 and 3 methods, and the uncertainties from each approach are combined to produce the final CH_4 emissions estimate using simple error propagation (IPCC 2006).

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.

Liming

Uncertainty regarding the amount of limestone and dolomite applied to soils was estimated at ±15 percent with normal densities (Tepordei 2003; Willett 2013). Analysis of the uncertainty associated with the emission factors included the fraction of 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 probability distribution functions for the fraction of lime dissolved by nitric acid and the portion of bicarbonate that leaches through the soil were represented as smoothed triangular distributions between ranges of zero and 100 percent of the estimates.

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, urea consumption data also have uncertainty that is propagated through the emission calculation using a Monte Carlo simulation approach as described by the IPCC (2006).

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

In order to quantify the uncertainties for emissions from forest fires calculated as described above, a Monte Carlo (IPCC Approach 2) sampling approach was employed to propagate uncertainty in the equation as it was applied for U.S. forest land. See IPCC (2006) and Annex 3.13 for the quantities and assumptions employed to define and propagate uncertainty.

N_2O Emissions from N Additions to 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 2015 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.

Drained Organic Soils

Uncertainties are based on the sampling error associated with forest area and the uncertainties provided in the Chapter 2 (IPCC 2013) emissions factors.

Land Converted to Forest Land

Uncertainty estimates for forest pool C stock changes were developed using the same methodologies as described in the *Forest Land Remaining Forest Land* section for aboveground and biomass ground biomass, dead wood, and litter. The exception was when IPCC default estimates were used for reference C stocks in certain conversion categories (i.e., *Cropland Converted to Forest Land* and *Grassland Converted to Forest Land*). In those cases, the uncertainties associated with the IPCC (2006) defaults were included in the uncertainty calculations.

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.

Mineral and Organic 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).

Land Converted to Cropland

Uncertainty analysis for mineral soil C stock changes using the Tier 3 and Tier 2 methodologies are based on the same method described for *Cropland Remaining Cropland*.

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

Grassland Remaining Grassland

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

Soil Carbon Stock Changes

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., Tier 2 and Tier 3).

Non-CO_2 Emissions from Grassland Fires

Uncertainty is associated with lack of reporting of emissions from biomass burning in grassland of Alaska.

Land Converted to Grassland

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

Coastal Wetlands

Underlying uncertainties in estimates of soil C stock changes and CH_4 include error in uncertainties associated with Tier 2 literature values of soil C stocks and CH_4 flux, assumptions that underlie the methodological approaches applied and uncertainties linked to interpretation of remote sensing data. Uncertainty specific to coastal wetlands include differentiation of palustrine and estuarine community classes which determines the soil C stock and methane flux applied. Soil C stocks and CH_4 fluxes applied are determined from vegetation community classes across the coastal zone and identified by NOAA C-CAP. Community classes are further subcategorized by climate zones and growth form (forest, shrub-scrub, marsh). Uncertainties for soil C stock data for all subcategories are not available and thus assumptions were applied using expert judgement about the most appropriate assignment of a soil C stock to a disaggregation of a community class.

Additionally, uncertainties in N_2O emissions from aquaculture are based on expert judgement for the NOAA *Fisheries of the United States* fisheries production data and stem from an overestimate of fisheries production from coastal wetland areas due to the inclusion of fish production in non-coastal wetland areas.

Land Converted to Coastal Wetlands

Underlying uncertainties in estimates of soil C removal factors and CH_4 include error in uncertainties associated with Tier 2 literature values of soil C removal estimates and CH_4 flux, assumptions that underlie the methodological approaches applied and uncertainties linked to interpretation of remote sensing data.

Settlements Remaining Settlements

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

Soil Carbon Stock Changes

Uncertainty of soil carbon stock changes is a result of soil C losses from drained organic soils in *Settlements Remaining Settlements*.

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 2015 emission estimates.

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

Several types of uncertainty are associated with the estimates of CH_4 emissions from MSW and industrial waste landfills when the first order decay model is applied. In other words, the first order decay methodology as applied in this Inventory is not facility-specific modeling and while this approach may over- or under-estimate CH_4 generation at some landfills if used at the facility-level, the result is expected to balance out because it is being applied nationwide. 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). There is less uncertainty in the GHGRP data because this methodology is facility-specific, uses directly measured CH_4 recovery data (when applicable), and allows for a variety of landfill gas collection efficiencies, destruction efficiencies, and/or oxidation factors to be used.

Aside from the uncertainty in estimating landfill CH_4 generation, uncertainty also exists in the estimates of the landfill gas oxidized. Another significant source of uncertainty lies with the estimates of CH_4 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.

The lack of landfill-specific information regarding the number and type of industrial waste landfills in the United States is a primary source of uncertainty with respect to the industrial waste generation and emissions estimates.

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.

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