

## 8. Waste

Waste management and treatment activities are sources of greenhouse gas emissions (see Figure 8-1). Landfills accounted for approximately 16.2 percent of total U.S. anthropogenic methane (CH<sub>4</sub>) emissions in 2010, the third largest contribution of any CH<sub>4</sub> source in the United States. Additionally, wastewater treatment and composting of organic waste accounted for approximately 2.5 percent and less than 1 percent of U.S. methane emissions, respectively. Nitrous oxide (N<sub>2</sub>O) emissions from the discharge of wastewater treatment effluents into aquatic environments were estimated, as were N<sub>2</sub>O emissions from the treatment process itself. N<sub>2</sub>O emissions from composting were also estimated. Together, these waste activities account for less than 3 percent of total U.S. N<sub>2</sub>O emissions. Nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), and non-CH<sub>4</sub> volatile organic compounds (NMVOCs) are emitted by waste activities, and are addressed separately at the end of this chapter. A summary of greenhouse gas emissions from the Waste chapter is presented in Table 8-1 and Table 8-2.

CO<sub>2</sub>, N<sub>2</sub>O, and CH<sub>4</sub> emissions from the incineration of waste are accounted for in the Energy sector rather than in the Waste sector because almost all incineration of municipal solid waste (MSW) in the United States occurs at waste-to-energy facilities where useful energy is recovered. Similarly, the Energy sector also includes an estimate of emissions from burning waste tires, because virtually all of the combustion occurs in industrial and utility boilers that recover energy. The incineration of waste in the United States in 2010 resulted in 12.4 Tg CO<sub>2</sub> Eq. emissions, nearly half of which is attributable to the combustion of plastics. For more details on emissions from the incineration of waste, see Section 3.3.

Figure 8-1: 2010 Waste Chapter Greenhouse Gas Sources

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Box 8-1: Methodological approach for estimating and reporting U.S. emissions and sinks

In following the UNFCCC requirement under Article 4.1 to develop and submit national greenhouse gas emission inventories, the emissions and sinks presented in this report, and this chapter, are organized by source and sink categories and calculated using internationally-accepted methods provided by the Intergovernmental Panel on Climate Change (IPCC).<sup>229</sup> Additionally, the calculated emissions and sinks in a given year for the United States are presented in a common manner in line with the UNFCCC reporting guidelines for the reporting of inventories under this international agreement.<sup>230</sup> The use of consistent methods to calculate emissions and sinks by all nations providing their inventories to the UNFCCC ensures that these reports are comparable. In this regard, U.S. emissions and sinks reported in this inventory report are comparable to emissions and sinks reported by other countries. Emissions and sinks provided in this inventory do not preclude alternative examinations,<sup>231</sup> but rather this inventory presents emissions and sinks in a common format consistent with how countries are to report inventories under the UNFCCC. The report itself, and this chapter, follows this standardized format, and provides an explanation of the IPCC methods used to calculate emissions and sinks, and the manner in which those calculations are conducted.

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Overall, in 2010, waste activities generated emissions of 132.5 Tg CO<sub>2</sub> Eq., or just under 2 percent of total U.S. greenhouse gas emissions.

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<sup>229</sup> See <http://www.ipcc-nggip.iges.or.jp/public/index.html>.

<sup>230</sup> See [http://unfccc.int/national\\_reports/annex\\_i\\_ghg\\_inventories/national\\_inventories\\_submissions/items/5270.php](http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/5270.php).

<sup>231</sup> For example, see <http://www.epa.gov/aboutepa/oswer.html>.

Table 8-1: Emissions from Waste (Tg CO<sub>2</sub> Eq.)

Gas/Source	1990	2005	2006	2007	2008	2009	2010
<b>CH<sub>4</sub></b>	<b>163.9</b>	<b>130.8</b>	<b>130.0</b>	<b>130.0</b>	<b>131.4</b>	<b>129.3</b>	<b>125.8</b>
Landfills	147.7	112.7	111.7	111.7	113.1	111.2	107.8
Wastewater Treatment	15.9	16.5	16.7	16.6	16.6	16.5	16.3
Composting	0.3	1.6	1.6	1.7	1.7	1.6	1.6
<b>N<sub>2</sub>O</b>	<b>3.8</b>	<b>6.4</b>	<b>6.5</b>	<b>6.7</b>	<b>6.8</b>	<b>6.7</b>	<b>6.8</b>
Domestic Wastewater Treatment	3.5	4.7	4.8	4.8	4.9	5.0	5.0
Composting	0.4	1.7	1.8	1.8	1.9	1.8	1.7
<b>Total</b>	<b>167.7</b>	<b>137.2</b>	<b>136.5</b>	<b>136.7</b>	<b>138.2</b>	<b>136.0</b>	<b>132.5</b>

Note: Totals may not sum due to independent rounding.

Table 8-2: Emissions from Waste (Gg)

Gas/Source	1990	2005	2006	2007	2008	2009	2010
<b>CH<sub>4</sub></b>	<b>7,805</b>	<b>6,228</b>	<b>6,189</b>	<b>6,191</b>	<b>6,258</b>	<b>6,157</b>	<b>5,988</b>
Landfills	7,032	5,367	5,320	5,320	5,386	5,295	5,135
Wastewater Treatment	758	785	794	791	792	787	779
Composting	15	75	75	79	80	75	75
<b>N<sub>2</sub>O</b>	<b>12</b>	<b>21</b>	<b>21</b>	<b>22</b>	<b>22</b>	<b>22</b>	<b>22</b>
Domestic Wastewater Treatment	11	15	15	16	16	16	16
Composting	1	6	6	6	6	6	6

Note: Totals may not sum due to independent rounding.

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#### Box 8-2: Waste Data from the Greenhouse Gas Reporting Program

On October 30, 2009, the U.S. EPA published a rule for the mandatory reporting of greenhouse gases from large GHG emissions sources in the United States. Implementation of 40 CFR Part 98 is referred to as EPA's Greenhouse Gas Reporting Program (GHGRP). 40 CFR part 98 applies to direct greenhouse gas emitters, fossil fuel suppliers, industrial gas suppliers, and facilities that inject CO<sub>2</sub> underground for sequestration or other reasons and requires reporting by 41 industrial categories. Reporting is at the facility level, except for certain suppliers of fossil fuels and industrial greenhouse gases. In general, the threshold for reporting is 25,000 metric tons or more of CO<sub>2</sub> Eq. per year. For calendar year 2010, the first year in which data were reported, facilities in 29 categories provided in 40 CFR part 98 were required to report their 2010 emissions by the September 30, 2011 reporting deadline.

EPA's GHGRP dataset and the data presented in this inventory report are complementary and, as indicated in the respective planned improvements sections for source categories in this chapter, EPA is analyzing how to use facility-level GHGRP data to improve the national estimates presented in this inventory. Most methodologies used in EPA's GHGRP are consistent with IPCC, though for EPA's GHGRP, facilities collect detailed information specific to their operations according to detailed measurement standards. This may differ with the more aggregated data collected for the inventory to estimate total, national U.S. emissions. In addition, it should be noted that the definitions and provisions for reporting fuel types in EPA's GHGRP may differ from those used in the national inventory in meeting the UNFCCC reporting guidelines. In line with the UNFCCC reporting guidelines<sup>232</sup>, the inventory report is a comprehensive accounting of all emissions from fuel types identified in the IPCC guidelines and provides a separate reporting of emissions from biomass. Further information on the reporting categorizations in EPA's GHGRP and specific data caveats associated with monitoring methods in EPA's GHGRP has been provided

<sup>232</sup> See <http://unfccc.int/resource/docs/2006/sbsta/eng/09.pdf>.

on the EPA's GHGRP website.<sup>233</sup>

EPA presents the data collected by EPA's GHGRP through a data publication tool<sup>234</sup> that allows data to be viewed in several formats including maps, tables, charts and graphs for individual facilities or groups of facilities.

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### **8.1. Landfills (IPCC Source Category 6A1)**

In 2010, landfill CH<sub>4</sub> emissions were approximately 107.8 Tg CO<sub>2</sub> Eq. (5,135 Gg of CH<sub>4</sub>), representing the third largest source of CH<sub>4</sub> emissions in the United States, behind natural gas systems and enteric fermentation. Emissions from municipal solid waste (MSW) landfills, which received about 69 percent of the total solid waste generated in the United States, accounted for about 94 percent of total landfill emissions, while industrial landfills accounted for the remainder. Approximately 1,900 operational landfills exist in the United States, with the largest landfills receiving most of the waste and generating the majority of the CH<sub>4</sub> (EPA 2010; *BioCycle* 2008, adjusted to include missing data from five states). While the number of landfills has decreased significantly over the past 20 years, from 6,326 in 1990 to 1,908 in 2009), the average landfill size has increased (EPA 2010).

After being placed in a landfill, waste (such as paper, food scraps, and yard trimmings) is initially decomposed by aerobic bacteria. After the oxygen has been depleted, the remaining waste is available for consumption by anaerobic bacteria, which break down organic matter into substances such as cellulose, amino acids, and sugars. These substances are further broken down through fermentation into gases and short-chain organic compounds that form the substrates for the growth of methanogenic bacteria. These CH<sub>4</sub>-producing anaerobic bacteria convert the fermentation products into stabilized organic materials and biogas consisting of approximately 50 percent biogenic carbon dioxide (CO<sub>2</sub>) and 50 percent CH<sub>4</sub>, by volume. Significant CH<sub>4</sub> production typically begins one or two years after waste disposal in a landfill and continues for 10 to 60 years or longer.

Methane emissions from landfills are a function of several factors, including: (1) the total amount of waste in MSW landfills, which is related to total waste landfilled annually; (2) the characteristics of landfills receiving waste (i.e., composition of waste-in-place, size, climate); (3) the amount of CH<sub>4</sub> that is recovered and either flared or used for energy purposes; and (4) the amount of CH<sub>4</sub> oxidized in landfills instead of being released into the atmosphere. From 1990 to 2010, net CH<sub>4</sub> emissions from landfills decreased by approximately 27 percent (see Table 8-3 and Table 8-4). This net CH<sub>4</sub> emissions decrease can be attributed to many factors, including changes in waste composition, an increase in the amount of landfill gas collected and combusted, a higher frequency of composting, and increased rates of recovery for degradable materials (e.g., paper and paperboard).

The estimated annual quantity of waste placed in MSW landfills increased from about 206 Tg in 1990 to 254 Tg in 2010, an increase of 23 percent (see Annex 3.14). Despite increased waste disposal, the amount of decomposable materials (i.e., paper and paperboard, food scraps, and yard trimmings) discarded in MSW landfills have decreased by approximately 21 percent from 1990 to 2009 (EPA 2010). In addition, the amount of landfill gas collected and combusted has increased. In 1990, for example, approximately 960 Gg of CH<sub>4</sub> were recovered and combusted (i.e., used for energy or flared) from landfills, while in 2010, 7,627 Gg CH<sub>4</sub> was combusted, which represents a 5 percent increase in the quantity of CH<sub>4</sub> recovered and combusted from 2009 levels (see Annex 3.14). In 2010, an estimated 54 new landfill gas-to-energy (LFGTE) projects and 46 new flares began operation (EPA 2011).

Over the past 9 years, however, the net CH<sub>4</sub> emissions have fluctuated from year to year, but a slowly increasing trend has been observed. While the amount of landfill gas collected and combusted continues to increase every year, the rate of increase in collection and combustion no longer exceeds the rate of additional CH<sub>4</sub> generation from the amount of organic MSW landfilled as the U.S. population grows.

Over the next several years, the total amount of municipal solid waste generated is expected to increase as the U.S. population continues to grow. The percentage of waste landfilled, however, may decline due to increased recycling

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<sup>233</sup> See

<<http://www.ccdsupport.com/confluence/display/ghgp/Detailed+Description+of+Data+for+Certain+Sources+and+Processes>>.

<sup>234</sup> See <<http://ghgdata.epa.gov>>.

and composting practices. In addition, the quantity of CH<sub>4</sub> that is recovered and either flared or used for energy purposes is expected to continue to increase as a result of 1996 federal regulations that require large municipal solid waste landfills to collect and combust landfill gas (see 40 CFR Part 60, Subpart Cc 2005 and 40 CFR Part 60, Subpart WWW 2005), voluntary programs that encourage CH<sub>4</sub> recovery and use such as EPA's Landfill Methane Outreach Program (LMOP), and federal and state incentives that promote renewable energy (e.g., tax credits, low interest loans, and Renewable Portfolio Standards).

Table 8-3: CH<sub>4</sub> Emissions from Landfills (Tg CO<sub>2</sub> Eq.)

Activity	1990	2005	2006	2007	2008	2009	2010
MSW Landfills	172.6	241.2	247.6	252.9	256.8	260.4	264.0
Industrial Landfills	11.6	15.4	15.4	15.5	15.7	15.8	15.9
<b>Recovered</b>							
Gas-to-Energy	(13.4)	(55.9)	(58.2)	(61.9)	(66.2)	(74.4)	(79.8)
Flared	(6.7)	(75.5)	(80.7)	(82.4)	(80.6)	(78.3)	(80.3)
Oxidized <sup>a</sup>	(16.4)	(12.5)	(12.4)	(12.4)	(12.6)	(12.4)	(12.0)
<b>Total</b>	<b>147.7</b>	<b>112.7</b>	<b>111.7</b>	<b>111.7</b>	<b>113.1</b>	<b>111.2</b>	<b>107.8</b>

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.

<sup>a</sup> Includes oxidation at both municipal and industrial landfills.

Table 8-4: CH<sub>4</sub> Emissions from Landfills (Gg)

Activity	1990	2005	2006	2007	2008	2009	2010
MSW Landfills	8,219	11,486	11,790	12,041	12,227	12,401	12,574
Industrial Landfills	554	733	736	740	746	752	758
<b>Recovered</b>							
Gas-to-Energy	(640)	(2,662)	(2,773)	(2,946)	(3,152)	(3,543)	(3,802)
Flared	(321)	(3,593)	(3,842)	(3,923)	(3,837)	(3,726)	(3,825)
Oxidized <sup>a</sup>	(781)	(596)	(591)	(591)	(598)	(588)	(571)
<b>Total</b>	<b>7,032</b>	<b>5,367</b>	<b>5,320</b>	<b>5,320</b>	<b>5,386</b>	<b>5,295</b>	<b>5,135</b>

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.

<sup>a</sup> Includes CH<sub>4</sub> oxidation at municipal and industrial landfills.

## Methodology

CH<sub>4</sub> emissions from landfills were estimated as the CH<sub>4</sub> produced from municipal solid waste landfills, plus the CH<sub>4</sub> produced by industrial landfills, minus the CH<sub>4</sub> recovered and combusted, minus the CH<sub>4</sub> oxidized before being released into the atmosphere:

$$\text{CH}_{4,\text{Solid Waste}} = [\text{CH}_{4,\text{MSW}} + \text{CH}_{4,\text{Ind}} - \text{R}] - \text{Ox}$$

where,

- CH<sub>4,Solid Waste</sub> = CH<sub>4</sub> emissions from solid waste
- CH<sub>4,MSW</sub> = CH<sub>4</sub> generation from municipal solid waste landfills,
- CH<sub>4,Ind</sub> = CH<sub>4</sub> generation from industrial landfills,
- R = CH<sub>4</sub> recovered and combusted, and
- Ox = CH<sub>4</sub> oxidized from MSW and industrial landfills before release to the atmosphere.

The methodology for estimating CH<sub>4</sub> emissions from municipal solid waste landfills is based on the first order decay model described by the Intergovernmental Panel on Climate Change (IPCC 2006). Values for the CH<sub>4</sub> generation potential (L<sub>0</sub>) and rate constant (k) were obtained from an analysis of CH<sub>4</sub> recovery rates for a database of 52 landfills and from published studies of other landfills (RTI 2004; EPA 1998; SWANA 1998; Peer, Thorneloe, and Epperson 1993). The rate constant was found to increase with average annual rainfall; consequently, values of k were developed for 3 ranges of rainfall. The annual quantity of waste placed in landfills was apportioned to the 3 ranges of rainfall based on the percent of the U.S. population in each of the 3 ranges, and historical census data were used to account for the shift in population to more arid areas over time. A detailed description of the methodology used to estimate CH<sub>4</sub> emissions from landfills can be found in Annex 3.14.

National landfill waste generation and disposal data for 2007, 2009, and 2010 were extrapolated based on *BioCycle* data for 2008 and the U.S. Census population from 2010. Data for 1989 through 2008 were obtained from *BioCycle* (BioCycle 2006, 2008, and 2010). Because *BioCycle* does not account for waste generated in U.S. territories, waste generation for the territories was estimated using population data obtained from the U.S. Census Bureau (2010) and national per capita solid waste generation from *BioCycle* (2010). Estimates of the annual quantity of waste landfilled for 1960 through 1988 were obtained from EPA's *Anthropogenic Methane Emissions in the United States, Estimates for 1990: Report to Congress* (EPA 1993) and an extensive landfill survey by the EPA's Office of Solid Waste in 1986 (EPA 1988). Although waste placed in landfills in the 1940s and 1950s contributes very little to current CH<sub>4</sub> generation, estimates for those years were included in the first order decay model for completeness in accounting for CH<sub>4</sub> generation rates and are based on the population in those years and the per capita rate for land disposal for the 1960s. For calculations in this Inventory, wastes landfilled prior to 1980 were broken into two groups: wastes disposed in landfills (Methane Conversion Factor, MCF, of 1) and those disposed in dumps (MCF of 0.6). Please see Annex 3.14 for more details.

The estimated landfill gas recovered per year was based on updated sales data collected from vendors of flaring equipment (referred to as the flare vendor database), a database of landfill gas-to-energy (LFGTE) projects compiled by LMOP (EPA 2011), and a database developed by the Energy Information Administration (EIA) for the voluntary reporting of greenhouse gases (EIA 2007). The three databases were carefully compared to identify landfills that were in two or all three of the databases to avoid double counting reductions. Based on the information provided by the EIA and flare vendor databases, the CH<sub>4</sub> combusted by flares in operation from 1990 to 2010 was estimated.

The flare vendor database estimates CH<sub>4</sub> combusted by flares using the midpoint of a flare's reported capacity while the EIA database uses landfill-specific measured gas flow. As the EIA database only includes data through 2006; 2007 to 2010 recovery for projects included in the EIA database were assumed to be the same as in 2006. This quantity likely underestimates flaring because these databases do not have information on all flares in operation. Additionally, the EIA and LMOP databases provided data on landfill gas flow and energy generation for landfills with LFGTE projects. If a landfill in the EIA database was also in the LMOP and/or the flare vendor database, the emissions avoided were based on the EIA data because landfill owners or operators reported the amount recovered based on measurements of gas flow and concentration, and the reporting accounted for changes over time. If both flare data and LMOP recovery data were available for any of the remaining landfills (i.e., not in the EIA database), then the emissions recovery was based on the LMOP data, which provides reported landfill-specific data on gas flow for direct use projects and project capacity (i.e., megawatts) for electricity projects. The flare data, on the other hand, only provided a range of landfill gas flow for a given flare size. Given that each LFGTE project is likely to also have a flare, double counting reductions from flares and LFGTE projects in the LMOP database was avoided by subtracting emission reductions associated with LFGTE projects for which a flare had not been identified from the emission reductions associated with flares (referred to as the flare correction factor). A further explanation of the methodology used to estimate the landfill gas recovered for the current Inventory can be found in Annex 3.14.

A destruction efficiency of 99 percent was applied to CH<sub>4</sub> recovered to estimate CH<sub>4</sub> emissions avoided. The value for efficiency was selected based on the range of efficiencies (86 to 99 percent) recommended for flares in EPA's AP-42 Compilation of Air Pollutant Emission Factors, Chapter 2.4 (EPA 2008), efficiencies used to establish new source performance standards (NSPS) for landfills, and in recommendations for closed flares used in LMOP.

Emissions from industrial landfills were estimated from activity data for industrial production (ERG 2011), waste disposal factors, and the first order decay model. As over 99 percent of the organic waste placed in industrial landfills originated from the food processing (meat, vegetables, fruits) and pulp and paper industries, estimates of industrial landfill emissions focused on these two sectors (EPA 1993). The amount of CH<sub>4</sub> oxidized by the landfill cover at both municipal and industrial landfills was assumed to be ten percent of the CH<sub>4</sub> generated that is not recovered (IPCC 2006, Mancinelli and McKay 1985, Czepiel et al. 1996). To calculate net CH<sub>4</sub> emissions, both CH<sub>4</sub> recovered and CH<sub>4</sub> oxidized were subtracted from CH<sub>4</sub> generated at municipal and industrial landfills.

## Uncertainty and Time-Series Consistency

Several types of uncertainty are associated with the estimates of CH<sub>4</sub> emissions from landfills. The primary uncertainty concerns the characterization of landfills. Information is not available on two fundamental factors affecting CH<sub>4</sub> production: the amount and composition of waste placed in every landfill for each year of its operation. The approach used here assumes that the CH<sub>4</sub> generation potential and the rate of decay that produces CH<sub>4</sub>, as determined from several studies of CH<sub>4</sub> recovery at landfills, are representative of U.S. landfills.

Additionally, the approach used to estimate the contribution of industrial wastes to total CH<sub>4</sub> generation introduces uncertainty. Aside from uncertainty in estimating CH<sub>4</sub> generation potential, uncertainty exists in the estimates of oxidation by cover soils. There is also uncertainty in the estimates of CH<sub>4</sub> that is recovered by flaring and energy projects. The IPCC default value of 10 percent for uncertainty in recovery estimates was used in the uncertainty analysis when metering was in place (for about 64 percent of the CH<sub>4</sub> estimated to be recovered). For flaring without metered recovery data (approximately 34 percent of the CH<sub>4</sub> estimated to be recovered), a much higher uncertainty of approximately 50 percent was used (e.g., when recovery was estimated as 50 percent of the flare’s design capacity).

N<sub>2</sub>O emissions from the application of sewage sludge on landfills are not explicitly modeled as part of greenhouse gas emissions from landfills. N<sub>2</sub>O emissions from sewage sludge applied to landfills would be relatively small because the microbial environment in landfills is not very conducive to the nitrification and denitrification processes that result in N<sub>2</sub>O emissions. Furthermore, the 2006 IPCC Guidelines (IPCC 2006) did not include a methodology for estimating N<sub>2</sub>O emissions from solid waste disposal sites “because they are not significant.” Therefore, any uncertainty or bias caused by not including N<sub>2</sub>O emissions from landfills is expected to be minimal.

The results of the IPCC Good Practice Guidance Tier 2 quantitative uncertainty analysis are summarized in Table 8-5. Landfill CH<sub>4</sub> emissions in 2010 were estimated to be between 51.3 and 154.5 Tg CO<sub>2</sub> Eq., which indicates a range of 52 percent below to 43 percent above the 2010 emission estimate of 107.8 Tg CO<sub>2</sub> Eq.

Table 8-5: Tier 2 Quantitative Uncertainty Estimates for CH<sub>4</sub> Emissions from Landfills (Tg CO<sub>2</sub> Eq. and Percent)

Source	Gas	2010 Emission Estimate (Tg CO <sub>2</sub> Eq.)	Uncertainty Range Relative to Emission Estimate <sup>a</sup>			
			Lower Bound	Upper Bound	Lower Bound (%)	Upper Bound (%)
<b>Landfills</b>	<b>CH<sub>4</sub></b>	<b>107.8</b>	<b>52.3</b>	<b>154.8</b>	<b>-52%</b>	<b>+44%</b>
MSW	CH <sub>4</sub>	93.5	38.6	138.6	-59%	+48%
Industrial	CH <sub>4</sub>	14.3	10.3	17.3	-28%	+21%

<sup>a</sup> Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2010. Details on the emission trends through time are described in more detail in the Methodology section, above.

## QA/QC and Verification

A QA/QC analysis was performed for data gathering and input, documentation, and calculation. A primary focus of the QA/QC checks was to ensure that CH<sub>4</sub> recovery estimates were not double-counted and that all LFGTE projects and flares were included in the respective project databases. Both manual and electronic checks were made to ensure that emission avoidance from each landfill was calculated in only one of the three databases. The primary calculation spreadsheet is tailored from the IPCC waste model and has been verified previously using the original, peer-reviewed IPCC waste model. All model input values were verified by secondary QA/QC review.

## Recalculations Discussion

No methodological changes were made for this Inventory. The national landfill waste generation data for 2007, 2008, and 2009 were recalculated using the most recent BioCycle data for 2008 (BioCycle 2010). These recalculations resulted in decreased waste generation amounts for those years and, in turn, decreased the total CH<sub>4</sub> emissions estimates from landfills for 2008 and 2009 compared to the previous year’s Inventory. The BioCycle survey is the only continually updated nationwide survey of waste generated and disposed in landfills in the United States. For years when BioCycle data are not available, the waste generation data used for the Inventory are extrapolated and later updated as later surveys are published, resulting in changes over the affected portion of the time series.

## Planned Improvements

Improvements to the inventory being examined include incorporating data from the EPA's GHGRP and modifying the default oxidation rate applied to MSW and industrial landfills.

Beginning in 2011, all MSW landfills that accepted waste on or after January 1, 1980 and generate CH<sub>4</sub> in amounts equivalent to 25,000 metric tons or more of carbon dioxide equivalent (CO<sub>2</sub> Eq.) were required to calculate and report their greenhouse gas emissions to EPA through its GHGRP. This consists of the landfill, landfill gas collection systems, and landfill gas destruction devices, including flares. The data collected from the GHGRP will be used in future Inventories to revise the parameters used in the CH<sub>4</sub> generation calculations, including degradable organic carbon (DOC), the flare correction factor, the methane correction factor (MCF), fraction of DOC dissimilated (DOC<sub>F</sub>), the destruction efficiency of flares, the oxidation factor, and the decay rate constant (k). The addition of this higher tier data will improve the emission calculations to provide a more accurate representation of greenhouse gas emissions from MSW landfills. . In examining data from EPA's GHGRP that would be useful to improve the emissions estimates for MSW landfills, particular attention will be made to ensure time series consistency, as the facility-level reporting data from the GHGRP are not available for all inventory years as reported in this inventory. In implementing improvements and integration of data from the GHGRP, the latest guidance from the IPCC on the use of facility-level data in national inventories will be relied upon<sup>235</sup>.

In addition to MSW landfills, industrial landfills at facilities generating CH<sub>4</sub> in amounts equivalent to 25,000 metric tons or more of CO<sub>2</sub> Eq. are required to report their GHG emissions in September 2012 through EPA's GHGRP. Similar data for industrial landfills as is required for the MSW landfills will be reported. Any additions or improvements to the Inventory using reported GHGRP data will be made for the industrial landfill portion of the inventory. Improvements may include breaking out the industrial waste landfills into three regions (dry, moderate, and wet) as is done for the MSW landfills, allowing for region-specific k values rather than a default IPCC value. As with MSW landfills, any improvements made to the emissions estimates for industrial landfills will include efforts to ensure time series consistency using the latest guidance from the IPCC.

As a first step toward investigating the possibility of increasing the oxidation rate used in the Inventory, a literature review was conducted in 2011 to assess the state of oxidation at a range of landfills (RTI 2011). A standard CH<sub>4</sub> oxidation rate of 10 percent has been used in the LFG inventory for both industrial and MSW landfills since the inventory began and is currently recommended as the default for well-managed landfills in the latest IPCC guidelines (2006). Recent comments on the Inventory methodology indicated that a default oxidation rate of 10 percent may be less than oxidation rates achieved at well-managed landfills with gas collection and control.

Changing the oxidation rate and calculating the amount of CH<sub>4</sub> oxidized from landfills with gas collection and control requires the estimation of waste disposed of in these types of landfills. The Inventory methodology uses waste generation data from the BioCycle State of Garbage reports, which reports the total amount of waste generated and disposed nationwide by state. In 2010, the State of Garbage survey requested data on the recovery of landfill gas for the first time. Twenty-eight states reported that 260 out of 1,414 (18 percent) operational landfills recovered gas (BioCycle 2010). However, the survey did not include closed landfills with gas collection and control systems. In the future, the amount of states collecting and reporting this information is expected to increase.

While the research findings indicate some evidence that landfills with gas collection and control achieve a 20 percent or higher oxidation rate, there is not sufficient certainty to adopt a higher oxidation rate at this time. It is expected that with increased reporting by states in the State of Garbage survey, as well as the data collected through the GHGRP, the oxidation rate for at least a subset of landfills may be increased in a future Inventory.

[Begin Text Box]

### Box 8-3: Biogenic Wastes in Landfills

Regarding the depositing of wastes of biogenic origin in landfills, empirical evidence shows that some of these wastes degrade very slowly in landfills, and the C they contain is effectively sequestered in landfills over a period of

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<sup>235</sup> See: [http://www.ipcc-nggip.iges.or.jp/meeting/pdfiles/1008\\_Model\\_and\\_Facility\\_Level\\_Data\\_Report.pdf](http://www.ipcc-nggip.iges.or.jp/meeting/pdfiles/1008_Model_and_Facility_Level_Data_Report.pdf)

time (Barlaz 1998, 2006). Estimates of C removals from landfilling of forest products, yard trimmings, and food scraps are further described in the Land Use, Land-Use Change, and Forestry chapter, based on methods presented in IPCC (2003) and IPCC (2006).

[End Box]

## **8.2. Wastewater Treatment (IPCC Source Category 6B)**

Wastewater treatment processes can produce anthropogenic CH<sub>4</sub> and N<sub>2</sub>O emissions. Wastewater from domestic<sup>236</sup> and industrial sources is treated to remove soluble organic matter, suspended solids, pathogenic organisms, and chemical contaminants. Treatment may either occur on site, most commonly through septic systems or package plants, or off site at centralized treatment systems. Centralized wastewater treatment systems may include a variety of processes, ranging from lagooning to advanced tertiary treatment technology for removing nutrients. In the United States, approximately 20 percent of domestic wastewater is treated in septic systems or other on-site systems, while the rest is collected and treated centrally (U.S. Census Bureau 2009).

Soluble organic matter is generally removed using biological processes in which microorganisms consume the organic matter for maintenance and growth. The resulting biomass (sludge) is removed from the effluent prior to discharge to the receiving stream. Microorganisms can biodegrade soluble organic material in wastewater under aerobic or anaerobic conditions, where the latter condition produces CH<sub>4</sub>. During collection and treatment, wastewater may be accidentally or deliberately managed under anaerobic conditions. In addition, the sludge may be further biodegraded under aerobic or anaerobic conditions. The generation of N<sub>2</sub>O may also result from the treatment of domestic wastewater during both nitrification and denitrification of the N present, usually in the form of urea, ammonia, and proteins. These compounds are converted to nitrate (NO<sub>3</sub>) through the aerobic process of nitrification. Denitrification occurs under anoxic conditions (without free oxygen), and involves the biological conversion of nitrate into dinitrogen gas (N<sub>2</sub>). N<sub>2</sub>O can be an intermediate product of both processes, but has typically been associated with denitrification. Recent research suggests that higher emissions of N<sub>2</sub>O may in fact originate from nitrification (Ahn et al. 2010).

The principal factor in determining the CH<sub>4</sub> generation potential of wastewater is the amount of degradable organic material in the wastewater. Common parameters used to measure the organic component of the wastewater are the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Under the same conditions, wastewater with higher COD (or BOD) concentrations will generally yield more CH<sub>4</sub> than wastewater with lower COD (or BOD) concentrations. BOD represents the amount of oxygen that would be required to completely consume the organic matter contained in the wastewater through aerobic decomposition processes, while COD measures the total material available for chemical oxidation (both biodegradable and non-biodegradable). Because BOD is an aerobic parameter, it is preferable to use COD to estimate CH<sub>4</sub> production. The principal factor in determining the N<sub>2</sub>O generation potential of wastewater is the amount of N in the wastewater. The variability of N in the influent to the treatment system, as well as the operating conditions of the treatment system itself, also impact the N<sub>2</sub>O generation potential.

In 2010, CH<sub>4</sub> emissions from domestic wastewater treatment were 7.8Tg CO<sub>2</sub> Eq. (370 Gg). Emissions gradually increased from 1990 through 1997, but have decreased since that time due to decreasing percentages of wastewater being treated in anaerobic systems, including reduced use of on-site septic systems and central anaerobic treatment systems. In 2010, CH<sub>4</sub> emissions from industrial wastewater treatment were estimated to be 8.6 Tg CO<sub>2</sub> Eq. (409 Gg). Industrial emission sources have increased across the time series through 1999 and then fluctuated up and down with production changes associated with the treatment of wastewater from the pulp and paper manufacturing, meat and poultry processing, fruit and vegetable processing, starch-based ethanol production, and petroleum refining industries. Table 8-6 and Table 8-7 provide CH<sub>4</sub> and N<sub>2</sub>O emission estimates from domestic and industrial wastewater treatment.

With respect to N<sub>2</sub>O, the United States identifies two distinct sources for N<sub>2</sub>O emissions from domestic wastewater: emissions from centralized wastewater treatment processes, and emissions from effluent from centralized treatment

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<sup>236</sup> Throughout the inventory, emissions from domestic wastewater also include any commercial and industrial wastewater collected and co-treated with domestic wastewater.



systems that has been discharged into aquatic environments. The 2010 emissions of N<sub>2</sub>O from centralized wastewater treatment processes and from effluent were estimated to be 0.3 Tg CO<sub>2</sub> Eq. (1 Gg) and 4.7 Tg CO<sub>2</sub> Eq. (15.3 Gg), respectively. Total N<sub>2</sub>O emissions from domestic wastewater were estimated to be 5.0 Tg CO<sub>2</sub> Eq. (16.3 Gg). N<sub>2</sub>O emissions from wastewater treatment processes gradually increased across the time series as a result of increasing U.S. population and protein consumption.

Table 8-6: CH<sub>4</sub> and N<sub>2</sub>O Emissions from Domestic and Industrial Wastewater Treatment (Tg CO<sub>2</sub> Eq.)

Activity	1990	2005	2006	2007	2008	2009	2010
<b>CH<sub>4</sub></b>	<b>15.9</b>	<b>16.5</b>	<b>16.7</b>	<b>16.6</b>	<b>16.6</b>	<b>16.5</b>	<b>16.3</b>
Domestic	8.8	8.3	8.2	8.1	8.0	8.0	7.8
Industrial*	7.1	8.2	8.5	8.5	8.6	8.5	8.6
<b>N<sub>2</sub>O</b>	<b>3.5</b>	<b>4.7</b>	<b>4.8</b>	<b>4.8</b>	<b>4.9</b>	<b>5.0</b>	<b>5.0</b>
Domestic	3.5	4.7	4.8	4.8	4.9	5.0	5.0
<b>Total</b>	<b>19.4</b>	<b>21.2</b>	<b>21.5</b>	<b>21.4</b>	<b>21.5</b>	<b>21.5</b>	<b>21.3</b>

\* Industrial activity includes the pulp and paper manufacturing, meat and poultry processing, fruit and vegetable processing, starch-based ethanol production, and petroleum refining industries.

Note: Totals may not sum due to independent rounding.

Table 8-7: CH<sub>4</sub> and N<sub>2</sub>O Emissions from Domestic and Industrial Wastewater Treatment (Gg)

Activity	1990	2005	2006	2007	2008	2009	2010
<b>CH<sub>4</sub></b>	<b>758</b>	<b>785</b>	<b>794</b>	<b>791</b>	<b>792</b>	<b>787</b>	<b>779</b>
Domestic	421	397	391	386	383	380	370
Industrial*	338	389	403	405	409	406	409
<b>N<sub>2</sub>O</b>	<b>11</b>	<b>15</b>	<b>15</b>	<b>16</b>	<b>16</b>	<b>16</b>	<b>16</b>
Domestic	11	15	15	16	16	16	16

\* Industrial activity includes the pulp and paper manufacturing, meat and poultry processing, fruit and vegetable processing, starch-based ethanol production, and petroleum refining industries.

Note: Totals may not sum due to independent rounding.

## Methodology

### Domestic Wastewater CH<sub>4</sub> Emission Estimates

Domestic wastewater CH<sub>4</sub> emissions originate from both septic systems and from centralized treatment systems, such as publicly owned treatment works (POTWs). Within these centralized systems, CH<sub>4</sub> emissions can arise from aerobic systems that are not well managed or that are designed to have periods of anaerobic activity (e.g., constructed wetlands), anaerobic systems (anaerobic lagoons and facultative lagoons), and from anaerobic digesters when the captured biogas is not completely combusted. CH<sub>4</sub> emissions from septic systems were estimated by multiplying the United States population by the percent of wastewater treated in septic systems (20 percent), an emission factor (10.7 g CH<sub>4</sub>/capita/day) and converting that to Gg/year. Methane emissions from POTWs were estimated by multiplying the total BOD<sub>5</sub> produced in the United States by the percent of wastewater treated centrally (80 percent), the relative percentage of wastewater treated by aerobic and anaerobic systems, the relative percentage of wastewater facilities with primary treatment, the percentage of BOD<sub>5</sub> treated after primary treatment (67.5 percent), the maximum CH<sub>4</sub>-producing capacity of domestic wastewater (0.6), and the relative MCFs for aerobic (zero or 0.3) and anaerobic (0.8) systems with all aerobic systems assumed to be well-managed. Methane emissions from anaerobic digesters were estimated by multiplying the amount of biogas generated by wastewater sludge treated in anaerobic digesters by the proportion of CH<sub>4</sub> in digester biogas (0.65), the density of CH<sub>4</sub> (662 g CH<sub>4</sub>/m<sup>3</sup> CH<sub>4</sub>), and the destruction efficiency associated with burning the biogas in an energy/thermal device (0.99). The methodological equations are:

$$\begin{aligned} \text{Emissions from Septic Systems} &= A \\ &= \text{US}_{\text{POP}} \times (\% \text{ onsite}) \times (\text{EF}_{\text{SEPTIC}}) \times 1/10^9 \times \text{Days} \end{aligned}$$

$$\begin{aligned} \text{Emissions from Centrally Treated Aerobic Systems} &= B \\ &= [(\% \text{ collected}) \times (\text{total BOD}_5 \text{ produced}) \times (\% \text{ aerobic}) \times (\% \text{ aerobic w/out primary}) + (\% \text{ collected}) \times (\text{total BOD}_5 \end{aligned}$$

produced) × (% aerobic) × (% aerobic w/primary) × (1-% BOD removed in prim. treat.)] × (% operations not well managed) × (B<sub>o</sub>) × (MCF-aerobic\_not\_well\_man) × 1/10<sup>6</sup>

*Emissions from Centrally Treated Anaerobic Systems = C*

= [(% collected) × (total BOD<sub>5</sub> produced) × (% anaerobic) × (% anaerobic w/out primary) + (% collected) × (total BOD<sub>5</sub> produced) × (% anaerobic) × (% anaerobic w/primary) × (1-%BOD removed in prim. treat.)] × (B<sub>o</sub>) × (MCF-anaerobic) × 1/10<sup>6</sup>

*Emissions from Anaerobic Digesters = D*

= [(POTW\_flow\_AD) × (digester gas)/ (per capita flow)] × conversion to m<sup>3</sup> × (FRAC\_CH<sub>4</sub>) × (365.25) × (density of CH<sub>4</sub>) × (1-DE) × 1/10<sup>9</sup>

Total CH<sub>4</sub> Emissions (Gg) = A + B + C + D

where,

US <sub>POP</sub>	= U.S. population
% onsite	= Flow to septic systems / total flow
% collected	= Flow to POTWs / total flow
% aerobic	= Flow to aerobic systems / total flow to POTWs
% anaerobic	= Flow to anaerobic systems / total flow to POTWs
% aerobic w/out primary	= Percent of aerobic systems that do not employ primary treatment
% aerobic w/primary	= Percent of aerobic systems that employ primary treatment
% BOD removed in prim. treat.	= 32.5%
% operations not well managed	= Percent of aerobic systems that are not well managed and in which some anaerobic degradation occurs
% anaerobic w/out primary	= Percent of anaerobic systems that do not employ primary treatment
% anaerobic w/primary	= Percent of anaerobic systems that employ primary treatment
EF <sub>SEPTIC</sub>	= Methane emission factor (10.7 g CH <sub>4</sub> /capita/day) – septic systems
Days	= days per year (365.25)
Total BOD <sub>5</sub> produced	= kg BOD/capita/day × U.S. population × 365.25 days/yr
B <sub>o</sub>	= Maximum CH <sub>4</sub> -producing capacity for domestic wastewater (0.60 kg CH <sub>4</sub> /kg BOD)
1/10 <sup>6</sup>	= Conversion factor, kg to Gg
MCF-aerobic_not_well_man.	= CH <sub>4</sub> correction factor for aerobic systems that are not well managed (0.3)
MCF-anaerobic	= CH <sub>4</sub> correction factor for anaerobic systems (0.8)
DE	= CH <sub>4</sub> destruction efficiency from flaring or burning in engine (0.99 for enclosed flares)
POTW_flow_AD digester gas	= Wastewater influent flow to POTWs that have anaerobic digesters (gal) = Cubic feet of digester gas produced per person per day (1.0 ft <sup>3</sup> /person/day) (Metcalf and Eddy 1991)
per capita flow	= Wastewater flow to POTW per person per day (100 gal/person/day)
conversion to m <sup>3</sup>	= Conversion factor, ft <sup>3</sup> to m <sup>3</sup> (0.0283)
FRAC_CH <sub>4</sub>	= Proportion CH <sub>4</sub> in biogas (0.65)
density of CH <sub>4</sub>	= 662 (g CH <sub>4</sub> /m <sup>3</sup> CH <sub>4</sub> )
1/10 <sup>9</sup>	= Conversion factor, g to Gg

U.S. population data were taken from the U.S. Census Bureau International Database (U.S. Census 2011) and include the populations of the United States, American Samoa, Guam, Northern Mariana Islands, Puerto Rico, and the Virgin Islands. Table 8-8 presents U.S. population and total BOD<sub>5</sub> produced for 1990 through 2010, while Table 8-9 presents domestic wastewater CH<sub>4</sub> emissions for both septic and centralized systems in 2010. The proportions of domestic wastewater treated onsite versus at centralized treatment plants were based on data from the 1989, 1991, 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2007, and 2009 American Housing Surveys conducted by the U.S. Census Bureau (U.S. Census 2009), with data for intervening years obtained by linear interpolation. The percent of wastewater flow to aerobic and anaerobic systems, the percent of aerobic and anaerobic systems that do and do not employ primary treatment, and the wastewater flow to POTWs that have anaerobic digesters were obtained from the

1992, 1996, 2000, and 2004 Clean Watershed Needs Survey (EPA 1992, 1996, 2000, and 2004). Data for intervening years were obtained by linear interpolation and the years 2004 through 2010 were forecasted from the rest of the time series. The BOD<sub>5</sub> production rate (0.09 kg/capita/day) and the percent BOD<sub>5</sub> removed by primary treatment for domestic wastewater were obtained from Metcalf and Eddy (1991 and 2003). The CH<sub>4</sub> emission factor (0.6 kg CH<sub>4</sub>/kg BOD<sub>5</sub>) and the MCF used for centralized treatment systems were taken from IPCC (2006), while the CH<sub>4</sub> emission factor (10.7 g CH<sub>4</sub>/capita/day) used for septic systems were taken from Leverenz et al. (2010). The CH<sub>4</sub> destruction efficiency for methane recovered from sludge digestion operations, 99 percent, was selected based on the range of efficiencies (98 to 100 percent) recommended for flares in AP-42 Compilation of Air Pollutant Emission Factors, Chapter 2.4 (EPA 1998), efficiencies used to establish new source performance standards (NSPS) for landfills, and in recommendations for closed flares used by the Landfill Methane Outreach Program (LMOP). The cubic feet of digester gas produced per person per day (1.0 ft<sup>3</sup>/person/day) and the proportion of CH<sub>4</sub> in biogas (0.65) come from Metcalf and Eddy (1991). The wastewater flow to a POTW (100 gal/person/day) was taken from the Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, "Recommended Standards for Wastewater Facilities (Ten-State Standards)" (2004).

Table 8-8: U.S. Population (Millions) and Domestic Wastewater BOD<sub>5</sub> Produced (Gg)

Year	Population	BOD <sub>5</sub>
1990	253	8,333
2005	300	9,864
2006	303	9,958
2007	306	10,057
2008	309	10,149
2009	311	10,236
2010	313	10,278

Source: U.S. Census Bureau (2011); Metcalf & Eddy 1991 and 2003.

Table 8-9: Domestic Wastewater CH<sub>4</sub> Emissions from Septic and Centralized Systems (2010)

	CH <sub>4</sub> emissions (Tg CO <sub>2</sub> Eq.)	% of Domestic Wastewater CH <sub>4</sub>
Septic Systems	5.1	65.4%
Centralized Systems	2.7	34.6%
<b>Total</b>	<b>7.8</b>	<b>100%</b>

Note: Totals may not sum due to independent rounding.

### Industrial Wastewater CH<sub>4</sub> Emission Estimates

Methane emissions estimates from industrial wastewater were developed according to the methodology described in IPCC (2006). Industry categories that are likely to produce significant CH<sub>4</sub> emissions from wastewater treatment were identified. High volumes of wastewater generated and a high organic wastewater load were the main criteria. The top five industries that meet these criteria are pulp and paper manufacturing; meat and poultry processing; vegetables, fruits, and juices processing; starch-based ethanol production; and petroleum refining. Wastewater treatment emissions for these sectors for 2010 are displayed in Table 8-10 below. Table 8-11 contains production data for these industries.

Table 8-10: Industrial Wastewater CH<sub>4</sub> Emissions by Sector (2010)

	CH <sub>4</sub> emissions (Tg CO <sub>2</sub> Eq.)	% of Industrial Wastewater CH <sub>4</sub>
Pulp & Paper	4.1	48%
Meat & Poultry	3.6	42%
Petroleum Refineries	0.6	7%
Fruit & Vegetables	0.1	1%
Ethanol Refineries	0.1	1%
<b>Total</b>	<b>8.6</b>	<b>100%</b>

Note: Totals may not sum due to independent rounding.

Table 8-11: U.S. Pulp and Paper, Meat, Poultry, Vegetables, Fruits and Juices, Ethanol, and Petroleum Refining Production (Tg)

Year	Pulp and Paper	Meat (Live Weight Killed)	Poultry (Live Weight Killed)	Vegetables, Fruits and Juices	Ethanol	Petroleum Refining
1990	128.9	27.3	14.6	38.7	2.7	702.4
2005	131.4	31.4	25.1	42.9	11.7	818.6
2006	137.4	32.5	25.5	42.9	14.5	826.7
2007	135.9	33.4	26.0	44.7	19.4	827.6
2008	134.5	34.4	26.6	45.1	26.9	836.8
2009	137.0	33.8	25.2	46.5	31.7	822.4
2010	137.0	33.7	25.9	43.7	39.5	848.6

Methane emissions from these categories were estimated by multiplying the annual product output by the average outflow, the organics loading (in COD) in the outflow, the percentage of organic loading assumed to degrade anaerobically, and the maximum CH<sub>4</sub> producing potential of industrial wastewater (B<sub>0</sub>). Ratios of BOD:COD in various industrial wastewaters were obtained from EPA (1997a) and used to estimate COD loadings. The B<sub>0</sub> value used for all industries is the IPCC default value of 0.25 kg CH<sub>4</sub>/kg COD (IPCC 2006).

For each industry, the percent of plants in the industry that treat wastewater on site, the percent of plants that have a primary treatment step prior to biological treatment, and the percent of plants that treat wastewater anaerobically were defined. The percent of wastewater treated anaerobically onsite (TA) was estimated for both primary treatment (%TA<sub>p</sub>) and secondary treatment (%TA<sub>s</sub>). For plants that have primary treatment in place, an estimate of COD that is removed prior to wastewater treatment in the anaerobic treatment units was incorporated.

The methodological equations are:

$$\text{CH}_4 (\text{industrial wastewater}) = [P \times W \times \text{COD} \times \%TA_p \times B_0 \times \text{MCF}] + [P \times W \times \text{COD} \times \%TA_s \times B_0 \times \text{MCF}]$$

$$\%TA_p = [\%Plants_o \times \%WW_{a,p} \times \%COD_p]$$

$$\%TA_s = [\%Plants_a \times \%WW_{a,s} \times \%COD_s] + [\%Plants_t \times \%WW_{a,t} \times \%COD_s]$$

where,

CH<sub>4</sub> (industrial wastewater) = Total CH<sub>4</sub> emissions from industrial wastewater (kg/year)

P = Industry output (metric tons/year)

W = Wastewater generated (m<sup>3</sup>/metric ton of product)

COD = Organics loading in wastewater (kg/m<sup>3</sup>)

%TA<sub>p</sub> = Percent of wastewater treated anaerobically on site in primary treatment

%TA<sub>s</sub> = Percent of wastewater treated anaerobically on site in secondary treatment

%Plants<sub>o</sub> = Percent of plants with onsite treatment

%WW <sub>a,p</sub>	= Percent of wastewater treated anaerobically in primary treatment
%COD <sub>p</sub>	= Percent of COD entering primary treatment
%Plants <sub>a</sub>	= Percent of plants with anaerobic secondary treatment
%Plants <sub>t</sub>	= Percent of plants with other secondary treatment
%WW <sub>a,s</sub>	= Percent of wastewater treated anaerobically in anaerobic secondary treatment
%WW <sub>a,t</sub>	= percent of wastewater treated anaerobically in other secondary treatment
%COD <sub>s</sub>	= percent of COD entering secondary treatment
B <sub>o</sub>	= Maximum CH <sub>4</sub> producing potential of industrial wastewater (default value of 0.25 kg CH <sub>4</sub> /kg COD)
MCF	= CH <sub>4</sub> correction factor, indicating the extent to which the organic content (measured as COD) degrades anaerobically

As described below, the values presented in Table 8-12 were used in the emission calculations and are described in detail in Aguiar and Bartram (2008).

Table 8-12: Variables Used to Calculate Percent Wastewater Treated Anaerobically by Industry (%)

Variable	Industry						
	Pulp and Paper	Meat Processing	Poultry Processing	Fruit/Vegetable Processing	Ethanol Production – Wet Mill	Ethanol Production – Dry Mill	Petroleum Refining
%TA <sub>p</sub>	0	0	0	0	0	0	0
%TA <sub>s</sub>	10.5	33	25	4.2	33.3	75	100
%Plants <sub>o</sub>	60	100	100	11	100	100	100
%Plants <sub>a</sub>	25	33	25	5.5	33.3	75	100
%Plants <sub>t</sub>	35	67	75	5.5	66.7	25	0
%WW <sub>a,p</sub>	0	0	0	0	0	0	0
%WW <sub>a,s</sub>	100	100	100	100	100	100	100
%WW <sub>a,t</sub>	0	0	0	0	0	0	0
%COD <sub>p</sub>	100	100	100	100	100	100	100
%COD <sub>s</sub>	42	100	100	77	100	100	100

Source: Aguiar and Bartram (2008) Planned Revisions of the Industrial Wastewater Inventory Emission Estimates for the 1990-2007 Inventory. August 10, 2008.

*Pulp and Paper.* Wastewater treatment for the pulp and paper industry typically includes neutralization, screening, sedimentation, and flotation/hydrocycloning to remove solids (World Bank 1999, Nemerow and Dasgupta 1991). Secondary treatment (storage, settling, and biological treatment) mainly consists of lagooning. In determining the percent that degrades anaerobically, both primary and secondary treatment were considered. In the United States, primary treatment is focused on solids removal, equalization, neutralization, and color reduction (EPA 1993). The vast majority of pulp and paper mills with on-site treatment systems use mechanical clarifiers to remove suspended solids from the wastewater. About 10 percent of pulp and paper mills with treatment systems use settling ponds for primary treatment and these are more likely to be located at mills that do not perform secondary treatment (EPA 1993). However, because the vast majority of primary treatment operations at U.S. pulp and paper mills use mechanical clarifiers, and less than 10 percent of pulp and paper wastewater is managed in primary settling ponds that are not expected to have anaerobic conditions, negligible emissions are assumed to occur during primary treatment.

Approximately 42 percent of the BOD passes on to secondary treatment, which consists of activated sludge, aerated stabilization basins, or non-aerated stabilization basins. No anaerobic activity is assumed to occur in activated sludge systems or aerated stabilization basins (note: although IPCC recognizes that some CH<sub>4</sub> can be emitted from anaerobic pockets, they recommend an MCF of zero). However, about 25 percent of the wastewater treatment systems used in the United States are non-aerated stabilization basins. These basins are typically 10 to 25 feet deep. These systems are classified as anaerobic deep lagoons (MCF = 0.8).

A time series of CH<sub>4</sub> emissions for 1990 through 2001 was developed based on production figures reported in the Lockwood-Post Directory (Lockwood-Post 2002). Published data from the American Forest and Paper Association, data published by Paper Loop, and other published statistics were used to estimate production for 2002 through 2010 (Pulp and Paper 2005, 2006, and monthly reports from 2003 through 2008; Paper 360° 2007). The overall

wastewater outflow was estimated to be 85 m<sup>3</sup>/metric ton, and the average BOD concentrations in raw wastewater was estimated to be 0.4 gram BOD/liter (EPA 1997b, EPA 1993, World Bank 1999).

*Meat and Poultry Processing.* The meat and poultry processing industry makes extensive use of anaerobic lagoons in sequence with screening, fat traps and dissolved air flotation when treating wastewater on site. About 33 percent of meat processing operations (EPA 2002) and 25 percent of poultry processing operations (U.S. Poultry 2006) perform on-site treatment in anaerobic lagoons. The IPCC default B<sub>0</sub> of 0.25 kg CH<sub>4</sub>/kg COD and default MCF of 0.8 for anaerobic lagoons were used to estimate the CH<sub>4</sub> produced from these on-site treatment systems. Production data, in carcass weight and live weight killed for the meat and poultry industry, were obtained from the USDA Agricultural Statistics Database and the Agricultural Statistics Annual Reports (USDA 2011). Data collected by EPA's Office of Water provided estimates for wastewater flows into anaerobic lagoons: 5.3 and 12.5 m<sup>3</sup>/metric ton for meat and poultry production (live weight killed), respectively (EPA 2002). The loadings are 2.8 and 1.5 g BOD/liter for meat and poultry, respectively.

*Vegetables, Fruits, and Juices Processing.* Treatment of wastewater from fruits, vegetables, and juices processing includes screening, coagulation/settling, and biological treatment (lagooning). The flows are frequently seasonal, and robust treatment systems are preferred for on-site treatment. Effluent is suitable for discharge to the sewer. This industry is likely to use lagoons intended for aerobic operation, but the large seasonal loadings may develop limited anaerobic zones. In addition, some anaerobic lagoons may also be used (Nemerow and Dasgupta 1991). Consequently, 4.2 percent of these wastewater organics are assumed to degrade anaerobically. The IPCC default B<sub>0</sub> of 0.25 kg CH<sub>4</sub>/kg COD and default MCF of 0.8 for anaerobic treatment were used to estimate the CH<sub>4</sub> produced from these on-site treatment systems. The USDA National Agricultural Statistics Service (USDA 2011) provided production data for potatoes, other vegetables, citrus fruit, non-citrus fruit, and grapes processed for wine. Outflow and BOD data, presented in Table 8-13, were obtained from EPA (1974) for potato, citrus fruit, and apple processing, and from EPA (1975) for all other sectors.

Table 8-13: Wastewater Flow (m<sup>3</sup>/ton) and BOD Production (g/L) for U.S. Vegetables, Fruits, and Juices Production

<b>Commodity</b>	<b>Wastewater Outflow (m<sup>3</sup>/ton)</b>	<b>BOD (g/L)</b>
<b>Vegetables</b>		
Potatoes	10.27	1.765
Other Vegetables	8.71	0.797
<b>Fruit</b>		
Apples	3.66	1.371
Citrus	10.11	0.317
Non-citrus	12.42	1.204
Grapes (for wine)	2.78	1.831

*Ethanol Production.* Ethanol, or ethyl alcohol, is produced primarily for use as a fuel component, but is also used in industrial applications and in the manufacture of beverage alcohol. Ethanol can be produced from the fermentation of sugar-based feedstocks (e.g., molasses and beets), starch- or grain-based feedstocks (e.g., corn, sorghum, and beverage waste), and cellulosic biomass feedstocks (e.g., agricultural wastes, wood, and bagasse). Ethanol can also be produced synthetically from ethylene or hydrogen and carbon monoxide. However, synthetic ethanol comprises only about 2 percent of ethanol production, and although the Department of Energy predicts cellulosic ethanol to greatly increase in the coming years, currently it is only in an experimental stage in the United States. According to the Renewable Fuels Association, 82 percent of ethanol production facilities use corn as the sole feedstock and 7 percent of facilities use a combination of corn and another starch-based feedstock. The fermentation of corn is the principal ethanol production process in the United States and is expected to increase through 2012, and potentially more; therefore, emissions associated with wastewater treatment at starch-based ethanol production facilities were estimated (ERG 2006).

Ethanol is produced from corn (or other starch-based feedstocks) primarily by two methods: wet milling and dry milling. Historically, the majority of ethanol was produced by the wet milling process, but now the majority is produced by the dry milling process. The wastewater generated at ethanol production facilities is handled in a variety of ways. Dry milling facilities often combine the resulting evaporator condensate with other process wastewaters, such as equipment wash water, scrubber water, and boiler blowdown and anaerobically treat this

wastewater using various types of digesters. Wet milling facilities often treat their steepwater condensate in anaerobic systems followed by aerobic polishing systems. Wet milling facilities may treat the stillage (or processed stillage) from the ethanol fermentation/distillation process separately or together with steepwater and/or wash water. CH<sub>4</sub> generated in anaerobic digesters is commonly collected and either flared or used as fuel in the ethanol production process (ERG 2006).

Available information was compiled from the industry on wastewater generation rates, which ranged from 1.25 gallons per gallon ethanol produced (for dry milling) to 10 gallons per gallon ethanol produced (for wet milling) (Ruocco 2006a,b; Merrick 1998; Donovan 1996; and NRBP 2001). COD concentrations were also found to be about 3 g/L (Ruocco 2006a; Merrick 1998; White and Johnson 2003). The amount of wastewater treated anaerobically was estimated, along with how much of the CH<sub>4</sub> is recovered through the use of biomethanators (ERG 2006). Methane emissions were then estimated as follows:

$$\text{Methane} = [\text{Production} \times \text{Flow} \times \text{COD} \times 3.785 \times (\% \text{Plants}_o \times \% \text{WW}_{a,p} \times \% \text{COD}_p) + [\% \text{Plants}_a \times \% \text{WW}_{a,s} \times \% \text{COD}_s] + [\% \text{Plants}_t \times \% \text{WW}_{a,t} \times \% \text{COD}_s)] \times B_o \times \text{MCF} \times \% \text{ Not Recovered}] + [\text{Production} \times \text{Flow} \times 3.785 \times \text{COD} \times (\% \text{Plants}_o \times \% \text{WW}_{a,p} \times \% \text{COD}_p) + [\% \text{Plants}_a \times \% \text{WW}_{a,s} \times \% \text{COD}_s] + [\% \text{Plants}_t \times \% \text{WW}_{a,t} \times \% \text{COD}_s)] \times B_o \times \text{MCF} \times (\% \text{ Recovered}) \times (1 - \text{DE})] \times 1/10^9$$

where,

Production	= gallons ethanol produced (wet milling or dry milling)
Flow	= gallons wastewater generated per gallon ethanol produced (1.25 dry milling, 10 wet milling)
COD	= COD concentration in influent (3 g/l)
3.785	= conversion, gallons to liters
%Plants <sub>o</sub>	= percent of plants with onsite treatment (100%)
%WW <sub>a,p</sub>	= percent of wastewater treated anaerobically in primary treatment (0%)
%COD <sub>p</sub>	= percent of COD entering primary treatment (100%)
%Plants <sub>a</sub>	= percent of plants with anaerobic secondary treatment (33.3% wet, 75% dry)
%Plants <sub>t</sub>	= percent of plants with other secondary treatment (66.7% wet, 25% dry)
%WW <sub>a,s</sub>	= percent of wastewater treated anaerobically in anaerobic secondary treatment (100%)
%WW <sub>a,t</sub>	= percent of wastewater treated anaerobically in other secondary treatment (0%)
%COD <sub>s</sub>	= percent of COD entering secondary treatment (100%)
B <sub>o</sub>	= maximum methane producing capacity (0.25 g CH <sub>4</sub> /g COD)
MCF	= methane conversion factor (0.8 for anaerobic systems)
% Recovered	= percent of wastewater treated in system with emission recovery
% Not Recovered	= 1 - percent of wastewater treated in system with emission recovery
DE	= destruction efficiency of recovery system (99%)
1/10 <sup>9</sup>	= conversion factor, g to Gg

A time series of CH<sub>4</sub> emissions for 1990 through 2010 was developed based on production data from the Renewable Fuels Association (RFA 2011).

*Petroleum Refining.* Petroleum refining wastewater treatment operations produce CH<sub>4</sub> emissions from anaerobic wastewater treatment. The wastewater inventory section includes CH<sub>4</sub> emissions from petroleum refining wastewater treated on site under intended or unintended anaerobic conditions. Most facilities use aerated biological systems, such as trickling filters or rotating biological contactors; these systems can also exhibit anaerobic conditions that can result in the production of CH<sub>4</sub>. Oil/water separators are used as a primary treatment method; however, it is unlikely that any COD is removed in this step.

Available information from the industry was compiled. The wastewater generation rate, from CARB (2007) and Timm (1985), was determined to be 35 gallons per barrel of finished product. An average COD value in the wastewater was estimated at 0.45 kg/m<sup>3</sup> (Benyahia et al. 2006).

The equation used to calculate CH<sub>4</sub> generation at petroleum refining wastewater treatment systems is presented below:

$$\text{Methane} = \text{Flow} \times \text{COD} \times B_o \times \text{MCF}$$

where,

Flow	= Annual flow treated through anaerobic treatment system (m <sup>3</sup> /year)
COD	= COD loading in wastewater entering anaerobic treatment system (kg/m <sup>3</sup> )
B <sub>0</sub>	= maximum methane producing potential of industrial wastewater (default value of 0.25 kg CH <sub>4</sub> /kg COD)
MCF	= methane conversion factor (0.3)

A time series of CH<sub>4</sub> emissions for 1990 through 2010 was developed based on production data from the Energy Information Association (EIA 2011).

### Domestic Wastewater N<sub>2</sub>O Emission Estimates

N<sub>2</sub>O emissions from domestic wastewater (wastewater treatment) were estimated using the IPCC (2006) methodology, including calculations that take into account N removal with sewage sludge, non-consumption and industrial/commercial wastewater N, and emissions from advanced centralized wastewater treatment plants:

- In the United States, a certain amount of N is removed with sewage sludge, which is applied to land, incinerated, or landfilled (N<sub>SLUDGE</sub>). The N disposal into aquatic environments is reduced to account for the sewage sludge application.
- The IPCC methodology uses annual, per capita protein consumption (kg protein/[person-year]). For this inventory, the amount of protein available to be consumed is estimated based on per capita annual food availability data and its protein content, and then adjusts that data using a factor to account for the fraction of protein actually consumed.
- Small amounts of gaseous nitrogen oxides are formed as byproducts in the conversion of nitrate to N gas in anoxic biological treatment systems. Approximately 7 g N<sub>2</sub>O is generated per capita per year if wastewater treatment includes intentional nitrification and denitrification (Scheehle and Doorn 2001). Analysis of the 2004 CWNS shows that plants with denitrification as one of their unit operations serve a population of 2.4 million people. Based on an emission factor of 7 g per capita per year, approximately 21.2 metric tons of additional N<sub>2</sub>O may have been emitted via denitrification in 2004. Similar analyses were completed for each year in the Inventory using data from CWNS on the amount of wastewater in centralized systems treated in denitrification units. Plants without intentional nitrification/denitrification are assumed to generate 3.2 g N<sub>2</sub>O per capita per year.

N<sub>2</sub>O emissions from domestic wastewater were estimated using the following methodology:

$$\begin{aligned}
 N_2O_{TOTAL} &= N_2O_{PLANT} + N_2O_{EFFLUENT} \\
 N_2O_{PLANT} &= N_2O_{NIT/DENIT} + N_2O_{WOUT\ NIT/DENIT} \\
 N_2O_{NIT/DENIT} &= [(US_{POPND}) \times EF_2 \times F_{IND-COM}] \times 1/10^9 \\
 N_2O_{WOUT\ NIT/DENIT} &= \{[(US_{POP} \times WWTP) - US_{POPND}] \times F_{IND-COM} \times EF_1\} \times 1/10^9 \\
 N_2O_{EFFLUENT} &= \{[(US_{POP} \times WWTP) - (0.9 \times US_{POPND})] \times Protein \times F_{NPR} \times F_{NON-CON} \times F_{IND-COM} - N_{SLUDGE}\} \times EF_3 \times 44/28 \times 1/10^6
 \end{aligned}$$

where,

N <sub>2</sub> O <sub>TOTAL</sub>	= Annual emissions of N <sub>2</sub> O (Gg)
N <sub>2</sub> O <sub>PLANT</sub>	= N <sub>2</sub> O emissions from centralized wastewater treatment plants (Gg)
N <sub>2</sub> O <sub>NIT/DENIT</sub>	= N <sub>2</sub> O emissions from centralized wastewater treatment plants with nitrification/denitrification (Gg)
N <sub>2</sub> O <sub>WOUT NIT/DENIT</sub>	= N <sub>2</sub> O emissions from centralized wastewater treatment plants without nitrification/denitrification (Gg)
N <sub>2</sub> O <sub>EFFLUENT</sub>	= N <sub>2</sub> O emissions from wastewater effluent discharged to aquatic environments (Gg)
US <sub>POP</sub>	= U.S. population
US <sub>POPND</sub>	= U.S. population that is served by biological denitrification (from CWNS)
WWTP	= Fraction of population using WWTP (as opposed to septic systems)



EF <sub>1</sub>	= Emission factor (3.2 g N <sub>2</sub> O/person-year) – plant with no intentional denitrification
EF <sub>2</sub>	= Emission factor (7 g N <sub>2</sub> O/person-year) – plant with intentional denitrification
Protein	= Annual per capita protein consumption (kg/person/year)
F <sub>NPR</sub>	= Fraction of N in protein, default = 0.16 (kg N/kg protein)
F <sub>NON-CON</sub>	= Factor for non-consumed protein added to wastewater (1.4)
F <sub>IND-COM</sub>	= Factor for industrial and commercial co-discharged protein into the sewer system (1.25)
N <sub>SLUDGE</sub>	= N removed with sludge, kg N/yr
EF <sub>3</sub>	= Emission factor (0.005 kg N <sub>2</sub> O -N/kg sewage-N produced) – from effluent
0.9	= Amount of nitrogen removed by denitrification systems (EPA 2008)
44/28	= Molecular weight ratio of N <sub>2</sub> O to N <sub>2</sub>

U.S. population data were taken from the U.S. Census Bureau International Database (U.S. Census 2011) and include the populations of the United States, American Samoa, Guam, Northern Mariana Islands, Puerto Rico, and the Virgin Islands. The fraction of the U.S. population using wastewater treatment plants is based on data from the 1989, 1991, 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2007, and 2009 American Housing Survey (U.S. Census 2009). Data for intervening years were obtained by linear interpolation. The emission factor (EF<sub>1</sub>) used to estimate emissions from wastewater treatment for plants without intentional denitrification was taken from IPCC (2006), while the emission factor (EF<sub>2</sub>) used to estimate emissions from wastewater treatment for plants with intentional denitrification was taken from Scheehle and Doorn (2001). Data on annual per capita protein intake were provided by U.S. Department of Agriculture Economic Research Service (USDA 2009). Protein consumption data for 2005 through 2010 were extrapolated from data for 1990 through 2004. Table 8-14 presents the data for U.S. population and average protein intake. An emission factor to estimate emissions from effluent (EF<sub>3</sub>) has not been specifically estimated for the United States, thus the default IPCC value (0.005 kg N<sub>2</sub>O-N/kg sewage-N produced) was applied. The fraction of N in protein (0.16 kg N/kg protein) was also obtained from IPCC (2006). The factor for non-consumed protein and the factor for industrial and commercial co-discharged protein were obtained from IPCC (2006). Sludge generation was obtained from EPA (1999) for 1988, 1996, and 1998 and from Beecher et al. (2007) for 2004. Intervening years were interpolated, and estimates for 2005 through 2009 were forecasted from the rest of the time series. An estimate for the N removed as sludge (N<sub>SLUDGE</sub>) was obtained by determining the amount of sludge disposed by incineration, by land application (agriculture or other), through surface disposal, in landfills, or through ocean dumping. In 2010, 274 Gg N was removed with sludge.

Table 8-14: U.S. Population (Millions), Available Protein (kg/person-year), and Protein Consumed (kg/person-year)

Year	Population	Available Protein	Protein Consumed
1990	253	38.7	29.6
2005	300	41.7	32.0
2006	303	41.9	32.2
2007	306	42.1	32.3
2008	309	42.2	32.4
2009	311	42.4	32.5
2010	313	42.6	32.7

Source: U.S. Census Bureau 2011, USDA 2009.

## Uncertainty and Time-Series Consistency

The overall uncertainty associated with both the 2010 CH<sub>4</sub> and N<sub>2</sub>O emission estimates from wastewater treatment and discharge was calculated using the IPCC Good Practice Guidance Tier 2 methodology (2000). Uncertainty associated with the parameters used to estimate CH<sub>4</sub> emissions 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<sub>2</sub>O 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.

The results of this Tier 2 quantitative uncertainty analysis are summarized in Table 8-15. Methane emissions from wastewater treatment were estimated to be between 12.3 and 21.5 Tg CO<sub>2</sub> Eq. at the 95 percent confidence level (or in 19 out of 20 Monte Carlo Stochastic Simulations). This indicates a range of approximately 25 percent below to 31 percent above the 2010 emissions estimate of 16.3 Tg CO<sub>2</sub> Eq. N<sub>2</sub>O emissions from wastewater treatment were estimated to be between 1.2 and 10.1 Tg CO<sub>2</sub> Eq., which indicates a range of approximately 77 percent below to 99 percent above the 2010 emissions estimate of 5.0 Tg CO<sub>2</sub> Eq.

Table 8-15: Tier 2 Quantitative Uncertainty Estimates for CH<sub>4</sub> Emissions from Wastewater Treatment (Tg CO<sub>2</sub> Eq. and Percent)

Source	Gas	2010 Emission Estimate (Tg CO <sub>2</sub> Eq.)	Uncertainty Range Relative to Emission Estimate <sup>a</sup>			
			(Tg CO <sub>2</sub> Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
<b>Wastewater Treatment</b>	<b>CH<sub>4</sub></b>	<b>16.3</b>	<b>12.3</b>	<b>21.5</b>	<b>-25%</b>	<b>+31%</b>
Domestic	CH <sub>4</sub>	7.8	5.8	9.9	-26%	+28%
Industrial	CH <sub>4</sub>	8.6	5.1	13.3	-41%	+54%
<b>Wastewater Treatment</b>	<b>N<sub>2</sub>O</b>	<b>5.0</b>	<b>1.2</b>	<b>10.1</b>	<b>-77%</b>	<b>+99%</b>

<sup>a</sup> Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2010. Details on the emission trends through time are described in more detail in the Methodology section, above.

## QA/QC and Verification

A QA/QC analysis was performed on activity data, documentation, and emission calculations. This effort included a Tier 1 analysis, including the following checks:

- Checked for transcription errors in data input;
- Ensured references were specified for all activity data used in the calculations;
- Checked a sample of each emission calculation used for the source category;
- Checked that parameter and emission units were correctly recorded and that appropriate conversion factors were used;
- Checked for temporal consistency in time series input data for each portion of the source category;
- Confirmed that estimates were calculated and reported for all portions of the source category and for all years;
- Investigated data gaps that affected emissions estimates trends; and
- Compared estimates to previous estimates to identify significant changes.

All transcription errors identified were corrected. The QA/QC analysis did not reveal any systemic inaccuracies or incorrect input values.

## Recalculations Discussion

For domestic wastewater CH<sub>4</sub> calculations, the emission estimations were updated for septic systems using new research from WERF (Leverenz et al. 2010). Previously, the septic equation used MCF and BOD produced (Gg/yr) along with percent of wastewater treated and B<sub>o</sub> to estimate emissions. In the current Inventory, that calculation was updated with a new emission factor of 10.7 g CH<sub>4</sub>/capita/day, which uses population along with percent of wastewater treated and B<sub>o</sub> for estimating emissions. This recalculation caused changes from the 1990 through 2009 Inventory for all years. Other minor updates in input data such as population and production resulted in slight changes in the later years of the Inventory.

For domestic wastewater N<sub>2</sub>O calculations, an update was made to the N<sub>2</sub>O<sub>EFFLUENT</sub> equation to make it more accurately reflect emissions. U.S. population is now multiplied by the fraction of the population not using septic systems for wastewater treatment. In addition, the factor for industrial and commercial co-discharged protein was previously left out of the calculations. This error was fixed in the current Inventory. These updates caused changes from the 1990 through 2010 Inventory for all years. Other minor updates in input data such as population resulted in slight changes in the later years of the Inventory.

## Planned Improvements

The methodology to estimate CH<sub>4</sub> emissions from domestic wastewater treatment currently utilizes estimates for the percentage of centrally treated wastewater that is treated by aerobic systems and anaerobic systems. These data come from the 1992, 1996, 2000, and 2004 CWNS. The question of whether activity data for wastewater treatment systems are sufficient across the time series to further differentiate aerobic systems with the potential to generate small amounts of CH<sub>4</sub> (aerobic lagoons) versus other types of aerobic systems, and to differentiate between anaerobic systems to allow for the use of different MCFs for different types of anaerobic treatment systems, continues to be explored. Recently available CWNS data for 2008 were evaluated for incorporation into the inventory, but due to significant changes in format, this dataset is not sufficiently detailed for inventory calculations. However, additional information and other data continue to be evaluated to update future years of the Inventory.

For industrial wastewater emissions, data recently collected by EPA's Office of Air for pulp and paper mills and petroleum refineries will be evaluated to determine if sufficient information is available to update the estimates of wastewater generated per unit of production and the percent of industry wastewater treated anaerobically in these industries (%TA). Initial evaluations of EPA's Office of Air data for pulp and paper manufacturing indicate there is sufficient information to update emission estimates in the next inventory year. Data collected under the EPA's GHGRP will also be investigated for updating this variable. Data collection from industrial wastewater treatment is expected to occur in 2012. In examining data from EPA's GHGRP that would be useful to improve the emission estimates for the industrial wastewater category, particular attention will be made to ensure time series consistency, as the facility-level reporting data from EPA's GHGRP are not available for all inventory years as reported in this inventory. In implementing improvements and integration of data from EPA's GHGRP, the latest guidance from the IPCC on the use of facility-level data in national inventories will be relied upon<sup>237</sup>.

Currently, it is assumed that all aerobic wastewater treatment systems are well managed and produce no CH<sub>4</sub> and that all anaerobic systems have an MCF of 0.8. Efforts to obtain better data reflecting emissions from various types of municipal treatment systems are currently being pursued.

With respect to estimating N<sub>2</sub>O emissions, the default emission factors for indirect N<sub>2</sub>O from wastewater effluent and direct N<sub>2</sub>O from centralized wastewater treatment facilities have a high uncertainty. Research is being conducted by WERF to measure N<sub>2</sub>O emissions from municipal treatment systems. In addition, a literature review has been conducted focused on N<sub>2</sub>O emissions from wastewater treatment to determine the state of such research and identify data to develop a country-specific N<sub>2</sub>O emission factor or alternate emission factor or method. Such data will continue to be reviewed as they are available to determine if a country-specific N<sub>2</sub>O emission factor can or should be developed, or if alternate emission factors should be used.

For the current Inventory, the use of new measurement data from WERF to develop U.S.-specific emission factors for N<sub>2</sub>O and CH<sub>4</sub> emissions from septic systems was investigated. The data available to develop an emission factor for CH<sub>4</sub> was determined to be of sufficient quality and was incorporated into the inventory emissions calculation.

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<sup>237</sup> See: [http://www.ipcc-nggip.iges.or.jp/meeting/pdfiles/1008\\_Model\\_and\\_Facility\\_Level\\_Data\\_Report.pdf](http://www.ipcc-nggip.iges.or.jp/meeting/pdfiles/1008_Model_and_Facility_Level_Data_Report.pdf).

Due to the high uncertainty of the measurements for N<sub>2</sub>O from septic systems, estimates of N<sub>2</sub>O emissions were not included in the current Inventory. Appropriate emission factors for septic system N<sub>2</sub>O emissions will continue to be investigated as the data collected by WERF indicate that septic soil systems are a source of N<sub>2</sub>O emissions.

In addition, the estimate of N entering municipal treatment systems is under review. The factor that accounts for non-sewage N in wastewater (bath, laundry, kitchen, industrial components) also has a high uncertainty. Obtaining data on the changes in average influent N concentrations to centralized treatment systems over the time series would improve the estimate of total N entering the system, which would reduce or eliminate the need for other factors for non-consumed protein or industrial flow. The dataset previously provided by the National Association of Clean Water Agencies (NACWA) was reviewed to determine if it was representative of the larger population of centralized treatment plants for potential inclusion into the inventory. However, this limited dataset was not representative of the number of systems by state or the service populations served in the United States, and therefore could not be incorporated into the inventory methodology. Additional data sources will continue to be researched with the goal of improving the uncertainty of the estimate of N entering municipal treatment systems.

The value used for N content of sludge continues to be investigated. This value is driving the N<sub>2</sub>O emissions for wastewater and is static over the time series. To date, new data has not been identified that would be able to establish a time series for this value.

A review of other industrial wastewater treatment sources for those industries believed to discharge significant loads of BOD and COD has been ongoing. Food processing industries have the highest potential for CH<sub>4</sub> generation due to the waste characteristics generated, and the greater likelihood to treat the wastes anaerobically. However, in all cases there is dated information available on U.S. treatment operations for these industries. Previously, both the organic chemicals and the seafood processing industry were investigated to estimate their potential to generate CH<sub>4</sub>. Despite the lack of current data, emissions were estimated for both sectors. The organic chemicals industry was estimated to emit 15 Gg/year of CH<sub>4</sub>, and seafood processing was estimated to emit 3.0-3.5 Gg/year. Due to the insignificant amount of CH<sub>4</sub> estimated to be emitted and the lack of reliable, up-to-date data, these industries were not selected for inclusion in the industry. Other industries will be reviewed as necessary for inclusion in future years of the Inventory using EPA's Permit Compliance System and Toxics Release inventory. In addition, information from EPA's GHGRP will be used to determine likely candidates for inclusion. As such, sugar processing (beet and cane sugar), beverage (wineries, distilleries, breweries, soft drinks), and dairy (including cheese making) industries have been identified for possible consideration in the future.

### **8.3. Composting (IPCC Source Category 6D)**

Composting of organic waste, such as food waste, garden (yard) and park waste, and sludge, is common in the United States. Advantages of composting include reduced volume in the waste material, stabilization of the waste, and destruction of pathogens in the waste material. The end products of composting, depending on its quality, can be recycled as fertilizer and soil amendment, or be disposed in a landfill.

Composting is an aerobic process and a large fraction of the degradable organic carbon in the waste material is converted into carbon dioxide (CO<sub>2</sub>). Methane (CH<sub>4</sub>) is formed in anaerobic sections of the compost, but it is oxidized to a large extent in the aerobic sections of the compost. Anaerobic sections are created in composting piles when there is excessive moisture or inadequate aeration (or mixing) of the compost pile. The estimated CH<sub>4</sub> released into the atmosphere ranges from less than 1 percent to a few percent of the initial C content in the material (IPCC 2006). Depending on the N content of the feedstock and how well the compost pile is managed, nitrous oxide (N<sub>2</sub>O) emissions can be produced. The sources of N<sub>2</sub>O formation are complicated, but are mainly associated with anaerobic conditions, ranging from less than 0.5 percent to 5 percent of the initial nitrogen content of the material (IPCC 2006). Animal manures are typically expected to generate more N<sub>2</sub>O than, for example, yard waste, however data are limited.

From 1990 to 2010, the amount of material composted in the United States has increased from 3,810 Gg to 18,763 Gg, an increase of approximately 392 percent. From 2000 to 2010, the amount of material composted in the United States has increased by approximately 26 percent. Emissions of CH<sub>4</sub> and N<sub>2</sub>O from composting have increased by the same percentage (see Table 8-16 and Table 8-17). In 2010, CH<sub>4</sub> emissions from composting were 1.6 Tg CO<sub>2</sub> Eq. (75 Gg), and N<sub>2</sub>O emissions from composting were 1.7 Tg CO<sub>2</sub> Eq. (5.6 Gg). The wastes that are composted include primarily yard trimmings (grass, leaves, and tree and brush trimmings) and food scraps from residences and commercial establishments (such as grocery stores, restaurants, and school and factory cafeterias). The composting

waste quantities reported here do not include backyard composting. The growth in composting since the 1990s is attributable to primarily two factors: (1) steady growth in population and residential housing, and (2) the enactment of legislation by state and local governments that discouraged the disposal of yard trimmings in landfills. In 1992, 11 states and the District of Columbia had legislation in effect that banned or discouraged disposal of yard trimmings in landfills. Currently, 23 states and the District of Columbia, representing about 50 percent of the nation's population, have enacted such legislation (EPA 2010). The total amount of waste composted has decreased slightly since 2008, by approximately 6 percent.

Table 8-16: CH<sub>4</sub> and N<sub>2</sub>O Emissions from Composting (Tg CO<sub>2</sub> Eq.)

Activity	1990	2005	2006	2007	2008	2009	2010
CH <sub>4</sub>	0.3	1.6	1.6	1.7	1.7	1.6	1.6
N <sub>2</sub> O	0.4	1.7	1.8	1.8	1.9	1.8	1.7
<b>Total</b>	<b>0.7</b>	<b>3.3</b>	<b>3.3</b>	<b>3.5</b>	<b>3.5</b>	<b>3.3</b>	<b>3.3</b>

Table 8-17: CH<sub>4</sub> and N<sub>2</sub>O Emissions from Composting (Gg)

Activity	1990	2005	2006	2007	2008	2009	2010
CH <sub>4</sub>	15	75	75	79	80	75	75
N <sub>2</sub> O	1	6	6	6	6	6	6

## Methodology

Methane and N<sub>2</sub>O emissions from composting depend on factors such as the type of waste composted, the amount and type of supporting material (such as wood chips and peat) used, temperature, moisture content and aeration during the process.

The emissions shown in Table 8-16 and Table 8-17 were estimated using the IPCC default (Tier 1) methodology (IPCC 2006), which is the product of an emission factor and the mass of organic waste composted (note: no CH<sub>4</sub> recovery is expected to occur at composting operations):

$$E_i = M \times EF_i$$

where,

- E<sub>i</sub> = CH<sub>4</sub> or N<sub>2</sub>O emissions from composting, Gg CH<sub>4</sub> or N<sub>2</sub>O,
- M = mass of organic waste composted in Gg,
- EF<sub>i</sub> = emission factor for composting, 4 g CH<sub>4</sub>/kg of waste treated (wet basis) and 0.3 g N<sub>2</sub>O/kg of waste treated (wet basis), and
- i = designates either CH<sub>4</sub> or N<sub>2</sub>O.

Estimates of the quantity of waste composted (M) are presented in Table 8-18. Estimates of the quantity composted for 1990 and 1995 were taken from the *Characterization of Municipal Solid Waste in the United States: 1996 Update* (Franklin Associates 1997); estimates of the quantity composted for 2000, 2005, 2006, 2007, 2008, and 2009 were taken from EPA's *Municipal Solid Waste In The United States: 2009 Facts and Figures* (EPA 2010); estimates of the quantity composted for 2010 were calculated using the 2009 quantity composted and a ratio of the U.S. population in 2009 and 2010 (U.S. Census Bureau 2011).

Table 8-18: U.S. Waste Composted (Gg)

Activity	1990	2005	2006	2007	2008	2009	2010
Waste Composted	3,810	18,643	18,852	19,695	20,049	18,870	18,763

Source: Franklin Associates 1997 and EPA 2009.

## Uncertainty and Time-Series Consistency

The estimated uncertainty from the 2006 IPCC Guidelines is  $\pm 50$  percent for the Tier 1 methodology. Emissions from composting in 2010 were estimated to be between 1.7 and 5.0 Tg CO<sub>2</sub> Eq., which indicates a range of 50 percent below to 50 percent above the actual 2010 emission estimate of 3.3 Tg CO<sub>2</sub> Eq. (see Table 8-19).

Table 8-19 : Tier 1 Quantitative Uncertainty Estimates for Emissions from Composting (Tg CO<sub>2</sub> Eq. and Percent)

Source	Gas	2010 Emission Estimate (Tg CO <sub>2</sub> Eq.)	Uncertainty Range Relative to Emission Estimate			
			(Tg CO <sub>2</sub> Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Composting	CH <sub>4</sub> , N <sub>2</sub> O	3.3	1.7	5.0	-50%	+50%

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2010. Details on the emission trends through time are described in more detail in the Methodology section, above.

## Planned Improvements

For future Inventories, additional efforts will be made to improve the estimates of CH<sub>4</sub> and N<sub>2</sub>O emissions from composting. For example, a literature search may be conducted to determine if emission factors specific to various composting systems and composted materials are available.

## 8.4. Waste Sources of Indirect Greenhouse Gases

In addition to the main greenhouse gases addressed above, waste generating and handling processes are also sources of indirect greenhouse gas emissions. Total emissions of NO<sub>x</sub>, CO, and NMVOCs from waste sources for the years 1990 through 2010 are provided in Table 8-20.

Table 8-20: Emissions of NO<sub>x</sub>, CO, and NMVOC from Waste (Gg)

Gas/Source	1990	2005	2006	2007	2008	2009	2010
<b>NO<sub>x</sub></b>	<b>+</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>2</b>
Landfills	+	2	2	2	2	2	2
Wastewater Treatment	+	+	+	+	+	+	+
Miscellaneous <sup>a</sup>	+	0	0	0	0	0	0
<b>CO</b>	<b>1</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>7</b>	<b>7</b>
Landfills	1	6	6	6	6	6	6
Wastewater Treatment	+	+	+	+	+	+	+
Miscellaneous <sup>a</sup>	+	+	+	+	+	+	+
<b>NMVOCs</b>	<b>673</b>	<b>114</b>	<b>113</b>	<b>111</b>	<b>109</b>	<b>76</b>	<b>76</b>
Wastewater Treatment	57	49	49	48	47	33	33
Miscellaneous <sup>a</sup>	557	43	43	42	41	29	29
Landfills	58	22	21	21	21	14	14

<sup>a</sup> Miscellaneous includes TSDFs (Treatment, Storage, and Disposal Facilities under the Resource Conservation and Recovery Act [42 U.S.C. § 6924, SWDA § 3004]) and other waste categories.

Note: Totals may not sum due to independent rounding.

+ Does not exceed 0.5 Gg.

## Methodology

Due to the lack of data available at the time of publication, emission estimates for 2010 rely on 2009 data as a proxy. Emission estimates for 2009 were obtained from preliminary data (EPA 2010, EPA 2009), and disaggregated based on EPA (2003), which, in its final iteration, will be published on the National Emission Inventory (NEI) Air Pollutant Emission Trends web site. Emission estimates of these gases were provided by sector, using a “top down”

estimating procedure—emissions were calculated either for individual sources or for many sources combined, using basic activity data (e.g., the amount of raw material processed) as an indicator of emissions. National activity data were collected for individual source categories from various agencies. Depending on the source category, these basic activity data may include data on production, fuel deliveries, raw material processed, etc.

### Uncertainty and Time-Series Consistency

No quantitative estimates of uncertainty were calculated for this source category. Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2010.





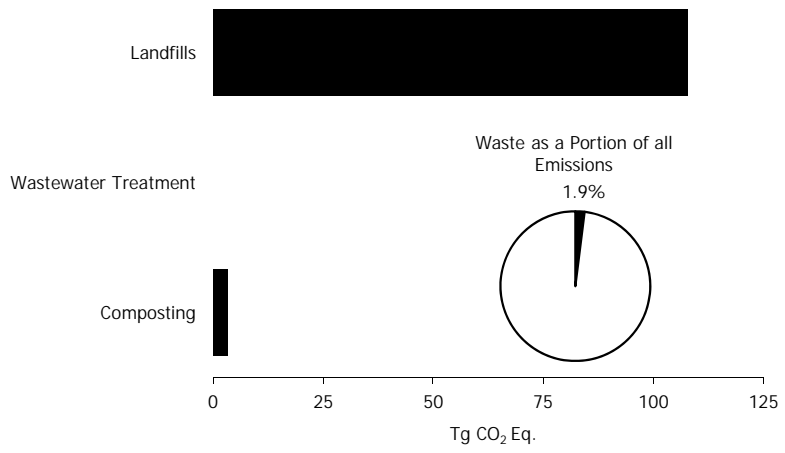


Figure 8-1: 2010 Waste Chapter Greenhouse Gas Sources