8. Waste

Waste management and treatment activities are sources of greenhouse gas emissions (see Figure 8-1). Landfills accounted for approximately 24 percent of total U.S. anthropogenic methane (CH_4) emissions in 2005,[1] the largest contribution of any CH_4 source in the United States. Additionally, wastewater treatment accounts for just under 5 percent of U.S. CH_4 emissions. Nitrous oxide (N_2O) emissions from the discharge of wastewater treatment effluents into aquatic environments were estimated, as were N_2O emissions from the treatment process itself. Nitrogen oxide (NO_x), carbon monoxide (CO), and non-CH_4 volatile organic compounds (NMVOCs) are emitted by waste activities, and are addressed separately at the end of this chapter. A summary of greenhouse gas and indirect greenhouse gas emissions from the Waste chapter is presented in Table 8-1 and Table 8-2.

Figure 8-1: 2005 Waste Chapter Greenhouse Gas Sources

Overall, in 2005, waste activities generated emissions of 165.4 Tg CO_2 Eq., or just over 2 percent of total U.S. greenhouse gas emissions.

Table 8-1: Emissions from Waste (Tg CO_2 Eq.)

Gas/Source	1990	1995	2000	2001	2002	2003	2004	2005
CH_4	**185.8**	**182.2**	**158.3**	**153.5**	**156.2**	**160.5**	**157.8**	**157.4**
Landfills	161.0	157.1	131.9	127.6	130.4	134.9	132.1	132.0
Wastewater Treatment	24.8	25.1	26.4	25.9	25.8	25.6	25.7	25.4
N_2O	**6.4**	**6.9**	**7.6**	**7.6**	**7.7**	**7.8**	**7.9**	**8.0**
Domestic Wastewater Treatment	6.4	6.9	7.6	7.6	7.7	7.8	7.9	8.0
Total	**192.2**	**189.1**	**165.9**	**161.1**	**163.9**	**168.4**	**165.7**	**165.4**

Note: Totals may not sum due to independent rounding.

Table 8-2: Emissions from Waste (Gg)

Gas/Source	1990	1995	2000	2001	2002	2003	2004	2005
CH_4	**8,848**	**8,674**	**7,537**	**7,310**	**7,439**	**7,645**	**7,514**	**7,496**
Landfills	7,668	7,479	6,280	6,078	6,210	6,425	6,292	6,286
Wastewater Treatment	1,180	1,195	1,257	1,232	1,229	1,220	1,222	1,210
N_2O	**21**	**22**	**24**	**25**	**25**	**25**	**26**	**26**
Domestic Wastewater Treatment	21	22	24	25	25	25	26	26
NO_x	**+**	**1**	**2**	**2**	**2**	**2**	**2**	**2**
CO	**1**	**2**	**8**	**8**	**7**	**7**	**7**	**7**
NMVOCs	**673**	**731**	**119**	**122**	**116**	**116**	**116**	**116**

Note: Totals may not sum due to independent rounding.

[1] Landfills also store carbon, due to incomplete degradation of organic materials such as wood products and yard trimmings, as described in the Land Use, Land-Use Change, and Forestry chapter.

8.1. Landfills (IPCC Source Category 6A1)

In 2005, landfill CH_4 emissions were approximately 132 Tg CO_2 Eq. (6,286 Gg), representing the largest source of CH_4 emissions in the United States. Emissions from municipal solid waste (MSW) landfills, which received about 64 percent of the total solid waste generated in the United States, accounted for about 89 percent of total landfill emissions, while industrial landfills accounted for the remainder. Approximately 1,800 operational landfills exist in the United States, with the largest landfills receiving most of the waste and generating the majority of the CH_4 (BioCycle 2006, adjusted to include missing data from five states).

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_4-producing anaerobic bacteria convert the fermentation products into stabilized organic materials and biogas consisting of approximately 50 percent carbon dioxide (CO_2) and 50 percent CH_4, by volume.[2] Significant CH_4 production typically begins one or two years after waste disposal in a landfill and continues for 10 to 60 years.

From 1990 to 2005, net CH_4 emissions from landfills decreased by approximately 18 percent (see Table 8-3 and Table 8-4), with small increases occurring in some interim years. This downward trend in overall emissions is the result of increases in the amount of landfill gas collected and combusted,[3] which has more than offset the additional CH_4 emissions resulting from an increase in the amount of municipal solid waste landfilled.

Methane emissions from landfills are a function of several factors, including: (1) the total amount of municipal solid waste in landfills, which is related to total municipal solid waste landfilled annually; (2) the characteristics of landfills receiving waste (i.e., composition of waste-in-place, size, climate); (3) the amount of CH_4 that is recovered and either flared or used for energy purposes; and (4) the amount of CH_4 oxidized in landfills instead of being released into the atmosphere. The estimated annual quantity of waste placed in landfills increased from about 209 Tg in 1990 to 304 Tg in 2005, an increase of 45 percent (see Annex 3.14). During this period, the estimated CH_4 recovered and combusted from landfills increased as well. In 1990, for example, approximately 1,079 Gg of CH_4 were recovered and combusted (i.e., used for energy or flared) from landfills. In 2005, the estimated quantity of CH_4 recovered and combusted increased to 5,668 Gg, a 7 percent increase from 2004 levels.

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 and composting practices. In addition, the quantity of CH_4 that is recovered and either flared or used for energy purposes is expected 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 encouraging CH_4 recovery and use such as EPA's Landfill Methane Outreach Program (LMOP), and federal and state economic incentives.

Table 8-3: CH_4 Emissions from Landfills (Tg CO_2 Eq.)

Activity	1990	1995	2000	2001	2002	2003	2004	2005
MSW Landfills	188.7	204.7	217.3	221.4	227.2	234.9	242.4	249.6
Industrial Landfills	12.9	13.9	15.4	15.6	15.7	15.9	16.0	16.1
Recovered								

[2] The percentage of CO_2 in biogas released from a landfill may be smaller because some CO_2 dissolves in landfill water (Bingemer and Crutzen 1987). Additionally, less than 1 percent of landfill gas is typically composed of non-CH_4 volatile organic compounds (NMVOCs).

[3] The CO_2 produced from combusted landfill CH_4 at landfills is not counted in national inventories as it is considered part of the natural C cycle of decomposition.

Gas-to-Energy	(17.6)	(22.3)	(49.0)	(54.3)	(54.4)	(54.9)	(57.1)	(58.6)
Flared	(5.0)	(21.8)	(37.1)	(40.8)	(43.7)	(46.0)	(54.4)	(60.4)
Oxidized[a]	(17.9)	(17.5)	(14.7)	(14.2)	(14.5)	(15.0)	(14.7)	(14.7)
Total	**161.0**	**157.1**	**131.9**	**127.6**	**130.4**	**134.9**	**132.1**	**132.0**

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.
[a] Includes oxidation at both municipal and industrial landfills.

Table 8-4: CH_4 Emissions from Landfills (Gg)

Activity	1990	1995	2000	2001	2002	2003	2004	2005
MSW Landfills	8,985	9,745	10,348	10,541	10,820	11,188	11,543	11,885
Industrial Landfills	614	664	731	744	749	757	761	767
Recovered								
Gas-to-Energy	(840)	(1,061)	(2,335)	(2,588)	(2,590)	(2,614)	(2,720)	(2,790)
Flared	(239)	(1,039)	(1,766)	(1,943)	(2,080)	(2,192)	(2,593)	(2,877)
Oxidized[a]	(852)	(831)	(698)	(675)	(690)	(714)	(699)	(698)
Total	**7,668**	**7,479**	**6,280**	**6,078**	**6,210**	**6,425**	**6,292**	**6,286**

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.
[a] Includes oxidation at municipal and industrial landfills.

Methodology

CH_4 emissions from landfills were estimated to equal the CH_4 produced from municipal solid waste landfills, plus the CH_4 produced by industrial landfills, minus the CH_4 recovered and combusted, minus the CH_4 oxidized before being released into the atmosphere:

$$CH_{4,\text{Solid Waste}} = [CH_{4,MSW} + CH_{4,ind} - R] - Ox$$

where,

$CH_{4,\text{Solid Waste}}$	= CH_4 emissions from solid waste
$CH_{4,MSW}$	= CH_4 generation from municipal solid waste landfills,
$CH_{4,ind}$	= CH_4 generation from industrial landfills,
R	= CH_4 recovered and combusted, and
Ox	= CH_4 oxidized from MSW and industrial landfills before release to the atmosphere.

The methodology for estimating CH_4 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_4 generation potential (L_0) and rate constant (k) were obtained from an analysis of CH_4 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. For further information, see Annex 3.14.

National landfill waste generation and disposal data for 1989 through 2005 were obtained from *BioCycle* (2006). 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 (2006) and national per capita solid waste generation from *BioCycle* (2006). 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_4 generation, estimates for those years were included in the first order decay model for completeness in accounting for CH_4 generation rates and are based on the population in those years and the per capita rate for land disposal for the 1960s.

The estimated landfill gas recovered per year was based on updated data collected from vendors of flaring equipment, a database of landfill gas-to-energy (LFGTE) projects compiled by LMOP (EPA 2006), and a database maintained by the Energy Information Administration (EIA) for the voluntary reporting of greenhouse gases (EIA 2006). 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_4 combusted by flares in operation from 1990 to 2005 was estimated. 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 emissions reductions associated with LFGTE projects for which a flare had not been identified from the emissions reductions associated with flares.

A destruction efficiency of 99 percent was applied to CH_4 recovered to estimate CH_4 emissions avoided. The value for efficiency was selected based on the range of efficiencies (98 to 100 percent) recommended for flares in EPA's *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 in LMOP.

Emissions from industrial landfills were estimated from activity data for industrial production, waste disposal factors, and the first order decay model. The amount of CH_4 oxidized by the landfill cover at both municipal and industrial landfills was assumed to be ten percent of the CH_4 generated that is not recovered (IPCC 2006, Mancinelli and McKay 1985, Czepiel et al. 1996). To calculate net CH_4 emissions, both CH_4 recovered and CH_4 oxidized were subtracted from CH_4 generated at municipal and industrial landfills.

Uncertainty

Several types of uncertainty are associated with the estimates of CH_4 emissions from landfills. The primary uncertainty concerns the characterization of landfills. Information is not available on two fundamental factors affecting CH_4 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_4 generation potential and the rate of decay that produces CH_4, as determined from several studies of CH_4 recovery at landfills, are representative of U.S. landfills.

Additionally, the approach used to estimate the contribution of industrial wastes to total CH_4 generation introduces uncertainty. Aside from uncertainty in estimating CH_4 generation potential, uncertainty exists in the estimates of oxidation by cover soils. There is also uncertainty in the estimates of methane 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 methane estimated to be recovered). For flaring without metered recovery data (approximately 34 percent of the methane 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_2O emissions from the application of sewage sludge on landfills are not explicitly modeled as part of greenhouse gas emissions from landfills. N_2O 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_2O emissions. The total nitrogen (N) in sewage sludge increased from 189 to 268 Gg total N between 1990 and 2005, however; the quantity of sewage sludge applied to landfills decreased from 28 to 10 percent from 1990 to 2005.[4]

The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 8-5. Landfill CH_4 emissions in 2005 were estimated to be between 80.5 and 174.2 Tg CO_2 Eq., which indicates a range of 39 percent below to 32 percent above the actual 2005 emission estimate of 132 Tg CO_2 Eq.

Table 8-5. Tier 2 Quantitative Uncertainty Estimates for CH_4 Emissions from Landfills (Tg CO_2 Eq. and Percent)

Source	Gas	2005 Emission Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Landfills	CH_4	132.0	80.5	174.2	-39%	+32%

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

Recalculations Discussion

Two recalculations affected the estimates of CH_4 generation from landfills. As recommended in IPCC (2006) for MSW landfills, the more accurate integrated form of the first order decay model was applied (see Annex 3A.1 of IPCC 2006), and a delay time of 6 months was incorporated. The integrated form of the FOD model captures a constantly changing rate of reaction, whereas the previously used method, which was not integrated, instead assumed that the rate of reaction remained constant throughout each year. The 6-month delay represents the time before substantial methane generation begins at a landfill. By recalculating previous emissions estimates using this method, estimates of CH_4 generation from MSW landfills were reduced by 4 percent over the time series. The second change was an improvement in the estimate of CH_4 generation from industrial landfills, which was based on industrial production, waste disposal factors, and the first order decay model. For previous inventories, the generation rate was estimated as simply 7 percent of CH_4 generation from MSW landfills. This change resulted in a decrease of 2 percent in the estimated CH_4 generation at industrial landfills relative to the previous inventory.

Another recalculation affecting estimates of CH_4 recovery was associated with updating the EIA, LMOP, and flare vendor databases. The estimates of gas recovery by LFGTE projects and flares from 1990 to 2004 increased by 0.7 percent based on changes to the current inventory. This change is due in part to updating the EIA database and identifying additional flares installed in 2004 that were not included in the previous inventory. The EIA database for 2004 did not become available until late in 2005; consequently, the gas recovery rate for 2004 was estimated from the 2003 data. The 2004 update showed that LFGTE projects in the EIA 2003 database reported more gas recovery in 2004 than 2003, and additional landfills were included in the 2004 database, both of which increased the estimate of CH_4 recovery. A recalculation that had a minor effect was the application of a destruction efficiency of 99 percent to CH_4 recovered to estimate CH_4 emissions avoided.

The overall effect of these recalculations was an average decrease of 5 percent in the estimated CH_4 emissions from landfills over the 1990 to 2004 time series.

[4] The methodology for estimating the quantity of N in sewage sludge disposed via incineration, land application, surface disposal, landfill, ocean dumping, and other is described in Annex 3.11 Methodology for Estimating N_2O Emissions From Agricultural Soil Management.

Planned Improvements

For future inventories, additional efforts will be made to improve the estimates of CH_4 generation at industrial landfills. Improvements to the flare database will be investigated, and an effort will be made to identify additional landfills that have flares.

[Begin Text Box]

Box 8-1: Biogenic Emissions and Sinks of Carbon

CO_2 emissions from the combustion or decomposition of biogenic materials (e.g., paper, wood products, and yard trimmings) grown on a sustainable basis are considered to mimic the closed loop of the natural carbon cycle—that is, they return to the atmosphere CO_2 that was originally removed by photosynthesis. In contrast, CH_4 emissions from landfilled waste occur due to the man-made anaerobic conditions conducive to CH_4 formation that exist in landfills, and are consequently included in this inventory.

Depositing wastes of biogenic origin in landfills causes the removal of carbon from its natural cycle between the atmosphere and biogenic materials. As empirical evidence shows, some of these wastes degrade very slowly in landfills, and the carbon they contain is effectively sequestered in landfills over a period of time (Barlaz 1998, 2005). Estimates of carbon 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_4 and N_2O emissions. Wastewater from domestic (municipal sewage) 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,[5] 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 21 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 2006b).

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_4. 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_2O may also result from the treatment of domestic wastewater during both nitrification and denitrification of the nitrogen present, usually in the form of urea, ammonia, and proteins. These compounds are converted to nitrate (NO_3) 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_2). N_2O can be an intermediate product of both processes, but is more often associated with denitrification.

The principal factor in determining the CH_4 generation potential of wastewater is the amount of degradable organic

[5] Package plants are treatment plants assembled in a factory, skid mounted, and transported to the treatment site.

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_4 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_4 production. The principal factor in determining the N_2O generation potential of wastewater is the amount of N in the wastewater.

In 2005, CH_4 emissions from domestic wastewater treatment were estimated to be 17.0 Tg CO_2 Eq. (809 Gg). Emissions fluctuated from 1990 through 1996, and have decreased since 1997 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 2005, CH_4 emissions from industrial wastewater treatment were estimated to be 8.4 Tg CO_2 Eq. (400 Gg). Industrial emission sources have increased across the time series through 1999 and then slightly decreased in keeping with production changes associated with the treatment of wastewater from the pulp and paper, meat and poultry, and the vegetables, fruits and juices processing industries.[6] Table 8-6 and Table 8-7 provide CH_4 and N_2O emission estimates from domestic and industrial wastewater treatment. With respect to N_2O, the United States identifies two distinct sources for N_2O emissions from domestic wastewater: emissions from centralized wastewater treatment processes, and emissions from effluent from centralized treatment systems that has been discharged into aquatic environments. The 2005 emissions of N_2O from centralized wastewater treatment processes and from effluent were estimated to be 0.2 Tg CO_2 Eq. (1 Gg) and 7.8 Tg CO_2 Eq. (25 Gg), respectively. Total N_2O emissions from domestic wastewater were estimated to be 8.0 Tg CO_2 Eq. (26 Gg). N_2O 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_4 and N_2O Emissions from Domestic and Industrial Wastewater Treatment (Tg CO_2 Eq.)

Activity	1990	1995	2000	2001	2002	2003	2004	2005
CH_4	**24.8**	**25.1**	**26.4**	**25.9**	**25.8**	**25.6**	**25.7**	**25.4**
Domestic	17.4	16.7	17.7	17.5	17.3	17.2	17.1	17.0
Industrial*	7.4	8.4	8.7	8.4	8.5	8.4	8.5	8.4
N_2O	**6.4**	**6.9**	**7.6**	**7.6**	**7.7**	**7.8**	**7.9**	**8.0**
Domestic	6.4	6.9	7.6	7.6	7.7	7.8	7.9	8.0
Total	**31.2**	**32.0**	**34.0**	**33.5**	**33.5**	**33.4**	**33.6**	**33.4**

* Industrial activity includes the pulp and paper, meat and poultry, and the vegetables, fruits and juices processing industries.
Note: Totals may not sum due to independent rounding.

Table 8-7. CH_4 and N_2O Emissions from Domestic and Industrial Wastewater Treatment (Gg)

Activity	1990	1995	2000	2001	2002	2003	2004	2005
CH_4	**1,180**	**1,195**	**1,257**	**1,232**	**1,229**	**1,220**	**1,222**	**1,210**
Domestic	826	797	842	832	826	820	815	809
Industrial*	354	398	415	400	402	400	407	400
N_2O	**21**	**22**	**24**	**25**	**25**	**25**	**26**	**26**
Domestic	21	22	24	25	25	25	26	26

* Industrial activity includes the pulp and paper, meat and poultry, and the vegetables, fruits and juices processing industries.
Note: Totals may not sum due to independent rounding.

[6]Emissions associated with refinery wastewater are estimated in Annex 2.3 Methodology for Estimating Carbon Emitted from Non-Energy Uses of Fossil Fuels. Other industrial sectors include organic chemicals, starch production, alcohol refining, creameries, and textiles; however, emissions from these sectors are considered to be insignificant.

Methodology

Domestic and Industrial Wastewater CH_4 Emission Estimates

Domestic wastewater CH_4 emissions originate from both septic systems and from centralized treatment systems, such as publicly owned treatment works (POTWs). Within these centralized systems, CH_4 emissions can arise from aerobic systems that are not well managed, anaerobic systems (anaerobic lagoons and facultative lagoons), and from anaerobic digesters when the captured biogas is not completely combusted. CH_4 emissions from septic systems were estimated by multiplying the total BOD_5 produced in the United States by the percent of wastewater treated in septic systems (21 percent), the maximum CH_4 producing capacity for domestic wastewater (0.60 kg CH_4/kg BOD), and the CH_4 correction factor (MCF) for septic systems (0.5). CH_4 emissions from POTWs were estimated by multiplying the total BOD_5 produced in the United States by the percent of wastewater treated centrally (79 percent), the relative percentage of wastewater treated by aerobic and anaerobic systems, the maximum CH_4-producing capacity of domestic wastewater, and the relative MCFs for aerobic (zero or 0.3) and anaerobic (0.8) systems. CH_4 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_4 in digester biogas, the density of CH_4, and the destruction efficiency associated with burning the biogas in an energy/thermal device.[7] The methodological equations are:

Emissions from Septic Systems = A
= (% onsite) × (total BOD_5 produced) × (B_o) × (MCF-septic) × 1/10^6

Emissions from Centrally Treated Aerobic Systems = B
= (% collected) × (total BOD_5 produced) × (% aerobic) × (% operations not well managed) × (B_o) × (MCF-aerobic_not_well_man) × 1/10^6

Emissions from Centrally Treated Anaerobic Systems = C
= (% collected) × (total BOD_5 produced) × (% anaerobic) × (B_o) × (MCF-anaerobic) × 1/10^6

Emissions from Anaerobic Digesters = D
= [(POTW_flow_AD) × (digester gas)/ (per capita flow)] × 0.0283 × (FRAC_CH_4) × (365.25) × (density of CH_4) × (1-DE) × 1/10^9

Total CH_4 Emissions (Gg) = A + B + C + D

where,

% 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
% operations not well managed =	Percent of aerobic systems that are not well managed and in which Some anaerobic degradation occurs
Total BOD_5 produced =	kg BOD/capita/day × U.S. population × 365.25 days/yr
B_o =	Maximum CH_4-producing capacity for domestic wastewater (0.60 kg CH_4/kg BOD)
MCF-septic =	CH_4 correction factor for septic systems (0.5)
1/10^6 =	Conversion factor, kg to Gg
MCF-aerobic_not_well_man. =	CH_4 correction factor for aerobic systems that are not well managed

[7] Anaerobic digesters at wastewater treatment plants generated 799 Gg CH_4 in 2005, 791 Gg of which was combusted in flares or energy devices (assuming a 99% destruction efficiency).

	(0.3)
MCF-anaerobic =	CH_4 correction factor for anaerobic systems (0.8)
DE =	CH_4 destruction efficiency from flaring or burning in engine (0.99 for enclosed flares)
POTW_flow_AD =	Wastewater influent flow to POTWs that have anaerobic digesters (gal)
digester gas =	Cubic feet of digester gas produced per person per day (1.0 ft^3/person/day) (Metcalf and Eddy 1991)
per capita flow =	Wastewater flow to POTW per person per day (100 gal/person/day)
0.0283 =	Conversion factor, ft^3 to m^3
FRAC_CH_4 =	Proportion CH_4 in biogas (0.65)
density of CH_4 =	662 (g CH_4/m^3 CH_4)
1/10^9 =	Conversion factor, g to Gg

U.S. population data were taken from the U.S. Census Bureau International Database (U.S. Census 2006a) 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_5 produced for 1990 through 2005. The proportions of domestic wastewater treated onsite versus at centralized treatment plants were based on data from the 1993, 1995, 1997, 1999, 2001, 2003, and 2005 American Housing Surveys conducted by the U.S. Census Bureau (U.S. Census 2006b), with data for intervening years obtained by linear interpolation. The wastewater flow to aerobic systems and anaerobic systems, and the wastewater flow to POTWs that have anaerobic digesters were obtained from the 1992, 1996, 2000, and 2004 Clean Watershed Needs Survey, collected by EPA (EPA 1992, 1996, 2000, and 2004a).[8] Data for intervening years were obtained by linear interpolation. The BOD_5 production rate per capita (0.09 kg/capita/day) for domestic wastewater was obtained from Metcalf and Eddy (1991and 2003). The CH_4 emission factor (0.6 kg CH_4/kg BOD_5) and the MCF data were taken from IPCC (2006a). The CH_4 destruction efficiency, 99 percent, was selected based on the range of efficiencies (98-100 percent) recommended for flares in EPA's "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 in the LMOP. The cubic feet of digester gas produced per person per day (1.0 ft^3/person/day) and the proportion of CH_4 in biogas (0.65) come from Metcalf and Eddy 1991. The wastewater flow to a POTW per person per day (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_5 Produced (Gg)

Year	Population	BOD_5
1990	254	8,350
1995	271	8,895
2000	287	9,419
2001	289	9,509
2002	292	9,597
2003	295	9,685
2004	297	9,774
2005	300	9,864

Source: U.S. Census Bureau (2006a); Metcalf & Eddy 1991 and 2003.

[8] Aerobic and anaerobic treatment were determined based on unit processes in use at the facilities. Because the list of unit processes became more extensive in the 2000 and 2004 surveys, the criteria used to identify aerobic and anaerobic treatment differ slightly across the time series. Once facilities were identified as aerobic or anaerobic, they were separated by whether or not they had anaerobic digestion in place. Once these classifications were determined, the flows associated with facilities in each category were summed.

CH_4 emissions estimates from industrial wastewater were developed according to the methodology described in IPCC (2006a). Industry categories that are likely to produce significant CH_4 emissions from wastewater treatment were identified. High volumes of wastewater generated and a high organic wastewater load were the main criteria. The top three industries that meet these criteria are pulp and paper manufacturing; meat and poultry processing; and vegetables, fruits, and juices processing. Table 8-9 contains production data for these industries.

Table 8-9. U.S. Pulp and Paper, Meat and Poultry, and Vegetables, Fruits and Juices Production (Tg)

Year	Pulp and Paper	Meat (Live Weight Killed)	Poultry (Live Weight Killed)	Vegetables, Fruits and Juices
1990	128.9	27.3	14.6	40.5
1995	140.9	30.8	18.9	49.0
2000	142.8	32.1	22.2	52.7
2001	134.3	31.6	22.8	46.7
2002	132.7	32.7	23.5	49.1
2003	131.9	32.3	23.7	46.2
2004	136.4	31.2	24.4	49.1
2005	131.4	31.4	25.1	43.6

CH_4 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 emission factor. Ratios of BOD:COD in various industrial wastewaters were obtained from the World Bank (1999) and used to estimate COD loadings. The B_o value used for all industries is the IPCC default value of 0.25 kg CH_4/kg COD (IPCC 2006a). The methodological equation is:

$$CH_4 \text{ (industrial wastewater)} = P \times W \times (COD) \times TA \times B_o \times MCF$$

where,

CH_4 (industrial wastewater)	= Total CH_4 emissions from industrial wastewater (kg/year)
P	= Industry output (metric tons/year)
W	= Wastewater generated (m^3/metric ton of product)
COD	= Organics loading in wastewater (kg /m^3)
TA	= Percent of wastewater treated anaerobically on site
MCF	= CH_4 correction factor, indicating the extent to which the organic content (measured as COD) degrades anaerobically
B_o	= Maximum CH_4 producing potential of industrial wastewater (default value of 0.25 kg CH_4/kg COD)

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. Primary treatment lagoons are aerated to reduce anaerobic activity. However, the lagoons are large and zones of anaerobic activity may occur and, consequently, the primary lagoons are assumed to be 1.4 percent anaerobic (based on expert judgment). Approximately 42 percent of the BOD passes on to secondary treatment, which is less likely to be aerated (EPA 1993a,b). Twenty-five percent of the BOD in secondary treatment lagoons was assumed to degrade anaerobically, while 10 percent passes through to be discharged with the effluent (EPA 1997a). Consequently, the overall percentage of wastewater organics that degrade anaerobically was determined to be 10.3 percent (i.e., 58 percent × 1.4 percent + 42 percent × 90 percent × 25 percent). A time series of CH_4 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 (AF&PA) and data published by Paper Loop were used to estimate production for 2002 through 2005 (Pulp and Paper 2005, 2006 and monthly reports from 2003–2006). The

overall wastewater outflow was estimated to be 85 m^3/metric ton, and the average BOD loading entering the secondary treatment lagoons was estimated to be 0.4 gram BOD/liter (EPA 1997b, EPA 1993a,b, World Bank 1999).

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_o of 0.25 kg COD/kg CH_4 and default MCF of 0.8 for anaerobic lagoons were used to estimate the CH_4 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 2006). Data collected by EPA's Office of Water provided estimates for wastewater flows into anaerobic lagoons: 5.3 and 12.5 m^3/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.

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, 5 percent of these wastewater organics are assumed to degrade anaerobically. EPA used the IPCC default B_o of 0.25 kg COD/kg CH_4 and default MCF of 0.8 for anaerobic treatment to estimate the CH_4 produced from these on-site treatment systems. The USDA National Agricultural Statistics Service (USDA 2006) provided production data for potatoes, other vegetables, citrus fruit, non-citrus fruit, and grapes processed for wine. Outflow and BOD data, presented in Table 8-10, were obtained from EPA (1974) for potato, citrus fruit, and apple processing, and from the World Bank (1999) for all other sectors.

Table 8-10. Wastewater Flow (m^3/ton) and BOD Production (g/L) for U.S. Vegetables, Fruits and Juices Production

Commodity	Wastewater Outflow (m^3/ton)	BOD (g/L)
Vegetables		
Potatoes	10.27	1.765
Other Vegetables	8.64	0.817
Fruit		
Apples	3.66	1.317
Citrus	10.11	0.317
Non-citrus	11.7	0.982
Grapes (for wine)	1.53	2.346

Domestic Wastewater N_2O Emission Estimates

N_2O emissions from domestic wastewater (wastewater treatment) were estimated using the updated IPCC (2006) methodology, including calculations that take into account N removal with sewage sludge, non-consumption and industrial 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_{SLUDGE}). The N disposal into aquatic environments is reduced to account for the sewage sludge application.[9]

[9] The methodology for estimating the quantity of sewage sludge N not entering aquatic environments is described in Annex 3.11

- The IPCC methodology uses annual, per capita protein consumption (kg protein/[person-year]). This number is likely to underestimate the amount of protein entering the sewer or septic system. Food (waste) that is not consumed is often washed down the drain, as a result of the use of garbage disposals. Also, bath and laundry water can be expected to contribute to N loadings. As a result, a factor of 1.4 for non-consumption N is introduced for each year in the Inventory.[10] Furthermore, a significant quantity of industrial wastewater (N) is co-discharged with domestic wastewater. To account for this, a factor of 1.25 is used.[11]
- Small amounts of gaseous nitrogen oxides are formed as by-products in the conversion of nitrate to N gas in anoxic biological treatment systems. Approximately 7 grams N_2O is generated per capita per year if wastewater treatment includes nitrification and denitrification (Scheehle and Doorn 2001). Analysis of the 2000 CWNS shows 88 treatment plants in the United States, serving a population of 2,636,668 persons, with denitrification as one of their unit operations. Based on an emission factor of 7 grams/capita/year, approximately 17.5 metric tons of additional N_2O may have been emitted via denitrification in 2000. Similar analysis was done for each year in the Inventory using data from CWNS on the amount of wastewater in centralized systems treated in denitrification units.

With the modifications described above, N_2O emissions from domestic wastewater were estimated using the following methodology:

$$N_2O_{TOTAL} = N_2O_{PLANT} + N_2O_{EFFLUENT}$$

$$N_2O_{PLANT} = N_2O_{NIT/DENIT} + N_2O_{WOUT\ NIT/DENIT}$$

$$N_2O_{NIT/DENIT} = [(US_{POPND}) \times EF_2] \times 1/10\text{^}9$$

$$N_2O_{WOUT\ NIT/DENIT} = \{[(US_{POP} \times WWTP) - US_{POPND}] \times EF_1\} \times 1/10\text{^}9$$

$$N_2O_{EFFLUENT} = \{[(US_{POP} \times Protein \times F_{NPR} \times F_{NON\text{-}CON} \times F_{IND\text{-}COM}) - N_{SLUDGE}] \times EF_3 \times 44/28\} \times 1/10\text{^}6$$

where,

N_2O_{TOTAL} =	Annual emissions of N_2O
N_2O_{PLANT} =	N_2O emissions from centralized wastewater treatment plants
$N_2O_{NIT/DENIT}$ =	N_2O emissions from centralized wastewater treatment plants with nitrification/denitrification
$N_2O_{WOUT\ NIT/DENIT}$ =	N_2O emissions from centralized wastewater treatment plants without nitrification/denitrification
$N_2O_{EFFLUENT}$ =	N_2O emissions from wastewater effluent discharged to aquatic environments
US_{POP} =	U.S. population
US_{POPND} =	U.S. population that is served by biological denitrification (from CWNS)
WWTP =	Fraction of population using WWTP (as opposed to septic systems)
EF_1 =	Emission factor (3.2 g N_2O/person-year)

[10] Metcalf & Eddy (1991) provide a typical influent nitrogen concentration of 40 mg/L Total Kjeldahl Nitrogen (TKN) for average wastewater from residences, which includes bathwater, laundry, and the use of garbage disposals. The factor for non-consumptive protein was estimated based on wastewater treated in 1990, the percent of population serviced by centralized treatment systems, and the per capita TKN loading, resulting in a factor of 1.4.

[11] The type, composition, and quantity of this co-discharged wastewater vary greatly between municipalities. Metcalf & Eddy (1991) provide a range of influent nitrogen concentrations of 20 to 85 mg/L TKN (average 55) for combined residential and industrial wastewater, while residential wastewater loading was roughly estimated at 40 mg TKN/liter (see previous footnote). Until better data become available, the amount of N in wastewater is increased by 10 mg/L to account for industrial co-discharge (factor of 1.25).

EF_2 =	Emission factor (7 g N_2O/person-year)
Protein =	Annual per capita protein consumption (kg/person/year)
F_{NPR} =	Fraction of N in protein, default = 0.16 (kg N/kg protein)
$F_{NON-CON}$ =	Factor for non-consumed protein added to wastewater
$F_{IND-COM}$ =	Factor for industrial and commercial co-discharged protein into the sewer system
N_{SLUDGE} =	N removed with sludge, kg N/yr
EF_3 =	Emission factor (0.005 kg N_2O -N/kg sewage-N produced)
44/28 =	Molecular weight ratio of N_2O to N_2

U.S. population data were taken from the U.S. Census Bureau International Database (U.S. Census 2006a) 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 1993, 1995, 1997, 1999, 2001, and 2003 American Housing Survey (U.S. Census 2006b). Data for intervening years were obtained by linear interpolation. The emission factor (EF_1) to estimate emissions from wastewater treatment was taken from IPCC (2006a). Data on annual per capita protein intake were provided by the United Nations Food and Agriculture Organization for the 1990 to 2003 time frame (FAO 2006). Protein consumption data for 2004 and 2005 were extrapolated from data for 1990 through 2003. Table 8-11 presents the data for U.S. population and average protein intake. An emission factor to estimate emissions from effluent (EF_3) has not been specifically estimated for the United States, thus the newly-revised default IPCC value (0.005 kg N_2O-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). An estimate for the nitrogen removed as sludge (N_{SLUDGE}) 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.

Table 8-11. U.S. Population (Millions) and Average Protein Intake [kg/(person-year)]

Year	Population	Protein
1990	254	39.2
1995	271	40.0
2000	287	41.6
2001	289	41.3
2002	292	41.3
2003	295	41.7
2004	297	41.9
2005	300	42.1

Source: U.S. Census Bureau 2006a, FAO 2006.

Uncertainty

The overall uncertainty associated with both the 2005 CH_4 and N_2O emissions 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_4 emissions included that of numerous input variables used to model emissions from domestic wastewater, and wastewater from the pulp and paper industry, meat and poultry processing, as well as from fruits, vegetables and juices processing. Uncertainty associated with the parameters used to estimate N_2O emissions included 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 8-12. CH_4 emissions from wastewater treatment were estimated to be between 15.8 and 37.3 Tg CO_2 Eq. at the 95 percent confidence level (or in 19 out of 20 Monte Carlo Stochastic Simulations). This indicates a range of approximately 38 percent below to 47 percent above the 2005 emissions estimate of 25.4 Tg CO_2 Eq. N_2O emissions from wastewater treatment were estimated to be between 1.7 and 15.4 Tg CO_2 Eq., which indicates a range of approximately 79 percent below to 93

percent above the actual 2005 emissions estimate of 8.0 Tg CO_2 Eq.

Table 8-12. Tier 2 Quantitative Uncertainty Estimates for CH_4 Emissions from Wastewater Treatment (Tg CO_2 Eq. and Percent)

Source	Gas	2005 Emission Estimate (Tg CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Wastewater Treatment	CH_4	25.4	15.8	37.3	-38%	+47%
Domestic	CH_4	17.0	8.6	28.2	-49%	+66%
Industrial	CH_4	8.4	4.6	13.5	-45%	+60%
Domestic Wastewater Treatment	N_2O	8.0	1.7	15.4	-79%	+93%

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

Recalculations Discussion

The 2005 estimates for CH_4 emissions from domestic wastewater include two major methodological refinements and one major data change. First, CH_4 emissions were estimated from four distinct source categories (septic systems, centrally treated aerobic systems, centrally treated anaerobic systems, and anaerobic digesters) rather than calculating an overall percentage of wastewater treated anaerobically from which to calculate emissions. Calculating emissions from anaerobic digesters constitutes the second methodological refinement to the inventory. Emissions from anaerobic digesters were included to account for the increasing number of facilities that produce and use digester biogas. The major data adjustment for the current inventory estimates involves the BOD per capita rate. In previous inventories, the BOD per capita rate varied across the time series. However, the 2005 estimates employ a standard value for the BOD per capita rate (0.09 kg/capita/day). This change resulted in varying differences in emissions estimates over time, ranging from an increase of 52 percent (1990) to a decrease of 15 percent (2004).

For industrial wastewater , production data for the entire time series were updated and other factors, such as wastewater outflow, BOD, and percent of waste treated anaerobically, were revised. Production data for potato processing, which accounts for about 45 percent of all vegetable processing in the United States, and about 25 percent of all fruit and vegetable processing, had not been included in previous inventories. However, the increase in industrial wastewater emissions due to the inclusion of potatoes was offset by other changes made to the inventory. Flow and BOD data for fruits and vegetable processing wastewater were updated to reflect commodity-specific data, which resulted in a decrease in emissions. In addition, the amount of meat and poultry processing wastewater treated on site anaerobically was substantially revised. Previously, it was assumed that all wastewater from meat and poultry processing was treated anaerobically. However, data from EPA's Office of Water and from U.S. Poultry and Egg Association became available to show that indirect dischargers do not treat wastewater anaerobically. Therefore, the percent of waste treated anaerobically was reduced (to 33 percent for meat processors and 25 percent for poultry processors), which resulted in a significant decrease in emission estimates. These changes resulted in overall decreases of industrial wastewater emissions between 45 and 50 percent across the time series.

Overall, the CH_4 emission estimates for wastewater treatment are on average 17 percent lower than the previous inventory.

For N_2O emissions from domestic wastewater, minor changes were made to the time series to include more specific estimates of the percent of U.S. population using centralized wastewater treatment, and a factor was introduced to account for the amount of biological denitrification occurring at centralized treatment plants. The calculation estimates for protein consumed were updated for the entire time series. These improvements resulted in minor decreases to the emission estimates across the time series, from 3 to 4 percent.

Finally, the default factor for N_2O emissions from N in effluent discharged to aquatic environments was updated from 0.01 to 0.005 kg N_2O -N/kg sewage-N, which resulted in a decrease of approximately 50 percent in emission estimates over the time series compared to the previous inventory. The effect of all changes was an overall decrease in emission estimates from 50.1 to 51.4 percent across the time series.

Overall, emissions from wastewater treatment and discharge (CH_4 and N_2O) decreased by an average of 28 percent from the previous inventory.

Planned Improvements Discussion

The methodology to estimate CH_4 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 designation of systems as aerobic or anaerobic could be further refined to differentiate aerobic systems with the potential to generate small amounts of CH_4 (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. Currently it is assumed that all aerobic systems are well managed and produce no CH_4, and that all anaerobic systems have an MCF of 0.8. Efforts to obtain better data are currently being pursued.

Currently, BOD removal is not explicitly included in inventory calculations. The appropriateness of including a factor to account for BOD that is not removed through treatment and therefore does not contribute to CH_4 emissions is being investigated.

The methodology to estimate emissions for industrial wastewater currently accounts for pulp and paper, meat and poultry processing, and fruits and vegetables processing wastewater treatment. Information is currently being collected on ethanol production in the United States to determine if this should be included in future Inventories.

With respect to estimating N_2O emissions, the default emission factor for N_2O from wastewater effluent has a high uncertainty. The IPCC recently updated this factor; however, future research may identify new studies that include updated data. The factor that accounts for non-sewage nitrogen in wastewater (bath, laundry, kitchen, industrial components) also has a high uncertainty. Obtaining data on the changes in average influent nitrogen 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. In addition, more research may be conducted to update the protein consumption data.

8.3. 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_x, CO, and NMVOCs from waste sources for the years 1990 through 2005 are provided in Table 8-13.

Table 8-13: Emissions of NO_x, CO, and NMVOC from Waste (Gg)

Gas/Source	1990	1995	2000	2001	2002	2003	2004	2005
NO_x	**+**	**1**	**2**	**2**	**2**	**2**	**2**	**2**
Landfills	+	1	2	2	2	2	2	2
Wastewater Treatment	+	+	+	+	+	+	+	+
Miscellaneous[a]	+	1	+	+	+	+	+	+
CO	**1**	**2**	**8**	**8**	**7**	**7**	**7**	**7**
Landfills	1	2	7	7	6	6	6	7
Wastewater Treatment	+	+	1	1	+	+	+	+
Miscellaneous[a]	+	1	+	+	+	+	+	+
NMVOCs	**673**	**731**	**119**	**122**	**116**	**116**	**116**	**116**
Wastewater Treatment	57	61	51	53	50	50	50	50
Miscellaneous[a]	558	602	46	46	44	44	44	44

Landfills	58	68	23	23	22	22	22	22

[a] 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

These emission estimates were obtained from preliminary data (EPA 2006), 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.

Activity data were used in conjunction with emission factors, which relate the quantity of emissions to the activity. Emission factors are generally available from the EPA's *Compilation of Air Pollutant Emission Factors, AP-42* (EPA 1997). The EPA currently derives the overall emission control efficiency of a source category from a variety of information sources, including published reports, the 1985 National Acid Precipitation and Assessment Program emissions inventory, and other EPA databases.

Uncertainty

No quantitative estimates of uncertainty were calculated for this source category. Uncertainties in these estimates, however, are primarily due to the accuracy of the emission factors used and accurate estimates of activity data.

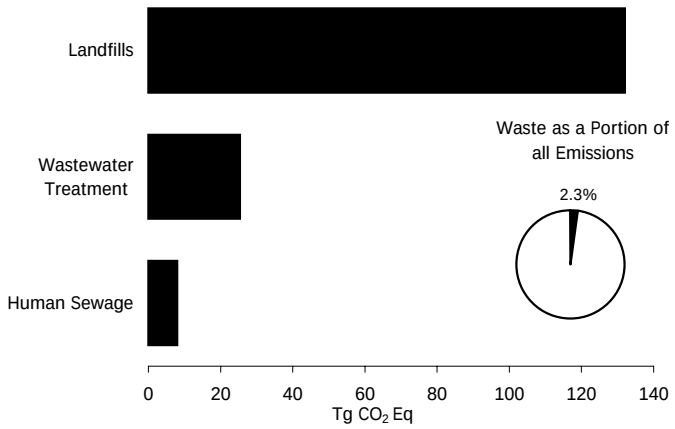

Figure 8-1: 2005 Waste Chapter Greenhouse Gas Sources