

7. Waste

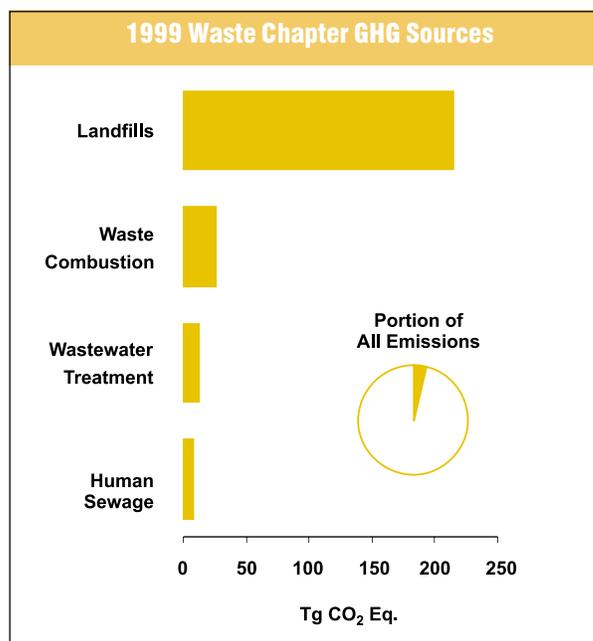
Waste management and treatment activities are sources of greenhouse gas emissions (see Figure 7-1). Landfills are the nation's largest source of anthropogenic methane (CH_4) emissions, accounting for 35 percent of the U.S. total.¹ Waste combustion is the second largest source in this sector, emitting carbon dioxide (CO_2) and nitrous oxide (N_2O). Smaller amounts of methane are emitted from wastewater systems by bacteria used in various treatment processes. Wastewater treatment systems are also a potentially significant source of N_2O emissions; however, methodologies are not currently available to develop a complete estimate. Nitrous oxide emissions from the treatment of the human sewage component of wastewater were estimated, however, using a simplified methodology. Nitrogen oxide (NO_x), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs) are emitted by each of these sources, and are addressed separately at the end of this chapter. A summary of greenhouse gas emissions from the Waste chapter is presented in Table 7-1 and Table 7-2.

Overall, in 1999, waste activities generated emissions of 261.3 Tg CO_2 Eq., or 3.9 percent of total U.S. greenhouse gas emissions.

Landfills

Landfills are the largest anthropogenic source of methane (CH_4) emissions in the United States. In 1999, landfill emissions were approximately 214.6 Tg CO_2 Eq. (10,221 Gg). Emissions from municipal solid waste (MSW) landfills, which received about 61 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. Over 2,200 operational landfills exist in the United States (BioCycle 2000), with the largest landfills receiving most of the waste and generating the majority of the methane.

Figure 7-1



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 Change and Forestry chapter.

Table 7-1: Emissions from Waste (Tg CO₂ Eq.)

Gas/Source	1990	1995	1996	1997	1998	1999
CH₄	228.5	234.7	231.0	229.8	225.7	226.9
Landfills	217.3	222.9	219.1	217.8	213.6	214.6
Wastewater Treatment	11.2	11.8	11.9	12.0	12.1	12.2
CO₂	17.6	23.1	24.0	25.7	25.1	26.0
Waste Combustion	17.6	23.1	24.0	25.7	25.1	26.0
N₂O	7.4	8.5	8.1	8.2	8.3	8.4
Human Sewage	7.1	8.2	7.8	7.9	8.1	8.2
Waste Combustion	0.3	0.3	0.3	0.3	0.2	0.2
Total	253.4	266.2	263.1	263.6	259.2	261.3

Note: Totals may not sum due to independent rounding.

Table 7-2: Emissions from Waste (Gg)

Gas/Source	1990	1995	1996	1997	1998	1999
CH₄	10,879	11,175	11,002	10,943	10,748	10,803
Landfills	10,346	10,614	10,435	10,371	10,171	10,221
Wastewater Treatment	533	561	567	572	577	583
CO₂	17,572	23,065	23,968	25,674	25,145	25,960
Waste Combustion	17,572	23,065	23,968	25,674	25,145	25,960
N₂O	24	27	26	26	27	27
Human Sewage	23	27	25	26	26	26
Waste Combustion	1	1	1	1	1	1

Note: Totals may not sum due to independent rounding.

Methane emissions result from the decomposition of organic landfill materials such as paper, food scraps, and yard trimmings. This decomposition process is a natural mechanism through which microorganisms derive energy. After being placed in a landfill, organic waste is initially digested by aerobic (i.e., in the presence of oxygen) bacteria. After the oxygen supply has been depleted, the remaining waste is consumed 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. Methane-producing anaerobic bacteria convert these fermentation products into stabilized organic materials and biogas consisting of approximately 50 percent carbon dioxide (CO₂) and 50 percent methane, by volume.² Methane production typically begins one or two years after waste disposal in a landfill and may last from 10 to 60 years.

Between 1990 and 1999, net methane emissions from landfills were relatively constant (see Table 7-3 and Table 7-4). The roughly constant emissions estimates are a result of two offsetting trends: (1) the amount of MSW in landfills contributing to methane emissions increased, thereby increasing the potential for emissions; and (2) the amount of landfill gas collected and combusted by landfill operators also increased, thereby reducing emissions.

Methane emissions from landfills are a function of several factors, including: (1) the total amount of MSW in landfills, which is related to total MSW landfilled annually for the last 30 years; (2) composition of the waste-in-place; (3) the amount of methane that is recovered and either flared or used for energy purposes; and (4) the amount of methane oxidized in landfills instead of being released into the atmosphere. The estimated total quantity of waste-in-place contributing to emissions increased from about 4,926 Gg in 1990 to 6,036 Gg in 1999, an in-

² The percentage of CO₂ in biogas released from a landfill may be smaller because some CO₂ dissolves in landfill water (Bingemer and Crutzen 1987). Additionally, less than 1 percent of landfill gas is composed of non-methane volatile organic compounds (NMVOCs).

Table 7-3: CH₄ Emissions from Landfills (Tg CO₂ Eq.)

Activity	1990		1995	1996	1997	1998	1999
MSW Landfills	221.1		254.8	261.0	267.1	272.7	279.6
Industrial Landfills	15.3		17.5	17.8	18.2	18.5	19.0
Recovered							
Gas-to-Energy	(14.7)		(21.8)	(24.3)	(28.8)	(36.1)	(42.7)
Flared	(4.5)		(27.6)	(35.3)	(38.8)	(41.5)	(41.2)
Net Emissions	217.3		222.9	219.1	217.8	213.6	214.6

Note: Totals may not sum due to independent rounding.

Table 7-4: CH₄ Emissions from Landfills (Gg)

Activity	1990		1995	1996	1997	1998	1999
MSW Landfills	10,531		12,133	12,427	12,720	12,985	13,315
Industrial Landfills	731		833	850	868	883	904
Recovered							
Gas-to-Energy	(702)		(1,037)	(1,159)	(1,372)	(1,720)	(2,034)
Flared	(213)		(1,314)	(1,683)	(1,846)	(1,977)	(1,964)
Net Emissions	10,346		10,614	10,435	10,371	10,171	10,221

Note: Totals may not sum due to independent rounding.

Box 7-1: Biogenic Emissions and Sinks of Carbon

For many countries, CO₂ emissions from the combustion or degradation of biogenic materials are important because of the significant amount of energy they derive from biomass (e.g., burning fuelwood). The fate of biogenic materials is also important when evaluating waste management emissions (e.g., the decomposition of paper). The carbon contained in paper was originally stored in trees during photosynthesis. Under natural conditions, this material would eventually degrade and cycle back to the atmosphere as CO₂. The quantity of carbon that these degradation processes cycle through the Earth's atmosphere, waters, soils, and biota is much greater than the quantity added by anthropogenic greenhouse gas sources. But the focus of the United Nations Framework Convention on Climate Change is on anthropogenic emissions—emissions resulting from human activities and subject to human control—because it is these emissions that have the potential to alter the climate by disrupting the natural balances in carbon's biogeochemical cycle, and enhancing the atmosphere's natural greenhouse effect.

Carbon dioxide emissions from 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 CO₂ that was originally removed by photosynthesis. However, CH₄ emissions from landfilled waste occur due to the man-made anaerobic conditions conducive to CH₄ formation that exist in landfills, and are consequently included in this Inventory.

The removal of carbon from the natural cycling of carbon between the atmosphere and biogenic materials—which occurs when wastes of biogenic origin are deposited in landfills—sequesters carbon. When wastes of sustainable, biogenic origin are landfilled, and do not completely decompose, the carbon that remains is effectively removed from the global carbon cycle. Landfilling of forest products and yard trimmings results in long-term storage of about 70 Tg CO₂ Eq. and 7 to 18 Tg CO₂ Eq. per year, respectively. Carbon storage that results from forest products and yard trimmings disposed in landfills is accounted for in the Land-Use Change and Forestry chapter, as recommended in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997) regarding the tracking of carbon flows.

Box 7-2: Recycling and Greenhouse Gas Emissions and Sinks

U.S. waste management patterns changed dramatically in the 1990s in response to changes in economic and regulatory factors. Perhaps the most significant change from a greenhouse gas perspective was the increase in the national average recycling rate, which climbed from 16 percent in 1990 to 28 percent in 1997 (EPA 1999).

This change has affected emissions in several ways, primarily by reducing emissions from waste and energy activities, as well as by enhancing forestry sinks. The impact of increased recycling on greenhouse gas emissions can be best understood when emissions are considered from a life cycle perspective (EPA 1998). When a material is recycled, it is used in place of virgin inputs in the manufacturing process, rather than being disposed and managed as waste. The substitution of recycled inputs for virgin inputs reduces three types of emissions throughout the product life cycle. First, manufacturing processes involving recycled inputs generally require less energy than those using virgin inputs. Second, the use of recycled inputs leads to reductions in process non-energy emissions (e.g., perfluorocarbon emissions from aluminum smelting). Third, recycling reduces disposal and waste management emissions, including methane from landfills and nitrous oxide and non-biogenic carbon dioxide emissions from combustion. In addition to greenhouse gas emission reductions from manufacturing and disposal, recycling of paper products—which are the largest component of the U.S. wastestream—results in increased forest carbon sequestration. When paper is recycled, fewer trees are needed as inputs in the manufacturing process; reduced harvest levels result in older average forest ages, with correspondingly more carbon stored.

crease of 23 percent (see Annex M). During this period, the estimated methane recovered and flared from landfills increased as well. In 1990, for example, approximately 915 Gg of methane was recovered and combusted (i.e., used for energy or flared) from landfills. In 1999, the estimated quantity of methane recovered and combusted increased to 3,998 Gg.

Over the next several years, the total amount of MSW generated is expected to increase slightly. The percentage of waste landfilled, however, may decline due to increased recycling and composting practices. In addition, the quantity of methane that is recovered and either flared or used for energy purposes is expected to increase, partially as a result of a 1996 regulation that requires large MSW landfills to collect and combust landfill gas (see 40 CFR Part 60, Subparts Cc and WWW).

Methodology

Based on available information, methane emissions from landfills were estimated to equal the methane produced from municipal landfills, minus the methane recovered and combusted, minus the methane oxidized before being released into the atmosphere, plus the methane produced by industrial landfills.

The methodology for estimating CH₄ emissions from municipal landfills is based on a model that updates the population of U.S. landfills each year. This model is based

on the pattern of actual waste disposal by each individual landfill surveyed by the EPA's Office of Solid Waste in 1987. A second model was employed to estimate emissions from the landfill population (EPA 1993). For each landfill in the data set, the amount of waste-in-place contributing to methane generation was estimated using its year of opening, its waste acceptance rate, year of closure, and design capacity. Data on national waste disposed in landfills each year was apportioned by landfill. Emissions from municipal landfills were then estimated by multiplying the quantity of waste contributing to emissions by emission factors (EPA 1993). For further information see Annex M.

The estimated landfill gas recovered per year was based on updated data collected from vendors of flaring equipment, and a database compiled by the EPA's Landfill Methane Outreach Program (LMOP). Based on the information provided by vendors, the methane combusted by the 487 flares in operation from 1990 to 1999 were estimated. This quantity likely under-estimates flaring. The EPA believes that more than 700 flares exist in the United States, and is working with the Solid Waste Association of North America (SWANA) to better characterize flaring activities. Additionally, the LMOP database provided sufficient data on landfill gas flow and energy generation for 273 of the approximately 315 operational landfill gas-to-energy projects (LFGTE). If both flare data and LFGTE

recovery data for a particular landfill were available, then the emissions recovery was based on the LFGTE data, which provides actual 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 size flare. Given that each LFGTE project was likely to also have had a flare, EPA avoided double counting reductions from flares and LFGTE projects by subtracting from the emissions reductions associated with flares, those emissions reductions associated with LFGTE projects.³

Emissions from industrial landfills were assumed to be equal to 7 percent of the total methane emissions from municipal landfills. The amount of methane oxidized was assumed to be 10 percent of the methane generated (Liptay et al. 1998). To calculate net methane emissions, both methane recovered and methane oxidized were subtracted from methane generated at municipal and industrial landfills.

Data Sources

The landfill population model, including actual waste disposal data from individual landfills, was developed from a survey performed by the EPA's Office of Solid Waste (EPA 1988). National landfill waste disposal data for 1991 through 1999 were obtained from *BioCycle* (2000).⁴ Documentation on the landfill methane emissions methodology employed is available in the EPA's *Anthropogenic Methane Emissions in the United States, Estimates for 1990: Report to Congress* (EPA 1993). Information on flares was obtained from vendors, and information on landfill gas-to-energy projects was obtained from the LMOP database.

Uncertainty

Several types of uncertainties are associated with the estimates of methane emissions from landfills. The primary uncertainty concerns the characterization of land-

fills. Information is lacking on the area landfilled and total waste-in-place—the fundamental factors that affect methane production. In addition, the statistical model used to estimate emissions is based upon methane generation at landfills that currently have developed energy recovery projects, and may not precisely capture the relationship between emissions and various physical characteristics of individual landfills. Overall, uncertainty in the landfill methane emission rate is estimated to be roughly ± 30 percent.

Waste Combustion

Combustion is used to manage both municipal solid wastes (MSW) and hazardous wastes. Combustion of either type of waste results in conversion of the organic inputs to carbon dioxide (CO₂). According to the IPCC Guidelines, when the CO₂ is of fossil origin, it is counted as an anthropogenic emission in national inventories. Thus, the emissions from waste combustion are driven by estimating the quantity of waste combusted, the fraction of the waste that is carbon, and the fraction of the carbon that is of fossil origin.

MSW is composed of garbage and non-hazardous solids. Most of the organic materials in MSW are of biogenic origin (e.g., paper, yard trimmings), and have their net carbon flows accounted for under the Land-Use Change and Forestry chapter (see Box 7-1). However, some components—plastics, synthetic rubber, and synthetic fibers—are of fossil origin. Plastics in the U.S. wastestream are primarily in the form of containers, packaging, and durable goods. Rubber is found in durable goods, like carpets, and in non-durable goods, such as clothing and footwear. Fibers in MSW are predominantly from clothing and home furnishings. Tires are also considered a “non-hazardous” waste and are included in the estimate, though waste disposal practices for tires differ from the rest of MSW.

³ Due to the differences in referencing landfills and incomplete data on the national population of flares, matching flare vendor data with the LMOP LFGTE data was problematic and EPA was not able to identify a flare for each of the LFGTE projects. Because each LFGTE project likely has a flare, the aggregate flare estimate of emission reductions was reduced by the LFGTE projects for which a specific flare could not be identified. This approach eliminated the potential for double counting emissions reductions at landfills with both flares and a LFGTE project.

⁴ At the time this section was prepared, *BioCycle* had not yet published its 1999 estimate for the percent of the total waste landfilled, so the previous year's figure (61 percent) was used.

In 1999, it was estimated that nearly 34 million metric tons of MSW were combusted in the United States (EPA 1999). Carbon dioxide emissions have risen 46 percent since 1990, to an estimated 20.5 Tg CO₂ Eq. (20,470 Gg) in 1999, as the volume of plastics in MSW has increased (see Table 7-5 and Table 7-6). In addition to CO₂, MSW combustion is a source of nitrous oxide (N₂O) emissions (De Soete 1993). Nitrous oxide emissions from MSW combustion were estimated to be 0.2 Tg CO₂ Eq. (1 Gg) in 1999, and have not changed significantly since 1990.

Hazardous wastes are defined by the EPA under the Resource Conservation and Recovery Act (RCRA).⁵ Industrial wastes, such as rejected products, spent reagents, reaction by-products, and sludges from wastewater or air pollution control, are federally regulated as hazardous wastes if they are found to be ignitable, corrosive, reactive, or toxic according to standardized tests or studies conducted by the EPA.

Hazardous wastes must be treated prior to disposal according to the federal regulations established under the authority of RCRA. Combustion is one of the most common techniques for hazardous waste treatment, par-

ticularly for those wastes that are primarily organic in composition or contain primarily organic contaminants. Generally speaking, combustion devices fall into two categories: incinerators that burn waste solely for the purpose of waste management, and boilers and industrial furnaces (BIFs) that burn waste in part to recover energy from the waste. The EPA's Office of Solid Waste requires biennial reporting of hazardous waste management activities, and these reports provide estimates of the amount of hazardous waste burned for incineration or energy recovery. Table 7-7 presents estimates of CO₂ emissions from hazardous waste combustion based on these estimates and assumptions about the composition of the wastes and efficiency of the combustion process.

Methodology

CO₂ from Plastics Combustion

In the report, *Characterization of Municipal Solid Waste in the United States* (EPA 2000c), the flows of plastics in the U.S. wastestream are reported for seven resin categories. The 1998 quantity generated, recovered, and discarded for each resin is shown in Table 7-8. The report

Table 7-5: CO₂ and N₂O Emissions from Municipal Solid Waste Combustion (Tg CO₂ Eq.)

Gas/Waste Product	1990	1995	1996	1997	1998	1999
CO₂	14.0	18.2	19.1	20.8	19.9	20.5
Plastics	10.3	11.1	11.5	12.5	12.9	13.3
Synthetic Rubber in Tires	0.2	1.4	1.5	1.7	1.1	1.2
Carbon Black in Tires	0.3	2.1	2.3	2.6	1.7	1.8
Synthetic Rubber in MSW	1.6	1.7	1.7	1.8	1.8	1.9
Synthetic Fibers	1.5	1.9	2.0	2.1	2.2	2.3
N₂O	0.3	0.3	0.3	0.3	0.2	0.2
Total	14.3	18.4	19.3	21.0	20.1	20.7

Table 7-6: CO₂ and N₂O Emissions from Municipal Solid Waste Combustion (Gg)

Gas/Waste Product	1990	1995	1996	1997	1998	1999
CO₂	14,014	18,154	19,061	20,770	19,871	20,470
Plastics	10,320	11,077	11,459	12,484	12,929	13,297
Synthetic Rubber in Tires	227	1,353	1,517	1,711	1,134	1,190
Carbon Black in Tires	348	2,077	2,329	2,627	1,741	1,827
Synthetic Rubber in MSW	1,584	1,708	1,737	1,807	1,833	1,870
Synthetic Fibers	1,535	1,938	2,018	2,141	2,233	2,285
N₂O	1	1	1	1	1	1

⁵ [42 U.S.C. §6924, SDWA §3004]

Table 7-7: CO₂ Emissions from Hazardous Waste Combustion

Year	Tg CO ₂ Eq.	Gg
1990	3.6	3,557
1995	4.9	4,911
1996	4.9	4,908
1997	4.9	4,904
1998*	5.3	5,274
1999*	5.5	5,490

*Projection based on 1989 to 1997 trend.

does not provide estimates for individual materials landfilled and combusted, although it does provide such an estimate for the waste stream as a whole. To estimate the quantity of plastics landfilled and combusted, total discards were apportioned based on the proportions of landfilling and combustion for the entire U.S. wastestream (76 percent and 24 percent, respectively).

Fossil fuel-based CO₂ emissions for 1998 were calculated as the product of plastic combusted, carbon content, and combustion efficiency (see Table 7-9). The car-

bon content of each of the six types of plastics is listed, with the value for “other plastics” assumed equal to the weighted average of the six categories. The fraction oxidized was assumed to be 98 percent.

Emissions for 1990 through 1997 were calculated using the same approach. Estimates of the portion of plastics in the wastestream in 1999 were not available; therefore, they were projected by assuming a 3 percent annual growth rate in generation and a 5.4 percent growth rate for recovery, based on reported trends (EPA 1999).

CO₂ from Combustion of Synthetic Rubber and Carbon Black in Tires

Emissions from tire combustion require two pieces of information: the amount of tires combusted and the carbon content of the tires. The *Scrap Tire Use/Disposal Study 1998/1999 Update* (STMC 1999) reports that 114 million of the 270 million scrap tires generated in 1998 (approximately 42 percent of generation) were used for fuel purposes. Using STMC estimates of average tire composition and weight, the weight of synthetic rubber and carbon black in scrap tires was determined. Synthetic rub-

Table 7-8: 1998 Plastics in the Municipal Solid Waste Stream by Resin (Gg)

Waste Pathway	PET	HDPE	PVC	LDPE/LLDPE	PP	PS	Other	Total
Generation	2,023	4,500	1,243	4,844	2,576	1,969	3,139	20,294
Recovery	354	399	0	127	154	18	45	1,098
Discard	1,669	4,101	1,243	4,717	2,422	1,950	3,094	19,196
Landfill	1,269	3,116	945	3,585	1,841	1,482	2,351	14,589
Combustion	401	984	298	1,132	581	468	742	4,607
Recovery*	17%	9%	0%	3%	6%	1%	1%	5%
Discard*	83%	91%	100%	97%	94%	99%	99%	95%
Landfill*	63%	69%	76%	74%	71%	75%	75%	72%
Combustion*	20%	22%	24%	23%	23%	24%	24%	23%

*As a percent of waste generation.

Note: Totals may not sum due to independent rounding. Abbreviations: PET (polyethylene terephthalate), HDPE (high density polyethylene), PVC (polyvinyl chloride), LDPE/LLDPE ((linear) low density polyethylene), PP (polypropylene), PS (polystyrene).

Table 7-9: 1998 Plastics Combusted (Gg), Carbon Content (%), and Carbon Combusted (Gg)

Factor	PET	HDPE	PVC	LDPE/LLDPE	PP	PS	Other	Total
Quantity Combusted	401	984	298	1,132	581	468	742	4,607
Carbon Content of Resin	63%	86%	38%	86%	86%	92%	66% ^a	-
Carbon in Resin Combusted	250	844	115	970	498	432	489	3,598
Emissions (Tg CO₂ Eq.)^b	0.9	3.0	0.4	3.5	1.8	1.6	1.8	12.9

^a Weighted average of other plastics produced in 1998 production.

^b Assumes a fraction oxidized of 98 percent.

ber in tires was estimated to be 90 percent carbon by weight, based on the weighted average carbon contents of the major elastomers used in new tire consumption (see Table 7-10).⁶ Carbon black is 100 percent carbon. Multiplying the proportion of scrap tires combusted by the total carbon content of the synthetic rubber and carbon black portion of scrap tires yielded CO₂ emissions, as shown in Table 7-11. Note that the disposal rate of rubber in tires (0.4 Tg/yr) is smaller than the consumption rate for tires shown in Table 7-10 (1.3 Tg/yr); this is due to the fact that much of the rubber is lost through tire wear during the product's lifetime and due to the lag time between consumption and disposal of tires.

CO₂ from Combustion of Synthetic Rubber in Municipal Solid Waste

Similar to the methodology for scrap tires, CO₂ emissions from synthetic rubber in MSW were estimated by

multiplying the amount of rubber combusted by an average rubber carbon content. The amount of rubber in the MSW stream was estimated from data provided in the *Characterization of Municipal Solid Waste in the United States* (EPA 2000c). The report organizes rubber found in MSW into three product categories: other durables (not including tires), non-durables (which includes clothing and footwear and other non-durables), and containers and packaging. Since there was negligible recovery for these product types, all the waste generated can be considered discarded. Similar to the plastics method, discards were apportioned based on the proportions of landfilling and combustion for the entire U.S. wastestream (76 percent and 24 percent, respectively). The report aggregates rubber and leather in the MSW stream; an assumed rubber content percentage was assigned to each product type, as shown in Table 7-12.⁷ A carbon content of 85 percent was assigned to synthetic rubber for all product types, according to the weighted average carbon content of rubber consumed for non-tire uses (See Table 7-10). For 1999, waste generation values were not provided in the report. Generation was forecast by multiplying the 1998 Rubber and Leather waste generation by the 1990 through 1998 average annual growth rate for that product category.

CO₂ from Combustion of Synthetic Fibers

Carbon dioxide emissions from synthetic fibers were estimated as the product of the amount of synthetic fiber discarded annually and the average carbon content of synthetic fiber. Fiber in the MSW stream was estimated from data provided in the *Characterization of Municipal Solid Waste in the United States* (EPA 2000c) for textiles. The amount of synthetic fiber in MSW was estimated by subtracting the amount recovered from the waste generated (see Table 7-13). As with the other materials in the MSW stream, discards were apportioned based on the proportions of landfilling and combustion for the entire U.S. wastestream (76 percent and 24 percent, respectively). It was assumed that approximately 55 percent of the fiber was synthetic in origin, based on information received from the Fiber Economics Bureau (DeZan 2000).

Table 7-10: Elastomers Consumed in 1998 (Gg)

Elastomer	Consumed	Carbon Content	Carbon Equivalent
Styrene butadiene rubber solid	908	91%	828
For Tires	743	91%	677
For Other Products*	165	91%	151
Polybutadiene	561	89%	499
For Tires	404	89%	359
For Other Products	157	89%	140
Ethylene Propylene	320	86%	274
For Tires	10	86%	8
For Other Products	310	86%	266
Polychloroprene	69	59%	40
For Tires	0	59%	0
For Other Products	69	59%	40
Nitrile butadiene rubber solid	87	77%	67
For Tires	1	77%	1
For Other Products	86	77%	67
Polyisoprene	78	88%	69
For Tires	65	88%	57
For Other Products	13	88%	12
Others	369	88%	324
For Tires	63	88%	56
For Other Products	306	88%	268
Total	2,392	-	2,101

*Used to calculate carbon content of non-tire rubber products in municipal solid waste.
 - Not applicable

⁶ 1,158,000 Tg for the carbon content of tires divided by 1,285,000 Tg for the mass of tires, equals 90 percent.

⁷ As a biogenic material, the combustion of leather is assumed to have no net carbon dioxide emissions.

Table 7-11: Scrap Tire Constituents and CO₂ Emissions from Scrap Tire Combustion in 1998

Material	Weight of Material (Tg)	Carbon Content	Percent Combusted	Emissions (Tg CO ₂ Eq.)*
Synthetic Rubber	0.4	90%	42%	1.1
Carbon Black	0.5	100%	42%	1.7
Total	0.8	-	-	2.9

* Assumes a fraction oxidized of 98 percent.
- Not applicable

Table 7-12: Rubber and Leather in Municipal Solid Waste in 1998

Product Type	Generation (Gg)	Synthetic Rubber (%)	Carbon Content (%)	Emissions (Tg CO ₂ Eq.)*
Durables (not Tires)	2,141	100%	85%	1.6
Non-Durables	744	100%	85%	0.2
Clothing and Footwear	526	25%	85%	0.1
Other Non-Durables	218	75%	85%	0.1
Containers and Packaging	18	100%	85%	+
Total	2,903	-	-	1.8

* Assumes a fraction oxidized of 98 percent.
+ Less than 0.05 Tg CO₂ Eq.
- Not applicable

Table 7-13: Textiles in MSW (Gg)

Year	Generation	Recovery	Discards	Combustion
1990	5,271	599	4,672	1,121
1991	5,599	622	4,977	1,195
1992	5,948	647	5,302	1,272
1993	6,319	672	5,647	1,355
1994	6,713	699	6,015	1,444
1995	6,713	816	5,897	1,415
1996	7,004	862	6,142	1,474
1997	7,475	962	6,514	1,563
1998	7,802	1,007	6,795	1,631
1999*	7,989	1,035	6,954	1,669

*Projected using 1998 data and the 1997 to 2000 Average Annual Growth Rate for Generation (EPA 1999).

An average carbon content of 70 percent was assigned to synthetic fiber using the production-weighted average of the carbon contents of the four major fiber types (polyester, nylon, olefin, and acrylic) produced in 1998 (see Table 7-14). The equation relating CO₂ emissions to the amount of textiles combusted is shown below. Since 1999 values were not provided in the *Characterization* report, generation and recovery were forecast by applying their respective average annual growth rates for 1990 through 1998 to the 1998 values.

$$\begin{aligned} \text{CO}_2 \text{ Emissions from the Combustion of Synthetic} \\ \text{Fibers} = & \text{Annual Textile Combustion (Gg)} \times \\ & (\text{Percent of Total Fiber that is Synthetic}) \times \\ & (\text{Average Carbon Content of Synthetic Fiber}) \times \\ & (44\text{g CO}_2/12\text{g C}) \end{aligned}$$

N₂O from Municipal Solid Waste Combustion

Estimates of N₂O emissions from MSW combustion in the United States are based on the methodology outlined in the EPA's Compilation of Air Pollutant Emis-

Table 7-14: Synthetic Fiber Production in 1998

Fiber	Proection (Tg)	Carbon Content	Carbon Equivalent (Tg CO ₂ Eq.)
Polyester	1.8	63%	4.1
Nylon	1.3	64%	3.0
Olefin	1.3	86%	4.1
Acrylic	0.2	68%	0.5
Total	4.6	-	11.7

- Not applicable

sion Factors (EPA 1997). According to this methodology, emissions of N₂O from MSW combustion are the product of the mass of MSW combusted, an emission factor of N₂O emitted per unit mass of waste combusted, and an N₂O emissions control removal efficiency. For MSW combustion in the United States, an emission factor of 30 g N₂O/metric ton MSW, and an estimated emissions control removal efficiency of zero percent were used. No information was available on the mass of waste combusted in 1999, so this was extrapolated, using least-squares linear regression, from the times series for 1990 through 1998.

CO₂ from Hazardous Waste Combustion

Hazardous wastes combusted are reported to the EPA, which stores the information in its Biennial Reporting System (BRS) database. Combusted wastes are identified based on management system types M041 through M049 (incineration) and M051 through M059 (energy recovery). Combusted quantities are grouped into four representative waste form categories based on the form codes reported in the BRS: aqueous liquids, organic liquids and sludges, organic solids, and inorganic solids. For this analysis, energy recovery was considered separately from incineration because regulations and practical considerations require wastes that are burned for energy recovery to have higher heating values than wastes sent to incineration. Based on these determinations, combusted waste quantities were grouped into categories representing the two types of combustion (incineration and energy recovery) and the four major waste forms.

To relate hazardous waste quantities to carbon emissions, “fuel equivalent” factors were derived for haz-

ardous waste by assuming that they are simple mixtures of a common fuel, water, and noncombustible ash. For liquids and sludges, crude oil is used as the fuel equivalent and coal is used to represent solids.

Fuel equivalent factors were multiplied by the tons of waste burned to obtain the tons of fuel equivalent. Multiplying the tons of fuel equivalent by the appropriate carbon content factors from Marland and Rotty (1984) yields tons of carbon emitted. Implied carbon content is calculated by dividing the tons of carbon emitted by the associated tons of waste burned.

This analysis was repeated for each of the BRS reporting years (odd numbered years from 1989 through 1997) assuming a constant average waste composition (see in Table 7-15) and fraction oxidized over the period. To obtain estimates for even numbered years, the average of the previous and subsequent years was used. A least-squares linear regression from the time series 1989 through 1997 was used for 1998 and 1999.

Table 7-15: Assumed Composition of Combusted Hazardous Waste by Weight (Percent)

Waste Type	Water	Noncombustibles	Fuel Equivalent
Energy Recovery			
Aqueous Waste	90	5	5
Organic Liquids and Sludges	30	10	60
Organic Solids	20	20	60
Inorganic Solids	20	40	40
Incineration			
Aqueous Waste	90	5	5
Organic Liquids and Sludges	40	20	40
Organic Solids	20	40	40
Inorganic Solids	20	70	10

Data Sources

For each of the CO₂ emissions methods used to calculate emissions from MSW combustion, there are generally two types of activity data needed: the quantity of product combusted and the carbon content of the product. For plastics, synthetic rubber in MSW, and synthetic fibers, the amount of material in MSW and its portion combusted was taken from the *Characterization of Municipal Solid Waste in the United States* (EPA 2000c).

For synthetic rubber and carbon black in scrap tires, this information was provided by the *Scrap Tire Use/Disposal Study 1998/1999 Update* (STMC 1999).

Average carbon contents for the “Other” plastics category, synthetic rubber in scrap tires, synthetic rubber in MSW, and synthetic fibers have been calculated from recent production statistics which divide their respective markets by chemical compound. The plastics production data set was taken from the website of the American Plastics Council (APC 2000); synthetic rubber production was taken from the website of the International Institute of Synthetic Rubber Producers (IISRP 2000); and synthetic fiber production was taken from the website of the Fiber Economics Bureau (FEB 2000). Personal communications with the APC (Eldredge-Roebuck 2000) and the FEB (DeZan 2000) validated the website information. All three sets of production data can also be found in Chemical and Engineering News, “Facts & Figures for the Chemical Industry.” Lastly, information about scrap tire composition was taken from the Scrap Tire Management Council’s webpage entitled “Scrap Tire Facts and Figures” (STMC 2000).

The assumption of 98 as the fraction of carbon oxidized, which applies to all municipal solid waste combustion categories for CO₂ emissions, was reported in the EPA’s life cycle analysis of greenhouse gas emissions and sinks from management of solid waste (EPA 1998).

The N₂O emission estimates are based on different data sources. The N₂O emissions are a function of total waste combusted, as reported in the April 1999 issue of *BioCycle* (Glenn 1999). Table 7-16 provides MSW generation and percentage combustion data for the total wastestream. The emission factor of N₂O emissions per quantity of MSW combusted was taken from Olivier (1993).

Waste quantity data for hazardous wastes were obtained from the EPA’s Biennial Reporting System (BRS) database for reporting years 1989, 1991, 1993, 1995, and 1997 (EPA 2000a). Combusted waste quantities were obtained from Form GM (Generation and Management) for wastes burned on site and Form WR (Wastes Received) for waste received from off-site for combustion. Carbon emission factors for equivalent fuels were obtained from Marland and Rotty (1984). All other estimates were assumed based on expert judgment.

Table 7-16: Municipal Solid Waste Generation (Metric Tons) and Percent Combusted

Year	Waste Generation	Combusted (%)
1990	266,541,881	11.5
1991	254,796,765	10.0
1992	264,843,388	11.0
1993	278,572,955	10.0
1994	293,109,556	10.0
1995	296,586,430	10.0
1996	297,268,188	10.0
1997	309,075,035	9.0
1998	340,090,022	7.5
1999	353,986,624	7.5

Uncertainty

There is uncertainty associated with the emissions estimates for both MSW and hazardous waste combustion. For MSW combustion, uncertainty arises from both the assumptions applied to the data and the quality of the data itself. For hazardous wastes, the primary source of uncertainty surrounds the composition of combusted wastes.

- MSW Combustion Rate:* A source of uncertainty affecting both fossil CO₂ and N₂O emissions is the estimate of the MSW combustion rate. The EPA (1999) estimates of materials generated, discarded, and combusted embody considerable uncertainty associated with the material flows methodology used to generate them. Similarly, the *BioCycle* (Glenn 1999) estimate of total waste combustion—used for the N₂O emissions estimate—is based on a survey of State officials, who use differing definitions of solid waste and who draw from a variety of sources of varying reliability and accuracy. Despite the differences in methodology and data sources, the two references—the EPA’s Office of Solid Waste (EPA 1999) and *BioCycle* (Glenn 1999)—provide estimates of total solid waste combusted that are relatively consistent (see Table 7-17).
- Fraction Oxidized:* Another source of uncertainty for the CO₂ emissions estimate is fraction oxidized. Municipal waste combustors vary considerably in their efficiency as a function of waste type, moisture content, combustion conditions, and other factors. The value of 98 percent assumed here may not be representative of typical conditions.

Table 7-17: U.S. Municipal Solid Waste Combusted by Data Source (Metric Tons)

Year	EPA	BioCycle
1990	28,939,680	30,652,316
1991	30,236,976	25,479,677
1992	29,656,638	29,132,773
1993	29,865,024	27,857,295
1994	29,474,928	29,310,956
1995	32,241,888	29,658,643
1996	32,740,848	29,726,819
1997	32,294,240	27,816,753
1998	NA	25,506,752
1999	NA	NA

NA (Not Available)

- *Use of 1998 Data on MSW Composition:* The materials that draw on the *Characterization* report (EPA 2000b) for data incur uncertainty in their 1999 emissions estimates. Emissions have been calculated from activity that has been extrapolated from reported 1998 values using average annual growth rates.
- *Average Carbon Contents:* Average carbon contents are applied to the mass of “Other” plastics combusted, synthetic rubber in tires and MSW, and synthetic fibers. These average values have been estimated from the average carbon content of the known products recently produced. The true carbon content of the combusted waste may differ from this estimate depending on differences in the formula between the known and unspecified materials, and differences between the composition of the material disposed and that produced. For rubber, this uncertainty is probably very small since the major elastomers’ carbon contents range from 77 to 91 percent; for plastics, where carbon contents range from 29 to 92 percent, it may be more significant. Overall, this is a small source of uncertainty.
- *Synthetic/Biogenic Assumptions:* A portion of the fiber and rubber in MSW is biogenic in origin. Assumptions have been made concerning the allocation between synthetic and biogenic materials based primarily on expert judgement.
- *Combustion Conditions Affecting N₂O Emissions:* Because insufficient data exist to provide detailed estimates of N₂O emissions for individual combus-

tion facilities, the estimates presented are highly uncertain. The emission factor for N₂O from MSW combustion facilities used in the analysis is a default value used to estimate N₂O emissions from facilities worldwide (Olivier 1993). As such, it has a range of uncertainty that spans an order of magnitude (between 25 and 293 g N₂O/metric ton MSW combusted) (Watanabe, et al. 1992). Due to a lack of information on the control of N₂O emissions from MSW combustion facilities in the United States, the estimate of zero percent for N₂O emissions control removal efficiency is also uncertain.

- *Hazardous Waste:* The greatest uncertainty in the hazardous waste combustion analysis is introduced by the assumptions about the composition of combusted hazardous wastes, including the characterization that hazardous wastes are similar to mixtures of water, noncombustibles, and fuel equivalent. Another limitation is the assumption that all of the carbon that enters hazardous waste combustion is emitted—some small fraction is likely to be sequestered in combustion ash—but given that the destruction and removal efficiency for hazardous organics is required to meet or exceed 99.99 percent, this is a minor source of uncertainty. Carbon emission estimates from hazardous waste should be considered central value estimates that are likely to be accurate to within ±50 percent.

Wastewater Treatment

Wastewater is treated to remove soluble organic matter, suspended solids, pathogenic organisms and other chemical contaminants. Soluble organic matter is generally removed using biological processes in which microorganisms consume organic waste for maintenance and generation of new cells. The resulting biomass is removed from the wastewater prior to discharge to the receiving stream. Microorganisms can biodegrade soluble organic material in wastewater under aerobic and anaerobic conditions. The biodegradation of soluble organic material in wastewater treatment systems produces methane when

it occurs under anaerobic conditions. The amount of methane produced is driven by the extent to which the organic material is broken down under anaerobic versus aerobic conditions. During collection and treatment, wastewater may be incidentally or deliberately managed under anaerobic conditions. In addition, the biomass (sludge) produced by the microorganisms that have consumed the wastewater's soluble organic material may be further biodegraded under aerobic or anaerobic conditions. The methane produced during deliberate anaerobic treatment is typically collected and flared or combusted for energy. However, whenever anaerobic conditions develop, some of the methane generated is incidentally released to the atmosphere. Untreated wastewater may also produce methane if contained under anaerobic conditions.

The organic content, expressed in terms of either biochemical oxygen demand (BOD) or chemical oxygen demand (COD), determines the methane producing potential of wastewater. BOD represents the amount of oxygen that would be required to completely consume the organic matter contained in the wastewater through aerobic decomposition processes. COD refers to the amount of oxygen consumed under specified conditions in the oxidation of the organic and oxidizable inorganic matter and is a parameter typically used to characterize industrial wastewater. Under anaerobic conditions and with all other conditions, such as temperature, being the same,

wastewater with higher BOD or COD concentrations will produce more methane than wastewater with lower BOD or COD.

In 1999, methane emissions from domestic or municipal wastewater treatment were 12.2 Tg CO₂ Eq. (583 Gg). Emissions have increased since 1990 in response to the increase in the U.S. human population. Since estimates of emissions from industrial wastewater contain only emissions from the pulp and paper industry at this time, these emissions are not included in totals. In 1999, methane emissions from industrial wastewater treatment were 0.2 Tg CO₂ Eq. (8 Gg). In the future, more research will be conducted to analyze and quantify methane emissions from wastewater treatment processes at other industries.

Table 7-18 and Table 7-19 provide emission estimates from domestic and industrial wastewater treatment.

Methodology

Domestic wastewater methane emissions are estimated using the default IPCC methodology (IPCC 2000). The total population for each year was multiplied by a per capita wastewater BOD production rate to determine total wastewater BOD produced. It was assumed that, per capita, 0.065 kilograms of wastewater BOD⁵ is produced per day and that 15 percent of wastewater BOD⁵ is anaerobically digested. This proportion of BOD was then multiplied by an emission factor of 0.6 kg CH₄/kg BOD⁵.

Table 7-18: CH₄ Emissions from Domestic and Industrial Wastewater Treatment (Tg CO₂ Eq.)

Activity	1990		1995	1996	1997	1998	1999
Domestic	11.2		11.8	11.9	12.0	12.1	12.2
Industrial*	0.2		0.2	0.2	0.2	0.2	0.2
Total	11.2		11.8	11.9	12.0	12.1	12.2

* Industrial activity only includes the pulp and paper industry.
Note: Emissions from industrial wastewater treatment are not included in totals.

Table 7-19: CH₄ Emissions from Domestic and Industrial Wastewater Treatment (Gg)

Activity	1990		1995	1996	1997	1998	1999
Domestic	533		561	567	572	577	583
Industrial*	7		8	8	8	8	8
Total	533		561	567	572	577	583

* Industrial activity only includes the pulp and paper industry.
Note: Emissions from industrial wastewater treatment are not included in totals.

⁵ The 5-day biochemical oxygen demand (BOD) measurement (Metcalf and Eddy 1972).

A top-down approach was used to develop estimates of methane emissions from industrial wastewater according to the methodology described in the IPCC *Good Practice Guidance* (IPCC 2000). Information on industrial wastewater sources contained in the IPCC *Good Practice Guidance* was used to help identify industries that were likely to have significant methane emissions from industrial wastewater. Industries were chosen that typically had both a high volume of wastewater generated and a high BOD or COD wastewater load. Five industries that met these criteria were:

- Pulp and paper manufacturing
- Food and beverage production
- Textile (natural) manufacturing
- Petroleum refineries
- Organic chemical manufacturing

Estimates of methane from petroleum refining wastewater processes are included elsewhere in this document under the category for petroleum systems. Regarding the other listed industries, national data on total BOD loadings were available only for the pulp and paper industry. Future efforts will attempt to include the other identified industries.

There are approximately 565 pulp and paper manufacturing facilities in the United States (EPA 1997a). Of these, 316 facilities operate wastewater treatment systems that discharge directly to receiving streams. These facilities do not discharge to a Publicly Owned Treatment Works (POTW). Wastewater discharges to POTWs are captured under domestic wastewater treatment. About 25 percent of the direct discharging pulp and paper facilities use fully-aerated activated sludge treatment, about 50 percent use aerated and non-aerated stabilization basins, while the remainder use other types of treatment. Industry experts (NCASI 2000) estimate that approximately 1 percent of direct discharging pulp and paper facilities operate anaerobic treatment systems from which methane (biogas) may be emitted.

Methane emissions for industrial wastewater treatment in the pulp and paper industry were calculated by multiplying an emission factor by one percent of the national BOD removal from the wastewater treatment pro-

cess at direct discharging pulp and paper mills. National BOD removal from industrial wastewater treatment by the pulp and paper industry was calculated using reported national values for raw wastewater load BOD from direct discharging mills and wastewater effluent load BOD from direct discharging mills (EPA 1993). The effluent load was subtracted from the raw wastewater load to estimate national BOD removal. The national BOD removal value was then multiplied by the emission factor of 0.6 kg CH₄/kg BOD to estimate national methane emissions for 1990. Emissions for the years 1991 through 1999 were then calculated by projecting the 1990 national BOD removal value using 1991 through 1999 annual production values for the pulp and paper industry.

Data Sources

National population data for 1990 to 1999 were supplied by the U.S. Census Bureau (2000). The emission factor (0.6 kg CH₄/kg BOD₅) employed for both domestic and industrial wastewater treatment was taken from IPCC (2000). Per-capita production of BOD₅ for domestic wastewater was obtained from the EPA (1997b).

Table 7-20 provides U.S. population and wastewater BOD data.

A time series of methane emissions for post-1990 years was developed based on production figures reported in the Lockwood-Post Directory (Lockwood-Post Directory 1992-1999). The relative proportion of the post-1990 year's production to the 1990 base year production was used to adjust the 1990 BOD removal value to the other years in the time series.

Table 7-20: U.S. Population (Millions) and Wastewater BOD Produced (Gg)

Year	Population	BOD ₅
1990	249.4	5,920
1991	252.0	5,984
1992	254.9	6,052
1993	257.7	6,118
1994	260.2	6,179
1995	262.7	6,238
1996	265.2	6,296
1997	267.7	6,356
1998	270.2	6,415
1999	272.6	6,473

Table 7-21 provides U.S. pulp and paper production and wastewater BOD data.

Table 7-21: U.S. Pulp and Paper Production (Million Metric Tons) and Wastewater BOD Removed (Gg)

Year	Population	BOD5
1990	128.9	1,200
1991	129.2	1,203
1992	134.5	1,253
1993	134.1	1,249
1994	139.3	1,297
1995	140.9	1,312
1996	140.3	1,306
1997	145.6	1,356
1998	145.2	1,352
1999	146.2	1,361

Uncertainty

Domestic wastewater emissions estimates are highly uncertain due to the lack of data on the occurrence of anaerobic conditions in treatment systems, especially incidental occurrences.

The estimated methane emissions from wastewater treatment processes in the pulp and paper industry are based on an estimated proportion of the national BOD removal that occurs at facilities operating anaerobic processes. Identifying these facilities and the actual BOD removal that is accomplished in their treatment systems would result in a more accurate estimate of methane emissions from the industry.

Human Sewage

Sewage, after treatment in a septic system or wastewater treatment facility, is disposed on land or discharged into aquatic environments such as rivers and estuaries. Nitrous oxide (N₂O) may be generated during treatment and disposal through nitrification and denitrification of the nitrogen that is present in sewage.⁹ Nitrification oc-

curs aerobically and converts ammonium (NH₄⁺) into nitrate (NO₃⁻), while denitrification occurs anaerobically, and converts nitrate into dinitrogen gas (N₂). Nitrous oxide can be an intermediate product of both processes. In general, temperature, pH, biochemical oxygen demand (BOD), and nitrogen concentration affect N₂O generation from human sewage. The amount of protein consumed by humans determines the quantity of nitrogen contained in sewage.

Nitrous oxide emissions from human sewage were estimated using the IPCC default methodology (IPCC/UNEP/OECD/IEA 1997) with one exception. The IPCC methodology assumes that N₂O emissions associated with land disposal and sewage treatment are negligible and all sewage nitrogen is discharged directly into aquatic environments. In the United States, however, a certain amount of sewage nitrogen is applied to soils via sewage sludge applications, and therefore, not all sewage nitrogen enters aquatic environments.¹⁰ The N₂O estimates presented here account for the amount of nitrogen in sewage sludge applied to soils.

Emissions of N₂O from sewage nitrogen discharged into aquatic environments were estimated to be 8.2 Tg CO₂ Eq. (26 Gg) in 1999. An increase in the U.S. population and the per capita protein intake resulted in an overall increase of 15 percent in N₂O emissions from human sewage between 1990 and 1999 (see Table 7-22).

Table 7-22: N₂O Emissions from Human Sewage

Year	Tg CO ₂ Eq.	Gg
1990	7.1	23
1995	8.2	27
1996	7.8	25
1997	7.9	26
1998	8.1	26
1999	8.2	26

⁹ This section focuses on N₂O emissions from human sewage. Methane emissions due to the treatment of human sewage in wastewater treatment facilities are addressed in the previous section of this chapter, *Wastewater Treatment*.

¹⁰ The IPCC methodology is based on the total amount of nitrogen in sewage, which is in turn based on human protein consumption and the fraction of nitrogen in protein (i.e., Frac_{NPR}). A portion of the total nitrogen in sewage in the United States is applied to soils in the form of sewage sludge each year. This amount is estimated as part of agricultural soil management (see Chapter 6) and is subtracted here from total nitrogen in human sewage to estimate sewage N₂O emissions.

Methodology

With the exception described above, N₂O emissions from human sewage were estimated using the IPCC default methodology (IPCC/UNEP/OECD/IEA 1997). This methodology is illustrated below:

$$N_2O(s) = \{[(Protein) \times (Frac_{NPR}) \times (U.S. Population)] - N_{Soil}\} \times (EF) \times (44/28)$$

where,

N₂O(s) = N₂O emissions from human sewage

Protein = Annual, per capita protein consumption

Frac_{NPR} = Fraction of nitrogen in protein

N_{Soil} = Quantity of sewage sludge N applied to soils

EF = Emission factor (kg N₂O-N/kg sewage-N produced)

(44/28) = The molecular weight ratio of N₂O to N₂

Data Sources

U.S. population data were taken from the U.S. Census Bureau (2000). Data on annual per capita protein consumption were provided by the United Nations Food and Agriculture Organization (FAO 2000) (see Table 7-23). Because data on protein intake were unavailable for 1999, the value of per capita protein consumption for the previous year was used. An emission factor has not been specifically estimated for the United States, so the default IPCC value (0.01 kg N₂O-N/kg sewage-N produced) was applied. Similarly, the fraction of nitrogen in protein (0.16 kg N/kg protein) was also obtained from IPCC/UNEP/OECD/IEA (1997).

Uncertainty

The U.S. population (NR people), per capita protein intake data (Protein), and fraction of nitrogen in protein (Frac_{NPR}) are believed to be fairly accurate. Significant uncertainty exists, however, in the emission factor (EF). This uncertainty is due to regional differences that would likely affect N₂O emissions but are not accounted for in the default IPCC factor. Moreover, the underlying

Table 7-23: U.S. Population (Millions) and Average Protein Intake (kg/Person/Year)

Year	Population	Protein
1990	249.4	39.1
1991	252.0	39.7
1992	254.9	39.9
1993	257.7	40.3
1994	260.2	41.4
1995	262.7	43.4
1996	265.2	41.0
1997	267.7	41.4
1998	270.2	42.0
1999	272.6	42.0

methodological assumption that negligible N₂O emissions result from sewage treatment may be incorrect. Taken together, these uncertainties present significant difficulties in estimating N₂O emissions from human sewage.

Waste Sources of Criteria Pollutants

In addition to the main greenhouse gases addressed above, waste generating and handling processes are also sources of criteria air pollutant emissions. Total emissions of nitrogen oxides (NO_x), carbon monoxide (CO), and nonmethane volatile organic compounds (NMVOCs) from waste sources for the years 1990 through 1999 are provided in Table 7-24.

Methodology and Data Sources

These emission estimates were taken directly from the EPA's *National Air Pollutant Emissions Trends, 1900-1999* (EPA 2000). This EPA report provides emission estimates of these gases 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.

Table 7-24: Emissions of NO_x, CO, and NMVOC from Waste (Gg)

Gas/Source	1990	1995	1996	1997	1998	1999
NO_x	83	89	92	92	93	83
Landfills	+	1	2	2	2	2
Wastewater Treatment	+	+	+	+	+	+
Waste Combustion ^a	82	88	89	89	91	80
Miscellaneous ^b	+	1	1	1	1	1
CO	979	1,075	1,012	1,024	1,035	3,439
Landfills	1	2	5	5	5	5
Wastewater Treatment	+	+	+	+	+	+
Waste Combustion ^a	978	1,073	1,006	1,019	1,030	3,434
Miscellaneous ^b	+	1	+	+	+	+
NMVOCs	895	968	378	382	388	532
Landfills	58	68	32	32	33	33
Wastewater Treatment	57	61	61	62	63	64
Waste Combustion ^a	222	237	222	225	228	369
Miscellaneous ^b	558	602	64	64	65	65

^a Includes waste incineration and open burning (EPA 2000)

^b 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

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 data bases.

Uncertainty

Uncertainties in these estimates are primarily due to the accuracy of the emission factors used and accurate estimates of activity data.

