4. Nitrous Oxide Emissions

Overview

U.S. Anthropogenic Nitrous Oxide Emissions, 1990-2003

	Nitrous Oxide	Carbon Dioxide Equivalent
Estimated 2003 Emissions (Thousand Metric Tons)	1,082	320,181
Change Compared to 2002 (Thousand Metric Tons)	-10	-2,999
Change from 2002 *(Percent)*	*-0.9%*	*-0.9%*
Change Compared to 1990 (Thousand Metric Tons)	-29	-8,486
Change from 1990 *(Percent)*	*-2.6%*	*-2.6%*

Estimated U.S. anthropogenic nitrous oxide emissions totaled 1,082 thousand metric tons in 2003, 0.9 percent less than in 2002 and 2.6 percent below 1990 levels (Table 24). Almost all of the decrease from 2002 can be attributed to reduced emissions from industrial sources and nitrogen fertilization of agricultural soils. Emissions from industrial sources decreased by 6 thousand metric tons of nitrous oxide compared with 2002 levels, and emissions from nitrogen fertilization of agricultural soils decreased by 5 thousand metric tons of nitrous oxide.

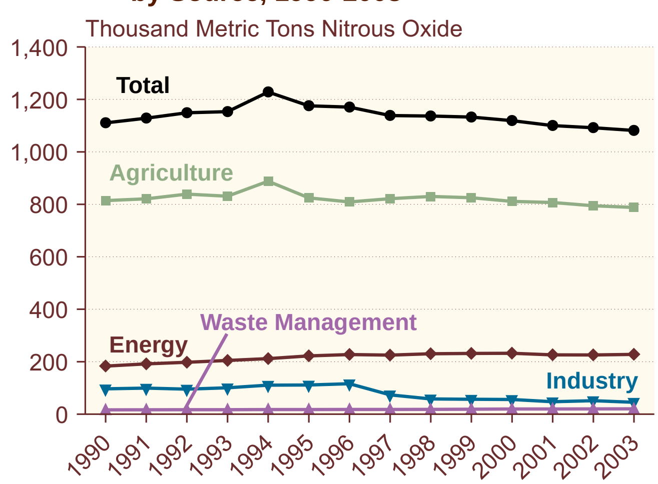
The 2003 decline in nitrous oxide emissions continues a downward trend that began in 1995 after emissions of nitrous oxide peaked at 1,228 thousand metric tons in 1994. The decrease in emissions of nitrous oxide from 1990 can also be attributed primarily to declines in the emissions from industrial sources (adipic acid and nitric acid production) and nitrogen fertilization of agricultural soils, which fell by a combined 73 thousand metric tons between 1990 and 2003, more than offsetting the increase of 39 thousand metric tons in emissions from mobile combustion sources since 1990.

Weighted by global warming potential, total nitrous oxide emissions in 2003 were equivalent to 320.2 million metric tons carbon dioxide, or 4.6 percent of total U.S. greenhouse gas emissions. In 2002, total nitrous oxide emissions were equivalent to 323.2 million metric tons of carbon dioxide, or 4.7 percent of total U.S. greenhouse gas emissions.

Sources of U.S. nitrous oxide emissions include energy use, agriculture, waste management, and industrial processes. The largest component of U.S. anthropogenic nitrous oxide emissions is emissions from agricultural activities, representing 72.9 percent of the total. Nitrogen fertilization of agricultural soils represents 73.8 percent of emissions from agricultural activities. Most of the remainder is from the handling of animal waste in managed systems. Small quantities of nitrous oxide are also released from the burning of crop residues. Estimated emissions of nitrous oxide from agricultural sources were 788 thousand metric tons (or 233.3 million metric tons carbon dioxide equivalent) in 2003, 0.8 percent below 2002 levels and 3.2 percent below 1990 levels (Figure 3).

The second-largest source of anthropogenic nitrous oxide emissions is energy consumption, which includes mobile source combustion from passenger cars, buses, motorcycles and trucks, and stationary source combustion from commercial, residential, industrial, and electric power sector energy use. Energy use was responsible for the release of 228 thousand metric tons of nitrous oxide or 67.5 million metric tons carbon dioxide equivalent in 2003 (21.1 percent of total U.S. nitrous oxide emissions). Although the 2003 level of emissions from energy sources is 1.0 percent lower than in 2002, it is 24.4 percent higher than in 1990.

Figure 3. U.S. Emissions of Nitrous Oxide by Source, 1990-2003



Source: Estimates presented in this chapter.

Sources of U.S. Anthropogenic Nitrous Oxide Emissions, 1990-2003

Source	Thousand Metric Tons Nitrous Oxide 1990	2003	*Percent Change* 1990-2003	2002-2003
Energy	183	228	*24.4%*	*1.0%*
Agriculture	814	788	*-3.2%*	*-0.8%*
Industrial	96	45	*-53.0%*	*-11.8%*
Waste Management	16	20	*23.7%*	*0.9%*

Industrial production of adipic and nitric acid, which releases nitrous oxide as a byproduct, accounted for emissions of 45 thousand metric tons of nitrous oxide or 13.4 million metric tons carbon dioxide equivalent in 2003 (4.2 percent of total U.S. nitrous oxide emissions), an 11.8-percent decrease from 2002 levels and a 53-percent decrease from 1990 levels. The decrease in emissions from this source in 2003 is primarily the result of a 7.9-percent reduction (608 thousand metric tons) in nitric acid production compared with 2002. The large decline in emissions of nitrous oxide from adipic acid production since 1990 is a result of the continuing utilization of emissions control technology at three of the four adipic acid plants operating in the United States.

Energy Use

U.S. Nitrous Oxide Emissions from Energy, 1990-2003

Estimated 2003 Emissions (Thousand Metric Tons Nitrous Oxide)	228
Change Compared to 2002 (Thousand Metric Tons Nitrous Oxide)	2
Change from 2002 *(Percent)*	*1.0%*
Change Compared to 1990 (Thousand Metric Tons Nitrous Oxide)	45
Change from 1990 *(Percent)*	*24.4%*

The energy use category includes nitrous oxide emissions from both mobile and stationary sources as byproducts of fuel combustion. Estimated 2003 energy-related emissions were 228 thousand metric tons, or 21.1 percent of total U.S. anthropogenic nitrous oxide emissions (Table 24). Emissions from energy use are dominated by mobile combustion (78.1 percent of nitrous oxide emissions from energy use in 2003).

Mobile Combustion

Nitrous oxide emissions from mobile source combustion in 2003 were 178 thousand metric tons or 52.7 million metric tons carbon dioxide equivalent, an increase of 1 thousand metric tons nitrous oxide or 0.4 million metric tons carbon dioxide equivalent (0.7 percent) from 2002 levels (Table 25). In addition to emissions from passenger cars and light-duty trucks, emissions from air, rail, and marine transportation and from farm and construction equipment are also included in the estimates. Motor vehicles, however, are the predominant source, accounting for 93.1 percent of nitrous oxide emissions from mobile combustion (Table 25).

Nitrous oxide emissions from motor vehicles are caused primarily by the conversion of nitrogen oxides (NO_x) into nitrous oxide (N_2O) by vehicle catalytic converters. The normal operating temperature of catalytic converters is high enough to cause the thermal decomposition of nitrous oxide. Consequently, it is probable that nitrous oxide emissions result primarily from "cold starts" of motor vehicles and from catalytic converters that are defective or operating under abnormal conditions. This implies that the primary determinant of the level of emissions is motor vehicle operating conditions; however, different types of catalytic converters appear to differ systematically in their emissions, and emissions probably vary with engine size. Thus, emissions also depend on the "mix" of vehicle age and type on the road.

Nitrous oxide emissions from mobile sources grew rapidly between 1990 and 1996 due to increasing motor vehicle use, the shifting composition of the light-duty vehicle fleet toward light trucks that have lower fuel economy and higher per-mile emission factors, and the gradual replacement of low emitting pre-1983 vehicles that did not use catalytic converters with higher emitting post-1983 vehicles that do use catalytic converters. This growth moderated between 1996 and 1999 due to the introduction of more advanced, lower-emitting catalytic converters. After peaking in 1999, emissions have declined slowly as vehicle turnover has led to a fleet dominated by the more advanced catalytic converters.

Stationary Combustion

In 2003, estimated nitrous oxide emissions from stationary combustion sources were 50 thousand metric tons or 14.8 million metric tons carbon dioxide equivalent, 1.9 percent higher than in 2002 and 12.2 percent higher than in 1990 (Table 26). The emissions increase from this source between 1990 and 2003 can be attributed principally to coal-fired electricity generation, which expanded by 26.1 percent during the period. This expansion, in response to the growing demand for electricity and lower costs associated with coal-fired generation, was achieved primarily through higher capacity utilization rates at existing facilities. Coal-fired combustion systems produced 64.0 percent (32 thousand metric tons) of the 2003 emissions of nitrous oxide from stationary combustion. Other fuels—including fuel oil (8 thousand metric tons), wood (8 thousand metric tons), and natural gas (2 thousand metric tons)—accounted for the balance. During combustion, nitrous oxide is produced as a result of chemical interactions between nitrogen oxides (mostly NO_2) and other combustion products. With most conventional stationary combustion systems, high temperatures destroy almost all nitrous oxide, limiting the quantity that escapes; therefore, emissions from these systems typically are low.

Agriculture

U.S. Nitrous Oxide Emissions from Agriculture, 1990-2003

Estimated 2003 Emissions (Thousand Metric Tons Nitrous Oxide)	788
Change Compared to 2002 (Thousand Metric Tons Nitrous Oxide)	-6
Change from 2002 *(Percent)*	*-0.8%*
Change Compared to 1990 (Thousand Metric Tons Nitrous Oxide)	-26
Change from 1990 *(Percent)*	*-3.2%*

Nitrous oxide emissions from agricultural activities fell by 6 thousand metric tons (0.8 percent) in 2003 compared with 2002 (788 and 795 thousand metric tons, respectively). Since 1990, nitrous oxide emissions from agricultural activities have fallen by 3.2 percent. Agricultural activities were responsible for 72.9 percent of U.S. nitrous oxide emissions in 2003, roughly the same percentage that agricultural practices contribute to nitrous oxide emissions globally.[70] At 233.3 million metric tons carbon dioxide equivalent, nitrous oxide emissions from agricultural activities represent 3.4 percent of total U.S. greenhouse gas emissions.

Nitrogen fertilization of agricultural soils accounted for 73.8 percent of U.S. agricultural emissions of nitrous oxide in 2003 (Table 24). Nearly all the remaining agricultural emissions can be traced to the management of the solid waste of domesticated animals. The disposal of crop residues by burning also produces nitrous oxide that is released into the atmosphere; however, the amount is relatively minor, at 2 thousand metric tons or 0.2 percent of total U.S. emissions of nitrous oxide from agricultural sources in 2003.

Nitrogen Fertilization of Agricultural Soils

EIA estimates that a total of 581 thousand metric tons of nitrous oxide (or 172.1 million metric tons carbon dioxide equivalent) was released into the atmosphere as a result of direct and indirect emissions associated with fertilization practices in 2003 (Table 27). Estimated emissions decreased by 0.8 percent compared with 2002 levels and were 3.7 percent lower than in 1990.

Nitrogen uptake and nitrous oxide emissions occur naturally as a result of nitrification and denitrification processes in soil and crops, generally through bacterial action. When nitrogen compounds are added to the soil, bacterial action is stimulated, and emissions generally increase, unless the application precisely matches plant uptake and soil capture.[71] Nitrogen may be added to the soil by synthetic or organic fertilizers, nitrogen-fixing crops, and crop residues. Nitrogen-rich soils, called "histosols," may also stimulate emissions. Direct emissions in 2003 (456 thousand metric tons) represented 78.3 percent of total emissions from nitrogen fertilization, with the primary components including the biological fixation of nitrogen in crops (176 thousand metric tons), nitrogen fertilizers (155 thousand metric tons), and crop residues (109 thousand metric tons).

Indirect emissions from nitrogen fertilization result from adding excess nitrogen to the soil, which in turn enriches ground and surface waters such as rivers and streams, and results in emissions of nitrous oxide. This source is referred to as "soil leaching." Additional indirect emissions occur from "atmospheric deposition," in which soils emit other nitrogen compounds that react to form nitrous oxide in the atmosphere. Indirect emissions in 2003 (126 thousand metric tons) represented 21.7 percent of total emissions from nitrogen fertilization, with soil leaching accounting for 107 thousand metric tons and atmospheric deposition totaling 19 thousand metric tons.

There are significant uncertainties associated with estimating the amount of emissions produced by adding nitrogen to agricultural soils. Models used to estimate the amount are based on limited sources of experimental data.[72] The uncertainty increases when moving from emissions associated with animal manure to soil

[70] A.R. Mosier, "Nitrous Oxide Emissions from Agricultural Soils," in A.R. van Amstel (ed.), *International IPCC Workshop Proceedings: Methane and Nitrous Oxide, Methods in National Emissions Inventories and Options for Control* (Bilthoven, Netherlands: RIVM, 1993), p. 277.

[71] A.F. Bouwman, "Exchange of Greenhouse Gases Between Terrestrial Ecosystems and the Atmosphere," in A.F. Bouwman (ed.), *Soils and the Greenhouse Effect* (New York, NY: John Wiley and Sons, 1990).

[72] Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.87-4.100, web site www.ipcc.ch/pub/guide.htm.

mineralization and atmospheric deposition, where both estimating the amount of emissions and segmenting anthropogenic from biogenic sources become increasingly difficult.

Solid Waste of Domesticated Animals

Estimated 2003 nitrous oxide emissions from animal waste management were 205 thousand metric tons (or 60.7 million metric tons carbon dioxide equivalent), down by 0.8 percent from 2002 levels and 2.0 percent lower than 1990 levels (Table 28), making animal waste the second-largest U.S. agricultural source of nitrous oxide emissions, after nitrogen fertilization of soils. Nitrous oxide emissions from animal waste are dominated by emissions from cattle waste, which in 2003 accounted for 92.7 percent of emissions from the solid waste of domesticated animals.

Nitrous oxide is released as part of the microbial denitrification of animal manure. The total volume of nitrous oxide emissions is a function of animal size and manure production, the amount of nitrogen in the animal waste, and the method of managing the animal waste. Waste managed by a solid storage or pasture range method may emit 20 times more nitrous oxide per unit of nitrogen content than does waste managed in anaerobic lagoon and liquid systems. Generally, solid waste from feedlot beef cattle is managed with the solid storage or pasture range method, accounting for the majority of nitrous oxide emissions. Solid waste from swine is generally managed in anaerobic lagoons and other liquid systems. Anaerobic digestion yields methane emissions but only negligible amounts of nitrous oxide. Thus, changes in estimated emissions result primarily from changes in cattle populations. For example, beef cattle populations grew during the first half of the 1990s, leading to higher emissions through 1995, but have since declined slowly, lowering emissions to below 1990 levels.

Crop Residue Burning

In 2003, estimated emissions of nitrous oxide from crop residue burning were 2 thousand metric tons (or 0.5 million metric tons carbon dioxide equivalent), down by less than 0.03 thousand metric tons nitrous oxide (1.6 percent) from 2002 levels (Table 24). The small decrease is mainly attributable to decreased corn and soybean production. Emissions from this source remain very small, at 0.2 percent of all U.S. nitrous oxide emissions. When crop residues are burned, the incomplete combustion of agricultural waste results in the production of nitrous oxide, as well as methane (discussed in Chapter 3).

Waste Management

U.S. Nitrous Oxide Emissions from Waste Management, 1990-2003

Estimated 2003 Emissions (Thousand Metric Tons Nitrous Oxide)	20
Change Compared to 2002 (Thousand Metric Tons Nitrous Oxide)	*
Change from 2002 *(Percent)*	*0.9%*
Change Compared to 1990 (Thousand Metric Tons Nitrous Oxide)	4
Change from 1990 *(Percent)*	*23.7%*

*Less than 0.5 thousand metric tons.

Nitrous oxide emissions from waste management are estimated at 20 thousand metric tons (or 6.0 million metric tons carbon dioxide equivalent) for 2003, 1.9 percent of all U.S. anthropogenic nitrous oxide emissions (Table 24). During 2003, emissions from human sewage in wastewater were responsible for 96.1 percent of the estimated emissions from this source, and the remainder was associated with waste combustion. Estimated emissions from waste management increased by 0.9 percent between 2002 and 2003 and by 23.7 percent between 1990 and 2003. Because of the lack of reliable data and an effective estimation method, no estimate of emissions from industrial wastewater was calculated, leaving estimated emissions from waste management lower than they otherwise would be had a viable estimation method been available.

Human Sewage in Wastewater

In 2003, nitrous oxide emissions from wastewater were 19 thousand metric tons (or 5.8 million metric tons carbon dioxide equivalent), a 0.8-percent increase from 2002 levels and a 24.7-percent increase from the 1990 level (Table 24). Estimates of nitrous oxide emissions from human waste are scaled to population size and per capita protein intake. U.S. population has grown by 16.6 percent since 1990. U.S. per capita protein intake rose steadily between 1990 and 1999, before declining slightly in 2000, 2001, and 2002. Today, U.S. per capita protein intake is 7.0 percent above 1990 levels. Data on protein intake are taken from the United Nations Food and Agriculture Organization (FAO).[73]

Nitrous oxide is emitted from wastewater that contains nitrogen-based organic materials, such as those found in human or animal waste. Two natural processes—

[73]Food and Agriculture Organization of the United Nations, statistical databases, web site http://apps.fao.org.

nitrification and denitrification—combine to produce nitrous oxide. Nitrification, an aerobic process, converts ammonia into nitrate; denitrification, an anaerobic process, converts nitrate to nitrous oxide. Factors that influence the amount of nitrous oxide generated from wastewater include temperature, acidity, biochemical oxygen demand (BOD),[74] and nitrogen concentration.

Waste Combustion

In 2003, estimated nitrous oxide emissions from waste combustion were 1 thousand metric tons, up 3.2 percent from 2002 levels and 2.5 percent above 1990 levels. Data on the amount of waste generated in the United States in 2003 were not available in time for this report; therefore, EIA scaled the 2003 estimates for waste combustion to the growth in U.S. gross domestic product. The share of waste burned is estimated to have been unchanged from 2002 to 2003, and the total volume of waste generated is estimated to have increased by 3.2 percent. The total volume of waste generated in the United States increased by 53.1 percent between 1990 and 2003; however, the share of waste burned in 2003 was just 7.7 percent, compared with 11.5 percent in 1990.[75]

Industrial Sources

U.S. Nitrous Oxide Emissions from Industrial Sources, 1990-2003

Estimated 2003 Emissions (Thousand Metric Tons Nitrous Oxide)	45
Change Compared to 2002 (Thousand Metric Tons Nitrous Oxide)	-6
Change from 2002 *(Percent)*	*-11.8%*
Change Compared to 1990 (Thousand Metric Tons Nitrous Oxide)	-51
Change from 1990 *(Percent)*	*-53.0%*

Emissions of nitrous oxide from industrial sources were 45 thousand metric tons (or 13.4 million metric tons carbon dioxide equivalent) in 2003, a decrease of 6 thousand metric tons or 1.8 million metric tons carbon dioxide equivalent (11.8 percent) from 2002 and a decrease of 51 thousand metric tons or 15.1 million metric tons carbon dioxide equivalent (53.0 percent) since 1990. Nitrous oxide is emitted as a byproduct of certain chemical production processes. Table 29 provides estimates of emissions from the production of adipic acid and nitric acid, the two principal known sources.

Adipic Acid Production

Emissions from adipic acid production fell from 13 thousand metric tons of nitrous oxide (or 3.9 million metric tons carbon dioxide equivalent) in 2002 to 10 thousand metric tons (or 3.0 million metric tons carbon dioxide equivalent) in 2003—a decrease of 22.9 percent. As discussed below, emissions from this source have been in the range of 12 to 13 thousand metric tons of nitrous oxide per year since 1998.

Adipic acid is a fine white powder that is used primarily in the manufacture of nylon fibers and plastics, such as carpet yarn, clothing, and tire cord. Other uses of adipic acid include production of plasticizer for polyvinyl chloride and polyurethane resins, lubricants, insecticides, and dyes. In the United States, three companies, which operate a total of four plants, manufacture adipic acid by oxidizing a ketone-alcohol mixture with nitric acid. Nitrous oxide is an intrinsic byproduct of this chemical reaction. For every metric ton of adipic acid produced, 0.3 metric ton of nitrous oxide is created.[76] Between 1990 and 1996, emissions from adipic acid manufacture grew by 23.2 percent, reaching 70 thousand metric tons of nitrous oxide (or 20.7 million metric tons carbon dioxide equivalent) before dropping sharply to 27 thousand metric tons of nitrous oxide (or 7.8 million metric tons carbon dioxide equivalent) in 1997 (Table 29).

Beginning in 1996, two of the four plants that manufacture adipic acid controlled emissions by thermally decomposing the nitrous oxide. This technique eliminates 98 percent of potential nitrous oxide emissions from the process.[77] During the first quarter of 1997, a third plant installed emissions controls, increasing the share of adipic acid production employing emissions abatement controls from 74.1 percent in 1996 to 91.6 percent in 1997. In 1998, with emissions controls in place for the full year, 97.4 percent of emissions from U.S. adipic acid production were controlled.[78] Estimated emissions of nitrous oxide from uncontrolled adipic acid production decreased from 22 thousand metric tons in 1997 to 5 thousand metric tons in 2003, and 2003 emissions of nitrous oxide from controlled plants remained relatively

[74]Biochemical oxygen demand is a measure of the organic content within the wastewater that is subject to decomposition.
[75]"Nationwide Survey: The State of Garbage in America," *Biocycle* (January 2004), p. 31. Waste streams were estimated for 2003 by scaling to economic growth, and the share of waste combusted was held constant at the 2002 level.
[76]M.H. Thiemens and W.C. Trogler, "Nylon Production: An Unknown Source of Atmospheric Nitrous Oxide," *Science*, Vol. 251, No. 4996 (February 1991).
[77]Radian Corporation, *Nitrous Oxide Emissions From Adipic Acid Manufacturing* (Rochester, NY, January 1992), p. 10.
[78]R.A. Reimer, R.A. Parrett, and C.S. Slaten, "Abatement of N_2O Emissions Produced in Adipic Acid," in *Proceedings of the Fifth International Workshop on Nitrous Oxide Emissions* (Tsukuba, Japan, July 1992).

constant at 5 thousand metric tons. With the share of adipic acid production employing abatement controls now at nearly 100 percent, future changes in nitrous oxide emissions from this source are expected to result primarily from changes in plant production levels in response to market demand.

Nitric Acid Production

The 6.4 million metric tons of nitric acid manufactured in 2003[79] resulted in estimated emissions of 35 thousand metric tons of nitrous oxide, equivalent to 10.4 million metric tons of carbon dioxide (Table 29). This estimate was 7.9 percent lower than 2002 levels and 11.2 percent lower than 1990 levels. The emissions factor used to estimate nitrous oxide emissions from the production of nitric acid was based on measurements at a single DuPont plant, which indicated an emissions factor of 2 to 9 grams of nitrous oxide emitted per kilogram of nitric acid manufactured, suggesting a significant range of uncertainty. Nitric acid, a primary ingredient in fertilizers, usually is manufactured by oxidizing ammonia (NH_3) with a platinum catalyst. Nitrous oxide emissions are a direct result of the oxidation.

[79]U.S. Department of Commerce, Bureau of Census, *Current Industrial Reports: Fertilizer Materials and Related Products, Fourth Quarter 2003*, MQ325B(03)-4 (Washington, DC, March 2004), Table 1.

Table 24. Estimated U.S. Emissions of Nitrous Oxide, 1990 and 1995-2003

Source	1990	1995	1996	1997	1998	1999	2000	2001	2002	P2003
Thousand Metric Tons Nitrous Oxide										
Energy										
Mobile Combustion	139	175	179	176	182	182	182	177	177	178
Stationary Combustion	45	47	49	49	48	49	50	49	49	50
Total	**183**	**222**	**227**	**225**	**230**	**231**	**232**	**226**	**226**	**228**
Agriculture										
Nitrogen Fertilization of Soils	604	601	587	604	616	613	601	598	586	581
Crop Residue Burning	2	2	2	2	2	2	2	2	2	2
Solid Waste of Domesticated Animals	209	222	220	216	212	211	209	208	207	205
Total	**814**	**825**	**809**	**822**	**830**	**825**	**811**	**807**	**795**	**788**
Waste Management										
Waste Combustion	1	1	1	1	1	1	1	1	1	1
Human Sewage in Wastewater	16	17	17	17	18	18	19	19	19	19
Total	**16**	**18**	**18**	**18**	**18**	**19**	**20**	**20**	**20**	**20**
Industrial Processes	**96**	**111**	**116**	**74**	**58**	**57**	**56**	**47**	**51**	**45**
Total	**1,110**	**1,175**	**1,170**	**1,138**	**1,137**	**1,132**	**1,119**	**1,100**	**1,092**	**1,082**
Million Metric Tons Carbon Dioxide Equivalent										
Energy										
Mobile Combustion	41.1	51.9	52.9	52.1	53.8	54.0	53.8	52.5	52.3	52.7
Stationary Combustion	13.2	13.8	14.4	14.5	14.3	14.5	14.9	14.4	14.6	14.8
Total	**54.2**	**65.7**	**67.3**	**66.6**	**68.2**	**68.5**	**68.7**	**66.9**	**66.8**	**67.5**
Agriculture										
Nitrogen Fertilization of Soils	178.6	178.0	173.9	178.9	182.2	181.4	177.7	176.9	173.5	172.1
Crop Residue Burning	0.5	0.5	0.5	0.5	0.6	0.5	0.6	0.6	0.5	0.5
Solid Waste of Domesticated Animals	61.9	65.6	65.1	63.8	62.9	62.4	61.8	61.4	61.2	60.7
Total	**241.0**	**244.1**	**239.5**	**243.2**	**245.7**	**244.3**	**240.1**	**238.9**	**235.2**	**233.3**
Waste Management										
Waste Combustion	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Human Sewage in Wastewater	4.6	5.0	5.1	5.1	5.2	5.4	5.6	5.6	5.7	5.8
Total	**4.8**	**5.3**	**5.4**	**5.4**	**5.4**	**5.6**	**5.8**	**5.9**	**5.9**	**6.0**
Industrial Processes	**28.6**	**32.9**	**34.3**	**21.8**	**17.2**	**16.8**	**16.6**	**14.0**	**15.2**	**13.4**
Total	**328.7**	**347.9**	**346.5**	**337.0**	**336.4**	**335.2**	**331.2**	**325.6**	**323.2**	**320.2**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2002*, DOE/EIA-0573(2002) (Washington, DC, October 2003). Totals may not equal sum of components due to independent rounding.

Sources: Estimates presented in this chapter. Emissions calculations based on Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.81-4.94, web site www.ipcc.ch/pub/guide.htm; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenter PublicationsGHGEmissionsUSEmissionsInventory2004.html.

Table 25. U.S. Nitrous Oxide Emissions from Mobile Combustion, 1990 and 1995-2003

Item	1990	1995	1996	1997	1998	1999	2000	2001	2002	P2003
Thousand Metric Tons Nitrous Oxide										
Motor Vehicles										
Passenger Cars	85	100	100	98	102	102	100	97	96	96
Buses	*	*	*	*	*	*	*	*	*	*
Motorcycles	*	*	*	*	*	*	*	*	*	*
Light-Duty Trucks	35	56	58	58	59	60	59	59	60	61
Other Trucks	6	7	7	8	8	8	8	8	8	8
Total	**127**	**163**	**166**	**164**	**170**	**170**	**168**	**165**	**164**	**166**
Other Mobile Sources	**12**	**12**	**13**	**12**	**12**	**13**	**13**	**13**	**12**	**12**
Total	**139**	**175**	**179**	**176**	**182**	**182**	**182**	**177**	**177**	**178**
Million Metric Tons Carbon Dioxide Equivalent										
Motor Vehicles										
Passenger Cars	25.2	29.5	29.7	28.9	30.1	30.1	29.7	28.8	28.4	28.4
Buses	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Motorcycles	*	*	*	*	*	*	*	*	*	*
Light-Duty Trucks	10.4	16.5	17.1	17.2	17.6	17.6	17.6	17.4	17.8	18.2
Other Trucks	1.7	2.1	2.2	2.3	2.3	2.4	2.4	2.5	2.3	2.3
Total	**37.4**	**48.2**	**49.1**	**48.5**	**50.2**	**50.3**	**49.9**	**48.8**	**48.6**	**49.0**
Other Mobile Sources	**3.6**	**3.6**	**3.7**	**3.6**	**3.6**	**3.7**	**3.9**	**3.7**	**3.7**	**3.7**
Total	**41.1**	**51.9**	**52.9**	**52.1**	**53.8**	**54.0**	**53.8**	**52.5**	**52.3**	**52.7**

*Less than 500 metric tons nitrous oxide or less than 50,000 metric tons carbon dioxide equivalent.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2002*, DOE/EIA-0573(2002) (Washington, DC, October 2003). Totals may not equal sum of components due to independent rounding.

Sources: Calculations based on vehicle miles traveled from U.S. Department of Transportation, *Federal Highway Statistics* (various years), Table VM-1, and current year preliminary estimates calculated using growth rates from EIA, *Short-Term Energy Outlook* (various years). Other Mobile Sources calculations based on Oak Ridge National Laboratory, *Transportation Energy Data Book*; EIA, *Fuel Oil and Kerosene Sales*, *State Energy Data Report*, and *Petroleum Supply Annual* (various years). Passenger car and light-duty truck emissions coefficients from U.S. Environmental Protection Agency, Office of Air and Radiation, *Emissions of Nitrous Oxide From Highway Mobile Sources: Comments on the Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-1996*, EPA-420-R-98-009 (Washington DC, August 1998). Emissions coefficients from Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 1.64-1.68, web site www.ipcc.ch/pub/guide.htm.

Table 26. U.S. Nitrous Oxide Emissions from Stationary Combustion, 1990 and 1995-2003

Source	1990	1995	1996	1997	1998	1999	2000	2001	2002	P2003
	Thousand Metric Tons Nitrous Oxide									
Residential										
Coal	*	*	*	*	*	*	*	*	*	*
Fuel Oil[a]	1	1	1	1	1	1	1	1	1	1
Natural Gas	*	*	1	*	*	*	*	*	*	1
Wood	2	2	2	2	2	2	2	1	1	1
Total	**4**	**4**	**4**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Commercial										
Coal	*	*	*	*	*	*	*	*	*	*
Fuel Oil[a]	1	*	*	*	*	*	*	*	*	*
Natural Gas	*	*	*	*	*	*	*	*	*	*
Wood	*	*	*	*	*	*	*	*	*	*
Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Industrial										
Coal	4	3	3	3	3	3	3	3	3	3
Fuel Oil[a]	5	5	5	6	5	6	6	6	6	6
Natural Gas	1	1	1	1	1	1	1	1	1	1
Wood	6	7	7	7	6	6	6	6	6	6
Total	**10**	**10**	**10**	**10**	**10**	**10**	**9**	**10**	**9**	**9**
Electric Power										
Coal	23	25	26	27	27	27	28	28	28	29
Fuel Oil[a]	1	*	*	1	1	1	1	1	1	1
Natural Gas	*	*	*	*	*	*	1	1	1	*
Wood	1	*	1	1	1	1	1	*	1	1
Total	**24**	**26**	**27**	**28**	**29**	**29**	**30**	**30**	**30**	**31**
Total All Sectors										
Coal	**27**	**28**	**30**	**30**	**30**	**30**	**32**	**31**	**31**	**32**
Fuel Oil[a]	**7**	**7**	**7**	**7**	**7**	**8**	**8**	**8**	**8**	**8**
Natural Gas	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Wood	**9**	**10**	**10**	**9**	**9**	**9**	**9**	**8**	**8**	**8**
Total	**45**	**47**	**49**	**49**	**48**	**49**	**50**	**49**	**49**	**50**

[a]Fuel oil use in the residential sector consists of distillate fuel only. In the other sectors it includes both distillate and residual fuel oil.
*Less than 500 metric tons nitrous oxide.
P = preliminary data. See notes and sources at end of table.

Table 26. U.S. Nitrous Oxide Emissions from Stationary Combustion, 1990 and 1995-2003 (Continued)

Source	1990	1995	1996	1997	1998	1999	2000	2001	2002	P2003
Thousand Metric Tons Carbon Dioxide Equivalent										
Residential										
Coal	11	7	7	7	5	6	5	5	5	5
Fuel Oil[a]	251	247	266	255	235	263	279	275	265	269
Natural Gas	129	142	153	145	133	138	146	140	143	149
Wood	677	694	693	504	451	482	504	431	365	418
Total	**1,067**	**1,090**	**1,119**	**912**	**824**	**889**	**934**	**851**	**777**	**841**
Commercial										
Coal	54	49	51	54	38	43	38	40	38	39
Fuel Oil[a]	170	131	134	126	118	118	134	135	122	124
Natural Gas	77	88	92	94	88	89	93	89	91	92
Wood	45	54	58	57	56	61	62	47	49	49
Total	**346**	**322**	**335**	**330**	**300**	**311**	**326**	**310**	**299**	**304**
Industrial										
Coal	1,131	1,020	995	977	914	893	906	929	873	896
Fuel Oil[a]	1,478	1,538	1,617	1,659	1,628	1,678	1,629	1,652	1,638	1,660
Natural Gas	242	274	283	283	279	268	271	248	254	238
Wood	1,680	1,924	1,961	2,017	1,867	1,887	1,906	1,681	1,784	1,775
Total	**2,851**	**2,832**	**2,895**	**2,920**	**2,820**	**2,839**	**2,802**	**2,830**	**2,764**	**2,794**
Electric Power										
Coal	6,770	7,278	7,680	7,878	8,008	8,034	8,426	8,205	8,342	8,539
Fuel Oil[a]	228	135	146	166	233	216	204	229	216	214
Natural Gas	94	123	110	118	133	140	151	153	164	143
Wood	150	146	161	160	160	161	156	147	175	188
Total	**7,242**	**7,682**	**8,097**	**8,321**	**8,534**	**8,551**	**8,937**	**8,733**	**8,897**	**9,084**
Total All Sectors										
Coal	**7,965**	**8,354**	**8,733**	**8,916**	**8,965**	**8,976**	**9,375**	**9,179**	**9,257**	**9,479**
Fuel Oil[a]	**2,128**	**2,051**	**2,163**	**2,205**	**2,214**	**2,275**	**2,243**	**2,291**	**2,240**	**2,268**
Natural Gas	**541**	**627**	**638**	**640**	**633**	**634**	**660**	**630**	**652**	**622**
Wood	**2,552**	**2,818**	**2,873**	**2,738**	**2,534**	**2,591**	**2,628**	**2,350**	**2,372**	**2,430**
Total	**13,187**	**13,850**	**14,406**	**14,499**	**14,345**	**14,476**	**14,906**	**14,405**	**14,521**	**14,799**

[a]Fuel oil use in the residential sector consists of distillate fuel only. In the other sectors it includes both distillate and residual fuel oil.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2002*, DOE/EIA-0573(2002) (Washington, DC, October 2003). Totals may not equal sum of components due to independent rounding.

Sources: Emissions coefficients from Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), p. 1.50, web site www.ipcc.ch/pub/guide.htm. Energy consumption data from Energy Information Administration, *State Energy Data Report 1998*, DOE/EIA-0214(98) (Washington, DC, September 2003); and *Monthly Energy Review*, DOE/EIA-0035(2003/08) (Washington, DC, August 2003).

Table 27. U.S. Nitrous Oxide Emissions from Nitrogen Fertilization of Agricultural Soils, 1990 and 1995-2003
(Thousand Metric Tons Nitrous Oxide)

Source	1990	1995	1996	1997	1998	1999	2000	2001	2002	P2003
Thousand Metric Tons Nitrous Oxide										
Direct Emissions										
Nitrogen Fertilizers	179	173	159	159	161	161	154	150	154	155
Animal Manure	4	5	4	4	4	4	4	4	4	4
Crop Residues	94	94	106	114	117	113	116	116	111	109
Soil Mineralization	10	10	10	10	10	11	11	11	11	11
Biological Fixation in Crops	171	179	178	187	194	193	191	195	182	176
Sewage Sludge	1	1	1	1	1	1	1	1	2	2
Total Direct Emissions	**459**	**461**	**459**	**475**	**486**	**482**	**476**	**476**	**461**	**456**
Indirect Emissions										
Soil Leaching	123	119	109	110	110	111	106	103	106	107
Atmospheric Deposition	22	21	20	20	20	20	19	18	19	19
Total Indirect Emissions	**144**	**140**	**129**	**129**	**130**	**130**	**125**	**122**	**125**	**126**
Total	**604**	**601**	**587**	**604**	**616**	**613**	**601**	**598**	**586**	**581**
Million Metric Tons Carbon Dioxide Equivalent										
Direct Emissions										
Nitrogen Fertilizers	53.1	51.2	47.1	47.2	47.5	47.7	45.6	44.4	45.6	46.0
Animal Manure	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Crop Residues	27.9	27.8	31.4	33.8	34.5	33.5	34.4	34.4	32.7	32.4
Soil Mineralization	3.0	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
Biological Fixation in Crops	50.7	53.1	52.8	55.2	57.3	57.2	56.4	57.6	53.8	52.0
Sewage Sludge	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.5
Total Direct Emissions	**135.9**	**136.5**	**135.7**	**140.6**	**143.8**	**142.8**	**140.8**	**140.9**	**136.6**	**134.8**
Indirect Emissions										
Soil Leaching	36.3	35.2	32.4	32.4	32.6	32.8	31.3	30.6	31.4	31.6
Atmospheric Deposition	6.5	6.3	5.8	5.8	5.8	5.8	5.6	5.5	5.6	5.6
Total Indirect Emissions	**42.8**	**41.4**	**38.2**	**38.2**	**38.5**	**38.6**	**36.9**	**36.0**	**37.0**	**37.3**
Total	**178.6**	**178.0**	**173.9**	**178.9**	**182.2**	**181.4**	**177.7**	**176.9**	**173.5**	**172.1**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2002*, DOE/EIA-0573(2002) (Washington, DC, October 2003). Totals may not equal sum of components due to independent rounding.

Sources: Estimates presented in this chapter. Emissions coefficients from Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.89-4.107, web site www.ipcc.ch/pub/guide.htm. Total nitrogen content of U.S. commercial fertilizer consumption—1988-1994, Tennessee Valley Authority; 1995-2002, Association of American Plant Food Control Officials, *Commercial Fertilizers* (Washington, DC, various years). Manure application based on cattle population data provided by the U.S. Department of Agriculture, National Agricultural Statistics Service, web sites www.usda.gov/nass/pubs/histdata.htm and www.nass.usda.gov/ipedb/. Typical animal sizes from U.S. Environmental Protection Agency, Office of Air and Radiation, *Anthropogenic Methane Emissions in the United States: Estimates for 1990* (Washington, DC, April 1993), p. 6-8. Manure production and waste management systems used from L.M. Safley, M.E. Casada et al., *Global Methane Emissions From Livestock and Poultry Manure* (Washington, DC, February 1992), and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html.

Table 28. U.S. Nitrous Oxide Emissions from Solid Waste of Domesticated Animals, 1990 and 1995-2003

Source	1990	1995	1996	1997	1998	1999	2000	2001	2002	P2003
Thousand Metric Tons Nitrous Oxide										
Cattle	194	206	205	200	197	195	194	192	192	190
Swine	5	5	5	6	6	6	5	6	6	6
Poultry	3	4	4	4	4	4	4	4	4	4
Sheep	3	3	3	2	2	2	2	2	2	2
Goats	1	1	1	1	1	1	1	1	1	1
Horses	2	2	2	2	2	2	2	2	2	2
Total	**209**	**222**	**220**	**216**	**212**	**211**	**209**	**208**	**207**	**205**
Million Metric Tons Carbon Dioxide Equivalent										
Cattle	57.5	61.1	60.6	59.2	58.3	57.9	57.4	56.9	56.7	56.3
Swine	1.5	1.6	1.5	1.7	1.7	1.6	1.6	1.6	1.6	1.7
Poultry	0.9	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Sheep	1.0	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6
Goats	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Horses	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Total	**61.9**	**65.6**	**65.1**	**63.8**	**62.9**	**62.4**	**61.8**	**61.4**	**61.2**	**60.7**

P = preliminary data.

Note: Totals may not equal sum of components due to independent rounding.

Sources: Estimates presented in this chapter. Nitrogen content of waste by species, manure management systems, and emissions coefficients from Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.89-4.107, web site www.ipcc.ch/pub/guide.htm. Population data for horses and goats extrapolated from U.S. Department of Commerce, Bureau of the Census, *Census of Agriculture* (1982, 1987, 1992, and 1997). All other animal populations from U.S. Department of Agriculture, National Agricultural Statistics Service, web sites www.usda.gov/nass/pubs/histdata.htm and www.nass.usda.gov/ipedb/. Typical animal sizes from U.S. Environmental Protection Agency, Office of Air and Radiation, *Anthropogenic Methane Emissions in the United States: Estimates for 1990* (Washington, DC, April 1993), p. 6-8. Cattle sizes adjusted by annual slaughter weight from U.S. Department of Agriculture, National Agricultural Statistics Service.

Table 29. U.S. Nitrous Oxide Emissions from Industrial Sources, 1990 and 1995-2003

Source	1990	1995	1996	1997	1998	1999	2000	2001	2002	P2003
Thousand Metric Tons Nitrous Oxide										
Adipic Acid										
Controlled Sources	3	4	4	5	5	5	5	5	5	5
Uncontrolled Sources	54	63	66	22	7	7	7	7	8	5
Total	57	67	70	27	12	12	13	12	13	10
Nitric Acid	40	44	46	47	46	45	43	35	38	35
Total Known Industrial Sources	**96**	**111**	**116**	**74**	**58**	**57**	**56**	**47**	**51**	**45**
Million Metric Tons Carbon Dioxide Equivalent										
Adipic Acid										
Controlled Sources	1.0	1.1	1.1	1.4	1.5	1.5	1.6	1.4	1.6	1.6
Uncontrolled Sources	15.9	18.7	19.6	6.4	2.0	2.1	2.1	2.1	2.3	1.4
Total	16.8	19.8	20.7	7.8	3.5	3.6	3.7	3.5	3.9	3.0
Nitric Acid	11.7	13.1	13.6	13.9	13.7	13.2	12.9	10.4	11.3	10.4
Total Known Industrial Sources	**28.6**	**32.9**	**34.3**	**21.8**	**17.2**	**16.8**	**16.6**	**14.0**	**15.2**	**13.4**

P = preliminary data.

Note: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2002*, DOE/EIA-0573(2002) (Washington, DC, October 2003). Totals may not equal sum of components due to independent rounding.

Sources: Data sources and methods documented in Energy Information Administration, *Documentation for Emissions of Greenhouse Gases in the United States 2002*, DOE/EIA-0638(2002) (Washington, DC, January 2004), and *Documentation for Emissions of Greenhouse Gases in the United States 2003*, DOE/EIA-0638(2003) (to be published).