4. Nitrous Oxide Emissions

Overview

U.S. Anthropogenic Nitrous Oxide Emissions, 1990-2001

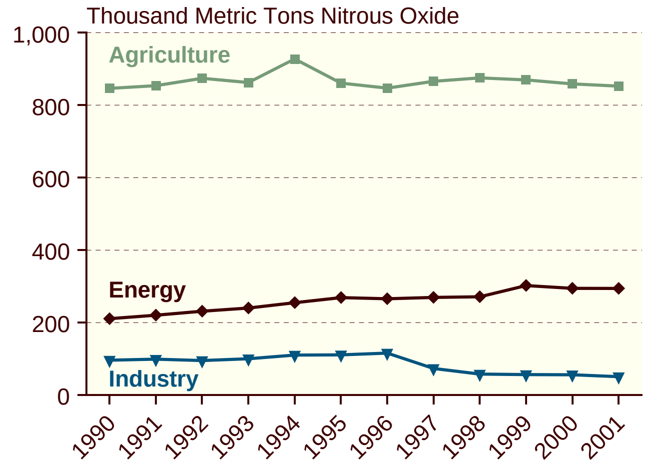
	Nitrous Oxide	Carbon Equivalent
Estimated 2001 Emissions (Thousand Metric Tons)	1,207	97,462
Change Compared to 2000 (Thousand Metric Tons)	-12	-954
Change from 2000 *(Percent)*	*-1.0%*	*-1.0%*
Change Compared to 1990 (Thousand Metric Tons)	37	3,004
Change from 1990 *(Percent)*	*3.2%*	*3.2%*

Estimated U.S. anthropogenic nitrous oxide emissions totaled 1,207 thousand metric tons in 2001, 1.0 percent less than in 2000 but still 3.2 percent above 1990 levels (Table 23). Nearly all of the increase from 1990 can be attributed to emissions from mobile combustion, which grew by 69 thousand metric tons between 1990 and 2001, more than offsetting the 45 thousand metric ton decrease in emissions from industrial sources (adipic acid and nitric acid production) since 1990. Weighted by global warming potential, total nitrous oxide emissions in 2001 were equivalent to 97.5 million metric tons carbon equivalent, or 5.2 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 70.6 percent of the total. Nitrogen fertilization of agricultural soils represents 72.8 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 852 thousand metric tons in 2001, 0.7 percent below 2000 levels but 0.7 percent above 1990 levels (Figure 4).

There are large uncertainties connected with the emissions consequences of adding nitrogen to agricultural soils. Models used for estimation are based on limited sources of experimental data.[62] The uncertainty increases when moving from emissions associated with animal manure to soil mineralization and atmospheric deposition, where both estimating emissions and partitioning emissions between anthropogenic and biogenic sources become increasingly difficult.

Figure 4. U.S. Emissions of Nitrous Oxide by Source, 1990-2001



Source: Estimates presented in this chapter.

Principal Sources of U.S. Anthropogenic Nitrous Oxide Emissions, 1990-2001

	Thousand Metric Tons Nitrous Oxide		*Percent Change*	
Source	1990	2001	1990-2001	2000-2001
Energy	211	284	*34.7%*	*-0.2%*
Agriculture	846	852	*0.7%*	*-0.7%*
Industrial	96	51	*-47.1%*	*-9.2%*

[62] 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.

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 284 thousand metric tons of nitrous oxide in 2001 (23.5 percent of total U.S. nitrous oxide emissions), 0.2 percent lower than in 2000 but 34.7 percent higher than in 1990.

Industrial production of adipic and nitric acid, which releases nitrous oxide as a byproduct, accounted for emissions of 51 thousand metric tons of nitrous oxide in 2001 (4.2 percent of total U.S. nitrous oxide emissions), a 47.1-percent decrease from 1990 levels and a 9.2-percent decline from 2000 levels. The large decline in emissions from this source since 1990 is a result of the implementation 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, 1990-2001

Estimated 2001 Emissions (Thousand Metric Tons Nitrous Oxide)	284
Change Compared to 2000 (Thousand Metric Tons Nitrous Oxide)	-1
Change from 2000 *(Percent)*	*-0.2%*
Change Compared to 1990 (Thousand Metric Tons Nitrous Oxide)	73
Change from 1990 *(Percent)*	*34.7%*

The energy use category includes nitrous oxide emissions from both mobile and stationary sources as byproducts of fuel combustion. Estimated 2001 energy-related emissions were 284 thousand metric tons, or 23.5 percent of total U.S. anthropogenic nitrous oxide emissions (Table 23). Emissions from energy use are dominated by mobile combustion (82.7 percent of nitrous oxide emissions from energy use in 2001).

Mobile Combustion

Nitrous oxide emissions from mobile source combustion in 2001 were 235 thousand metric tons, nearly unchanged from 2000 levels (Table 24). 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 are the source of 93.8 percent of nitrous oxide emissions from mobile combustion (Table 24). Emissions grew rapidly between 1990 and 1995 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. The shift to advanced three-way catalytic converters (so-called because they reduce three pollutants: carbon monoxide, volatile organic compounds, and oxides of nitrogen) in 1996 through 2001 model year cars has slowed but not abated emissions growth from this source.

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.

Stationary Combustion

In 2001, estimated nitrous oxide emissions from stationary combustion sources were 49 thousand metric tons, 2.0 percent lower than in 2000 but 10.4 percent higher than in 1990 (Table 25). The emissions increase from this source between 1990 and 2001 can be attributed principally to coal-fired electricity generation, which grew in response to the growing demand for electricity and lower costs and improved availability at coal-fired power plants. Coal-fired combustion systems produced 62.7 percent of the 2001 emissions of nitrous oxide from stationary combustion, and the electric power sector accounted for 70.3 percent of all nitrous oxide emissions from stationary combustion sources. 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, 1990-2001

Estimated 2001 Emissions (Thousand Metric Tons Nitrous Oxide)	852
Change Compared to 2000 (Thousand Metric Tons Nitrous Oxide)	-6
Change from 2000 *(Percent)*	*-0.7%*
Change Compared to 1990 (Thousand Metric Tons Nitrous Oxide)	6
Change from 1990 *(Percent)*	*0.7%*

Nitrous oxide emissions from agricultural activities grew by 0.7 percent between 1990 and 2001. Agricultural activities were responsible for 70.6 percent of U.S. nitrous oxide emissions in 2001, roughly the same percentage that agricultural practices contribute to nitrous oxide emissions globally.[63] Nitrogen fertilization of agricultural soils accounted for 72.8 percent of U.S. agricultural emissions of nitrous oxide (Table 23). 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 2001.

Nitrogen Fertilization of Agricultural Soils

EIA estimates that a total of 621 thousand metric tons of nitrous oxide was released into the atmosphere as a result of direct and indirect emissions associated with fertilization practices in 2001 (Table 26). Estimated emissions decreased by 0.8 percent compared with 2000 levels but were still 0.8 percent higher than in 1990. Nitrous oxide emissions from the application of nitrogen-based fertilizers and biological fixation in crops accounted for 61.6 percent of total nitrous oxide emissions from this source during 2001.

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.[64] 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. Adding excess nitrogen to the soil also enriches ground and surface waters, such as rivers and streams, which generate indirect emissions of nitrous oxide. Additional indirect emissions occur from "atmospheric deposition," in which soils emit other nitrogen compounds that react to form nitrous oxide in the atmosphere.

Crop Residue Burning

In 2001, estimated emissions of nitrous oxide from crop residue burning were 2 thousand metric tons, up by less than 0.5 thousand metric tons (less than 0.1 percent) from 2000 levels (Table 23). The small increase is mainly attributable to increased 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).

Solid Waste of Domesticated Animals

Estimated 2001 nitrous oxide emissions from animal waste management were 230 thousand metric tons, down by 0.4 percent from 2000 levels but 0.5 percent higher than 1990 levels (Table 27), 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 account for 93.9 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,

[63] 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.

[64] 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).

beef cattle populations grew during the first half of the 1990s, leading to higher emissions through 1995, but have since declined slowly, lowering emissions nearly to 1991 levels.

Waste Management

U.S. Nitrous Oxide Emissions from Waste Management, 1990-2001	
Estimated 2001 Emissions (Thousand Metric Tons Nitrous Oxide)	20
Change Compared to 2000 (Thousand Metric Tons Nitrous Oxide)	*
Change from 2000 *(Percent)*	*0.9%*
Change Compared to 1990 (Thousand Metric Tons Nitrous Oxide)	3
Change from 1990 *(Percent)*	*19.9%*

*Less than 0.5 thousand metric tons.

Nitrous oxide emissions from waste management are estimated at 20 thousand metric tons for 2001, 1.6 percent of all U.S. anthropogenic nitrous oxide emissions (Table 23). During 2001, emissions from human sewage in wastewater were responsible for 95.8 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 2000 and 2001 and by 19.9 percent between 1990 and 2001. 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.

Waste Combustion

In 2001, estimated nitrous oxide emissions from waste combustion were 1 thousand metric tons, down 8.9 percent from 2000 levels and 0.3 percent above 1990 levels. Data on the amount of waste generated in the United States in 2001 were not available in time for this report; therefore, EIA scaled the 2001 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 2000 to 2001, and the total volume of waste generated is estimated to have increased by 9.0 percent. The total volume of waste generated in the United States increased by 58.2 percent between 1990 and 2001; however, the share of waste burned in 2001 was just 7.5 percent, compared with 11.5 percent in 1990.[65]

Human Sewage in Wastewater

In 2001, nitrous oxide emissions from wastewater were 19 thousand metric tons, a 0.9-percent increase from 2000 levels and a 21.6-percent increase from the 1990 level (Table 23). Estimates of nitrous oxide emissions from human waste are scaled to population size and per capita protein intake. U.S. population has grown by 13.7 percent since 1990. U.S. per capita protein intake rose steadily between 1990 and 1999, before declining slightly in 2000 and 2001. Today, U.S. per capita protein intake is 6.5 percent above 1990 levels. Data on protein intake are taken from the United Nations Food and Agriculture Organization (FAO).[66]

Nitrous oxide is emitted from wastewater that contains nitrogen-based organic materials, such as those found in human or animal waste. Two natural processes—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),[67] and nitrogen concentration.

Industrial Processes

U.S. Nitrous Oxide Emissions from Industrial Processes, 1990-2001	
Estimated 2001 Emissions (Thousand Metric Tons Nitrous Oxide)	51
Change Compared to 2000 (Thousand Metric Tons Nitrous Oxide)	-5
Change from 2000 *(Percent)*	*-9.2%*
Change Compared to 1990 (Thousand Metric Tons Nitrous Oxide)	-45
Change from 1990 *(Percent)*	*-47.1%*

Emissions from industrial processes were 51 thousand metric tons in 2001, a decrease of 45 thousand metric tons (47.1 percent) since 1990 and a decrease of 5 thousand metric tons (9.2 percent) from 2000. Nitrous oxide is emitted as a byproduct of certain chemical production

[65]"Nationwide Survey: The State of Garbage in America 1999," *Biocycle* (April 2000). Waste streams were estimated for 2001 by scaling to economic growth, and the share of waste combusted was held constant at the 2000 level.

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

[67]Biochemical oxygen demand is a measure of the organic content within the wastewater that is subject to decomposition.

processes. Table 28 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 14 thousand metric tons of nitrous oxide in 2000 to 12 thousand metric tons in 2001—a decrease of 13.7 percent. As discussed below, emissions from this source have been in the range of 12 to 14 thousand metric tons 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.[68] Between 1990 and 1996, emissions from adipic acid manufacture grew by 23.2 percent, reaching 70 thousand metric tons before dropping sharply to 27 thousand metric tons in 1997 (Table 28).

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.[69] 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.[70] Estimated emissions of nitrous oxide from uncontrolled adipic acid production decreased from 22 thousand metric tons in 1997 to 7 thousand metric tons in 2001, and 2001 emissions of nitrous oxide from controlled plants remained relatively 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 7.1 million metric tons of nitric acid manufactured in 2001 resulted in estimated emissions of 39 thousand metric tons of nitrous oxide (Table 28). This estimate was 7.7 percent lower than 2000 levels and 1.4 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 an uncertainty of plus or minus 75 percent in the emissions estimate.[71] 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.

[68] M.H. Thiemens and W.C. Trogler, "Nylon Production: An Unknown Source of Atmospheric Nitrous Oxide," *Science*, Vol. 251, No. 4996 (February 1991).

[69] Radian Corporation, *Nitrous Oxide Emissions From Adipic Acid Manufacturing* (Rochester, NY, January 1992), p. 10.

[70] 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).

[71] 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 2.18, web site www.ipcc.ch/pub/guide.htm.

Table 23. Estimated U.S. Emissions of Nitrous Oxide, 1990-2001
(Thousand Metric Tons Nitrous Oxide)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	P2001
Energy												
Mobile Combustion	166	176	186	195	209	222	217	221	222	244	234	235
Stationary Combustion	45	44	45	46	46	47	49	49	49	49	50	49
Total	**211**	**220**	**232**	**240**	**255**	**269**	**266**	**270**	**271**	**293**	**285**	**284**
Agriculture												
Nitrogen Fertilization of Soils	616	621	639	624	686	617	607	628	640	636	626	621
Crop Residue Burning	2	2	2	1	2	2	2	2	2	2	2	2
Solid Waste of Domesticated Animals	229	231	234	237	239	242	238	236	233	232	231	230
Total	**846**	**854**	**874**	**862**	**927**	**861**	**847**	**866**	**875**	**870**	**859**	**852**
Waste Management												
Waste Combustion	1	1	1	1	1	1	1	1	1	1	1	1
Human Sewage in Wastewater	16	16	16	16	17	17	17	17	18	18	19	19
Total	**17**	**17**	**17**	**17**	**18**	**18**	**18**	**18**	**18**	**19**	**20**	**20**
Industrial Processes	**96**	**99**	**95**	**100**	**110**	**111**	**116**	**74**	**58**	**57**	**56**	**51**
Total	**1,170**	**1,190**	**1,218**	**1,220**	**1,311**	**1,259**	**1,247**	**1,227**	**1,223**	**1,238**	**1,219**	**1,207**

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 2000*, DOE/EIA-0573(2000) (Washington, DC, November 2001). 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 1990-1999*, EPA-236-R-01-001 (Washington, DC, April 2001), web site www.epa.gov.

Table 24. U.S. Nitrous Oxide Emissions from Mobile Combustion, 1990-2001
(Thousand Metric Tons Nitrous Oxide)

Item	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	P2001
Motor Vehicles												
Passenger Cars	99	107	115	112	111	108	109	109	110	112	108	107
Buses	*	*	*	*	*	*	*	*	*	*	*	*
Motorcycles	*	*	*	*	*	*	*	*	*	*	*	*
Light-Duty Trucks	49	51	53	64	78	94	88	91	92	111	104	104
Other Trucks	6	6	6	6	7	7	7	8	8	8	8	8
Total	**154**	**164**	**174**	**183**	**196**	**210**	**205**	**208**	**210**	**231**	**221**	**220**
Other Mobile Sources	**12**	**12**	**12**	**12**	**12**	**12**	**13**	**12**	**12**	**13**	**14**	**14**
Total	**166**	**176**	**186**	**195**	**209**	**222**	**217**	**221**	**222**	**244**	**234**	**235**

*Less than 500 metric tons of nitrous oxide.

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 2000*, DOE/EIA-0573(2000) (Washington, DC, November 2001). 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. 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 25. U.S. Nitrous Oxide Emissions from Stationary Combustion, 1990-2001
(Thousand Metric Tons Nitrous Oxide)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	P2001
Residential												
Coal	*	*	*	*	*	*	*	*	*	*	*	*
Fuel Oil[a]	1	1	1	1	1	1	1	1	1	1	1	1
Natural Gas	*	*	*	*	*	*	1	*	*	*	*	*
Wood	2	2	3	2	2	2	2	2	2	2	2	2
Total	**4**	**4**	**4**	**4**	**3**	**4**	**4**	**3**	**3**	**3**	**3**	**3**
Commercial												
Coal	*	*	*	*	*	*	*	*	*	*	*	*
Fuel Oil[a]	1	1	*	*	*	*	*	*	*	*	*	*
Natural Gas	*	*	*	*	*	*	*	*	*	*	*	*
Wood	*	*	*	*	*	*	*	*	*	*	*	*
Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Industrial												
Coal	4	4	4	4	4	4	3	3	3	3	3	3
Fuel Oil[a]	5	5	5	5	5	5	5	6	5	6	6	6
Natural Gas	1	1	1	1	1	1	1	1	1	1	1	1
Wood	6	6	6	6	6	7	7	7	6	6	6	6
Total	**10**	**9**	**10**	**9**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**9**
Electric Power												
Coal	23	23	23	24	24	25	26	27	27	27	28	28
Fuel Oil[a]	1	1	1	1	1	*	*	1	1	1	1	1
Natural Gas	*	*	*	*	*	*	*	*	*	*	*	*
Wood	*	*	1	1	1	*	1	1	1	1	1	1
Total	**25**	**24**	**25**	**26**	**26**	**26**	**27**	**28**	**29**	**29**	**30**	**30**
Fuel Totals												
Coal	**27**	**27**	**27**	**28**	**28**	**28**	**30**	**30**	**30**	**30**	**32**	**31**
Fuel Oil[a]	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**8**	**8**	**8**
Natural Gas	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Wood	**9**	**9**	**9**	**9**	**9**	**10**	**10**	**9**	**9**	**9**	**9**	**9**
Total	**45**	**44**	**45**	**46**	**46**	**47**	**49**	**49**	**49**	**49**	**50**	**49**

*Less than 500 metric tons of nitrous oxide.

P = preliminary data.

[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.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 1999*, DOE/EIA-0573(99) (Washington, DC, October 2000). 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 2001); and *Monthly Energy Review*, DOE/EIA-0035(2002/08) (Washington, DC, August 2002).

Table 26. U.S. Nitrous Oxide Emissions from Nitrogen Fertilization of Agricultural Soils, 1990-2001
(Thousand Metric Tons Nitrous Oxide)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	P2001
Direct Emissions												
Nitrogen Fertilizers	179	182	183	193	195	173	159	159	161	161	154	148
Animal Manure	6	6	6	6	6	6	6	6	6	6	6	6
Crop Residues	94	91	104	86	112	94	106	114	116	113	116	116
Soil Mineralization	7	7	7	7	7	7	7	7	7	7	7	7
Biological Fixation in Crops	198	201	203	190	222	210	212	224	232	230	229	235
Total	**484**	**487**	**504**	**482**	**543**	**490**	**489**	**511**	**522**	**517**	**512**	**511**
Indirect Emissions												
Soil Leaching	112	114	115	121	122	109	100	101	101	102	97	93
Atmospheric Deposition	19	20	20	21	21	19	17	17	17	17	17	16
Total	**132**	**134**	**135**	**142**	**143**	**128**	**118**	**118**	**119**	**119**	**114**	**109**
Total	**616**	**621**	**639**	**624**	**686**	**617**	**607**	**628**	**640**	**636**	**626**	**621**

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 2000*, DOE/EIA-0573(2000) (Washington, DC, November 2001). 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; 1995-2001, 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 1990-1999*, EPA-236-R-01-001 (Washington, DC, April 2001), web site www.epa.gov.

Table 27. U.S. Nitrous Oxide Emissions from Solid Waste of Domesticated Animals, 1990-2001
(Thousand Metric Tons Nitrous Oxide)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	P2001
Cattle	215	217	219	223	225	228	224	221	218	218	217	216
Swine	5	5	5	5	6	5	5	6	6	6	6	5
Poultry	3	3	3	4	4	4	4	4	4	4	4	4
Sheep	3	3	3	3	3	3	3	2	2	2	2	2
Goats	1	1	1	1	1	1	1	1	1	1	1	1
Horses	1	1	1	1	1	1	1	1	1	1	1	1
Total	**229**	**231**	**234**	**237**	**239**	**242**	**238**	**236**	**233**	**232**	**231**	**230**

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 28. U.S. Nitrous Oxide Emissions from Industrial Processes, 1990-2001
(Thousand Metric Tons Nitrous Oxide)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	P2001
Adipic Acid												
Controlled Sources	3	4	3	3	4	4	4	5	5	5	5	5
Uncontrolled Sources	54	56	52	56	63	63	66	22	7	7	9	7
Total	**57**	**60**	**55**	**59**	**67**	**67**	**70**	**27**	**12**	**12**	**14**	**12**
Nitric Acid	**40**	**40**	**41**	**41**	**43**	**44**	**46**	**47**	**46**	**45**	**42**	**39**
Total	**96**	**99**	**95**	**100**	**110**	**111**	**116**	**74**	**58**	**57**	**56**	**51**

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 2000*, DOE/EIA-0573(2000) (Washington, DC, November 2001). Totals may not equal sum of components due to independent rounding.

Sources: Data sources and methods documented in Appendix A, "Estimation Methods."