Executive Summary

Central to any study of climate change is the development of an emissions inventory that identifies and quantifies a country's primary anthropogenic[1] sources and sinks of greenhouse gases. This inventory adheres to both 1) a comprehensive and detailed methodology for estimating sources and sinks of anthropogenic greenhouse gases; and 2) a common and consistent mechanism that enables signatory countries to the United Nations Framework Convention on Climate Change (UNFCCC) to compare the relative contribution of different emission sources and greenhouse gases to climate change. Moreover, systematically and consistently estimating national and international emissions is a prerequisite for accounting for reductions and evaluating mitigation strategies.

In June of 1992, the United States signed, and later ratified in October, the UNFCCC. The objective of the UNFCCC is "to achieve…stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."[2]

Parties to the Convention, by signing, make commitments "to develop, periodically update, publish and make available…national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies…"[3] The United States views this report as an opportunity to fulfill this commitment.

This chapter summarizes the latest information on U.S. anthropogenic greenhouse gas emission trends from 1990 through 1999. To ensure that the U.S. emissions inventory is comparable to those of other UNFCCC signatory countries, the estimates presented here were calculated using methodologies consistent with those recommended in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997). For most source categories, the IPCC default methodologies were expanded, resulting in a more comprehensive and detailed estimate of emissions.

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as halons. CFCs, HCFCs, and halons are stratospheric ozone depleting substances and are therefore covered under the *Montreal Protocol on Substances that Deplete the Ozone Layer*. The UNFCCC defers to

[1] The term "anthropogenic," in this context, refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities (IPCC/UNEP/OECD/IEA 1997).

[2] Article 2 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change. See <http://www.unfccc.de>.

[3] Article 4 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change (also identified in Article 12). See <http://www.unfccc.de>.

this earlier international treaty in addressing these ozone depleting substances; however, some other fluorine-containing halogenated substances—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—do not deplete stratospheric ozone but are potent greenhouse gases. These latter substances are addressed by the UNFCCC and accounted for in national greenhouse gas inventories.

There are also several gases that do not have a direct global warming effect but indirectly affect terrestrial radiation absorpon by influencing the formation and destruction of tropospheric and stratospheric ozone. These gases—referred to as ozone precursors—include carbon monoxide (CO), oxides of nitrogen (NO_x), and nonmethane volatile organic compounds (NMVOCs).[4] Aerosols—extremely small particles or liquid droplets often produced by emissions of sulfur dioxide (SO_2)—can also affect the absorptive characteristics of the atmosphere.

Although CO_2, CH_4, and N_2O occur naturally in the atmosphere, their atmospheric concentrations have been affected by human activities. Since pre-industrial time (i.e., since about 1750), concentrations of these greenhouse gases have increased by 28, 145, and 13 percent, respectively (IPCC 1996). This build-up has altered the chemical composition of the earth's atmosphere, and therefore effected the global climate system.

Beginning in the 1950s, the use of CFCs and other stratospheric ozone depleting substances (ODSs) increased by nearly 10 percent per year until the mid-1980s, when international concern about ozone depletion led to the signing of the *Montreal Protocol*. Since then, a phase-out of the production of ODSs has been occurring. In recent years, use of ODS substitutes such as HFCs and PFCs has grown as they begin to be phased in as replacements for CFCs and HCFCs.

Box ES-1: Emission Reporting Nomenclature

The Global Warming Potential (GWP) weighted emissions of all direct greenhouse gases presented throughout this report are presented in terms of equivalent emissions of carbon dioxide (CO_2), using units of teragrams of carbon dioxide equivalents (Tg CO_2 Eq.) In previous year's inventories emissions were reported in terms of carbon—versus carbon dioxide—equivalent emissions, using units of million metric tons of carbon equivalents (MMTCE). This change of units for reporting was implemented so that the U.S. Inventory would be more consistent with international practices, which are to report emissions in carbon dioxide equivalent units.

In order to convert the emission estimates presented in this report to those provided previously, the following equation can be employed:

Tg CO_2 Eq. = MMTCE $\times$ ($^{44}/_{12}$)

There are two elements to the conversion. The first element is simply nomenclature, since one teragram is equal to one million metric tons:

Tg = 10^9 kg = 10^6 metric tons = 1 megaton= 1 million metric tons

The second element is the conversion, by weight, from carbon to carbon dioxide. The molecular weight of carbon is 12, and the molecular weight of oxygen is 16; therefore, the molecular weight of CO_2 is 44 (i.e., 12+[16 $\times$ 2]), as compared to 12 for carbon alone. Thus, carbon comprises 12/44^{ths} of carbon dioxide by weight.

Recent Trends in U.S. Greenhouse Gas Emissions

Total U.S. greenhouse gas emissions rose in 1999 to 6,746.0 teragrams of carbon dioxide equivalents (Tg CO_2 Eq.)[5] (11.7 percent above 1990 emissions). The single year increase in emissions from 1998 to 1999 was 0.9 percent (59.2 Tg CO_2 Eq.), less than the average annual rate of increase for 1990 through 1999 (1.2 percent). The lower than average increase in emissions, especially given the robust economic growth in 1999, was primarily attributable to the following factors: 1) warmer than normal summer and winter conditions; 2) significantly increased output from existing nuclear power plants; and 3) reduced CH_4 emissions from coal mines and HFC-23 by-product emissions from the chemical manufacture of HCFC-22. Figure ES-1 through Figure ES-3 illustrate the overall trends in total U.S. emissions by gas, annual changes, and absolute change since 1990. Table ES-1 provides a detailed summary of U.S. greenhouse gas emissions and sinks for 1990 through 1999.

[4] Also referred to in the U.S. Clean Air Act as "criteria pollutants."

[5] Estimates are presented in units of teragrams of carbon dioxide equivalents (Tg CO_2 Eq.), which weight each gas by its Global Warming Potential, or GWP, value. (see following section).

Figure ES-1

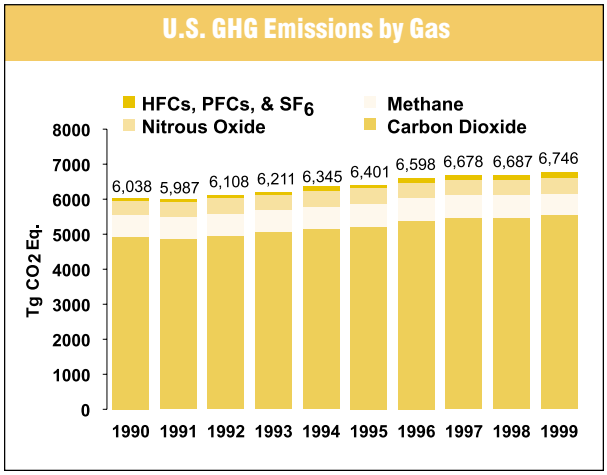


Figure ES-2

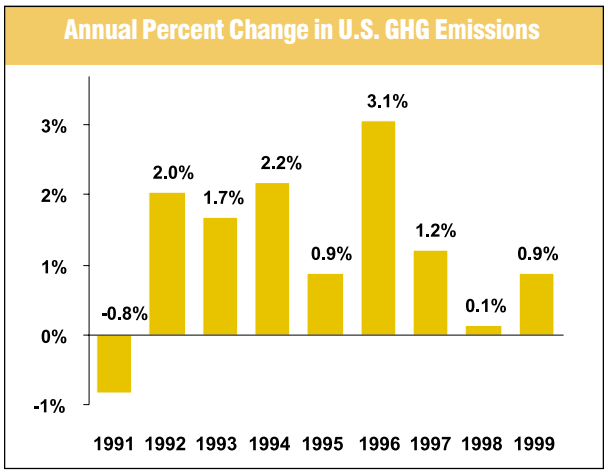


Figure ES-3

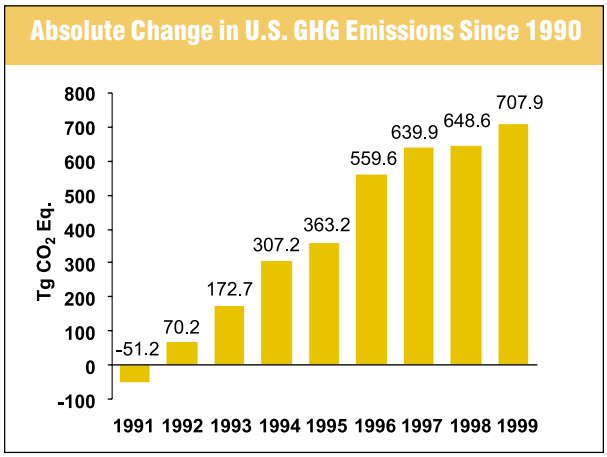


Figure ES-4

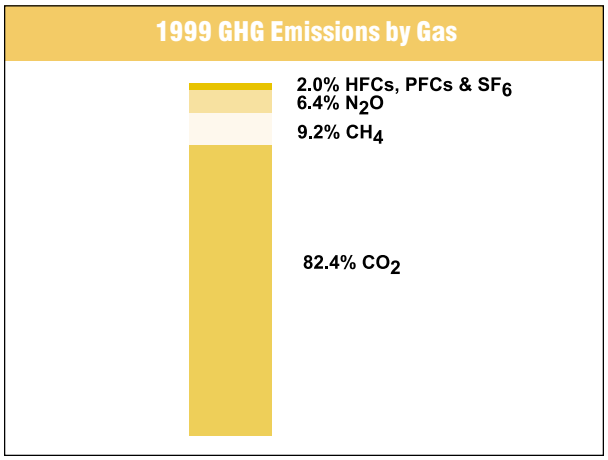


Figure ES-4 illustrates the relative contribution of the direct greenhouse gases to total U.S. emissions in 1999. The primary greenhouse gas emitted by human activities was CO_2. The largest source of CO_2, and of overall greenhouse gas emissions in the United States, was fossil fuel combustion. Methane emissions resulted primarily from decomposition of wastes in landfills, enteric fermentation associated with domestic livestock, natural gas systems, and coal mining. Emissions of N_2O were dominated by agricultural soil management and mobile source fossil fuel combustion. The emissions of substitutes for ozone depleting substances and emissions of HFC-23 during the production of HCFC-22 were the primary contributors to aggregate HFC emissions. Electrical transmission and distribution systems emitted the majority of SF_6, while PFC emissions came mainly from primary aluminum production.

As the largest source of U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion accounted for a nearly constant 80 percent of global warming potential (GWP) weighted emissions in the 1990s.[6] Emissions from this source category grew by 13 percent (617.4 Tg CO_2 Eq.) from 1990 to 1999 and were responsible for the majority of the increase in national emissions during this period. The annual increase in CO_2 emissions from fossil fuel combustion was 1.2 percent in 1999, a figure close to the source's average annual rate of 1.4 percent during the 1990s. Historically, changes in emissions from fossil fuel combustion have been the dominant factor affecting U.S. emission trends.

[6] If a full accounting of emissions from fossil fuel combustion is made by including emissions from the combustion of international bunker fuels and CH_4 and N_2O emissions associated with fuel combustion, then this percentage increases to a constant 82 percent during the 1990s.

Table ES-1: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Tg CO_2 Eq.)

Gas/Source	1990	1995	1996	1997	1998	1999
CO_2	**4,913.0**	**5,219.8**	**5,403.2**	**5,478.7**	**5,489.7**	**5,558.1**
Fossil Fuel Combustion	4,835.7	5,121.3	5,303.0	5,374.9	5,386.8	5,453.1
Cement Manufacture	33.3	36.8	37.1	38.3	39.2	39.9
Waste Combustion	17.6	23.1	24.0	25.7	25.1	26.0
Lime Manufacture	11.2	12.8	13.5	13.7	13.9	13.4
Natural Gas Flaring	5.1	13.6	13.0	12.0	10.8	11.7
Limestone and Dolomite Use	5.1	7.0	7.3	8.3	8.1	8.3
Soda Ash Manufacture and Consumption	4.1	4.3	4.3	4.4	4.3	4.2
Carbon Dioxide Consumption	0.8	1.0	1.1	1.3	1.4	1.6
Land-Use Change and Forestry (Sink)[a]	(1,059.9)	(1,019.1)	(1,021.6)	(981.9)	(983.3)	(990.4)
International Bunker Fuels[b]	114.0	101.0	102.2	109.8	112.8	107.3
CH_4	**644.5**	**650.5**	**638.0**	**632.0**	**624.8**	**619.6**
Landfills	217.3	222.9	219.1	217.8	213.6	214.6
Enteric Fermentation	129.5	136.3	132.2	129.6	127.5	127.2
Natural Gas Systems	121.2	124.2	125.8	122.7	122.1	121.8
Coal Mining	87.9	74.6	69.3	68.8	66.5	61.8
Manure Management	26.4	31.0	30.7	32.6	35.2	34.4
Petroleum Systems	27.2	24.5	24.0	24.0	23.3	21.9
Wastewater Treatment	11.2	11.8	11.9	12.0	12.1	12.2
Rice Cultivation	8.7	9.5	8.8	9.6	10.1	10.7
Stationary Combustion	8.5	8.9	9.0	8.1	7.6	8.1
Mobile Combustion	5.0	4.9	4.8	4.7	4.6	4.5
Petrochemical Production	1.2	1.5	1.6	1.6	1.6	1.7
Agricultural Residue Burning	0.5	0.5	0.6	0.6	0.6	0.6
Silicon Carbide Production	+	+	+	+	+	+
International Bunker Fuels[b]	+	+	+	+	+	+
N_2O	**396.9**	**431.9**	**441.6**	**444.1**	**433.7**	**432.6**
Agricultural Soil Management	269.0	285.4	294.6	299.8	300.3	298.3
Mobile Combustion	54.3	66.8	65.3	65.2	64.2	63.4
Nitric Acid	17.8	19.9	20.7	21.2	20.9	20.2
Manure Management	16.0	16.4	16.8	17.1	17.2	17.2
Stationary Combustion	13.6	14.3	14.9	15.0	15.1	15.7
Adipic Acid	18.3	20.3	20.8	17.1	7.3	9.0
Human Sewage	7.1	8.2	7.8	7.9	8.1	8.2
Agricultural Residue Burning	0.4	0.4	0.4	0.4	0.5	0.4
Waste Combustion	0.3	0.3	0.3	0.3	0.2	0.2
International Bunker Fuels[b]	1.0	0.9	0.9	1.0	1.0	1.0
HFCs, PFCs, and SF_6	**83.9**	**99.0**	**115.1**	**123.3**	**138.6**	**135.7**
Substitution of Ozone Depleting Substances	0.9	24.0	34.0	42.1	49.6	56.7
HCFC-22 Production	34.8	27.1	31.2	30.1	40.0	30.4
Electrical Transmission and Distribution	20.5	25.7	25.7	25.7	25.7	25.7
Aluminum Production	19.3	11.2	11.6	10.8	10.1	10.0
Semiconductor Manufacture	2.9	5.5	7.0	7.0	6.8	6.8
Magnesium Production and Processing	5.5	5.5	5.6	7.5	6.3	6.1
Total Emissions	**6,038.2**	**6,401.3**	**6,597.8**	**6,678.0**	**6,686.8**	**6,746.0**
Net Emissions (Sources and Sinks)	**4,978.3**	**5,382.3**	**5,576.2**	**5,696.2**	**5,703.5**	**5,755.7**

+ Does not exceed 0.05 Tg CO_2 Eq.
[a] Sinks are only included in net emissions total, and are based partially on projected activity data.
[b] Emissions from International Bunker Fuels are not included in totals.
Note: Totals may not sum due to independent rounding.
Note: Parentheses indicate negative values (or sequestration).

Changes in CO_2 emissions from fossil fuel combustion are influenced by many long-term and short-term factors, including population and economic growth, energy price fluctuations, technological changes, and seasonal temperatures. On an annual basis, the overall demand for fossil fuels in the United States and other countries generally fluctuates in response to changes in general economic conditions, energy prices, weather, and the availability of non-fossil alternatives. For example, a year with increased consumption of goods and services, low fuel prices, severe summer and winter weather conditions, nuclear plant closures, and lower precipitation feeding hydroelectric dams would be expected to have proportionally greater fossil fuel consumption than a year with poor economic performance, high fuel prices, mild temperatures, and increased output from nuclear and hydroelectric plants.

Longer-term changes in energy consumption patterns, however, tend to be more a function of changes that affect the scale of consumption (e.g., population, number of cars, and size of houses), the efficiency with which energy is used in equipment (e.g., cars, power plants, steel mills, and light bulbs) and consumer behavior (e.g., walking, bicycling, or telecommuting to work instead of driving).

Energy-related CO_2 emissions are also a function of the type fuel or energy consumed and its carbon intensity. Producing heat or electricity using natural gas instead of coal, for example, can reduce the CO_2 emissions associated with energy consumption because of the lower carbon content of natural gas per unit of useful energy produced. Table ES-2 shows annual changes in emissions during the last few years of the 1990s for particular fuel types and sectors.

Carbon dioxide emissions from fossil fuel combustion grew rapidly in 1996, due primarily to two factors: 1) fuel switching by electric utilities from natural gas to more carbon intensive coal as colder winter conditions and the associated rise in demand for natural gas from residential, commercial, and industrial customers for heating caused gas prices to rise sharply; and 2) higher consumption of petroleum fuels for transportation. Milder weather conditions in summer and winter moderated the growth in emissions in 1997; however, the shut-down of several nuclear power plants lead electric utilities to increase their consumption of coal and other fuels to offset the lost capacity. In 1998, weather conditions were again a dominant factor in slowing the growth in emissions. Warm winter temperatures resulted in a significant drop in residential, commercial, and industrial natural gas consumption. This drop in emissions from natural gas used for heating was primarily offset by two factors: 1) electric utility emissions, which increased in part due to a hot summer and its associated air conditioning demand; and 2) increased motor gasoline consumption for transportation.

In 1999, the increase in emissions from fossil fuel combustion was driven largely by growth in petroleum consumption for transportation. In addition, heating fuel demand partially recovered in the residential, commercial, and industrial sectors as winter temperatures dropped relative to 1998, although temperatures were still warmer than normal. These increases were offset, in part, by a

Table ES-2: Annual Change in CO_2 Emissions from Fossil Fuel Combustion for Selected Fuels and Sectors (Tg CO_2 Eq. and Percent)

Sector	Fuel Type	1995 to 1996		1996 to 1997		1997 to 1998		1998 to 1999	
Electric Utility	Coal	89.9	5.7%	52.0	3.1%	14.3	0.8%	-32.1	-1.8%
Electric Utility	Natural Gas	-25.3	-14.7%	13.1	9.0%	16.2	10.1%	-7.8	-4.4%
Electric Utility	Petroleum	5.1	10.0%	8.1	14.4%	26.7	41.6%	-17.4	-19.1%
Transportation[a]	Petroleum	38.8	2.5%	7.6	0.5%	34.1	2.1%	57.6	3.6%
Residential	Natural Gas	21.4	8.1%	-14.0	-4.9%	-24.0	-8.9%	8.5	3.4%
Commercial	Natural Gas	7.0	4.3%	3.1	1.8%	-11.1	-6.4%	2.9	1.8%
Industrial	Coal	-7.3	-2.7%	2.0	0.8%	-1.1	-0.4%	29.2	11.2%
Industrial	Natural Gas	17.8	3.4%	-0.5	-0.1%	-14.5	-2.7%	1.6	0.3%
All Sectors[b]	**All Fuels**	**181.7**	**3.5%**	**71.9**	**1.4%**	**11.9**	**0.2%**	**66.4**	**1.2%**

[a] Excludes emissions from International Bunker Fuels.
[b] Includes fuels and sectors not shown in table.

decline in emissions from electric utilities due primarily to: 1) an increase in net generation of electricity by nuclear plants (8 percent) to record levels, which reduced demand from fossil fuel plants; and 2) moderated summer temperatures compared to the previous year—thereby reducing electricity demand for air conditioning. Utilization of existing nuclear power plants, measured as a plant's capacity factor,[7] has increased from just over 70 percent in 1990 to over 85 percent in 1999.

Another factor that does not affect total emissions, but does affect the interpretation of emission trends is the allocation of emissions from nonutility power producers. The Energy Information Administration (EIA) currently includes fuel consumption by nonutilities with the industrial end-use sector. In 1999, there was a large shift in generating capacity from utilities to nonutilities, as restructuring legislation spurred the sale of 7 percent of utility generating capability (EIA 2000b). This shift is illustrated by the increase in industrial end-use sector emissions from coal and the associated decrease in electric utility emissions. However, emissions from the industrial end-use sector did not increase as much as would be expected even though net generation by nonutilities increased from 11 to 15 percent of total U.S. electricity production (EIA 2000b).[8]

Overall, from 1990 to 1999, total emissions of CO_2 and N_2O increased by 645.2 (13 percent) and 35.7 Tg CO_2 Eq. (9 percent), respectively, while CH_4 emissions decreased by 24.9 Tg CO_2 Eq. (4 percent). During the same period, aggregate weighted emissions of HFCs, PFCs, and SF_6 rose by 51.8 Tg CO_2 Eq. (62 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, and SF_6 are significant because many of them have extremely high global warming potentials and, in the cases of PFCs and SF_6, long atmospheric lifetimes. Conversely, U.S. greenhouse gas emissions were partly offset by carbon sequestration in forests and in landfilled carbon, which were estimated to be 15 percent of total emissions in 1999.

Other significant trends in emissions from additional source categories over the nine year period from 1990 through 1999 included the following:

- Aggregate HFC and PFC emissions resulting from the substitution of ozone depleting substances (e.g., CFCs) increased by 55.8 Tg CO_2 Eq. This increase was partly offset, however, by reductions in PFC emissions from aluminum production (9.2 Tg CO_2 Eq. or 48 percent), and reductions in emissions of HFC-23 from the production of HCFC-22 (4.4 Tg CO_2 Eq. or 13 percent). Reductions in PFC emissions from aluminum production were the result of both voluntary industry emission reduction efforts and lower domestic aluminum production. HFC-23 emissions from the production of HCFC-22 decreased due to a reduction in the intensity of emissions from that source, despite increased HCFC-22 production.
- Emissions of N_2O from mobile combustion rose by 9.1 Tg CO_2 Eq. (17 percent), primarily due to increased rates of N_2O generation in highway vehicles.
- Methane emissions from coal mining dropped by 26 Tg CO_2 Eq. (30 percent) as a result of the mining of less gassy coal from underground mines and the increased use of methane from degasification systems.
- Nitrous oxide emissions from agricultural soil management increased by 29.3 Tg CO_2 Eq. (11 percent) as fertilizer consumption and cultivation of nitrogen fixing crops rose.
- By 1998, all of the three major adipic acid producing plants had voluntarily implemented N_2O abatement technology, and as a result, emissions fell by 9.3 Tg CO_2 Eq. (51 percent). The majority of this decline occurred from 1997 to 1998, despite increased production.

The following sections describe the concept of Global Warming Potentials (GWPs), present the anthropogenic sources and sinks of greenhouse gas emissions in the United States, briefly discuss emission pathways, further summarize the emission estimates, and explain the relative importance of emissions from each source category.

[7] The capacity factor is defined as the ratio of the electrical energy produced by a generating unit for a given period of time to the electrical energy that could have been produced at continuous full- power operation during the same period (DOE/EIA 2000).

[8] It is unclear whether reporting problems for electric utilities and the industrial end-use sector have increased with the dramatic growth in nonutilities and the opening of the electric power industry to increased competition.

Box ES-2: Recent Trends in Various U.S. Greenhouse Gas Emissions-Related Data

There are several ways to assess a nation's greenhouse gas emitting intensity. The basis for measures of intensity can be 1) per unit of aggregate energy consumption, because energy-related activities are the largest sources of emissions; 2) per unit of fossil fuel consumption, because almost all energy-related emissions involve the combustion of fossil fuels; 3) per unit of electricity consumption, because the electric power industry—utilities and nonutilities combined—were the largest sources of U.S. greenhouse gas emissions in 1999; 4) per unit of total gross domestic product as a measure of national economic activity; or 5) on a per capita basis. Depending upon the measure used, the United States could appear to have reduced or increased its national greenhouse gas intensity during the 1990s.

Table ES-3 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. Greenhouse gas emissions in the U.S. have grown at an average annual rate of 1.2 percent since 1990. This rate is slightly slower than that for total energy or fossil fuel consumption—thereby indicating an improved or lower greenhouse gas emitting intensity—and much slower than that for either electricity consumption or overall gross domestic product. Emissions, however, are growing faster than national population, thereby indicating a worsening or higher greenhouse gas emitting intensity on a per capita basis (see Figure ES-5). Overall, global atmospheric CO_2 concentrations—a function of many complex anthropogenic and natural processes—are increasing at 0.4 percent per year.

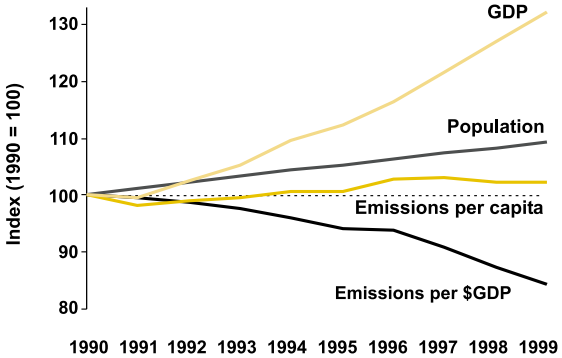
Table ES-3: Recent Trends in Various U.S. Data (Index 1990 = 100)

Variable	1991	1992	1993	1994	1995	1996	1997	1998	1999	Growth Rate[f]
GHG Emissions[a]	99	101	103	105	106	109	111	111	112	1.2%
Energy Consumption[b]	100	101	104	106	108	111	112	112	115	1.5%
Fossil Fuel Consumption[b]	99	101	103	105	107	110	112	112	113	1.4%
Electricity Consumption[b]	102	102	105	108	111	114	116	119	120	2.1%
GDP[c]	100	103	105	110	112	116	122	127	132	3.2%
Population[d]	101	102	103	104	105	106	107	108	109	1.0%
Atmospheric CO_2 Concentration[e]	100	101	101	101	102	102	103	104	104	0.4%

[a] GWP weighted values
[b] Energy content weighted values. (EIA 2000a)
[c] Gross Domestic Product in chained 1996 dollars (BEA 2000)
[d] (U.S. Census Bureau 2000)
[e] Mauna Loa Observatory, Hawaii (Keeling and Whorf 2000)
[f] Average annual growth rate

Figure ES-5

U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product



Source: BEA (2000), U.S. Census Bureau (2000), and emission estimates in this report.

Box ES- 3: Weather and Non-Fossil Energy Adjustments to CO_2 from Fossil Fuel Combustion Trends

An analysis was performed using EIA's Short-Term Integrated Forecasting (STIFS) model to examine the effects of variations in weather and output from nuclear and hydroelectric generating plants on U.S. energy-related CO_2 emissions.[9] Weather conditions affect energy demand because of the impact they have on residential, commercial, and industrial end-use sector heating and cooling demands. Warmer winters tend to reduce demand for heating fuels—especially natural gas—while cooler summers tend to reduce air conditioning-related electricity demand. Changes in electricity output from hydroelectric and nuclear power plants do not necessarily affect final energy demand, but increased output from these plants does offset electricity generation by fossil fuel power plants, and therefore leads to reduced CO_2 emissions.

The results of this analysis show that CO_2 emissions from fossil fuel combustion would have been roughly 1.9 percent higher (102 Tg CO_2 Eq.) if weather conditions and hydroelectric and nuclear power generation had remained at normal levels (see Figure ES-6). Similarly, emissions in 1997 and 1998 would have been roughly 0.5 and 1.2 percent (7 and 17 Tg CO_2 Eq.) greater under normal conditions, respectively.

In addition to the absolute level of emissions being greater, the growth rate in CO_2 emissions from fossil fuel combustion from 1998 to 1999 would have been 2.0 percent instead of the actual 1.2 percent if both weather conditions and nonfossil electricity generation had been normal (see Figure ES-7). Similarly, emissions in 1998 would have increased by 0.9 percent under normal conditions versus the actual rate of 0.2 percent.

Figure ES-6

Percent Difference in Adjusted and Actual Energy-Related CO_2 Emissions

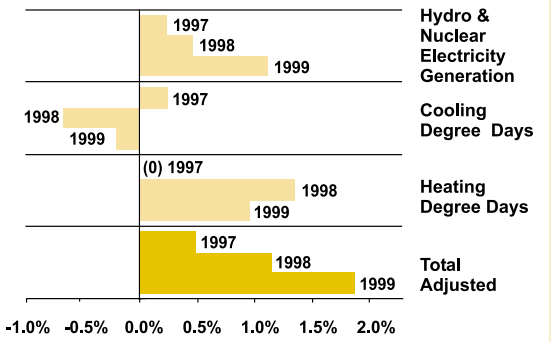
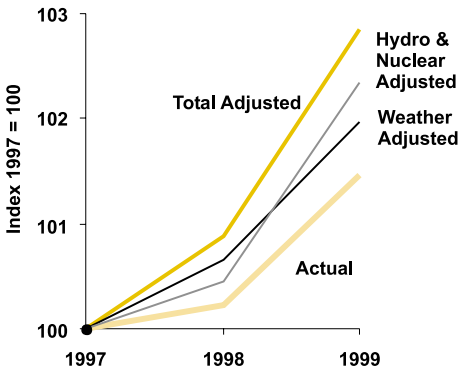


Figure ES-7

Recent Trends in Adjusted and Actual Energy-Related CO_2 Emissions



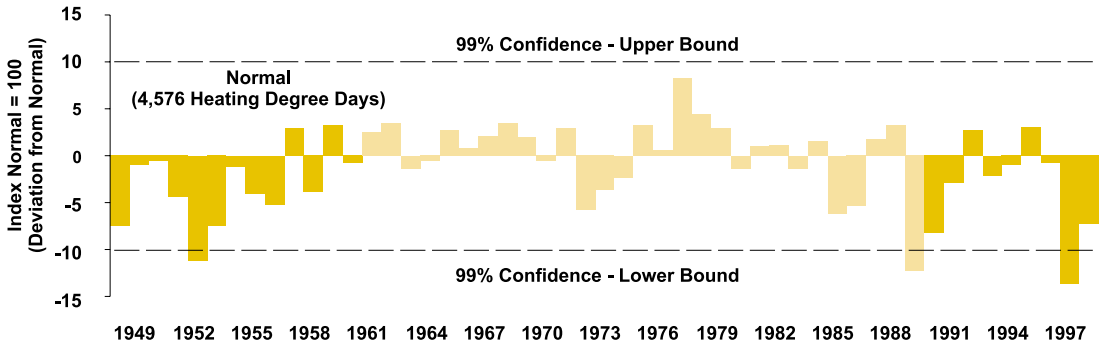
Warmer winter conditions in both 1998 and 1999 had a significant effect on U.S. CO_2 emissions by reducing demand for heating fuels. Heating degree days in the United States in 1998 and 1999 were 14 and 7 percent below normal, respectively (see Figure ES-8).[10] These warm winters, however, were partially countered by increased electricity demand that resulted from hotter summers. Cooling degree days in 1998 and 1999 were 18 and 3 percent above normal, respectively (see Figure ES-9).

[9] The STIFS model is employed in producing EIA's *Short-Term Energy Outlook* (DOE/EIA-0202). Complete model documentation can be found at < http://www.eia.doe.gov/emeu/steo/pub/contents.html>. A variety of other factors that influence energy-related CO_2 emissions were also examined such as: changes in output from energy intensive manufacturing industries, and changes in fossil fuel prices. These additional factors, however, were not found to have a significant effect on emission trends.

[10] Degree days are relative measurements of outdoor air temperature. Heating degree days are deviations of the mean daily temperature below 65° F, while cooling degree days are deviations of the mean daily temperature above 65° F. Excludes Alaska and Hawaii. Normals are based on data from 1961 through 1990. The variation in these normals during this time period was ±10 percent and ±14 percent for heating and cooling degree days, respectively (99 percent confidence interval).

Figure ES-8

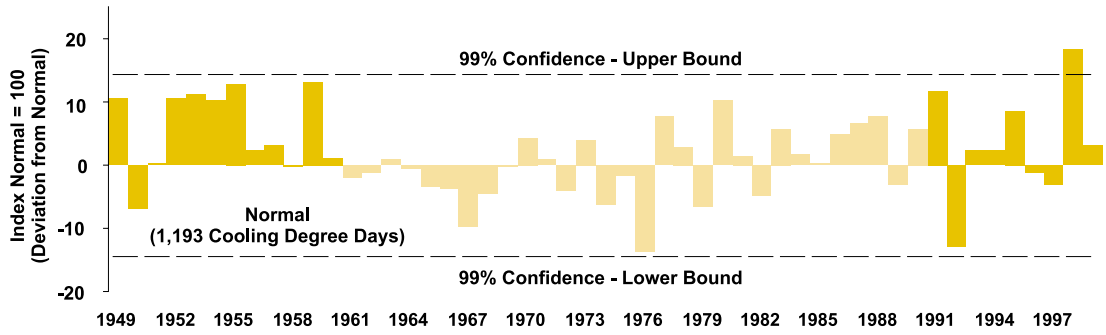
Annual Deviations from Normal Heating Degree Days for the United States (1949-1999)



Note: Climatological normal data is highlighted. Statistical confidence interval for "normal" climatology period of 1961 through 1990.
Source: NOAA (2000b)

Figure ES-9

Annual Deviations from Normal Cooling Degree Days for the United States (1949-1999)

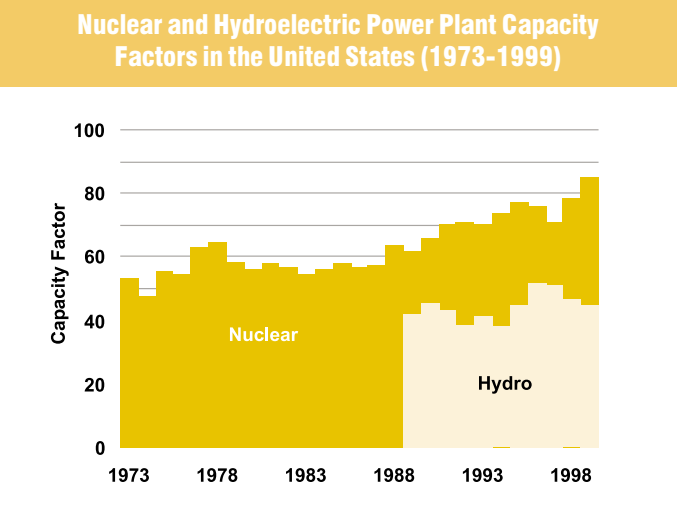


Note: Climatological normal data is highlighted. Statistical confidence interval for "normal" climatology period of 1961 through 1990.
Source: NOAA (2000b)

Although no new U.S. nuclear power plants have been constructed in many years, the utilization (i.e., capacity factors[11]) of existing plants reached record levels in 1998 and 1999, approaching 90 percent. This increase in utilization translated into an increase in electricity output by nuclear plants of slightly more than 7 percent in both years. This increase in nuclear plant output, however, was partially offset by reduced electricity output by hydroelectric power plants, which declined by 10 and 4 percent in 1998 and 1999, respectively. Electricity generated by nuclear plants provides approximately twice as much of the energy consumed in the United States as hydroelectric plants. Nuclear and hydroelectric power plant capacity factors since 1973 are shown in Figure ES-10.

[11] The capacity factor is defined as the ratio of the electrical energy produced by a generating unit for a given period of time to the electrical energy that could have been produced at continuous full- power operation during the same period (DOE/EIA 2000).

Figure ES-10



Box ES-4: Greenhouse Gas Emissions from Transportation Activities

Motor vehicle usage is increasing all over the world, including in the United States. Since the 1970s, the number of highway vehicles registered in the United States has increased faster than the overall population, according to the Federal Highway Administration (FHWA). Likewise, the number of miles driven—up 13 percent from 1990 to 1999—and gallons of gasoline consumed each year in the United States have increased steadily since the 1980s, according to the FHWA and Energy Information Administration, respectively. These increases in motor vehicle usage are the result of a confluence of factors including population growth, economic growth, urban sprawl, low fuel prices, and increasing popularity of sport utility vehicles and other light-duty trucks that tend to have lower fuel efficiency.[12] A similar set of social and economic trends has led to a significant increase in air travel and freight transportation—by both air and road modes—during the 1990s.

One of the unintended consequences of these changes is a slowing of progress toward cleaner air in both urban and rural parts of the country. Passenger cars, trucks, motorcycles, and buses emit significant quantities of air pollutants with local, regional, and global effects. Motor vehicles are major sources of carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), nonmethane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x), nitrous oxide (N_2O), and hydrofluorocarbons (HFCs). Motor vehicles are also important contributors to many serious air pollution problems, including ground-level ozone (i.e., smog), acid rain, fine particulate matter, and global warming. Within the United States and abroad, government agencies have taken actions to reduce these emissions. Since the 1970s, the EPA has required the reduction of lead in gasoline, developed strict emission standards for new passenger cars and trucks, directed States to enact comprehensive motor vehicle emission control programs, required inspection and maintenance programs, and more recently, introduced the use of reformulated gasoline. New vehicles are now equipped with advanced emissions controls, which are designed to reduce emissions of NO_x, hydrocarbons, and CO.

Table ES-4 summarizes greenhouse gas emissions from all transportation-related activities. Overall, transportation activities—excluding international bunker fuels—accounted for an almost constant 26 percent of total U.S. greenhouse gas emissions from 1990 to 1999. These emissions were primarily CO_2 from fuel combustion, which increased by 16 percent from 1990 to 1999. However, because of larger increases in N_2O and HFC emissions during this period, overall emissions from transportation activities actually increased by 18 percent.

[12] The average miles per gallon achieved by the U.S. highway vehicle fleet actually decreased by slightly less than one percent in both 1998 and 1999.

Table ES-4: Transportation-Related Greenhouse Gas Emissions (Tg CO_2 Eq.)

Gas/Vehicle Type	1990	1995	1996	1997	1998	1999
CO_2	**1,474.4**	**1,581.8**	**1,621.2**	**1,631.4**	**1,659.0**	**1,716.4**
Passenger Cars	620.0	641.9	654.1	660.2	674.5	688.9
Light-Duty Trucks	283.1	325.3	333.5	337.3	356.9	364.8
Other Trucks	206.0	235.9	248.1	257.0	257.9	269.7
Buses	10.7	13.5	11.3	12.0	12.3	12.9
Aircraft[a]	176.7	171.5	180.2	179.0	183.0	184.6
Boats and Vessels	59.4	66.9	63.8	50.2	47.9	65.6
Locomotives	28.4	31.5	33.4	34.4	33.6	35.1
Other[b]	90.1	95.3	96.7	101.4	93.0	94.9
International Bunker Fuels[c]	114.0	101.0	102.2	109.8	112.8	107.3
CH_4	**5.0**	**4.9**	**4.8**	**4.7**	**4.6**	**4.5**
Passenger Cars	2.4	2.0	2.0	2.0	2.0	1.9
Light-Duty Trucks	1.6	1.9	1.6	1.6	1.5	1.4
Other Trucks and Buses	0.4	0.5	0.7	0.7	0.7	0.7
Aircraft	0.2	0.1	0.1	0.2	0.1	0.2
Boats and Vessels	0.1	0.1	0.1	0.1	0.1	0.1
Locomotives	0.1	0.1	0.1	0.1	+	+
Other[d]	0.2	0.2	0.2	0.2	0.2	0.2
International Bunker Fuels[c]	+	+	+	+	+	+
N_2O	**54.3**	**66.8**	**65.3**	**65.2**	**64.2**	**63.4**
Passenger Cars	31.0	33.0	32.7	32.4	32.1	31.5
Light-Duty Trucks	17.8	27.1	23.9	24.0	23.3	22.7
Other Trucks and Buses	2.6	3.6	5.6	5.8	5.9	6.1
Aircraft[a]	1.7	1.7	1.8	1.7	1.8	1.8
Boats and Vessels	0.4	0.5	0.4	0.3	0.3	0.4
Locomotives	0.3	0.3	0.3	0.2	0.2	0.2
Other[d]	0.6	0.6	0.6	0.6	0.6	0.6
International Bunker Fuels[c]	1.0	0.9	0.9	1.0	1.0	1.0
HFCs	**+**	**9.5**	**13.5**	**17.2**	**20.6**	**23.7**
Mobile Air Conditioners[e]	+	9.5	13.5	17.2	20.6	23.7
Total[c]	**1,533.7**	**1,663.0**	**1,704.8**	**1,718.5**	**1,748.4**	**1,808.0**

+ Does not exceed 0.05 Tg CO_2 Eq.

Note: Totals may not sum due to independent rounding.

[a] Aircraft emissions consist of emissions from all jet fuel (less bunker fuels) and aviation gas consumption.

[b] "Other" CO_2 emissions include motorcycles, construction equipment, agricultural machinery, pipelines, and lubricants.

[c] Emissions from International Bunker Fuels include emissions from both civilian and military activities, but are not included in totals.

[d] "Other" CH_4 and N_2O emissions include motorcycles, construction equipment, agricultural machinery, gasoline-powered recreational, industrial, lawn and garden, light commercial, logging, airport service, other equipment; and diesel-powered recreational, industrial, lawn and garden, light construction, airport service.

[e] Includes primarily HFC-134a.

Box ES- 5: Greenhouse Gas Emissions from Electric Utilities

Like transportation, activities related to the generation, transmission, and distribution of electricity in the United States resulted in a significant fraction of total U.S. greenhouse gas emissions. The electric power industry in the United States is composed of traditional electric utilities as well as other entities, such as power marketers and nonutility power producers. Table ES-5 presents emissions from electric utility-related activities. Aggregate emissions from electric utilities of all greenhouse gases increased by 11 percent from 1990 to 1999, and accounted for a relatively constant 29 percent of U.S. emissions during the same period. Emissions from nonutility generators are not included in these estimates. Nonutilities were estimated to have produced about 15 percent of the electricity generated in the United States in 1999, up from 11 percent in 1998 (EIA 2000c). Therefore, a more complete accounting of greenhouse gas emissions from the electric power industry (i.e., utilities and nonutilities combined) would account for roughly 40 percent of U.S. CO_2 emissions (EIA 2000d).

The majority of electric utility-related emissions resulted from the combustion of coal in boilers to produce steam that is passed through a turbine to generate electricity. Overall, the generation of electricity—especially when nonutility generator are included—results in a larger portion of total U.S. greenhouse gas emissions than any other activity.

Table ES-5: Electric Utility-Related Greenhouse Gas Emissions (Tg CO_2 Eq.)

Gas/Fuel Type or Source	1990	1995	1996	1997	1998	1999
CO_2	**1,757.3**	**1,810.6**	**1,880.3**	**1,953.5**	**2,010.7**	**1,953.4**
Coal	1,509.3	1,587.7	1,677.7	1,729.7	1,744.0	1,711.9
Natural Gas	151.1	171.8	146.5	159.6	175.8	168.0
Petroleum	96.8	51.0	56.0	64.1	90.8	73.4
Geothermal	0.2	0.1	0.1	0.1	0.1	+
CH_4	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
Stationary Combustion (Utilities)	0.5	0.5	0.5	0.5	0.5	0.5
N_2O	**7.4**	**7.8**	**8.2**	**8.5**	**8.7**	**8.6**
Stationary Combustion (Utilities)	7.4	7.8	8.2	8.5	8.7	8.6
SF_6	20.5	25.7	25.7	25.7	25.7	25.7
Electrical Transmission and Distribution	20.5	25.7	25.7	25.7	25.7	25.7
Total	**1,785.7**	**1,844.5**	**1,914.7**	**1,988.2**	**2,045.6**	**1,988.2**

+ Does not exceed 0.05 Tg CO_2 Eq.
Note: Totals may not sum due to independent rounding. Excludes emissions from non-utilities, which are currently accounted for under the industrial end-use sector.

Global Warming Potentials

Gases in the atmosphere can contribute to the greenhouse effect both directly and indirectly. Direct effects occur when the gas itself is a greenhouse gas. Indirect radiative forcing occurs when chemical transformations of the original gas produce a gas or gases that are greenhouse gases, when a gas influences the atmospheric lifetimes of other gases, and/or when a gas affects other atmospheric processes that alter the radiative balance of the earth (e.g., affect cloud formation or albedo). The concept of a Global Warming Potential (GWP) has been developed to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to another gas. Carbon dioxide (CO_2) was chosen as the reference gas to be consistent with IPCC guidelines.

Global Warming Potentials are not provided for the criteria pollutants CO, NO_x, NMVOCs, and SO_2 because there is no agreed upon method to estimate the contribution of gases that are short-lived in the atmosphere and have only indirect effects on radiative forcing (IPCC 1996).

All gases in this executive summary are presented in units of teragrams of carbon dioxide equivalents (Tg CO_2 Eq.) The relationship between gigagrams (Gg) of a gas and Tg CO_2 Eq. can be expressed as follows:

$$\text{Tg CO}_2\text{ Eq.} = (\text{Gg of gas}) \times (\text{GWP}) \times \left(\frac{\text{Tg}}{1{,}000\text{ Gg}}\right)$$

The GWP of a greenhouse gas is the ratio of global warming, or radiative forcing—both direct and indirect—from one unit mass of a greenhouse gas to that of one

unit mass of carbon dioxide over a period of time. While any time period can be selected, the 100 year GWPs recommended by the IPCC and employed by the United States for policy making and reporting purposes were used in this report (IPCC 1996). GWP values are listed below in Table ES-6.

Table ES-6: Global Warming Potentials (100 Year Time Horizon)

Gas	GWP
Carbon dioxide (CO_2)	1
Methane (CH_4)*	21
Nitrous oxide (N_2O)	310
HFC-23	11,700
HFC-125	2,800
HFC-134a	1,300
HFC-143a	3,800
HFC-152a	140
HFC-227ea	2,900
HFC-236fa	6,300
HFC-4310mee	1,300
CF_4	6,500
C_2F_6	9,200
C_4F_{10}	7,000
C_6F_{14}	7,400
SF_6	23,900

Source: IPCC (1996)
* The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

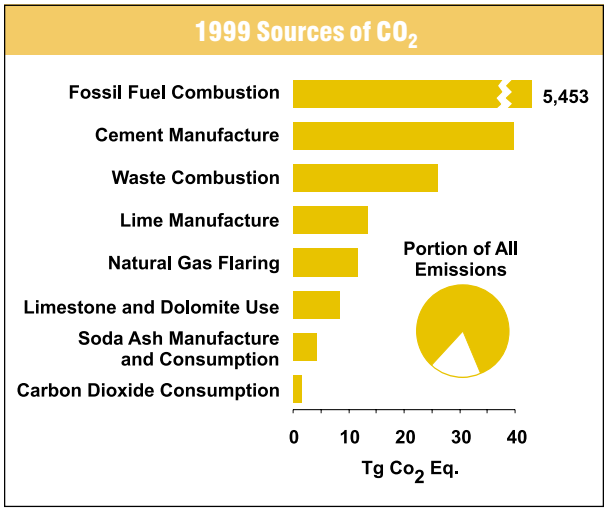
Carbon Dioxide Emissions

The global carbon cycle is made up of large carbon flows and reservoirs. Hundreds of billions of tons of carbon in the form of CO_2 are absorbed by oceans and living biomass (sinks) and are emitted to the atmosphere annually through natural processes (sources). When in equilibrium, carbon fluxes among these various reservoirs are roughly balanced.

Since the Industrial Revolution, this equilibrium of atmospheric carbon has been altered. Atmospheric concentrations of CO_2 have risen about 28 percent (IPCC 1996), principally because of fossil fuel combustion, which accounted for 98 percent of total U.S. CO_2 emissions in 1999. Changes in land use and forestry practices can also emit CO_2 (e.g., through conversion of forest land to agricultural or urban use) or can act as a sink for CO_2 (e.g., through net additions to forest biomass).

Figure ES-11 and Table ES-7 summarize U.S. sources and sinks of CO_2. The remainder of this section then discusses CO_2 emission trends in greater detail.

Figure ES-11



Energy

Energy-related activities accounted for the vast majority of U.S. CO_2 emissions for the period of 1990 through 1999. Carbon dioxide from fossil fuel combustion was the dominant contributor. In 1999, approximately 84 percent of the energy consumed in the United States was produced through the combustion of fossil fuels. The remaining 16 percent came from other energy sources such as hydropower, biomass, nuclear, wind, and solar (see Figure ES-12 and Figure ES-13). A discussion of specific trends related to CO_2 emissions from energy consumption is presented below.

Fossil Fuel Combustion

As fossil fuels are combusted, the carbon stored in them is almost entirely emitted as CO_2. The amount of carbon in fuels per unit of energy content varies significantly by fuel type. For example, coal contains the highest amount of carbon per unit of energy, while petroleum has about 25 percent less carbon than coal, and natural gas about 45 percent less. From 1990 through 1999, petroleum supplied the largest share of U.S. energy demands, accounting for an average of 39 percent of total energy consumption. Natural gas and coal followed in order of importance, accounting for an average of 24 and 23 percent of total energy consumption, respectively. Most

Table ES-7: U.S. Sources of CO_2 Emissions and Sinks (Tg CO_2 Eq.)

Source or Sink	1990	1995	1996	1997	1998	1999
Fossil Fuel Combustion	4,835.7	5,121.3	5,303.0	5,374.9	5,386.8	5,453.1
Cement Manufacture	33.3	36.8	37.1	38.3	39.2	39.9
Waste Combustion	17.6	23.1	24.0	25.7	25.1	26.0
Lime Manufacture	11.2	12.8	13.5	13.7	13.9	13.4
Natural Gas Flaring	5.1	13.6	13.0	12.0	10.8	11.7
Limestone and Dolomite Use	5.1	7.0	7.3	8.3	8.1	8.3
Soda Ash Manufacture and Consumption	4.1	4.3	4.3	4.4	4.3	4.2
Carbon Dioxide Consumption	0.8	1.0	1.1	1.3	1.4	1.6
Land-Use Change and Forestry (Sink)[a]	(1,059.9)	(1,019.1)	(1,021.6)	(981.9)	(983.3)	(990.4)
International Bunker Fuels[b]	114.0	101.0	102.2	109.8	112.8	107.3
Total Emissions	**4,913.0**	**5,219.8**	**5,403.2**	**5,478.7**	**5,489.7**	**5,558.1**
Net Emissions (Sources and Sinks)	**3,853.0**	**4,200.8**	**4,381.6**	**4,496.8**	**4,506.4**	**4,567.8**

[a] Sinks are only included in net emissions total, and are based partially on projected activity data.
[b] Emissions from International Bunker Fuels are not included in totals.
Note: Totals may not sum due to independent rounding.
Note: Parentheses indicate negative values (or sequestration).

Figure ES-12

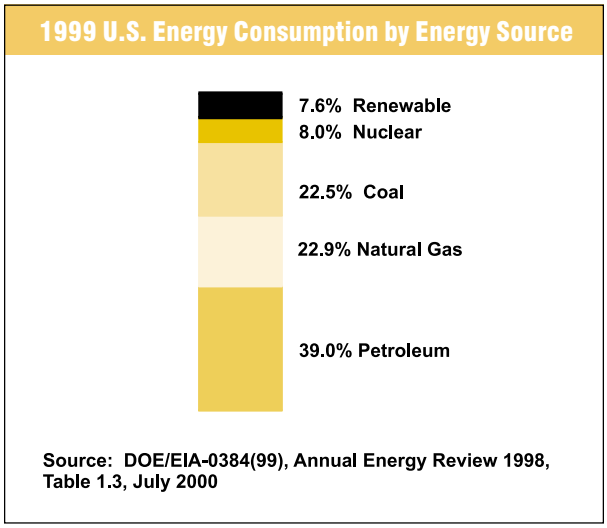
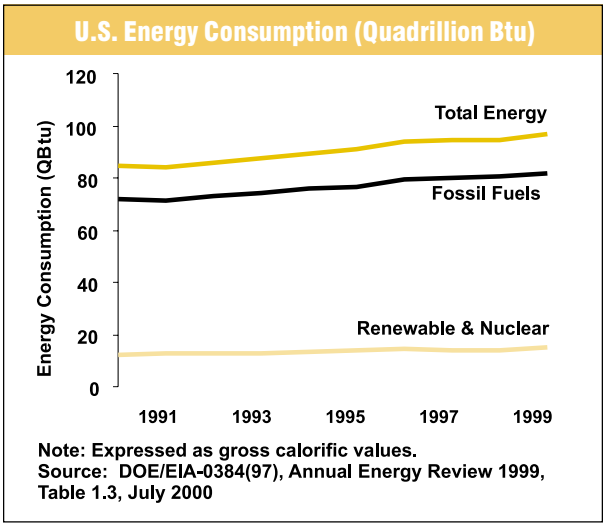


Figure ES-13



petroleum was consumed in the transportation end-use sector, while the vast majority of coal was used by electric utilities, and natural gas was consumed largely in the industrial and residential end-use sectors.

Emissions of CO_2 from fossil fuel combustion increased at an average annual rate of 1.4 percent from 1990 to 1999. The fundamental factors behind this trend include (1) a robust domestic economy, (2) relatively low energy prices as compared to 1990, (3) fuel switching by electric utilities, and (4) heavier reliance on nuclear energy. After 1990, when CO_2 emissions from fossil fuel combustion were 4,835.7 Tg CO_2 Eq., there has been a relatively steady increase to 5,453.1 Tg CO_2 Eq. in 1999. Overall, CO_2 emissions from fossil fuel combustion increased by 13 percent over the ten year period.

In 1999, fossil fuel emission trends were primarily driven by a strong economy and an increased reliance on carbon-neutral nuclear power for electricity generation. Although the price of crude oil increased over 40 percent from 1998 and relatively mild weather conditions moderated energy consumption for heating and cooling, emissions from fossil fuels still rose 1.2 percent from 1998. Emissions from the combustion of petroleum products in 1999 grew the most (64 Tg CO_2 Eq. or about 3 percent), although emissions from the combustion of petroleum by electric utilities decreased 19 percent. That decrease was

offset by increased emissions from petroleum combustion in the residential, commercial, industrial, and especially transportation end-use sectors. Emissions from the combustion of natural gas in 1999 increased slightly (5 Tg CO_2 Eq. or 0.4 percent) and emissions from coal consumption decreased slightly (3 Tg CO_2 Eq. or 0.1 percent) as the industrial end-use sector substituted more natural gas for coal in 1999.

As introduced above, the four end-use sectors contributing to CO_2 emissions from fossil fuel combustion include industrial, transportation, residential, and commercial. Electric utilities also emit CO_2, although these emissions are produced as they consume fossil fuel to provide electricity to one of the four end-use sectors. For the discussion below, electric utility emissions have been distributed to each end-use sector based upon their fraction of aggregate electricity consumption. This method of distributing emissions assumes that each end-use sector consumes electricity that is generated with the national average mix of fuels according to their carbon intensity. In reality, sources of electricity vary widely in carbon intensity. By giving equal carbon-intensity weight to each sector's electricity consumption, for example, emissions attributed to the residential sector may be overestimated, while emissions attributed to the industrial sector may be underestimated. Emissions from electric utilities are addressed separately after the end-use sectors have been discussed.

It is important to note, though, that all emissions resulting from the generation of electricity by the growing number of nonutility power plants are currently allocated to the industrial sector. Nonutilities supplied 15 percent of the electricity consumed in the United States in 1999. Emissions from U.S. territories are also calculated separately due to a lack of end-use-specific consumption data. Table ES-8, Figure ES-14, and Figure ES-15 summarize CO_2 emissions from fossil fuel combustion by end-use sector.

Industrial End-Use Sector. Industrial CO_2 emissions resulting from direct fossil fuel combustion and from the generation of electricity by utilities consumed by industry accounted for 33 percent of CO_2 from fossil fuel combustion in 1999. About two-thirds of these emissions resulted from direct fossil fuel combustion to produce steam and/or heat for industrial processes or by non-utilities to generate electricity, the latter of which is growing rapidly. The remaining third of emissions resulted from consuming electricity from electric utilities for motors, electric furnaces, ovens, lighting, and other applications.

Transportation End-Use Sector. Transportation activities—excluding international bunker fuels—accounted for 31 percent of CO_2 emissions from fossil fuel combustion in 1999.[13] Virtually all of the energy consumed in this end-use sector came from petroleum products. Just under two thirds of the emissions resulted from gasoline consumption in motor vehicles. The remaining emissions came from other transportation activities, including the combustion of diesel fuel in heavy-duty vehicles and jet fuel in aircraft.

Residential and Commercial End-Use Sectors. The residential and commercial end-use sectors accounted for 19 and 16 percent, respectively, of CO_2 emissions from fossil fuel con-

Table ES-8: CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector (Tg CO_2 Eq.)*

End-Use Sector	1990	1995	1996	1997	1998	1999
Industrial	1,636.0	1,709.5	1,766.0	1,783.6	1,758.8	1,783.9
Transportation	1,474.4	1,581.8	1,621.2	1,631.4	1,659.0	1,716.4
Residential	930.7	988.7	1,047.5	1,044.2	1,040.9	1,035.8
Commercial	760.8	797.2	828.2	872.9	880.2	864.0
U.S. Territories	33.7	44.0	40.1	42.8	47.9	53.0
Total	**4,835.7**	**5,121.3**	**5,303.0**	**5,374.9**	**5,386.8**	**5,453.1**

* Emissions from electric utilities are allocated based on aggregate electricity consumption in each end-use sector.

[13] If emissions from international bunker fuels are included, the transportation end-use sector accounted for 33 percent of U.S. emissions from fossil fuel combustion in 1999.

Figure ES-14

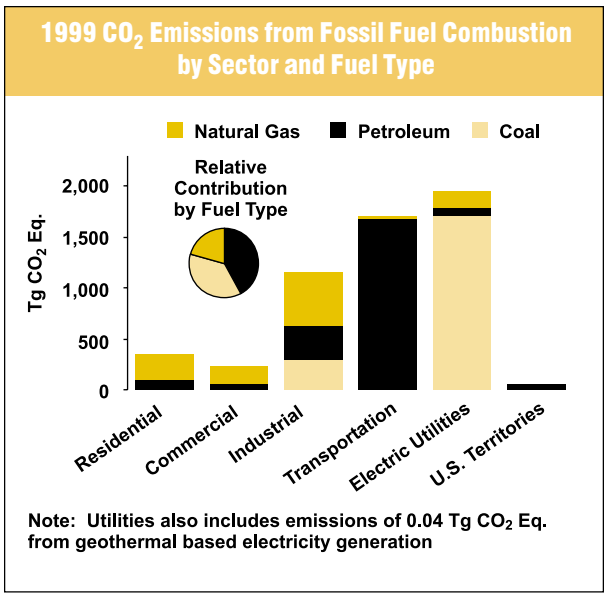
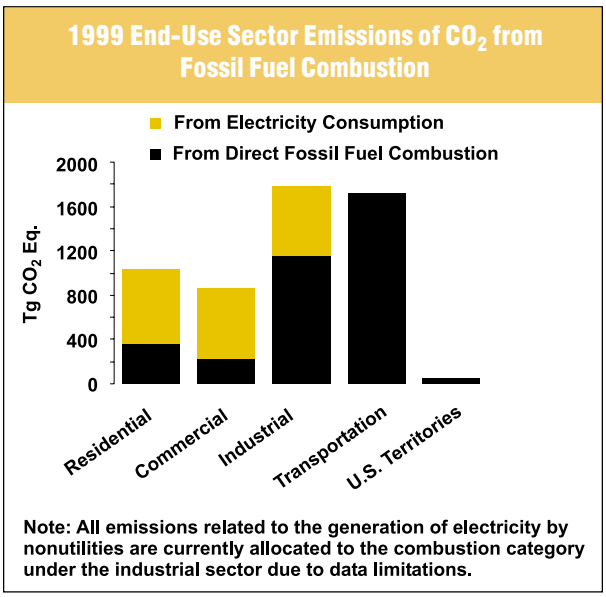


Figure ES-15



sumption in 1999. Both sectors relied heavily on electricity for meeting energy needs, with 66 and 74 percent, respectively, of their emissions attributable to electricity consumption for lighting, heating, cooling, and operating appliances. The remaining emissions were largely due to the consumption of natural gas and petroleum, primarily for meeting heating and cooking needs.

Electric Utilities. The United States relies on electricity to meet a significant portion of its energy demands, especially for lighting, electric motors, heating, and air conditioning. Electric utilities are responsible for consuming 27 percent of U.S. energy from fossil fuels and emitted 36 percent of the CO_2 from fossil fuel combustion in 1999. The type of fuel combusted by utilities has a significant effect on their emissions. For example, some electricity is generated with low CO_2 emitting energy technologies, particularly non-fossil options such as nuclear, hydroelectric, or geothermal energy. However, electric utilities rely on coal for over half of their total energy requirements and accounted for 85 percent of all coal consumed in the United States in 1999. Consequently, changes in electricity demand have a significant impact on coal consumption and associated CO_2 emissions. Note, again, that all emissions resulting from the generation of electricity by nonutility plants are currently allocated to the industrial end-use sector.

Natural Gas Flaring

Carbon dioxide is produced when natural gas from oil wells is flared (i.e., combusted) to relieve rising pressure or to dispose of small quantities of gas that are not commercially marketable. In 1999, flaring activities emitted approximately 11.7 Tg CO_2 Eq., or about 0.2 percent of U.S. CO_2 emissions.

Biomass Combustion

Biomass—in the form of fuel wood and wood waste—was used primarily by the industrial end-use sector, while the transportation end-use sector was the predominant user of biomass-based fuels, such as ethanol from corn and woody crops. Ethanol and ethanol blends, such as gasohol, are typically used to fuel public transport vehicles.

Although these fuels do emit CO_2, in the long run the CO_2 emitted from biofuel consumption does not increase atmospheric CO_2 concentrations if the biogenic carbon emitted is offset by the growth of new biomass. For example, fuel wood burned one year but re-grown the next only recycles carbon, rather than creating a net increase in total atmospheric carbon. Net carbon fluxes from changes in biogenic carbon reservoirs in wooded or croplands are accounted for under Land-Use Change and Forestry.

Gross CO_2 emissions from biomass combustion were 234.1 Tg CO_2 Eq. in 1999, with the industrial sector accounting for 81 percent of the emissions, and the residential sector 14 percent. Ethanol consumption by the transportation sector accounted for only 3 percent of CO_2 emissions from biomass combustion.

Industrial Processes

Emissions are produced as a by-product of many non-energy-related activities. For example, industrial processes can chemically transform raw materials. This transformation often releases greenhouse gases such as CO_2. The major production processes that emit CO_2 include cement manufacture, lime manufacture, limestone and dolomite use (e.g., in iron and steel making), soda ash manufacture and consumption, and CO_2 consumption. Total CO_2 emissions from these sources were approximately 67.4 Tg CO_2 Eq. in 1999, accounting for about 1 percent of total CO_2 emissions. Since 1990, emissions from each of these sources increased, except for emissions from soda ash manufacture and consumption, which has remained relatively constant.

Cement Manufacture (39.9 Tg CO_2 Eq.)

Carbon dioxide is produced primarily during the production of clinker, an intermediate product from which finished Portland and masonry cement are made. Specifically, CO_2 is created when calcium carbonate ($CaCO_3$) is heated in a cement kiln to form lime and CO_2. This lime combines with other materials to produce clinker, while the CO_2 is released into the atmosphere.

Lime Manufacture (13.4 Tg CO_2 Eq.)

Lime is used in steel making, construction, pulp and paper manufacturing, and water and sewage treatment. It is manufactured by heating limestone (mostly calcium carbonate, $CaCO_3$) in a kiln, creating calcium oxide (quicklime) and CO_2, which is normally emitted to the atmosphere.

Limestone and Dolomite Use (8.3 Tg CO_2 Eq.)

Limestone ($CaCO_3$) and dolomite ($CaCO_3MgCO_3$) are basic raw materials used by a wide variety of industries, including the construction, agriculture, chemical, and metallurgical industries. For example, limestone can be used as a purifier in refining metals. In the case of iron ore, limestone heated in a blast furnace reacts with impurities in the iron ore and fuels, generating CO_2 as a by-product. Limestone is also used in flue gas desulfurization systems to remove sulfur dioxide from the exhaust gases.

Soda Ash Manufacture and Consumption (4.2 Tg CO_2 Eq.)

Commercial soda ash (sodium carbonate, Na_2CO_3) is used in many consumer products, such as glass, soap and detergents, paper, textiles, and food. During the manufacturing of soda ash, some natural sources of sodium carbonate are heated and transformed into a crude soda ash, in which CO_2 is generated as a by-product. In addition, CO_2 is often released when the soda ash is consumed.

Carbon Dioxide Consumption (1.6 Tg CO_2 Eq.)

Carbon dioxide is used directly in many segments of the economy, including food processing, beverage manufacturing, chemical processing, and a host of industrial and other miscellaneous applications. For the most part, the CO_2 used in these applications is eventually released to the atmosphere.

Land-Use Change and Forestry

Land-Use Change and Forestry (Sink) (990.4 Tg CO_2 Eq.)

When humans alter the terrestrial biosphere through land use, changes in land-use, and forest management practices, they alter the natural carbon flux between biomass, soils, and the atmosphere. Forest management practices, the management of agricultural soils, and landfilling of yard trimmings have resulted in a net uptake (sequestration) of carbon in the United States that is equivalent to about 15 percent of total U.S. gross emissions. Forests (including vegetation, soils, and harvested wood) accounted for approximately 91 percent of the total sequestration, agricultural soils (including mineral and organic soils and the application of lime) accounted for 8 percent, and landfilled yard trim-

mings accounted for less than 1 percent of the total sequestration. The net forest sequestration is largely a result of improved forest management practices, the regeneration of previously cleared forest areas, and timber harvesting. In agricultural soils, mineral soils account for a net carbon sink that is more than three times larger than the sum of emissions from organic soils and liming. Net sequestration in agricultural mineral soils is largely due to improved cropland and grazing land management practices, especially the adoption of conservation tillage practices and leaving residues on the field after harvest, and to taking erodable lands out of production and planting them with grass or trees through the Conservation Reserve Program. The landfilled yard trimmings net sequestration is due to the long-term accumulation of yard trimming carbon in landfills.

Waste

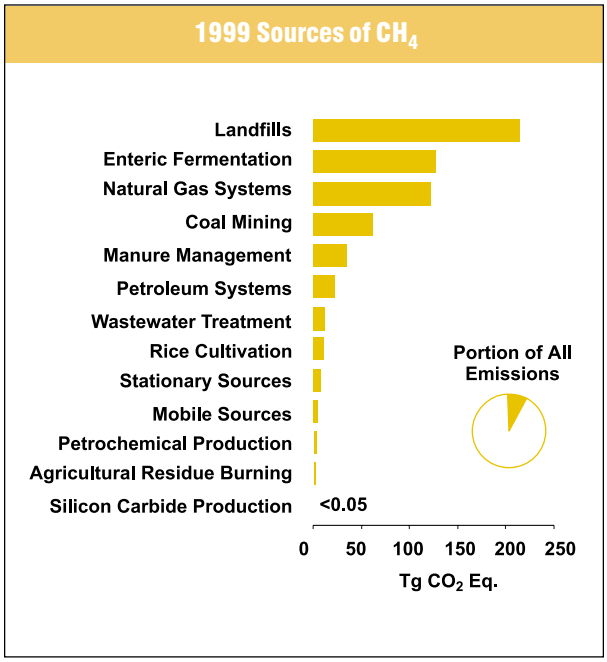
Waste Combustion (26.0 Tg CO_2 Eq.)

Waste combustion involves the burning of garbage and non-hazardous solids, referred to as municipal solid waste (MSW), as well as the burning of hazardous waste. Carbon dioxide emissions arise from the organic (i.e., carbon) materials found in these wastes. Within MSW, many products contain carbon of biogenic origin, and the CO_2 emissions from their combustion are reported under the Land-Use Change and Forestry Chapter. However, several components of MSW—plastics, synthetic rubber, synthetic fibers, and carbon black—are of fossil fuel origin, and are included as sources of CO_2 emissions.

Methane Emissions

Atmospheric methane (CH_4) is an integral component of the greenhouse effect, second only to CO_2 as a contributor to anthropogenic greenhouse gas emissions. Methane's overall contribution to global warming is significant because it has been estimated to be 21 times more effective at trapping heat in the atmosphere than CO_2 (i.e., the GWP value of methane is 21). Over the last two centuries, methane's concentration in the atmosphere has more than doubled (IPCC 1996). Experts believe these atmospheric increases were due largely to increasing emissions from anthropogenic sources, such as landfills, natural gas and petroleum systems, agricultural activities, coal mining, stationary and mobile combustion, wastewater treatment, and certain industrial processes (see Figure ES-16 and Table ES-9).

Figure ES-16



Landfills

Landfills are the largest source of anthropogenic methane emissions in the United States. In an environment where the oxygen content is low or nonexistent, organic materials, such as yard waste, household waste, food waste, and paper, can be decomposed by bacteria, resulting in the generation of methane and biogenic CO_2. Methane emissions from landfills are affected by site-specific factors such as waste composition, moisture, and landfill size.

Methane emissions from U.S. landfills in 1999 were 214.6 Tg CO_2 Eq., down 1 percent since 1990. The relatively constant emission estimates are a result of two offsetting trends: (1) the amount of municipal solid waste in landfills contributing to methane emissions has increased, thereby increasing the potential for emissions; and (2) the amount of landfill gas collected and combusted by landfill operators has also increased, thereby reducing emissions. Emissions from U.S. municipal solid waste landfills accounted for 94 percent of total landfill emissions, while industrial landfills accounted for the remainder. Approximately 28 percent of the methane generated

Table ES-9: U.S. Sources of Methane Emissions (Tg CO_2 Eq.)

Source	1990	1995	1996	1997	1998	1999
Landfills	217.3	222.9	219.1	217.8	213.6	214.6
Enteric Fermentation	129.5	136.3	132.2	129.6	127.5	127.2
Natural Gas Systems	121.2	124.2	125.8	122.7	122.1	121.8
Coal Mining	87.9	74.6	69.3	68.8	66.5	61.8
Manure Management	26.4	31.0	30.7	32.6	35.2	34.4
Petroleum Systems	27.2	24.5	24.0	24.0	23.3	21.9
Wastewater Treatment	11.2	11.8	11.9	12.0	12.1	12.2
Rice Cultivation	8.7	9.5	8.8	9.6	10.1	10.7
Stationary Combustion	8.5	8.9	9.0	8.1	7.6	8.1
Mobile Combustion	5.0	4.9	4.8	4.7	4.6	4.5
Petrochemical Production	1.2	1.5	1.6	1.6	1.6	1.7
Agricultural Residue Burning	0.5	0.5	0.6	0.6	0.6	0.6
Silicon Carbide Production	+	+	+	+	+	+
International Bunker Fuels*	+	+	+	+	+	+
Total*	**644.5**	**650.5**	**638.0**	**632.0**	**624.8**	**619.6**

+ Does not exceed 0.05 Tg CO_2 Eq.
* Emissions from International Bunker Fuels are not included in totals.
Note: Totals may not sum due to independent rounding.

in U.S. landfills in 1999 was recovered and combusted, often for energy.

A regulation promulgated in March 1996 requires the largest U.S. landfills to begin collecting and combusting their landfill gas to reduce emissions of NMVOCs. It is estimated that by the year 2000, this regulation will have reduced landfill methane emissions by more than 50 percent.

Natural Gas and Petroleum Systems

Methane is the major component of natural gas. During the production, processing, transmission, and distribution of natural gas, fugitive emissions of methane often occur. Because natural gas is often found in conjunction with petroleum deposits, leakage from petroleum systems is also a source of emissions. Emissions vary greatly from facility to facility and are largely a function of operation and maintenance procedures and equipment conditions. In 1999, methane emissions from U.S. natural gas systems were estimated to be 121.8 Tg CO_2 Eq., accounting for approximately 20 percent of U.S. methane emissions.

Petroleum is found in the same geological structures as natural gas, and the two are retrieved together. Methane is also saturated in crude oil, and volatilizes as the oil is exposed to the atmosphere at various points along the system. Methane emissions from the components of petroleum systems—including crude oil production, crude oil refining, transportation, and distribution—generally occur as a result of system leaks, disruptions, and routine maintenance. In 1999, emissions from petroleum systems were estimated to be 21.9 Tg CO_2 Eq., or just under 4 percent of U.S. methane emissions.

From 1990 to 1999, combined methane emissions from natural gas and petroleum systems decreased by 3 percent. Emissions from natural gas systems have remained fairly constant, while emissions from petroleum systems have declined gradually since 1990 primarily due to production declines.

Coal Mining

Produced millions of years ago during the formation of coal, methane trapped within coal seams and surrounding rock strata is released when the coal is mined. The quantity of methane released to the atmosphere during coal mining operations depends primarily upon the depth and type of the coal that is mined.

Methane from surface mines is emitted directly to the atmosphere as the rock strata overlying the coal seam are removed. Because methane in underground mines is explosive at concentrations of 5 to 15 percent in air, most active underground mines are required to vent this methane, typically to the atmosphere. At some mines, methane-recovery systems may supplement these ventilation sys-

tems. Recovery of methane in the United States has increased in recent years. During 1999, coal mining activities emitted 61.8 Tg CO_2 Eq. of methane, or 10 percent of U.S. methane emissions. From 1990 to 1999, emissions from this source decreased by 30 percent due to increased use of the methane collected by mine degasification systems.

Agriculture

Agriculture accounted for 28 percent of U.S. methane emissions in 1999, with enteric fermentation in domestic livestock, manure management, and rice cultivation accounting for the majority. Agricultural waste burning also contributed to methane emissions from agricultural activities.

Enteric Fermentation (127.2 Tg CO_2 Eq.)

During animal digestion, methane is produced through the process of enteric fermentation, in which microbes residing in animal digestive systems break down the feed consumed by the animal. Ruminants, which include cattle, buffalo, sheep, and goats, have the highest methane emissions among all animal types because they have a rumen, or large fore-stomach, in which methane-producing fermentation occurs. Non-ruminant domestic animals, such as pigs and horses, have much lower methane emissions. In 1999, enteric fermentation was the source of about 21 percent of U.S. methane emissions, and more than half of the methane emissions from agriculture. From 1990 to 1999, emissions from this source decreased by 2 percent. Emissions from enteric fermentation have been generally decreasing since 1995, primarily due to declining dairy cow and beef cattle populations.

Manure Management (34.4 Tg CO_2 Eq.)

The decomposition of organic animal waste in an anaerobic environment produces methane. The most important factor affecting the amount of methane produced is how the manure is managed, because certain types of storage and treatment systems promote an oxygen-free environment. In particular, liquid systems tend to encourage anaerobic conditions and produce significant quantities of methane, whereas solid waste management approaches produce little or no methane. Higher temperatures and moist climatic conditions also promote methane production.

Emissions from manure management were about 6 percent of U.S. methane emissions in 1999, and 20 percent of the methane emissions from agriculture. From 1990 to 1999, emissions from this source increased by 8.0 Tg CO_2 Eq.—the largest absolute increase of all the methane source categories. The bulk of this increase was from swine and dairy cow manure, and is attributed to the shift in the composition of the swine and dairy industries towards larger facilities. Larger swine and dairy farms tend to use liquid management systems.

Rice Cultivation (10.7 Tg CO_2 Eq.)

Most of the world's rice, and all of the rice in the United States, is grown on flooded fields. When fields are flooded, anaerobic conditions develop and the organic matter in the soil decomposes, releasing methane to the atmosphere, primarily through the rice plants. In 1999, rice cultivation was the source of 2 percent of U.S. methane emissions, and about 6 percent of U.S. methane emissions from agriculture. Emission estimates from this source have increased about 23 percent since 1990, due to an increase in the area harvested.

Agricultural Residue Burning (0.6 Tg CO_2 Eq.)

Burning crop residue releases a number of greenhouse gases, including methane. Because field burning is not common in the United States, it was responsible for only 0.1 percent of U.S. methane emissions in 1999.

Other Sources

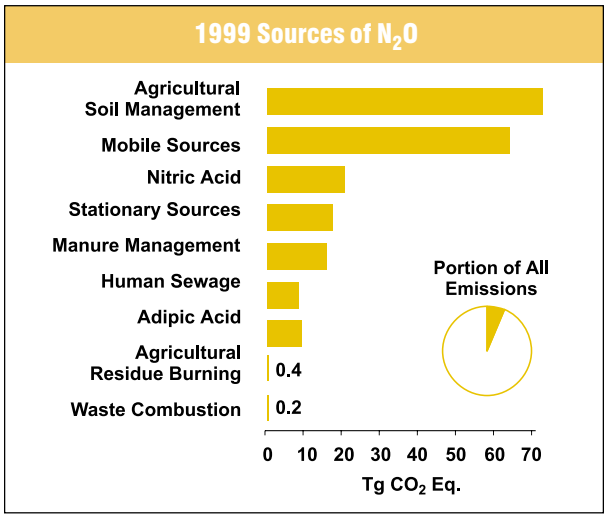
Methane is also produced from several other sources in the United States, including wastewater treatment, fuel combustion, and some industrial processes. Methane emissions from domestic wastewater treatment totaled 12.2 Tg CO_2 Eq. in 1999. Stationary and mobile combustion were responsible for methane emissions of 8.1 and 4.5 Tg CO_2 Eq., respectively. The majority of emissions from stationary combustion resulted from the burning of wood in the residential end-use sector. The combustion of gasoline in highway vehicles was responsible for the majority of the methane emitted from mobile combustion. Methane emissions from two industrial

sources—petrochemical and silicon carbide production—were also estimated, totaling 1.7 Tg CO_2 Eq.

Nitrous Oxide Emissions

Nitrous oxide (N_2O) is a greenhouse gas that is produced both naturally—from a wide variety of biological sources in soil and water—and anthropogenically by a variety of agricultural, energy-related, industrial, and waste management activities. While total N_2O emissions are much smaller than CO_2 emissions, N_2O is approximately 310 times more powerful than CO_2 at trapping heat in the atmosphere (IPCC 1996). During the past two centuries, atmospheric concentrations of N_2O have risen by approximately 13 percent. The main anthropogenic activities producing N_2O in the United States were agricultural soil management, fuel combustion in motor vehicles, and adipic and nitric acid production processes (see Figure ES-17 and Table ES-10).

Figure ES-17



Agricultural Soil Management

Nitrous oxide (N_2O) is produced naturally in soils through microbial processes of nitrification and denitrification. A number of anthropogenic activities add to the amount of nitrogen available to be emitted as N_2O by these microbial processes. These activities may add nitrogen to soils either directly or indirectly. Direct additions occur through the application of synthetic and organic fertilizers; production of nitrogen-fixing crops; the application of livestock manure, crop residues, and sewage sludge; cultivation of high-organic-content soils; and direct excretion by animals onto soil. Indirect additions result from volatilization and subsequent atmospheric deposition, and from leaching and surface run-off, of some of the nitrogen applied to soils as fertilizer, livestock manure, and sewage sludge.

In 1999, agricultural soil management accounted for 298.3 Tg CO_2 Eq., or 69 percent of U.S. N_2O emissions. From 1990 to 1999, emissions from this source increased by 11 percent as fertilizer consumption, manure production, and crop production rose.

Fuel Combustion

Nitrous oxide is a product of the reaction that occurs between nitrogen and oxygen during fuel combustion. Both mobile and stationary combustion emit N_2O, and the quantity emitted varies according to the type of

Table ES-10: U.S. Sources of Nitrous Oxide Emissions (Tg CO_2 Eq.)

Source	1990	1995	1996	1997	1998	1999
Agricultural Soil Management	269.0	285.4	294.6	299.8	300.3	298.3
Mobile Combustion	54.3	66.8	65.3	65.2	64.2	63.4
Nitric Acid	17.8	19.9	20.7	21.2	20.9	20.2
Manure Management	16.0	16.4	16.8	17.1	17.2	17.2
Stationary Combustion	13.6	14.3	14.9	15.0	15.1	15.7
Adipic Acid	18.3	20.3	20.8	17.1	7.3	9.0
Human Sewage	7.1	8.2	7.8	7.9	8.1	8.2
Agricultural Residue Burning	0.4	0.4	0.4	0.4	0.5	0.4
Waste Combustion	0.3	0.3	0.3	0.3	0.2	0.2
International Bunker Fuels*	1.0	0.9	0.9	1.0	1.0	1.0
Total*	**396.9**	**431.9**	**441.6**	**444.1**	**433.7**	**432.6**

* Emissions from International Bunker Fuels are not included in totals.
Note: Totals may not sum due to independent rounding.

fuel, technology, and pollution control device used, as well as maintenance and operating practices. For example, catalytic converters installed to reduce motor vehicle pollution can result in the formation of N_2O.

In 1999, N_2O emissions from mobile combustion totaled 63.4 Tg CO_2 Eq., or 15 percent of U.S. N_2O emissions. Emissions of N_2O from stationary combustion were 15.7 Tg CO_2 Eq., or 4 percent of U.S. N_2O emissions. From 1990 to 1999, combined N_2O emissions from stationary and mobile combustion increased by 16 percent, primarily due to increased rates of N_2O generation in motor vehicles.

Adipic Acid Production

The majority of the adipic acid produced in the United States is used to manufacture nylon 6,6. Adipic acid is also used to produce some low-temperature lubricants and to add a "tangy" flavor to foods. Nitrous oxide is emitted as a by-product of the chemical synthesis of adipic acid.

In 1999, U.S. adipic acid plants emitted 9.0 Tg CO_2 Eq. of N_2O, or 2 percent of U.S. N_2O emissions. Even though adipic acid production has increased, by 1998, all three major adipic acid plants in the United States had voluntarily implemented N_2O abatement technology. As a result, emissions have decreased by 51 percent since 1990.

Nitric Acid Production

Nitric acid production is another industrial source of N_2O emissions. Used primarily to make synthetic commercial fertilizer, this raw material is also a major component in the production of adipic acid and explosives.

Virtually all of the nitric acid manufactured in the United States is produced by the oxidation of ammonia, during which N_2O is formed and emitted to the atmosphere. In 1999, N_2O emissions from nitric acid production were 20.2 Tg CO_2 Eq., or 5 percent of U.S. N_2O emissions. From 1990 to 1999, emissions from this source category increased by 13 percent as nitric acid production grew.

Manure Management

Nitrous oxide is produced as part of microbial nitrification and denitrification processes in managed and unmanaged manure, the latter of which is addressed under agricultural soil management. Total N_2O emissions from managed manure systems in 1999 were 17.2 Tg CO_2 Eq., accounting for 4 percent of U.S. N_2O emissions. From 1990 to 1999, emissions from this source category increased by 7 percent, as poultry and swine populations have increased.

Other Sources

Other sources of N_2O included agricultural residue burning, waste combustion, and human sewage in wastewater treatment systems. In 1999, agricultural residue burning and municipal solid waste combustion each emitted less than 1 Tg CO_2 Eq. of N_2O. The human sewage component of domestic wastewater resulted in emissions of 8.2 Tg CO_2 Eq. in 1999.

HFC, PFC, and SF_6 Emissions

Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are categories of synthetic chemicals that are being used as alternatives to the ozone depleting substances (ODSs), which are being phased out under the *Montreal Protocol* and Clean Air Act Amendments of 1990. Because HFCs and PFCs do not directly deplete the stratospheric ozone layer, they are not controlled by the *Montreal Protocol*.

These compounds, however, along with sulfur hexafluoride (SF_6), are potent greenhouse gases. In addition to having high global warming potentials, SF_6 and PFCs have extremely long atmospheric lifetimes, resulting in their essentially irreversible accumulation in the atmosphere. Sulfur hexafluoride is the most potent greenhouse gas the IPCC has evaluated.

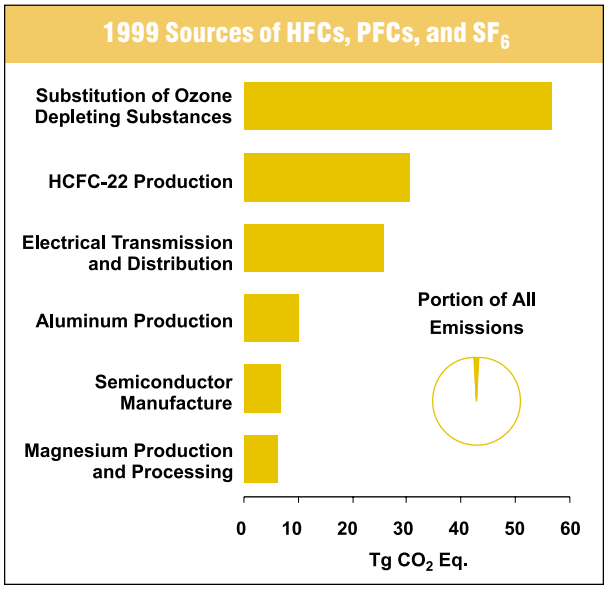
Other emissive sources of these gases include aluminum production, HCFC-22 production, semiconductor manufacturing, electrical transmission and distribution systems, and magnesium production and processing. Figure ES-18 and Table ES-11 present emission estimates for HFCs, PFCs, and SF_6, which totaled 135.7 Tg CO_2 Eq. in 1999.

Table ES-11: Emissions of HFCs, PFCs, and SF_6 (Tg CO_2 Eq.)

Source	1990	1995	1996	1997	1998	1999
Substitution of Ozone Depleting Substances	0.9	24.0	34.0	42.1	49.6	56.7
HCFC-22 Production	34.8	27.1	31.2	30.1	40.0	30.4
Electrical Transmission and Distribution	20.5	25.7	25.7	25.7	25.7	25.7
Aluminum Production	19.3	11.2	11.6	10.8	10.1	10.0
Semiconductor Manufacture	2.9	5.5	7.0	7.0	6.8	6.8
Magnesium Production and Processing	5.5	5.5	5.6	7.5	6.3	6.1
Total	**83.9**	**99.0**	**115.1**	**123.3**	**138.6**	**135.7**

Note: Totals may not sum due to independent rounding.

Figure ES-18



Substitution of Ozone Depleting Substances

The use and subsequent emissions of HFCs and PFCs as substitutes for ozone depleting substances (ODS) increased from small amounts in 1990 to 56.7 Tg CO_2 Eq. in 1999. This increase was the result of efforts to phase-out CFCs and other ODSs in the United States, especially the introduction of HFC-134a as a CFC substitute in refrigeration applications. In the short term, this trend is expected to continue, and will likely accelerate in the next decade as HCFCs, which are interim substitutes in many applications, are themselves phased-out under the provisions of the Copenhagen Amendments to the *Montreal Protocol.* Improvements in the technologies associated with the use of these gases, however, may help to offset this anticipated increase in emissions.

Other Industrial Sources

HFCs, PFCs, and SF_6 are also emitted from a number of other industrial processes. During the production of primary aluminum, two PFCs—CF_4 and C_2F_6—are emitted as intermittent by-products of the smelting process. Emissions from aluminum production, which totaled 10.0 Tg CO_2 Eq. were estimated to have decreased by 48 percent between 1990 and 1999 due to voluntary emission reduction efforts by the industry and falling domestic aluminum production.

HFC-23 is a by-product emitted during the production of HCFC-22. Emissions from this source were 30.4 Tg CO_2 Eq. in 1999, and have decreased by 13 percent since 1990. The intensity of HFC-23 emissions (i.e., the amount of HFC-23 emitted per kilogram of HCFC-22 manufactured) has declined significantly since 1990, although production has been increasing.

The semiconductor industry uses combinations of HFCs, PFCs, SF_6, and other gases for plasma etching and to clean chemical vapor deposition tools. For 1999, it was estimated that the U.S. semiconductor industry emitted a total of 6.8 Tg CO_2 Eq. Emissions from this source category have increased with the growth in the semiconductor industry and the rising intricacy of chip designs.

The primary use of SF_6 is as a dielectric in electrical transmission and distribution systems. Fugitive emissions of SF_6 occur from leaks in and servicing of substations and circuit breakers, especially from older equipment. Estimated emissions from this source increased by 25 percent since 1990, to 25.7 Tg CO_2 Eq. in 1999.

Box ES-6: Emissions of Ozone Depleting Substances

Chlorofluorocarbons (CFCs) and other halogenated compounds were first emitted into the atmosphere this century. This family of man-made compounds includes CFCs, halons, methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). These substances have been used in a variety of industrial applications, including refrigeration, air conditioning, foam blowing, solvent cleaning, sterilization, fire extinguishing, coatings, paints, and aerosols.

Because these compounds have been shown to deplete stratospheric ozone, they are typically referred to as ozone depleting substances (ODSs). However, they are also potent greenhouse gases.

Recognizing the harmful effects of these compounds on the ozone layer, in 1987 many governments signed the *Montreal Protocol on Substances that Deplete the Ozone Layer* to limit the production and importation of a number of CFCs and other halogenated compounds. The United States furthered its commitment to phase-out ODSs by signing and ratifying the Copenhagen Amendments to the *Montreal Protocol* in 1992. Under these amendments, the United States committed to ending the production and importation of halons by 1994, and CFCs by 1996.

The IPCC Guidelines and the UNFCCC do not include reporting instructions for estimating emissions of ODSs because their use is being phased-out under the *Montreal Protocol*. The United States believes, however, that a greenhouse gas emissions inventory is incomplete without these emissions; therefore, estimates for several Class I and Class II ODSs are provided in Table ES-12. Compounds are grouped by class according to their ozone depleting potential. Class I compounds are the primary ODSs; Class II compounds include partially halogenated chlorine compounds (i.e., HCFCs), some of which were developed as interim replacements for CFCs. Because these HCFC compounds are only partially halogenated, their hydrogen-carbon bonds are more vulnerable to oxidation in the troposphere and, therefore, pose only one-tenth to one-hundredth the threat to stratospheric ozone compared to CFCs.

It should be noted that the effects of these compounds on radiative forcing are not provided. Although many ODSs have relatively high direct GWPs, their indirect effects from ozone—also a greenhouse gas—destruction are believed to have negative radiative forcing effects, and therefore could significantly reduce the overall magnitude of their radiative forcing effects. Given the uncertainties surrounding the net effect of these gases, emissions are reported on an unweighted basis.

Table ES-12: Emissions of Ozone Depleting Substances (Gg)

Compound	1990	1995	1996	1997	1998	1999
Class I						
CFC-11	52.4	19.1	11.7	10.7	9.8	9.2
CFC-12	226.9	71.1	72.2	63.6	54.9	64.4
CFC-113	39.0	7.6	+	+	+	+
CFC-114	0.7	0.8	0.8	0.8	0.6	+
CFC-115	2.2	1.6	1.6	1.4	1.1	1.1
Carbon Tetrachloride	25.1	5.5	+	+	+	+
Methyl Chloroform	27.9	8.7	1.6	+	+	+
Halon-1211	+	0.7	0.8	0.8	0.8	0.8
Halon-1301	1.0	1.8	1.9	1.9	1.9	1.9
Class II						
HCFC-22	33.9	46.2	48.8	50.6	52.3	83.0
HCFC-123	+	0.6	0.7	0.8	0.9	1.0
HCFC-124	+	5.6	5.9	6.2	6.4	6.5
HCFC-141b	+	20.6	25.4	25.1	26.7	28.7
HCFC-142b	+	7.3	8.3	8.7	9.0	9.5
HCFC-225ca/cb	+	+	+	+	+	+

Source: EPA
+ Does not exceed 0.05 Gg

Lastly, SF_6 is also used as a protective covergas for the casting of molten magnesium. Estimated emissions from primary magnesium production and magnesium casting were 6.1 Tg CO_2 Eq. in 1999, an increase of 11 percent since 1990.

Criteria Pollutant Emissions

In the United States, carbon monoxide (CO), nitrogen oxides (NO_x), nonmethane volatile organic compounds (NMVOCs), and sulfur dioxide (SO_2) are commonly referred to as "criteria pollutants," as termed in the Clean Air Act. Criteria pollutants do not have a direct global warming effect, but indirectly affect terrestrial radiation absorption by influencing the formation and destruction of tropospheric and stratospheric ozone, or, in the case of SO_2, by affecting the absorptive characteristics of the atmosphere. Carbon monoxide is produced when carbon-containing fuels are combusted incompletely. Nitrogen oxides (i.e., NO and NO_2) are created by lightning, fires, fossil fuel combustion, and in the stratosphere from nitrous oxide (N_2O). NMVOCs—which include such compounds as propane, butane, and ethane—are emitted primarily from transportation, industrial processes, and non-industrial consumption of organic solvents. In the United States, SO_2 is primarily emitted from the combustion of coal by the electric power industry and by the metals industry.

In part because of their contribution to the formation of urban smog—and acid rain in the case of SO_2 and NO_x—criteria pollutants are regulated under the Clean Air Act. These gases also indirectly affect the global climate by reacting with other chemical compounds in the atmosphere to form compounds that are greenhouse gases. Unlike other criteria pollutants, SO_2 emitted into the atmosphere is believed to affect the Earth's radiative budget negatively; therefore, it is discussed separately.

One of the most important indirect climate change effects of criteria pollutants is their role as precursors for tropospheric ozone formation. They can also alter the atmospheric lifetimes of other greenhouse gases. For example, CO interacts with the hydroxyl radical—the major atmospheric sink for methane emissions—to form CO_2. Therefore, increased atmospheric concentrations of CO limit the number of hydroxyl molecules (OH) available to destroy methane.

Since 1970, the United States has published estimates of annual emissions of criteria pollutants (EPA 2000).[14] Table ES-13 shows that fuel combustion accounts for the majority of emissions of these gases. Industrial processes—such as the manufacture of chemical and allied products, metals processing, and industrial uses of solvents—are also significant sources of CO, NO_x, and NMVOCs.

Box ES-7: Sources and Effects of Sulfur Dioxide

Sulfur dioxide (SO_2) emitted into the atmosphere through natural and anthropogenic processes affects the Earth's radiative budget through its photochemical transformation into sulfate aerosols that can (1) scatter sunlight back to space, thereby reducing the radiation reaching the Earth's surface; (2) affect cloud formation; and (3) affect atmospheric chemical composition (e.g., stratospheric ozone, by providing surfaces for heterogeneous chemical reactions). The overall effect of SO_2 derived aerosols on radiative forcing is believed to be negative (IPCC 1996). However, because SO_2 is short-lived and unevenly distributed in the atmosphere, its radiative forcing impacts are highly uncertain.

Sulfur dioxide is also a major contributor to the formation of urban smog, which can cause significant increases in acute and chronic respiratory diseases. Once SO_2 is emitted, it is chemically transformed in the atmosphere and returns to the Earth as the primary source of acid rain. Because of these harmful effects, the United States has regulated SO_2 emissions in the Clean Air Act.

Electric utilities are the largest source of SO_2 emissions in the United States, accounting for 67 percent in 1999. Coal combustion contributes nearly all of those emissions (approximately 93 percent). Sulfur dioxide emissions have decreased in recent years, primarily as a result of electric utilities switching from high sulfur to low sulfur coal.

[14] NO_x and CO emission estimates from agricultural residue burning were estimated separately, and therefore not taken from EPA (2000).

Table ES-13: Emissions of NO_x, CO, NMVOCs, and SO_2 (Gg)

Gas/Activity	1990	1995	1996	1997	1998	1999
NO_x	**21,955**	**22,755**	**23,663**	**23,934**	**23,613**	**23,042**
Stationary Fossil Fuel Combustion	9,884	9,822	9,541	9,589	9,408	9,070
Mobile Fossil Fuel Combustion	10,900	11,870	12,893	13,095	13,021	12,794
Oil and Gas Activities	139	100	126	130	130	130
Industrial Processes	921	842	977	992	924	930
Solvent Use	1	3	3	3	3	3
Agricultural Burning	28	28	32	33	34	33
Waste	83	89	92	92	93	83
CO	**85,846**	**80,678**	**87,196**	**87,012**	**82,496**	**82,982**
Stationary Fossil Fuel Combustion	4,999	5,383	5,620	4,968	4,575	4,798
Mobile Fossil Fuel Combustion	69,523	68,072	72,390	71,225	70,288	68,179
Oil and Gas Activities	302	316	321	333	332	332
Industrial Processes	9,502	5,291	7,227	8,831	5,612	5,604
Solvent Use	4	5	1	1	1	1
Agricultural Burning	537	536	625	630	653	629
Waste	979	1,075	1,012	1,024	1,035	3,439
NMVOCs	**18,843**	**18,663**	**17,353**	**17,586**	**16,554**	**16,128**
Stationary Fossil Fuel Combustion	912	973	971	848	778	820
Mobile Fossil Fuel Combustion	8,154	7,725	8,251	8,023	7,928	7,736
Oil and Gas Activities	555	582	433	442	440	385
Industrial Processes	3,110	2,805	2,354	2,793	2,352	2,281
Solvent Use	5,217	5,609	4,963	5,098	4,668	4,376
Agricultural Burning	NA	NA	NA	NA	NA	NA
Waste	895	969	381	382	387	531
SO_2	**21,481**	**17,408**	**17,109**	**17,565**	**17,682**	**17,115**
Stationary Fossil Fuel Combustion	18,407	14,724	14,727	15,106	15,192	14,598
Mobile Fossil Fuel Combustion	1,339	1,189	1,081	1,116	1,145	1,178
Oil and Gas Activities	390	334	304	312	310	309
Industrial Processes	1,306	1,117	958	993	996	996
Solvent Use	0	1	1	1	1	1
Agricultural Burning	NA	NA	NA	NA	NA	NA
Waste	38	43	37	37	38	33

Source: (EPA 2000) except for estimates from agricultural residue burning.
+ Does not exceed 0.5 Gg
NA (Not Available)
Note: Totals may not sum due to independent rounding.