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 gas emissions. 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 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 under UNFCCC.

This chapter summarizes the latest information on U.S. anthropogenic greenhouse gas emission trends from 1990 through 1998. 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 con-

[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>.

tain bromine are referred to as halons. CFCs, HCFCs, and halons are stratospheric ozone depleting substances and are covered under the Montreal Protocol. Other fluorine containing halogenated substances include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). HFCs, PFCs, and SF_6 do not deplete stratospheric ozone.

There are also several gases that 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. 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 composition of the earth's atmosphere, and affects 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 on Substances that Deplete the Ozone Layer*. Since then, the consumption of ODSs has been undergoing a phase-out. In contrast, use of ODS substitutes such as HFCs, PFCs, and SF_6 has grown significantly during this time.

Recent Trends in U.S. Greenhouse Gas Emissions

Total U.S. greenhouse gas emissions rose in 1998 to 1,834.6 million metric tons of carbon equivalents (MMTCE)[5] (11.2 percent above 1990 baseline). The single year increase in emissions from 1997 to 1998 was 0.4 percent (6.8 MMTCE), less than the average annual rate of increase for 1990 through 1998 (1.2 percent). 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

Figure ES-1

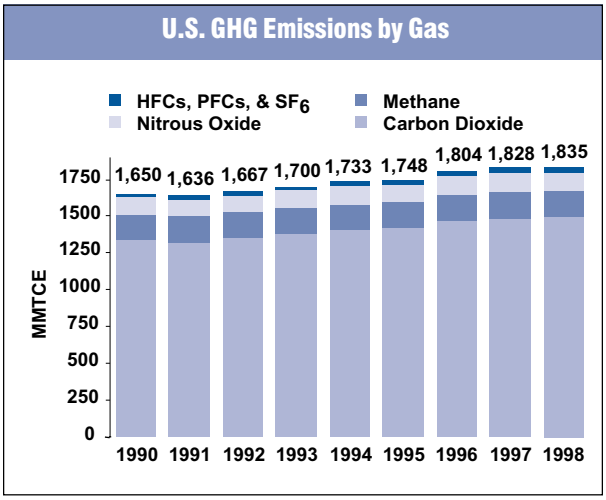
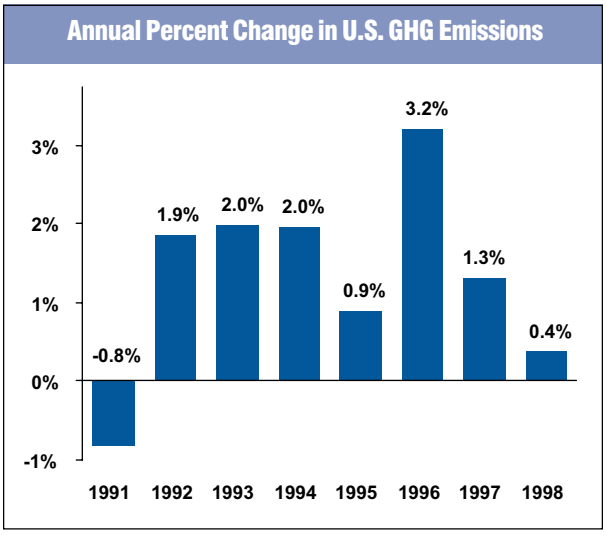


Figure ES-2



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

[5] Estimates are presented in units of millions of metric tons of carbon equivalents (MMTCE), which weights each gas by its GWP value, or Global Warming Potential (see following section).

detailed summary of U.S. greenhouse gas emissions and sinks for 1990 through 1998.

Figure ES-4 illustrates the relative contribution of the direct greenhouse gases to total U.S. emissions in 1998. 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, manure and 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 substitution of ozone depleting substances and emissions of HFC-23 during the production of HCFC-22 were the primary contributors to aggregate HFC emissions. PFC emissions came mainly from primary aluminum production, while electrical transmission and distribution systems emitted the majority of SF_6.

As the largest source of U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion, accounted for 80 percent of weighted emissions in 1998. Emissions from this source grew by 11 percent (148.1 MMTCE) from 1990 to 1998 and were also responsible for over 80 percent of the increase in national emissions during this period. The annual increase in CO_2 emissions from this source was only 0.5 percent in 1998 lower than the source's average annual rate of 1.3 percent during the 1990s despite a strong 3.9 percent increase in U.S. gross domestic product.

Figure ES-3

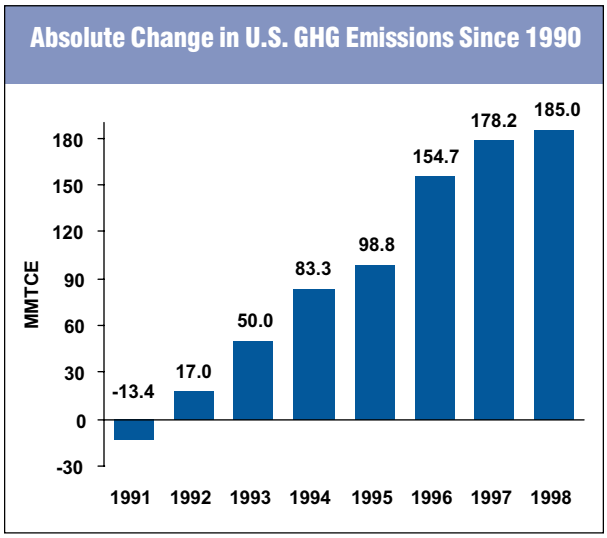
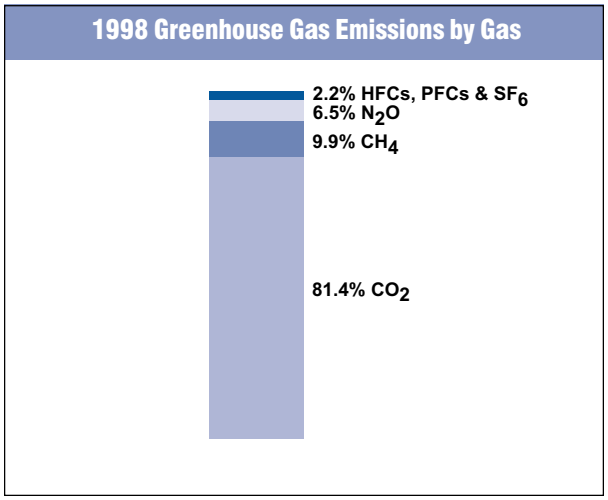


Figure ES-4



In addition to economic growth, changes in CO_2 emission from fossil fuel combustion are also correlated with energy prices and seasonal temperatures. Exceptionally mild winter conditions in 1998 moderated growth in CO_2 emissions from fossil fuel combustion below what would have been expected given the strength of the economy and continued low fuel prices. 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 increased dramatically in 1996, due primarily to two factors: 1) fuel switching by electric utilities from natural gas to more carbon intensive coal as to 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 to offset the lost capacity. In 1998, weather conditions were 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 de-

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

Gas/Source	1990	1991	1992	1993	1994	1995	1996	1997	1998
CO_2	**1,340.3**	**1,326.1**	**1,350.4**	**1,383.3**	**1,404.8**	**1,416.5**	**1,466.2**	**1,486.4**	**1,494.0**
Fossil Fuel Combustion	1,320.1	1,305.8	1,330.1	1,361.5	1,382.0	1,392.0	1,441.3	1,460.7	1,468.2
Cement Manufacture	9.1	8.9	8.9	9.4	9.8	10.0	10.1	10.5	10.7
Natural Gas Flaring	2.5	2.8	2.8	3.7	3.8	4.7	4.5	4.2	3.9
Lime Manufacture	3.0	3.0	3.1	3.1	3.2	3.4	3.6	3.7	3.7
Waste Combustion	2.8	3.0	3.0	3.1	3.1	3.0	3.1	3.4	3.5
Limestone and Dolomite Use	1.4	1.3	1.2	1.1	1.5	1.9	2.0	2.3	2.4
Soda Ash Manufacture and Consumption	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2
Carbon Dioxide Consumption	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4
Land-Use Change and Forestry (Sink)[a]	(316.4)	(316.3)	(316.2)	(212.7)	(212.3)	(211.8)	(211.3)	(211.1)	(210.8)
International Bunker Fuels[b]	32.2	32.7	30.0	27.2	26.7	27.5	27.9	29.9	31.3
CH_4	**177.9**	**177.7**	**179.4**	**178.7**	**181.6**	**184.1**	**183.1**	**183.8**	**180.9**
Landfills	58.2	58.1	59.1	59.6	59.9	60.5	60.2	60.2	58.8
Enteric Fermentation	32.7	32.8	33.2	33.7	34.5	34.9	34.5	34.2	33.7
Natural Gas Systems	33.0	33.4	33.9	34.6	34.3	34.0	34.6	34.1	33.6
Manure Management	15.0	15.5	16.0	17.1	18.8	19.7	20.4	22.1	22.9
Coal Mining	24.0	22.8	22.0	19.2	19.4	20.3	18.9	18.8	17.8
Petroleum Systems	7.4	7.5	7.2	6.9	6.7	6.7	6.5	6.5	6.3
Rice Cultivation	2.4	2.3	2.6	2.4	2.7	2.6	2.4	2.6	2.7
Stationary Sources	2.3	2.4	2.4	2.4	2.4	2.5	2.6	2.3	2.3
Mobile Sources	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.3
Wastewater Treatment	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Petrochemical Production	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Agricultural Residue Burning	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Silicon Carbide Production	+	+	+	+	+	+	+	+	+
International Bunker Fuels[b]	+	+	+	+	+	+	+	+	+
N_2O	**108.2**	**110.5**	**113.3**	**113.8**	**121.5**	**118.8**	**121.5**	**122.4**	**119.4**
Agricultural Soil Management	75.3	76.3	78.2	77.3	83.5	80.4	82.4	84.2	83.9
Mobile Sources	13.8	14.6	15.7	16.5	17.1	17.4	17.5	17.3	17.2
Nitric Acid	4.9	4.9	5.0	5.1	5.3	5.4	5.6	5.8	5.8
Stationary Sources	3.8	3.8	3.9	3.9	4.0	4.0	4.2	4.2	4.3
Manure Management	3.4	3.6	3.5	3.7	3.8	3.7	3.8	3.9	4.0
Human Sewage	2.0	2.0	2.0	2.0	2.1	2.1	2.1	2.1	2.2
Adipic Acid	5.0	5.2	4.8	5.2	5.5	5.5	5.7	4.7	2.0
Agricultural Residue Burning	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Waste Combustion	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
International Bunker Fuels[b]	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.3
HFCs, PFCs, and SF_6	**23.3**	**22.0**	**23.5**	**23.8**	**25.1**	**29.0**	**33.5**	**35.3**	**40.3**
Substitution of Ozone Depleting Substances	0.3	0.2	0.4	1.4	2.7	7.0	9.9	12.3	14.5
HCFC-22 Production	9.5	8.4	9.5	8.7	8.6	7.4	8.5	8.2	10.9
Electrical Transmission and Distribution	5.6	5.9	6.2	6.4	6.7	7.0	7.0	7.0	7.0
Magnesium Production and Processing	1.7	2.0	2.2	2.5	2.7	3.0	3.0	3.0	3.0
Aluminum Production	5.4	4.7	4.4	3.8	3.2	3.1	3.2	3.0	2.8
Semiconductor Manufacture	0.8	0.8	0.8	1.0	1.1	1.5	1.9	1.9	2.1
Total Emissions	**1,649.7**	**1,636.2**	**1,666.6**	**1,699.7**	**1,733.0**	**1,748.5**	**1,804.4**	**1,827.9**	**1,834.6**
Net Emission (Sources and Sinks)	**1,333.3**	**1,320.0**	**1,350.5**	**1,487.0**	**1,520.7**	**1,536.6**	**1,593.1**	**1,616.8**	**1,623.8**

+ Does not exceed 0.05 MMTCE

[a] Sinks are only included in net emissions total. Estimates of net carbon sequestration due to land-use change and forestry activities exclude non-forest soils, and are based partially upon projections of forest carbon stocks.

[b] Emissions from International Bunker Fuels are not included in totals.

Note: Totals may not sum due to independent rounding.

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

Sector	Fuel Type	1995 to 1996		1996 to 1997		1997 to 1998	
Electric Utility	Coal	24.5	5.7%	14.3	3.1%	5.5	1.2%
Electric Utility	Petroleum	1.4	10.0%	2.2	14.4%	7.3	41.6%
Electric Utility	Natural Gas	(6.9)	(14.6%)	3.3	8.1%	4.2	9.8%
Transportation[a]	Petroleum	13.8	3.3%	1.1	0.2%	7.2	1.7%
Residential	Natural Gas	5.8	8.1%	(3.8)	(4.9%)	(7.4)	(10.0%)
Commercial	Natural Gas	1.9	4.2%	0.9	1.9%	(2.7)	(5.7%)
Industrial	Natural Gas	4.7	3.4%	(1.4)	(1.0%)	(2.9)	(2.0%)
All Sectors[b]	**All Fuels[b]**	**49.4**	**3.5%**	**19.4**	**1.3%**	**7.5**	**0.5%**

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

mand; and 2) increased motor gasoline consumption for transportation.

Overall, from 1990 to 1998, total emissions of CO_2, CH_4, and N_2O increased by 153.7 (11 percent), 3.1 (2 percent), and 11.1 MMTCE (10 percent), respectively. During the same period, weighted emissions of HFCs, PFCs, and SF_6 rose by 17.0 MMTCE (73 percent). Despite being emitted in smaller quantities relative to the other principle greenhouse gases, emissions of HFCs, PFCs, and SF_6 are significant because of their 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 12 percent of total emissions in 1998.

Other significant trends in emissions from additional source categories over the nine year period from 1990 through 1998 included the following:

- Aggregate HFC and PFC emissions resulting from the substitution of ozone depleting substances (e.g., CFCs) increased by 14.2 MMTCE. This increase was partly offset, however, by reductions in PFC emissions from aluminum production by 2.6 MMTCE (48 percent), which were the result of both voluntary industry emission reduction efforts and lower domestic aluminum production.
- Combined N_2O and CH_4 emissions from mobile combustion rose by 3.3 MMTCE (22 percent), primarily due to increased rates of N_2O generation in highway vehicles.
- Methane emissions from the manure management activities have increased by 7.9 MMTCE (53 percent) as the composition of the swine and dairy industries shift toward larger facilities. An increased number of large facilities leads to an increased use of liquid systems, which translates into increased methane production.
- Methane emissions from coal mining dropped by 6.2 MMTCE (26 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 8.5 MMTCE (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; as a result, emissions fell by 3.0 MMTCE (60 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.

Box ES-1: Recent Trends in Various U.S. Greenhouse Gas Emissions-Related Data

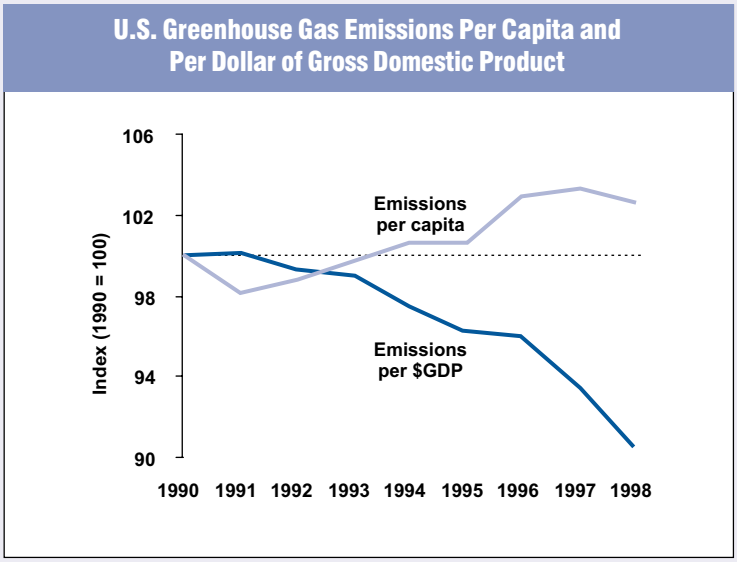
There are several ways to assess a nation's greenhouse gas emitting intensity. These measures of intensity could be based on aggregate energy consumption because energy-related activities[6] are the largest sources of emissions, on fossil fuel consumption only because almost all energy-related emissions involve the combustion of fossil fuels, on electricity consumption because electric utilities were the largest sources of U.S. greenhouse gas emissions in 1998, on total gross domestic product as a measure of national economic activity, or on a per capita basis. Depending upon which of these measures is used, the United States could appear to have reduced or increased its national greenhouse gas intensity. 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 1.3 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, 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	Growth Rate[f]
GHG Emissions[a]	99	101	103	105	106	109	111	111	1.3%
Energy Consumption[b]	100	101	104	106	108	112	112	112	1.4%
Fossil Fuel Consumption[b]	99	101	103	105	106	110	111	111	1.4%
Electricity Consumption[b]	102	102	105	108	111	114	116	119	2.2%
GDP[c]	99	102	104	108	110	114	118	123	2.6%
Population[d]	101	102	103	104	105	106	107	108	1.0%
Atmospheric CO_2 Concentration[e]	100	101	101	101	102	102	103	104	0.4%

[a] GWP weighted values
[b] Energy content weighted values. (DOE/EIA)
[c] Gross Domestic Product in chained 1992 dollars (BEA 1999)
[d] (U.S. Census Bureau 1999)
[e] Mauna Loa Observatory, Hawaii (Keeling and Whorf 1999)
[f] Average annual growth rate

Figure ES-5



[6] Energy-related activities are those that involve fossil fuel combustion (industrial, transportation, residential, and commercial end-use sectors), and the production, transmission, storage, and distribution of fossil fuels.

pathways further summarize the emission estimates, and explain the relative importance of emissions from each source category.

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, or when a gas influences the atmospheric lifetimes of other gases. 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 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 have only indirect effects on radiative forcing (IPCC 1996).

All gases in this executive summary are presented in units of million metric tons of carbon equivalents (MMTCE). Carbon comprises $12/44^{ths}$ of carbon dioxide by weight. The relationship between gigagrams (Gg) of a gas and MMTCE can be expressed as follows:

$$\text{MMTCE} = (\text{Gg of gas}) \times \left(\frac{\text{MMT}}{1{,}000\ \text{Gg}}\right) \times (\text{GWP}) \times \left(\frac{12}{44}\right)$$

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.

Box ES-2: 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 21 percent from 1990 to 1998 and gallons of gasoline consumed each year in the United States have increased relatively 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, increasing urban sprawl, and low fuel prices.

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 nitrogen oxides, hydrocarbons, and carbon monoxide.

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 1998. These emissions were primarily CO_2 from fuel combustion, which increased by 11 percent from 1990 to 1998. However, because of larger increases in N_2O and HFC emissions during this period, overall emissions from transportation activities actually increased by 13 percent.

Table ES-4: Transportation-Related Greenhouse Gas Emissions (MMTCE)

Gas/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998
CO_2	**399.6**	**391.5**	**401.1**	**409.1**	**422.3**	**427.7**	**441.7**	**443.4**	**450.3**
Passenger Cars	169.1	167.6	171.7	173.3	172.2	175.0	178.5	180.0	185.1
Light-Duty Trucks	77.4	77.1	77.1	80.4	87.1	88.9	91.1	92.1	94.6
Other Trucks	56.3	54.2	55.9	59.1	62.1	63.6	67.7	70.1	70.3
Buses	2.7	2.8	2.9	3.0	3.3	3.5	3.0	3.2	3.2
Aircraft[a]	48.2	46.1	45.5	45.8	48.0	46.8	49.1	48.8	49.4
Boats and Vessels	15.1	14.4	18.5	17.3	17.0	17.0	18.1	13.7	12.5
Locomotives	7.3	6.8	7.3	6.7	7.9	8.1	8.7	9.0	9.0
Other[b]	23.6	22.3	22.3	23.6	24.8	24.8	25.4	26.5	26.3
International Bunker Fuels[c]	32.2	32.7	30.0	27.2	26.7	27.5	27.9	29.9	31.3
CH_4	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.4**	**1.4**	**1.4**	**1.3**
Passenger Cars	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
Light-Duty Trucks	0.5	0.5	0.6	0.6	0.6	0.6	0.5	0.5	0.5
Other Trucks and Buses	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Aircraft	+	+	+	+	+	+	+	+	+
Boats and Vessels	+	+	+	+	+	+	+	+	+
Locomotives	+	+	+	+	+	+	+	+	+
Other[d]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
International Bunker Fuels[c]	+	+	+	+	+	+	+	+	+
N_2O	**13.8**	**14.6**	**15.7**	**16.5**	**17.1**	**17.4**	**17.5**	**17.3**	**17.2**
Passenger Cars	8.1	8.0	8.4	8.6	8.8	8.9	8.9	8.7	8.6
Light-Duty Trucks	4.2	5.1	5.8	6.4	6.6	6.8	6.8	6.8	6.8
Other Trucks and Buses	0.6	0.7	0.7	0.7	0.8	0.8	0.9	0.9	1.0
Aircraft[d]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Boats and Vessels	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Locomotives	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other[d]	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
International Bunker Fuels[c]	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.3
HFCs	**+**	**+**	**0.2**	**0.7**	**1.8**	**2.6**	**3.7**	**4.7**	**4.7**
Mobile Air Conditioners[e]	+	+	0.2	0.7	1.8	2.6	3.7	4.7	4.7
Total[c]	**414.8**	**407.5**	**418.4**	**427.8**	**442.7**	**449.2**	**464.3**	**466.8**	**473.5**

+ Does not exceed 0.05 MMTCE

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- 3: Greenhouse Gas Emissions from Electric Utilities

Like transportation, activities related to the generation, transmission, and distribution of electricity in the United States result in significant greenhouse gas emissions. Table ES-5 presents greenhouse gas emissions from electric utility-related activities. Aggregate emissions from electric utilities of all greenhouse gases increased by 16 percent from 1990 to 1998, and accounted for a relatively constant 29 percent of U.S. greenhouse emissions during the same period.[7] The majority of these 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 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 (MMTCE)

Gas/Fuel Type or Source	1990	1991	1992	1993	1994	1995	1996	1997	1998
CO_2	**476.6**	**473.2**	**472.7**	**490.5**	**493.9**	**494.0**	**513.0**	**532.8**	**549.9**
Coal	409.0	407.2	411.8	428.7	429.5	433.0	457.5	471.8	477.3
Natural Gas	41.2	41.1	40.7	39.5	44.0	47.2	40.3	43.6	47.8
Petroleum	26.4	24.9	20.2	22.3	20.5	13.9	15.3	17.5	24.8
Geothermal	0.1	0.1	0.1	0.1	+	+	+	+	+
CH_4	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Stationary Combustion (Utilities)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N_2O	**2.0**	**2.0**	**2.0**	**2.1**	**2.1**	**2.1**	**2.2**	**2.3**	**2.3**
Stationary Combustion (Utilities)	2.0	2.0	2.0	2.1	2.1	2.1	2.2	2.3	2.3
SF_6	**5.6**	**5.9**	**6.2**	**6.4**	**6.7**	**7.0**	**7.0**	**7.0**	**7.0**
Electrical Transmission and Distribution	5.6	5.9	6.2	6.4	6.7	7.0	7.0	7.0	7.0
Total	**484.3**	**481.2**	**481.0**	**499.1**	**502.9**	**503.2**	**522.4**	**542.2**	**559.3**

+ Does not exceed 0.05 MMTCE
Note: Totals may not sum due to independent rounding.

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 1998. 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).

[7] Emissions from nonutility generators are not included in these estimates. Nonutilties were estimated to produce about 10 percent of the electricity generated in the United States in 1998 (DOE and EPA 1999).

Figure ES-6

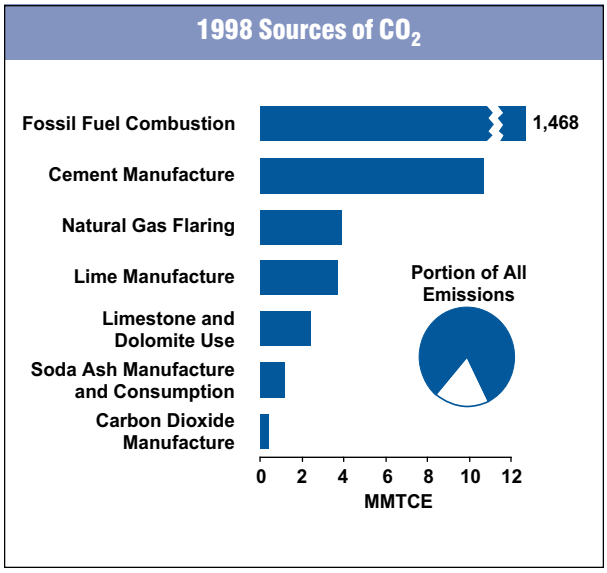


Figure ES-6 and Table ES-7 summarize U.S. sources and sinks of CO_2. The remainder of this section then discusses CO_2 emission trends in greater detail.

Energy

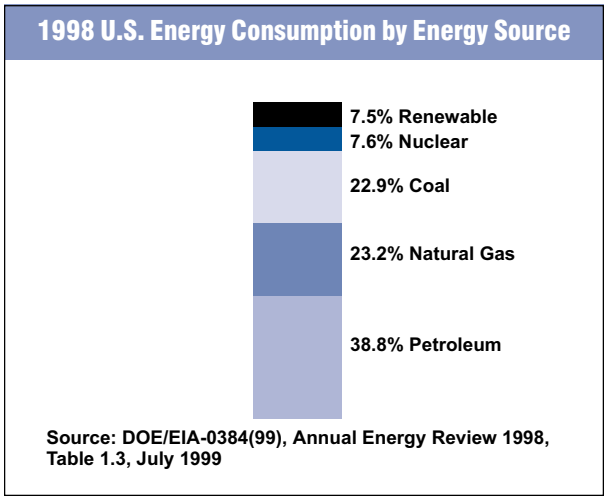
Energy-related activities accounted for almost all U.S. CO_2 emissions for the period of 1990 through 1998. Carbon dioxide from fossil fuel combustion was the dominant contributor. In 1998, approximately 85 percent of the energy consumed in the United States was produced through the combustion of fossil fuels. The remaining 15 percent came from other energy sources such as hydropower, biomass, nuclear, wind, and solar (see Figure ES-7 and Figure ES-8). 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 1998, 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 22 percent of total energy consumption, respectively. Most petroleum was consumed in the transportation sector, while the vast majority of coal was used by electric utilities, and natural gas was consumed largely in the industrial and residential sectors.

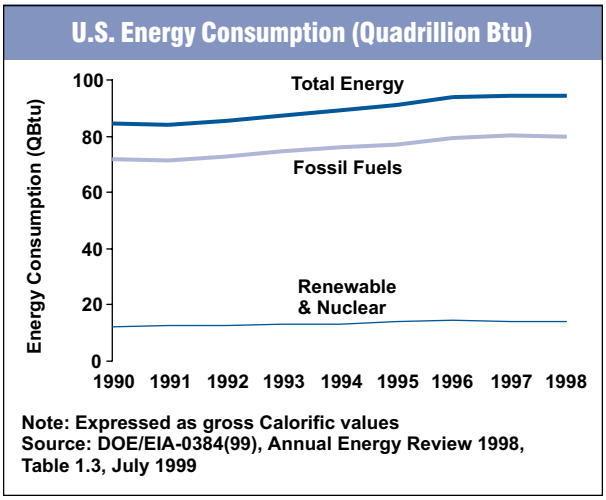
Emissions of CO_2 from fossil fuel combustion increased at an average annual rate of 1.3 percent from 1990 to 1998. The fundamental factors behind this trend include (1) a robust domestic economy, (2) relatively low energy prices, and (3) fuel switching by electric utilities. After 1990, when CO_2 emissions from fossil fuel combustion were 1,320.1 MMTCE, there was a slight decline in emissions in 1991, due in large part to an economic recession, followed by a relatively steady in-

Figure ES-7



Source: DOE/EIA-0384(99), Annual Energy Review 1998, Table 1.3, July 1999

Figure ES-8



Note: Expressed as gross Calorific values
Source: DOE/EIA-0384(99), Annual Energy Review 1998, Table 1.3, July 1999

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

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998
Fossil Fuel Combustion	1,320.1	1,305.8	1,330.1	1,361.5	1,382.0	1,392.0	1,441.3	1,460.7	1,468.2
Cement Manufacture	9.1	8.9	8.9	9.4	9.8	10.0	10.1	10.5	10.7
Natural Gas Flaring	2.5	2.8	2.8	3.7	3.8	4.7	4.5	4.2	3.9
Lime Manufacture	3.0	3.0	3.1	3.1	3.2	3.4	3.6	3.7	3.7
Waste Combustion	2.8	3.0	3.0	3.1	3.1	3.0	3.1	3.4	3.5
Limestone and Dolomite Use	1.4	1.3	1.2	1.1	1.5	1.9	2.0	2.3	2.4
Soda Ash Manufacture and Consumption	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2
Carbon Dioxide Consumption	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4
Land-Use Change and Forestry (Sink)[a]	(316.4)	(316.3)	(316.2)	(212.7)	(212.3)	(211.8)	(211.3)	(211.1)	(210.8)
International Bunker Fuels[b]	32.2	32.7	30.0	27.2	26.7	27.5	27.9	29.9	31.3
Total Emissions	**1,340.3**	**1,326.1**	**1,350.4**	**1,383.3**	**1,404.8**	**1,416.5**	**1,466.2**	**1,486.4**	**1,494.0**
Net Emissions (Sources and Sinks)	**1,023.9**	**1,009.8**	**1,034.2**	**1,170.6**	**1,192.5**	**1,204.7**	**1,254.9**	**1,275.3**	**1,283.2**

[a] Sinks are only included in net emissions total. Estimates of net carbon sequestration due to land-use change and forestry activities exclude non-forest soils, and are based partially upon projections of forest carbon stocks.
[b] Emissions from International Bunker Fuels are not included in totals.
Note: Totals may not sum due to independent rounding.

crease to 1,468.2 MMTCE in 1998. Overall, CO_2 emissions from fossil fuel combustion increased by 11 percent over the nine year period and rose by 0.5 percent in the final year.

In 1998, mild weather and low petroleum prices comprised the major forces affecting emission trends. A very mild winter more than offset the effects of a slightly hotter summer, resulting in significantly lower fuel consumption for residential and commercial heating compared to previous years. Emissions from the combustion of petroleum products grew the most (11.5 MMTCE or 1.9 percent) due in large part to low prices. Alone, emissions from the combustion of petroleum by electric utilities increased by 7.3 MMTCE (42 percent) from 1997 to 1998. Emissions from the combustion of coal in 1998 increased by 5.5 MMTCE (1 percent) from the previous year, driven almost entirely by increased emissions by electric utilities. These increases were offset by a decrease in natural gas combustion emissions in every sector (9.1 MMTCE or 3 percent).

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. Emissions from U.S. territories are also calculated separately due to a lack of end-use-specific consumption data. Table ES-8, Figure ES-9, and Figure ES-10 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 consumed by the sector accounted for 33 percent of U.S. emissions from fossil fuel combustion in 1998. About two-thirds of these emissions resulted from producing steam and process heat from fossil fuel combustion, while the remaining third resulted from consuming electricity for powering motors, electric furnaces, ovens, and lighting.

Transportation End-Use Sector. Transportation

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

End-Use Sector	1990	1991	1992	1993	1994	1995	1996	1997	1998
Residential	252.9	257.0	255.8	271.6	268.2	269.8	285.4	284.7	286.8
Commercial	206.7	206.3	205.4	212.0	213.8	218.3	225.9	238.0	239.3
Industrial	451.7	440.3	458.0	458.0	466.2	464.4	477.3	482.5	478.9
Transportation	399.6	391.5	401.1	409.1	422.3	427.7	441.7	443.4	450.3
U.S. Territories	9.2	10.7	9.8	10.7	11.5	11.8	11.0	12.0	13.0
Total	**1,320.1**	**1,305.8**	**1,330.1**	**1,361.5**	**1,382.0**	**1,392.0**	**1,441.3**	**1,460.7**	**1,468.2**

* Emissions from fossil fuel combustion by electric utilities are allocated based on electricity consumption by each end-use sector.
Note: Totals may not sum due to independent rounding.

activities excluding international bunker fuels accounted for 31 percent of CO_2 emissions from fossil fuel combustion in 1998.[8] Virtually all of the energy consumed in this end-use sector came from petroleum products. 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 20 and 16 percent, respectively, of CO_2 emissions from fossil fuel consumption in 1998. Both sectors relied heavily on electricity for meeting energy needs, with 67 and 75 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 29 percent of U.S. energy from fossil fuels and emitted 37 percent of the CO_2 from fossil fuel combustion in 1998. 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

Figure ES-9

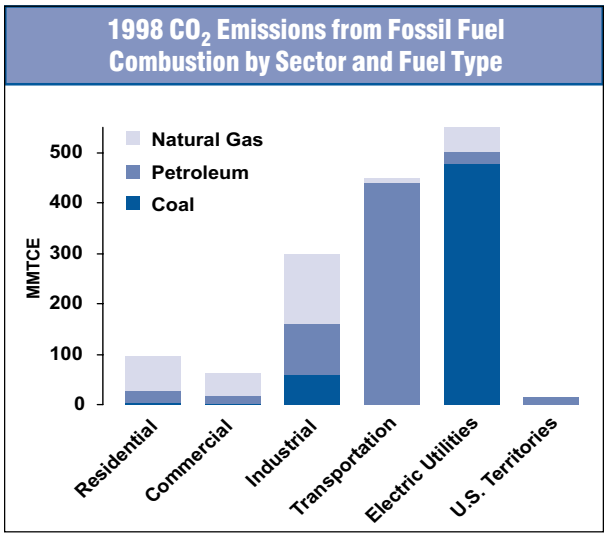
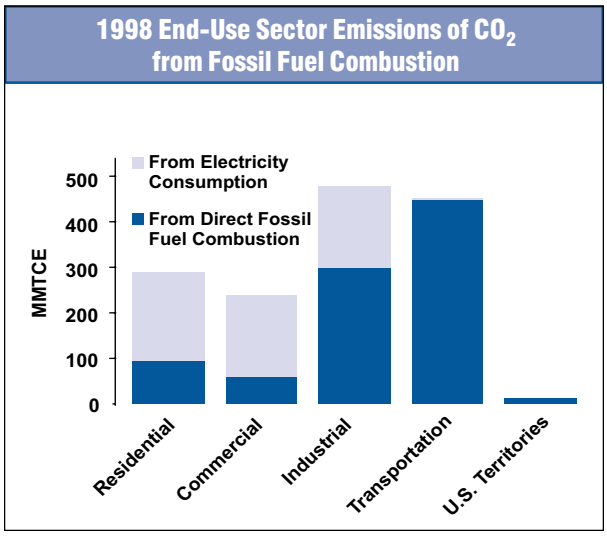


Figure ES-10



[8] 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 1998.

coal for over half of their total energy requirements and accounted for 88 percent of all coal consumed in the United States in 1998. Consequently, changes in electricity demand have a significant impact on coal consumption and associated CO_2 emissions.

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 1998, flaring activities emitted approximately 3.9 MMTCE, 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 crop lands are accounted for under Land-Use Change and Forestry.

Gross CO_2 emissions from biomass combustion were 66.2 MMTCE, with the industrial sector accounting for 81 percent of the emissions, and the residential sector 15 percent. Ethanol consumption by the transportation sector accounted for only 3 percent of CO_2 emissions from biomass combustion.

Industrial Processes

Emissions are often produced as a by-product of various non-energy-related activities. For example, industrial processes can chemically transform raw materials. This transformation often releases greenhouse gases such as CO_2. The 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 18.4 MMTCE in 1998, 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 remained relatively constant.

Cement Manufacture (10.7 MMTCE)

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 (3.7 MMTCE)

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 (2.4 MMTCE)

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 (1.2 MMTCE)

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 (0.4 MMTCE)

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

When humans alter the biosphere through changes in land-use and forest management practices, they alter the natural carbon flux between biomass, soils, and the atmosphere. Improved forest management practices and the regeneration of previously cleared forest areas have resulted in a net uptake (sequestration) of carbon in U.S. forest lands, which cover about 298 million hectares (737 million acres) (Powell et al. 1993). This uptake is an ongoing result of land-use changes in previous decades. For example, because of improved agricultural productivity and the widespread use of tractors, the rate of clearing forest land for crop cultivation and pasture slowed greatly in the late 19th century, and by 1920 this practice had all but ceased. As farming expanded in the Midwest and West, large areas of previously cultivated land in the East were brought out of crop production, primarily between 1920 and 1950, and were allowed to revert to forest land or were actively reforested.

Since the early 1950s, the managed growth of private forest land in the East has nearly doubled the biomass density there. The 1970s and 1980s saw a resurgence of federally sponsored tree-planting programs (e.g., the Forestry Incentive Program) and soil conservation programs (e.g., the Conservation Reserve Program), which have focused on reforesting previously harvested lands, improving timber-management, combating soil erosion, and converting marginal cropland to forests.

In 1998, the CO_2 flux from land-use change and forestry activities was estimated to have been a net uptake of 210.8 MMTCE. This carbon was sequestered in trees, understory, litter, soils in forests, wood products, and wood in landfills. This net carbon uptake represents an offset of about 14 percent of the CO_2 emissions from fossil fuel combustion in 1998. The amount of carbon sequestered through U.S. forestry and land-use practices is estimated to have declined by about a third between 1990 and 1998, largely due to the maturation of existing forests and the slowed expansion of Eastern forest cover and a gradual decrease in the rate of yard trimmings disposed in landfills. Due to the lack of a national survey of land use and management more recent than 1992, carbon flux estimates for non-forest mineral and organic soils were not calculated for the 1993 through 1998 period. Therefore, carbon flux estimates from non-forest soils are not included in the total fluxes reported.

Waste

Waste Combustion (3.5 MMTCE)

Waste combustion involves the burning of garbage and non-hazardous solids, referred to as municipal solid waste (MSW). In 1996, there were approximately 137 municipal waste combustion plants in operation within the United States (EPA 1998a). Most of the organic (i.e., carbon) materials in MSW are of biogenic origin. Therefore, the CO_2 emissions from their combustion are reported under the Land Use Change and Forestry Chapter. However, one component plastics is of fossil fuel origin, and is included as a source of CO_2 emissions.

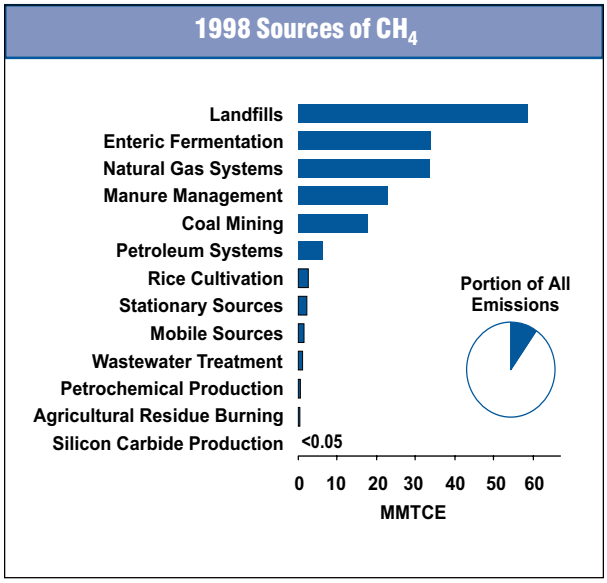
Methane Emissions

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 is 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-11 and Table ES-9).

Landfills

Figure ES-11



Landfills are the largest single anthropogenic source of 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 1998 were 58.8 MMTCE, only a 1 percent increase since 1990. The relatively constant emission estimates are a result of two offsetting trends: (1) the amount of MSW 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, which received about 61 percent of the municipal solid waste generated in the United States, accounted for 93 percent of total landfill emissions, while industrial landfills accounted for the remainder. Approximately 26 percent of the methane generated in U.S. landfills in 1998 was recovered and combusted, often for energy.

Table ES-9: U.S. Sources of Methane Emissions (MMTCE)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998
Landfills	58.2	58.1	59.1	59.6	59.9	60.5	60.2	60.2	58.8
Enteric Fermentation	32.7	32.8	33.2	33.7	34.5	34.9	34.5	34.2	33.7
Natural Gas Systems	33.0	33.4	33.9	34.6	34.3	34.0	34.6	34.1	33.6
Manure Management	15.0	15.5	16.0	17.1	18.8	19.7	20.4	22.1	22.9
Coal Mining	24.0	22.8	22.0	19.2	19.4	20.3	18.9	18.8	17.8
Petroleum Systems	7.4	7.5	7.2	6.9	6.7	6.7	6.5	6.5	6.3
Rice Cultivation	2.4	2.3	2.6	2.4	2.7	2.6	2.4	2.6	2.7
Stationary Sources	2.3	2.4	2.4	2.4	2.4	2.5	2.6	2.3	2.3
Mobile Sources	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.3
Wastewater Treatment	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Petrochemical Production	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Agricultural Residue Burning	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Silicon Carbide Production	+	+	+	+	+	+	+	+	+
International Bunker Fuels*	+	+	+	+	+	+	+	+	+
Total*	**177.9**	**177.7**	**179.4**	**178.7**	**181.6**	**184.1**	**183.1**	**183.8**	**180.9**

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

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 1998, methane emissions from U.S. natural gas systems were estimated to be 33.6 MMTCE, accounting for approximately 19 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 1998, emissions from petroleum systems were estimated to be 6.3 MMTCE, or 3.5 percent of U.S. methane emissions.

From 1990 to 1998, combined methane emissions from natural gas and petroleum systems decreased by about 1 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 systems. U.S. recovery of methane has been increasing in recent years. During 1998, coal mining activities emitted 17.8 MMTCE of methane, or 10 percent of U.S. methane emissions. From 1990 to 1998, emissions from this source decreased by 26 percent due to increased use of the methane collected by mine degasification systems.

Agriculture

Agriculture accounted for 33 percent of U.S. methane emissions in 1998, with enteric fermentation in domestic livestock and manure management accounting for the majority. Other agricultural activities contributing directly to methane emissions included rice cultivation and agricultural waste burning.

Enteric Fermentation (33.7 MMTCE)

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 1998, enteric fermentation was the source of about 19 percent of U.S. methane emissions, and more than half of the methane emissions from agriculture. From 1990 to 1998, emissions from this source increased by 3 percent. Emissions from enteric fermentation have been decreasing since 1995, primarily due to declining dairy cow and beef cattle populations.

Manure Management (22.9 MMTCE)

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 13 percent of U.S. methane emissions in 1998, and 38 percent of the methane emissions from agriculture. From 1990 to 1998, emissions from this source increased by 53 percent—the largest 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. Thus the shift towards larger facilities is translated into an increasing use of liquid systems, which in turn translates to increased methane production.

Rice Cultivation (2.7 MMTCE)

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 1998, rice cultivation was the source of 1.5 percent of U.S. methane emissions, and about 5 percent of U.S. methane emissions from agriculture. Emission estimates from this source have increased about 15 percent since 1990, due primarily to an increase in the area harvested.

Agricultural Residue Burning (0.2 MMTCE)

Burning crop residue releases a number of greenhouse gases, including methane. Agricultural residue burning is considered to be a net source of methane emissions because, unlike CO_2, methane released during burning is not reabsorbed by crop regrowth during the next growing season. Because field burning is not common in the United States, it was responsible for only 0.1 percent of U.S. methane emissions in 1998.

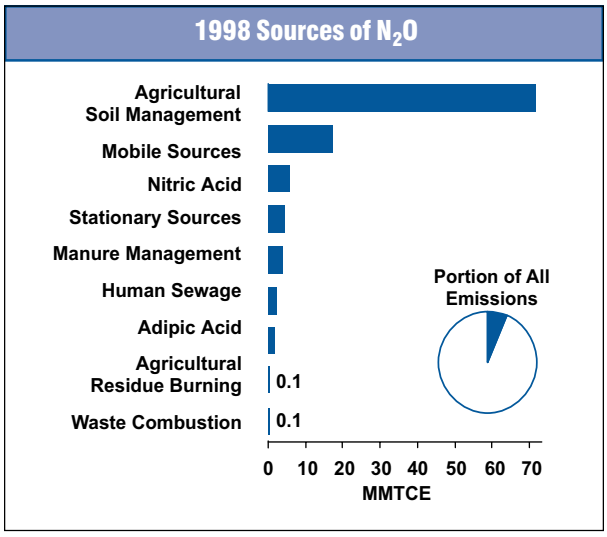
Other Sources

Methane is also produced from several other sources in the United States, including fuel combustion, wastewater treatment, and some industrial processes. Stationary and mobile combustion were responsible for methane emissions of 2.3 and 1.3 MMTCE, respectively, in 1998. The majority of emissions from stationary combustion resulted from the burning of wood in the residential sector. The combustion of gasoline in highway vehicles was responsible for the majority of the methane emitted from mobile combustion. Wastewater treatment was a smaller source of methane, emitting 0.9 MMTCE in 1998. Methane emissions from two industrial sources petrochemical and silicon carbide production were also estimated, totaling 0.4 MMTCE.

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 N_2O emissions are much lower 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 (see Figure ES-12 and Table ES-10).

Figure ES-12



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. Direct additions of nitrogen occur through the application of synthetic and organic fertilizers, cultivation of nitrogen-fixing crops, cultivation of high-organic-content soils, the application of livestock manure on croplands and pasture, the incorporation of crop residues in soils, and direct excretion by animals onto soil. Indirect emissions result from volatilization and subsequent atmospheric deposition of ammonia (NH_3) and oxides of nitrogen (NO_x) and from leaching and surface run-off. These indirect emissions originate from nitrogen applied to soils as fertilizer and from managed and unmanaged livestock wastes.

In 1998, agricultural soil management accounted for 83.9 MMTCE, or 70 percent of U.S. N_2O emissions. From 1990 to 1998, emissions from this source increased by 11 percent as fertilizer consumption and cultivation of nitrogen fixing crops 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 volume emitted varies according to the type of fuel, technology, and pollution control device used, as well as maintenance and operating practices. For example, catalytic converters installed to reduce highway vehicle pollution can result in the formation of N_2O.

In 1998, N_2O emissions from mobile combustion totaled 17.2 MMTCE, or 14 percent of U.S. N_2O emissions. Emissions of N_2O from stationary combustion were 4.3 MMTCE, or 4 percent of U.S. N_2O emissions. From 1990 to 1998, combined N_2O emissions from stationary and mobile combustion increased by 21 percent, primarily due to increased rates of N_2O generation in motor vehicles.

Table ES-10: U.S. Sources of Nitrous Oxide Emissions (MMTCE)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998
Agricultural Soil Management	75.3	76.3	78.2	77.3	83.5	80.4	82.4	84.2	83.9
Mobile Sources	13.8	14.6	15.7	16.5	17.1	17.4	17.5	17.3	17.2
Nitric Acid	4.9	4.9	5.0	5.1	5.3	5.4	5.6	5.8	5.8
Stationary Sources	3.8	3.8	3.9	3.9	4.0	4.0	4.2	4.2	4.3
Manure Management	3.4	3.6	3.5	3.7	3.8	3.7	3.8	3.9	4.0
Human Sewage	2.0	2.0	2.0	2.0	2.1	2.1	2.1	2.1	2.2
Adipic Acid	5.0	5.2	4.8	5.2	5.5	5.5	5.7	4.7	2.0
International Bunker Fuels*	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.3
Agricultural Residue Burning	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Waste Combustion	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total*	**108.2**	**110.5**	**113.3**	**113.8**	**121.5**	**118.8**	**121.5**	**122.4**	**119.4**

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

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 1998, U.S. adipic acid plants emitted 2.0 MMTCE of N_2O, or 2 percent of U.S. N_2O emissions. Since 1990, even though adipic acid production increased, by 1998, all of the three major adipic acid plants in the United States had voluntarily implemented N_2O abatement technology. As a result, emissions in 1998 decreased by 58 percent relative to the previous year.

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 1998, N_2O emissions from nitric acid production were 5.8 MMTCE, or 5 percent of U.S. N_2O emissions. From 1990 to 1998, emissions from this source increased by 18 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 1998 were 4.0 MMTCE, accounting for 3 percent of U.S. N_2O emissions. Emissions increased by 19 percent from 1990 to 1998.

Other Sources

Other sources of N_2O included agricultural residue burning, waste combustion, and human sewage in wastewater treatment systems. In 1998, agricultural residue burning and municipal solid waste combustion each emitted approximately 0.1 MMTCE of N_2O. Although N_2O emissions from wastewater treatment were not fully estimated because of insufficient data availability, the human sewage component of domestic wastewater resulted in emissions of 2.2 MMTCE in 1998.

HFCs, PFCs 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*.

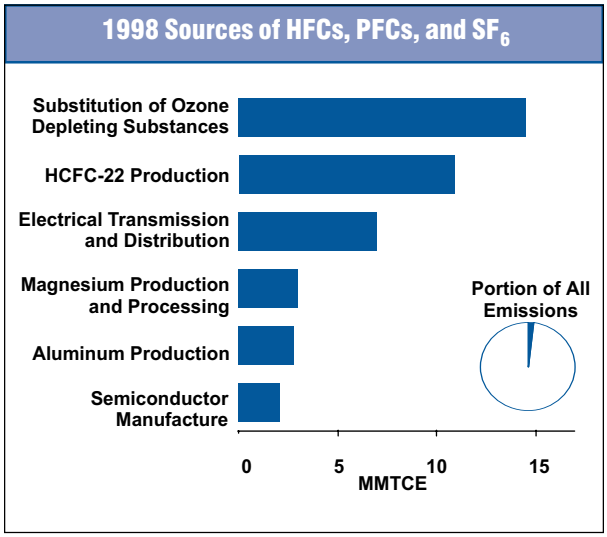
These compounds, however, along with sulfur hexafluoride (SF_6), are potent greenhouse gases. In addition to having high global warming potentials, SF_6 and many HFCs and PFCs have extremely long atmospheric lifetimes, resulting in their essentially irreversible accumulation in the atmosphere. Sulfur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

In addition to their use as substitutes for ozone depleting substances, the other emissive sources of these gases are aluminum production, HCFC-22 production, semiconductor manufacturing, electrical transmission and distribution, and magnesium production and processing. Figure ES-13 and Table ES-11 present emission estimates for HFCs, PFCs, and SF_6, which totaled 40.3 MMTCE in 1998.

Substitution of Ozone Depleting Substances

The use and subsequent emissions of HFCs and PFCs as ODS substitutes increased dramatically from small amounts in 1990 to 14.5 MMTCE in 1998. 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

Figure ES-13



applications. This trend is expected to continue for many years, and will accelerate in the early part of the next century as HCFCs, which are interim substitutes in many applications, are themselves phased-out under the provisions of the Copenhagen Amendments to the *Montreal Protocol*.

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 were estimated to have decreased by 48 percent between 1990 and 1998 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 10.9 MMTCE in 1998, and have increased by 15 percent since 1990. This increase is attributable to the 30 percent increase in HCFC-22 production that has occurred since 1990; one third of this increase occurred between 1997 and 1998. The intensity of HFC-23 emissions (i.e., the amount of HFC-23 emitted per kilogram of HCFC-22 manufactured), however, has declined significantly since 1990.

The semiconductor industry uses combinations of HFCs, PFCs, SF_6, and other gases for plasma etching and chemical vapor deposition processes. For 1998, it was estimated that the U.S. semiconductor industry emitted a total of 2.1 MMTCE. 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 from 1990, to 7.0 MMTCE in 1998.

Table ES-11: Emissions of HFCs, PFCs, and SF_6 (MMTCE)

Source	1990	1991	1992	1993	1994	1995	1996	1997	1998
Substitution of Ozone Depleting Substances	0.3	0.2	0.4	1.4	2.7	7.0	9.9	12.3	14.5
Aluminum Production	5.4	4.7	4.4	3.8	3.2	3.1	3.2	3.0	2.8
HCFC-22 Production	9.5	8.4	9.5	8.7	8.6	7.4	8.5	8.2	10.9
Semiconductor Manufacture	0.8	0.8	0.8	1.0	1.1	1.5	1.9	1.9	2.1
Electrical Transmission and Distribution	5.6	5.9	6.2	6.4	6.7	7.0	7.0	7.0	7.0
Magnesium Production and Processing	1.7	2.0	2.2	2.5	2.7	3.0	3.0	3.0	3.0
Total	**23.3**	**22.0**	**23.5**	**23.8**	**25.1**	**29.0**	**33.5**	**35.3**	**40.3**

Note: Totals may not sum due to independent rounding.

Box ES-4: 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 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	1991	1992	1993	1994	1995	1996	1997	1998
Class I									
CFC-11	53.5	48.3	45.1	45.4	36.6	36.2	26.6	25.1	24.9
CFC-12	112.6	103.5	80.5	79.3	57.6	51.8	35.5	23.1	21.0
CFC-113	26.4	20.6	17.1	17.1	8.6	8.6	+	+	+
CFC-114	4.7	3.6	3.0	3.0	1.6	1.6	0.3	0.1	0.1
CFC-115	4.2	4.0	3.8	3.6	3.3	3.0	3.2	2.9	2.7
Carbon Tetrachloride	32.3	31.0	21.7	18.6	15.5	4.7	+	+	+
Methyl Chloroform	158.3	154.7	108.3	92.9	77.4	46.4	+	+	+
Halon-1211	1.0	1.1	1.0	1.1	1.0	1.1	1.1	1.1	1.1
Halon-1301	1.8	1.8	1.7	1.7	1.7	1.8	1.9	1.9	1.9
Class II									
HCFC-22	79.8	79.5	79.5	71.2	71.4	72.3	73.2	74.2	75.1
HCFC-123	+	+	0.3	0.3	0.5	0.6	0.7	0.8	0.9
HCFC-124	+	+	0.4	2.6	4.8	5.2	5.6	5.9	6.1
HCFC-141b	+	+	+	5.0	12.4	20.6	25.4	25.1	26.7
HCFC-142b	+	+	0.7	1.7	4.6	7.3	8.3	8.7	9.0
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 3.0 MMTCE in 1998, an increase of 76 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 fossil fuels 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 1999).[9] 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-5: 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 62 percent in 1998. Coal combustion contributes nearly all of those emissions (approximately 96 percent). Sulfur dioxide emissions have decreased in recent years, primarily as a result of electric utilities switching from high sulfur to low sulfur coal.

[9] NO_x and CO emission estimates from agricultural residue burning were estimated separately, and therefore not taken from EPA (1999).

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

Gas/Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998
NO_x	**21,798**	**21,936**	**22,176**	**22,398**	**22,683**	**22,177**	**22,034**	**22,153**	**22,066**
Stationary Combustion	9,884	9,779	9,914	10,080	9,993	9,822	9,553	9,728	9,719
Mobile Combustion	10,744	11,132	11,224	11,294	11,508	11,294	11,261	11,289	11,184
Oil and Gas Activities	139	110	134	111	106	100	121	121	122
Industrial Processes	921	802	785	774	939	842	979	890	915
Solvent Use	1	2	2	2	2	3	3	3	2
Agricultural Residue Burning	26	26	29	23	32	27	30	32	34
Waste	83	86	87	112	103	89	87	89	90
CO	**85,394**	**87,485**	**84,589**	**84,716**	**88,911**	**80,093**	**82,028**	**79,284**	**78,082**
Stationary Combustion	4,999	5,313	5,583	5,068	5,007	5,383	5,405	4,455	4,491
Mobile Combustion	68,985	73,177	71,543	72,210	74,057	67,433	66,674	65,301	63,780
Oil and Gas Activities	302	313	337	337	307	316	287	292	296
Industrial Processes	9,502	7,088	5,401	5,421	7,708	5,291	7,899	7,432	7,669
Solvent Use	4	4	5	4	5	5	5	5	5
Agricultural Residue Burning	623	578	688	544	717	590	675	704	733
Waste	979	1,012	1,032	1,133	1,111	1,075	1,083	1,095	1,107
NMVOCs	**18,795**	**18,929**	**18,527**	**18,708**	**19,290**	**18,613**	**17,624**	**17,469**	**17,011**
Stationary Combustion	912	975	1,011	901	898	973	951	770	776
Mobile Combustion	8,037	8,239	7,862	7,919	8,223	7,621	7,398	7,169	7,065
Oil and Gas Activities	555	581	574	588	587	582	459	461	464
Industrial Processes	3,179	2,983	2,811	2,893	3,043	2,859	2,859	3,002	3,066
Solvent Use	5,217	5,245	5,353	5,458	5,590	5,609	5,569	5,672	5,239
Agricultural Residue Burning	NA	NA	NA	NA	NA	NA	NA	NA	NA
Waste	895	907	916	949	949	968	388	394	400
SO_2	**21,465**	**20,903**	**20,689**	**20,381**	**19,840**	**17,401**	**18,695**	**19,216**	**19,441**
Stationary Combustion	18,407	17,959	17,684	17,459	17,134	14,724	15,981	16,458	16,635
Mobile Combustion	1,322	1,373	1,402	1,351	1,172	1,183	1,208	1,235	1,261
Oil and Gas Activities	390	343	377	347	344	334	300	301	303
Industrial Processes	1,306	1,187	1,186	1,159	1,135	1,117	1,167	1,184	1,204
Solvent Use	+	+	+	1	1	1	+	1	1
Agricultural Residue Burning	NA	NA	NA	NA	NA	NA	NA	NA	NA
Waste	38	40	40	65	54	43	37	37	38

Source: (EPA 1999) 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.