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 1992, the United States signed and ratified 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. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."[2]

Parties to the Convention, by ratifying, committed "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 2002. To ensure that the U.S. emissions inventory is comparable to those of other UNFCCC Parties, 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) and the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000). The structure of this report is consistent with the new UNFCCC guidelines for inventory reporting.[4] For most source categories, the IPCC methodologies were expanded, resulting in a more comprehensive and detailed estimate of emissions.

ES.1. Background Information

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 bromofluorocarbons (i.e., halons). As stratospheric ozone depleting substances, CFCs, HCFCs, and halons are covered under the *Montreal Protocol on Substances that Deplete the Ozone Layer*. The UNFCCC defers to this earlier international treaty. Consequently, Parties are not required to include these gases in their national greenhouse gas inventories.[5] Some other fluorine containing halogenated substances—

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[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://unfccc.int>.

[3] Article 4(1)(a) of the United Nations Framework Convention on Climate Change (also identified in Article 12). See <http://unfccc.int>.

[4] See <http://unfccc.int/resource/docs/cop8/08.pdf>.

[5] Emissions estimates of CFCs, HCFCs, halons and other ozone-depleting substances are included in this document for informational purposes.

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 and/or solar radiation absorption by influencing the formation or destruction of other greenhouse gases, including tropospheric and stratospheric ozone. These gases include carbon monoxide (CO), oxides of nitrogen (NO_x), and non-methane volatile organic compounds (NMVOCs). Aerosols, which are extremely small particles or liquid droplets, such as those produced by sulfur dioxide (SO_2) or elemental carbon emissions, can also affect the absorptive characteristics of the atmosphere.

Although the direct greenhouse gases CO_2, CH_4, and N_2O occur naturally in the atmosphere, human activities have changed their atmospheric concentrations. Since the pre-industrial era (i.e., ending about 1750), concentrations of these greenhouse gases have increased by 31, 150, and 16 percent, respectively (IPCC 2001).

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 entry into force of the *Montreal Protocol*. Since then, the production of ODSs is being phased out. 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. Accordingly, atmospheric concentrations of these substitutes have been growing (IPCC 2001).

Global Warming Potentials

Gases in the atmosphere can contribute to the greenhouse effect both directly and indirectly. Direct effects occur when the gas itself absorbs radiation. Indirect radiative forcing occurs when chemical transformations of the substance produce other greenhouse gases, when a gas influences the atmospheric lifetimes of other gases, and/or when a gas affects atmospheric processes that alter the radiative balance of the earth (e.g., affect cloud formation or albedo).[6] The IPCC developed the Global Warming Potential (GWP) concept to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to another gas.

The GWP of a greenhouse gas is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas (IPCC 2001). Direct radiative effects occur when the gas itself is a greenhouse gas. The reference gas used is CO_2, and therefore GWP-weighted emissions are measured in teragrams of CO_2 equivalents (Tg CO_2 Eq.).[7] All gases in this executive summary are presented in units of Tg CO_2 Eq. The relationship between gigagrams (Gg) of a gas and Tg CO_2 Eq. can be expressed as follows:

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

While any time period can be selected, this report uses the 100 year GWPs recommended by the IPCC, and adopted by the UNFCCC for reporting purposes (IPCC 1996). GWP values are listed below in Table ES-1.

Table ES-1: Global Warming Potentials (100 Year Time Horizon) Used in this Report

Gas	GWP
Carbon dioxide (CO_2)	1
Methane (CH_4)*	21

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[6] Albedo is a measure of the Earth's reflectivity; see the Glossary (Annex 6.8) for definition.

[7] Carbon comprises 12/44ths of carbon dioxide by weight.

Nitrous oxide (N_2O)	310
HFC-23	11,700
HFC-32	650
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.

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

[Begin Box]

Box ES-1: The IPCC Third Assessment Report and Global Warming Potentials

In its Third Assessment Report (TAR), the IPCC updated the global warming potentials (GWPs) of several gases relative to the Second Assessment Report (SAR), and new GWPs were calculated for an expanded set of gases. Since the Second Assessment Report, the IPCC has applied an improved calculation of CO_2 radiative forcing and an improved CO_2 response function (presented in WMO 1999). The GWPs in the TAR are drawn from WMO (1999) and the Second Assessment Report, with updates for those cases where significantly different new laboratory or radiative transfer results have been published. Additionally, the atmospheric lifetimes of some gases were recalculated. Because the revised radiative forcing of CO_2 is about 12 percent lower than that in the Second Assessment Report, the GWPs of the other gases relative to CO_2 tend to be larger, taking into account revisions in lifetimes. In addition, the values for radiative forcing and lifetimes have been calculated for a variety of halocarbons that were not presented in the Second Assessment Report. Table ES-2 presents the new Global Warming Potentials, relative to those presented in the Second Assessment Report.

Table ES-2: Comparison of 100 Year GWPs

Gas	SAR	TAR	Change	
Carbon dioxide (CO_2)	1	1	NC	NC
Methane (CH_4)*	21	23	2	10%
Nitrous oxide (N_2O)	310	296	(14)	(5%)
HFC-23	11,700	12,000	300	3%
HFC-32	650	550	(100)	(15%)
HFC-125	2,800	3,400	600	21%
HFC-134a	1,300	1,300	NC	NC
HFC-143a	3,800	4,300	500	13%
HFC-152a	140	120	(20)	(14%)
HFC-227ea	2,900	3,500	600	21%
HFC-236fa	6,300	9,400	3,100	49%
HFC-4310mee	1,300	1,500	200	15%
CF_4	6,500	5,700	(800)	(12%)
C_2F_6	9,200	11,900	2,700	29%

C_4F_{10}	7,000	8,600	1,600	23%
C_6F_{14}	7,400	9,000	1,600	22%
SF_6	23,900	22,200	(1,700)	(7%)

Source: (IPCC 2001, 1996)
NC (No Change)
* The methane GWP includes the direct effects and those indirect effects due to the formation of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

Although the GWPs have been updated by the IPCC, estimates of emissions presented in this report use the GWPs from the Second Assessment Report. The UNFCCC reporting guidelines for national inventories[8] were updated in 2002, but continue to require the use of GWPs from the SAR so that current estimates of aggregated greenhouse gas emissions for 1990 through 2002 are consistent with estimates developed prior to the publication of the TAR. Therefore, to comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using SAR GWP values. Overall, these revisions to GWP values do not have a significant effect on U.S. emission trends, and all estimates are provided throughout this report in both CO_2 equivalents and unweighted units. A comparison of emission values using the SAR GWPs versus the TAR GWPs can be found in Chapter 1 and in more detail in Annex 6.1.

[End Box]

ES.2. Recent Trends in U.S. Greenhouse Gas Emissions and Sinks

In 2002, total U.S. greenhouse gas emissions were 6,934.0 teragrams of carbon dioxide equivalents (Tg CO_2 Eq.)[9] (13 percent above 1990 emissions). Overall, total U.S. emissions have risen by 13 percent from 1990 to 2002, while the U.S. gross domestic product has increased by 42 percent over the same period (BEA 2004). Emissions rose slightly from 2001 to 2002, increasing by 0.7 percent (50.0 Tg CO_2 Eq.). The following factors were primary contributors to this increase: 1) moderate economic growth in 2002, leading to increased demand for electricity and fossil fuels, and 2) much hotter summer conditions in 2002, causing an increase in electricity use for air-conditioning. (See the following section for an analysis of emission trends by general economic sectors.)

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-3 provides a detailed summary of U.S. greenhouse gas emissions and sinks for 1990 through 2002.

Figure ES-1: U.S. GHG Emissions by Gas

Figure ES-2: Annual Percent Change in U.S. GHG Emissions

Figure ES-3: Absolute Change in U.S. Greenhouse Gas Emissions Since 1990

Table ES-3: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Tg CO_2 Eq.)

Gas/Source	**1990**		**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
CO_2	**5,002.3**		**5,498.5**	**5,577.6**	**5,602.5**	**5,676.3**	**5,859.0**	**5,731.8**	**5,781.6**

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[8] See < http://unfccc.int/resource/docs/cop8/08.pdf >.

[9] 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 section on Global Warming Potentials, Chapter 1.)

Fossil Fuel Combustion	4,814.7	5,310.1	5,384.0	5,412.4	5,488.8	5,673.6	5,558.8	5,611.0
Iron and Steel Production	85.4	68.3	71.9	67.4	64.4	65.7	59.1	54.4
Cement Manufacture	33.3	37.1	38.3	39.2	40.0	41.2	41.4	42.0
Waste Combustion	10.9	17.2	17.8	17.1	17.6	18.0	18.8	18.8
Ammonia Production and Urea Application	19.3	20.3	20.7	21.9	20.6	19.6	16.2	17.7
Lime Manufacture	11.2	13.5	13.7	13.9	13.5	13.3	12.8	12.3
Limestone and Dolomite Use	5.5	7.8	7.2	7.4	8.1	6.0	5.7	5.8
Natural Gas Flaring	5.8	8.5	7.9	6.6	6.9	5.8	5.4	5.3
Aluminum Production	6.3	5.6	5.6	5.8	5.9	5.7	4.1	4.2
Soda Ash Manufacture and Consumption	4.1	4.2	4.4	4.3	4.2	4.2	4.1	4.1
Titanium Dioxide Production	1.3	1.7	1.8	1.8	1.9	1.9	1.9	2.0
Phosphoric Acid Production	1.5	1.6	1.5	1.6	1.5	1.4	1.3	1.3
Ferroalloys	2.0	2.0	2.0	2.0	2.0	1.7	1.3	1.3
Carbon Dioxide Consumption	0.9	0.8	0.8	0.9	0.9	1.0	0.8	1.3
Land-Use Change and Forestry (Sink)[a]	*(957.9)*	*(1,055.2)*	*(821.0)*	*(705.8)*	*(675.8)*	*(690.2)*	*(689.7)*	*(690.7)*
International Bunker Fuels[b]	*113.9*	*102.3*	*109.9*	*115.1*	*105.3*	*101.4*	*97.9*	*86.8*
Biomass Combustion[b]	*216.7*	*244.3*	*233.2*	*217.2*	*222.3*	*226.8*	*204.4*	*207.1*
CH_4	**642.6**	**637.0**	**628.8**	**620.1**	**613.0**	**614.4**	**605.1**	**598.1**
Landfills	210.0	208.8	203.4	196.6	197.8	199.3	193.2	193.0
Natural Gas Systems	122.0	127.4	126.1	124.5	120.9	125.7	124.9	121.8
Enteric Fermentation	117.9	120.5	118.3	116.7	116.6	115.7	114.3	114.4
Coal Mining	81.9	63.2	62.6	62.8	58.9	56.2	55.6	52.2
Manure Management	31.0	34.6	36.3	38.8	38.6	38.0	38.8	39.5
Wastewater Treatment	24.1	26.9	27.4	27.7	28.2	28.4	28.1	28.7
Petroleum Systems	28.9	25.6	25.5	25.0	23.7	23.5	23.5	23.2
Stationary Sources	8.2	8.7	7.7	7.2	7.4	7.7	7.2	6.8
Rice Cultivation	7.1	7.0	7.5	7.9	8.3	7.5	7.6	6.8
Mobile Sources	5.0	4.8	4.7	4.5	4.5	4.4	4.3	4.2
Abandoned Coal Mines	3.4	6.0	5.6	4.8	4.4	4.4	4.2	4.1
Petrochemical Production	1.2	1.6	1.6	1.7	1.7	1.7	1.4	1.5
Iron and Steel Production	1.3	1.3	1.3	1.2	1.2	1.2	1.1	1.0
Agricultural Residue Burning	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.7
Silicon Carbide Production	+	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O	**393.1**	**436.8**	**436.2**	**432.0**	**428.3**	**425.7**	**417.2**	**415.8**
Agricultural Soil Management	262.8	288.1	293.2	294.2	292.1	289.7	288.6	287.3
Mobile Sources	50.7	60.7	60.3	59.6	58.6	57.4	55.0	52.9
Manure Management	16.2	17.0	17.3	17.3	17.4	17.7	18.0	17.8
Nitric Acid	17.8	20.7	21.2	20.9	20.1	19.6	15.9	16.7
Human Sewage	12.8	14.2	14.4	14.7	15.2	15.3	15.4	15.6
Stationary Sources	12.6	13.8	13.9	13.7	13.8	14.3	13.8	13.9
Adipic Acid	15.2	17.0	10.3	6.0	5.5	6.0	4.9	5.9
N_2O Product Usage	4.3	4.5	4.8	4.8	4.8	4.8	4.8	4.8
Field Burning of Agricultural Residues	0.4	0.4	0.4	0.5	0.4	0.5	0.5	0.4
Waste Combustion	0.4	0.4	0.4	0.3	0.3	0.4	0.4	0.4
International Bunker Fuels[b]	*1.0*	*0.9*	*1.0*	*1.0*	*0.9*	*0.9*	*0.9*	*0.8*
HFCs, PFCs, and SF_6	**99.4**	**118.3**	**124.4**	**136.5**	**134.9**	**139.3**	**130.0**	**138.6**
Substitution of Ozone Depleting Substances	0.3	35.0	46.4	56.6	66.0	75.3	83.6	92.0
HCFC-22 Production	35.0	31.1	30.0	40.2	30.4	29.8	19.8	19.8

Electrical Transmission and Distribution	37.6	27.7	24.3	17.7	16.4	15.9	15.6	14.8
Semiconductor Manufacture	2.9	5.5	6.3	7.1	7.2	6.3	4.5	4.4
Aluminum Production	18.1	12.5	11.0	9.0	8.9	8.9	4.0	5.2
Magnesium Production and Processing	5.4	6.5	6.3	5.8	6.0	3.2	2.5	2.4
Total	**6,137.4**	**6,690.6**	**6,767.0**	**6,791.1**	**6,852.5**	**7,038.4**	**6,884.0**	**6,934.0**
Net Emissions (Sources and Sinks)	**5,179.6**	**5,635.4**	**5,946.1**	**6,085.3**	**6,176.7**	**6,348.3**	**6,194.3**	**6,243.3**

+ Does not exceed 0.05 Tg CO_2 Eq.

[a] For the most recent years, a portion of the sink estimate is based on historical and projected data; see Chapter 6 for a complete breakdown of this sector. Parentheses indicate negative values (or sequestration).

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

Note: Totals may not sum due to independent rounding.

Figure ES-4 illustrates the relative contribution of the direct greenhouse gases to total U.S. emissions in 2002. The primary greenhouse gas emitted by human activities in the United States was CO_2, representing approximately 83 percent of total greenhouse gas emissions. The largest source of CO_2, and of overall greenhouse gas emissions, was fossil fuel combustion. Methane emissions resulted primarily from decomposition of wastes in landfills, natural gas systems, and enteric fermentation associated with domestic livestock. Agricultural soil management and mobile source fossil fuel combustion were the major sources of N_2O emissions. 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 accounted for most SF_6 emissions, while the majority of PFC emissions resulted as a by-product of primary aluminum production.

Figure ES-4: 2002 Greenhouse Gas Emissions by Gas

As the largest source of U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion has accounted for a nearly constant 80 percent of global warming potential (GWP) weighted emissions since 1990. Emissions from this source category grew by 17 percent (796.3 Tg CO_2 Eq.) from 1990 to 2002 and were responsible for most of the increase in national emissions during this period. From 2001 to 2002, these emissions increased by 52.2 Tg CO_2 Eq. (0.9 percent), slightly lower than the source's average annual growth rate of 1.3 percent from 1990 through 2002. Historically, changes in emissions from fossil fuel combustion have been the dominant factor affecting U.S. emission trends.

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 consumption of fossil fuels in the United States generally fluctuates in response to changes in general economic conditions, energy prices, weather, and the availability of non-fossil alternatives. For example, in 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, there would likely be 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.

In the longer-term energy consumption patterns respond to 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 also depend on the type of fuel or energy consumed and its carbon intensity. Producing a unit of heat or electricity using natural gas instead of coal, for example, can reduce the CO_2 emissions because of the lower carbon content of natural gas. Table ES-4 shows annual changes in emissions during the last six years for coal, petroleum, and natural gas in selected sectors.

Table ES-4: Annual Change in CO_2 Emissions from Fossil Fuel Combustion for Selected Fuels and Sectors (Tg CO_2 Eq. and Percent)

Sector	Fuel Type	1997 to 1998		1998 to 1999		1999 to 2000		2000 to 2001		2001 to 2002	
Electricity Generation	Coal	29.1	2%	5.9	0%	88.0	5%	-61.9	-3%	39.9	2%
Electricity Generation	Natural Gas	29.1	13%	11.9	5%	20.8	8%	8.4	3%	10.0	3%
Electricity Generation	Petroleum	29.8	40%	-7.6	-7%	-5.6	-6%	9.8	11%	-27.9	-28%
Transportation[a]	Petroleum	36.2	2%	57.5	4%	46.9	3%	-17.4	-1%	32.5	2%
Residential	Natural Gas	-23.7	-9%	10.0	4%	13.9	5%	-10.9	-4%	7.7	3%
Commercial	Natural Gas	-10.8	-6%	1.7	1%	9.0	5%	-9.3	-5%	4.3	3%
Industrial	Coal	-8.1	-6%	-5.5	-4%	1.6	1%	-4.9	-4%	-3.0	-2%
Industrial	Natural Gas	-11.9	-2%	-17.9	-4%	7.6	2%	-39.7	-8%	-10.4	-2%
All Sectors[b]	**All Fuels[b]**	**28.5**	**1%**	**76.4**	**1%**	**185.3**	**3%**	**-114.1**	**-2%**	**52.0**	**1%**

[a] Excludes emissions from International Bunker Fuels.

[b] Includes fuels and sectors not shown in table.

Emissions from fuel combustion resumed a modest growth in 2002, slightly less than the average annual growth rate since 1990. There were a number of reasons behind this increase. The U.S. economy experienced moderate growth, recovering from weaker conditions in 2001. Prices for fuels remained at or below 2001 levels; the cost of natural gas, motor gasoline, and electricity were all lower—triggering an increase in demand for fuel. In addition, the United States experienced one of the hottest summers on record, causing a significant increase in electricity use in the residential sector as the use of air-conditioners increased. Partially offsetting this increased consumption of fossil fuels, however, were increases in the use of nuclear and renewable fuels. Nuclear facilities operated at the highest capacity on record in 2002. Furthermore, there was a considerable increase in the use of hydroelectric power in 2002 after a very low output the previous year.

Other significant trends in emissions from additional source categories over the thirteen-year period from 1990 through 2002 included the following:

- Carbon dioxide emissions from waste combustion increased by 7.9 Tg CO_2 Eq. (72 percent), as the volume of plastics and other fossil carbon-containing materials in municipal solid waste grew.
- Net CO_2 sequestration from land use change and forestry decreased by 267.1 Tg CO_2 Eq. (28 percent), primarily due to a decline in the rate of net carbon accumulation in forest carbon stocks. This decline largely resulted from a decrease in the estimated rate of forest soil sequestration caused by a slowing rate of increase in forest area after 1997.
- Methane emissions from coal mining dropped by 29.7 Tg CO_2 Eq. (36 percent) as a result of the mining of less gassy coal from underground mines and the increased use of methane collected from degasification systems.
- 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. (61 percent). The majority of this decline occurred from 1996 to 1998, despite increased production.
- Nitrous oxide emissions from agricultural soil management increased by 24.5 Tg CO_2 Eq. (9 percent) as crop and forage production, manure production, and fertilizer consumption rose.
- Aggregate HFC and PFC emissions resulting from the substitution of ozone depleting substances (e.g., CFCs) increased by 91.7 Tg CO_2 Eq. This increase was significantly offset, however, by reductions in PFC emissions from aluminum production (12.9 Tg CO_2 Eq. or 71 percent), reductions in emissions of HFC-23 from the production of HCFC-22 (15.2 Tg CO_2 Eq. or 43 percent), and reductions of SF_6 from electric power transmission and distribution systems (22.8 Tg CO_2 Eq. or 61 percent). Reductions in PFC emissions from aluminum production resulted from both industry emission reduction efforts and lower domestic aluminum production. HFC-23 emissions from the production of HCFC-22 decreased because a reduction in the intensity of emissions from that source offset an increase in HCFC-22 production. Reduced emissions of SF_6 from electric power transmission and distribution systems are primarily the result of higher purchase prices for SF_6 and efforts by industry to reduce emissions.

Overall, from 1990 to 2002, total emissions of CO_2 and N_2O increased by 779.3 Tg CO_2 Eq. (16 percent) and 22.6 Tg CO_2 Eq. (6 percent), respectively, while CH_4 emissions decreased by 44.6 Tg CO_2 Eq. (7 percent). During the same period, aggregate weighted emissions of HFCs, PFCs, and SF_6 rose by 39.2 Tg CO_2 Eq. (39 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, trees in urban areas, agricultural soils, and landfilled yard trimmings, which was estimated to be 10 percent of total emissions in 2002.

ES.3. Overview of Source and Sink Emission Trends

Carbon Dioxide Emissions

The global carbon cycle is made up of large carbon flows and reservoirs. Billions of tons of carbon in the form of CO_2 are absorbed by oceans and living biomass (i.e., sinks) and are emitted to the atmosphere annually through natural processes (i.e., sources). When in equilibrium, carbon fluxes among these various reservoirs are roughly balanced. Since the Industrial Revolution, this equilibrium of atmospheric carbon has been disrupted. Atmospheric concentrations of CO_2 have risen about 31 percent (IPCC 2001), principally because of fossil fuel combustion, which accounted for 97 percent of total U.S. CO_2 emissions in 2002. Globally, approximately 23,300 Tg of CO_2 were added to the atmosphere through the combustion of fossil fuels at the end of the 1990s, of which the United States accounted for about 24 percent (see Figure ES-6).[10] 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-5 and Table ES-5 summarize U.S. sources and sinks of CO_2. The remainder of this section discusses CO_2 emission trends in greater detail.

Figure ES-5: 2002 Sources of CO_2

Figure ES-6: 2002 U.S. Fossil Carbon Flows (Tg CO_2 Eq.) TO BE UPDATED

Table ES-5: U.S. Sources of CO_2 Emissions and Sinks (Tg CO_2 Eq.)

Source or Sink	**1990**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Fossil Fuel Combustion	4,814.7	5,310.1	5,384.0	5,412.4	5,488.8	5,673.6	5,558.8	5,611.0
Electricity Generation	1,792.4	1,992.2	2,060.5	2,148.5	2,158.7	2,261.9	2,218.2	2,240.1
Transportation	1,458.2	1,604.8	1,614.8	1,644.9	1,702.9	1,749.6	1,730.6	1,764.4
Industrial	966.6	1,045.9	1,058.4	1,018.1	1,001.9	999.7	970.8	955.8
Residential	339.6	388.9	370.6	338.6	359.3	379.3	366.9	373.1
Commercial	224.2	237.0	237.2	219.7	222.3	237.1	227.3	231.2
U.S. Territories	33.7	41.3	42.6	42.6	43.7	45.9	45.0	46.5
Iron and Steel Production	85.4	68.3	71.9	67.4	64.4	65.7	59.1	54.4
Cement Manufacture	33.3	37.1	38.3	39.2	40.0	41.2	41.4	42.0
Waste Combustion	10.9	17.2	17.8	17.1	17.6	18.0	18.8	18.8
Ammonia Production and Urea Application	19.3	20.3	20.7	21.9	20.6	19.6	16.2	17.7
Lime Manufacture	11.2	13.5	13.7	13.9	13.5	13.3	12.8	12.3
Limestone and Dolomite Use	5.5	7.8	7.2	7.4	8.1	6.0	5.7	5.8
Natural Gas Flaring	5.8	8.5	7.9	6.6	6.9	5.8	5.4	5.3
Aluminum Production	6.3	5.6	5.6	5.8	5.9	5.7	4.1	4.2

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[10] Global CO_2 emissions from fossil fuel combustion were taken from Marland et al. (2002) <http://cdiac.esd.ornl.gov/trends/emis/meth_reg.htm>.

Soda Ash Manufacture and Consumption	4.1		4.2	4.4	4.3	4.2	4.2	4.1	4.1
Titanium Dioxide Production	1.3		1.7	1.8	1.8	1.9	1.9	1.9	2.0
Phosphoric Acid Production	1.5		1.6	1.5	1.6	1.5	1.4	1.3	1.3
Ferroalloys	2.0		2.0	2.0	2.0	2.0	1.7	1.3	1.3
Carbon Dioxide Consumption	0.9		0.8	0.8	0.9	0.9	1.0	0.8	1.3
Land-Use Change and Forestry (Sink)[a]	*(957.9)*		*(1,055.2)*	*(821.0)*	*(705.8)*	*(675.8)*	*(690.2)*	*(689.7)*	*(690.7)*
International Bunker Fuels[b]	*113.9*		*102.3*	*109.9*	*115.1*	*105.3*	*101.4*	*97.9*	*86.8*
Biomass Combustion[b]	*216.7*		*244.3*	*233.2*	*217.2*	*222.3*	*226.8*	*204.4*	*207.1*
Total	**5,002.3**		**5,498.5**	**5,577.6**	**5,602.5**	**5,676.3**	**5,859.0**	**5,731.8**	**5,781.6**
Net Emissions (Sources and Sinks)	**4,044.5**		**4,443.3**	**4,756.7**	**4,896.7**	**5,000.5**	**5,168.8**	**5,042.0**	**5,090.9**

[a] Sinks are only included in net emissions total, and are based partially on projected activity data. Parentheses indicate negative values (or sequestration).

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

Note: Totals may not sum due to independent rounding.

Energy

Energy-related activities, primarily fossil fuel combustion, accounted for the vast majority of U.S. CO_2 emissions for the period of 1990 through 2002. In 2002, approximately 86 percent of the energy consumed in the United States was produced through the combustion of fossil fuels. The remaining 14 percent came from other energy sources such as hydropower, biomass, nuclear, wind, and solar energy (see Figure ES-7 and Figure ES-8). A discussion of specific trends related to CO_2 emissions from energy consumption is presented below.

Figure ES-7: 2002 U.S. Energy Consumption by Energy Source

Figure ES-8: U.S. Energy Consumption (Quadrillion Btu)

Fossil Fuel Combustion (5,611.0 Tg CO_2 Eq.)

As fossil fuels are combusted, the carbon stored in them is emitted almost entirely 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 and natural gas have about 25 percent and 45 percent less carbon than coal, respectively. From 1990 through 2002, 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. Petroleum was consumed primarily in the transportation end-use sector, the vast majority of coal was used by electric power generators, 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 1.3 percent from 1990 to 2002. The fundamental factors influencing this trend include (1) a growing domestic economy over the last 11 years, and (2) significant growth in emissions from transportation activities and electricity generation. Between 1990 and 2002, CO_2 emissions from fossil fuel combustion increased from 4,814.7 Tg CO_2 Eq. to 5,611.0 Tg CO_2 Eq.—a 17 percent total increase over the twelve-year period.

The four major end-use sectors contributing to CO_2 emissions from fossil fuel combustion are industrial, transportation, residential, and commercial. Electricity generation also emits 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, electricity generation emissions have been distributed to each end-use sector on the basis of each sector's share of aggregate electricity consumption. This method of distributing emissions assumes that each end-use sector consumes electricity that is generated from the national average mix of fuels according to their carbon intensity. In reality, sources of electricity vary widely in carbon intensity. By assuming the same carbon intensity for each end-use sector's electricity consumption, for example, emissions attributed to the residential end-use sector may be underestimated, while emissions attributed to the industrial end-use sector may be overestimated. Emissions from electricity generation are also addressed separately after the end-use sectors have been discussed.

Note that emissions from U.S. territories are calculated separately due to a lack of specific consumption data for the individual end-use sectors. Table ES-6, Figure ES-9, and Figure ES-10 summarize CO_2 emissions from fossil fuel combustion by end-use sector.

Table ES-6: CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector (Tg CO_2 Eq.)

End-Use Sector	**1990**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Transportation	**1,461.2**	**1,607.8**	**1,617.8**	**1,648.0**	**1,706.1**	**1,753.0**	**1,734.1**	**1,767.5**
Combustion	1,458.2	1,604.8	1,614.8	1,644.9	1,702.9	1,749.6	1,730.6	1,764.4
Electricity	3.0	3.0	3.1	3.1	3.2	3.4	3.5	3.2
Industrial	**1,638.5**	**1,769.6**	**1,800.7**	**1,778.4**	**1,768.4**	**1,782.5**	**1,687.5**	**1,677.1**
Combustion	966.6	1,045.9	1,058.4	1,018.1	1,001.9	999.7	970.8	955.8
Electricity	671.9	723.7	742.3	760.3	766.4	782.8	716.7	721.3
Residential	**925.5**	**1,053.1**	**1,043.5**	**1,047.5**	**1,066.5**	**1,127.5**	**1,117.5**	**1,149.2**
Combustion	339.6	388.9	370.6	338.6	359.3	379.3	366.9	373.1
Electricity	585.9	664.2	673.0	708.9	707.3	748.3	750.7	776.2
Commercial	**755.7**	**838.3**	**879.4**	**895.9**	**904.2**	**964.6**	**974.6**	**970.6**
Combustion	224.2	237.0	237.2	219.7	222.3	237.1	227.3	231.2
Electricity	531.6	601.3	642.2	676.2	681.9	727.5	747.3	739.4
U.S. Territories	**33.7**	**41.3**	**42.6**	**42.6**	**43.7**	**45.9**	**45.0**	**46.5**
Total	**4,814.7**	**5,310.1**	**5,384.0**	**5,412.4**	**5,488.8**	**5,673.6**	**5,558.8**	**5,611.0**
Electricity Generation	**1,792.4**	**1,992.2**	**2,060.5**	**2,148.5**	**2,158.7**	**2,261.9**	**2,218.2**	**2,240.1**

Note: Totals may not sum due to independent rounding. Combustion-related emissions from electricity generation are allocated based on aggregate national electricity consumption by each end-use sector.

Figure ES-9: 2002 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type

Figure ES-10: 2002 End-Use Sector Emissions of CO_2 from Fossil Fuel Combustion

Transportation End-Use Sector. Transportation activities (excluding international bunker fuels) accounted for 32 percent of CO_2 emissions from fossil fuel combustion in 2002.[11] Virtually all of the energy consumed in this end-use sector came from petroleum products. Just over half of the emissions resulted from gasoline consumption for personal vehicle use. The remaining emissions came from other transportation activities, including the combustion of diesel fuel in heavy-duty vehicles and jet fuel in aircraft.

Industrial End-Use Sector. Industrial CO_2 emissions, resulting both directly from the combustion of fossil fuels and indirectly from the generation of electricity that is consumed by industry, accounted for 30 percent of CO_2 from fossil fuel combustion in 2002. About half of these emissions resulted from direct fossil fuel combustion to produce

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[11] 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 2002.

steam and/or heat for industrial processes. The other half of the emissions resulted from consuming electricity for motors, electric furnaces, ovens, lighting, and other applications.

Residential and Commercial End-Use Sectors. The residential and commercial end-use sectors accounted for 20 and 17 percent, respectively, of CO_2 emissions from fossil fuel combustion in 2002. Both sectors relied heavily on electricity for meeting energy demands, with 68 and 76 percent, respectively, of their emissions attributable to electricity consumption for lighting, heating, cooling, and operating appliances. The remaining emissions were due to the consumption of natural gas and petroleum for heating and cooking.

Electricity Generation. The United States relies on electricity to meet a significant portion of its energy demands, especially for lighting, electric motors, heating, and air conditioning. Electricity generators consumed 35 percent of U.S. energy from fossil fuels and emitted 40 percent of the CO_2 from fossil fuel combustion in 2002. The type of fuel combusted by electricity generators 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, electricity generators rely on coal for over half of their total energy requirements and accounted for 93 percent of all coal consumed for energy in the United States in 2002. Consequently, changes in electricity demand have a significant impact on coal consumption and associated CO_2 emissions.

Waste Combustion (18.8 Tg CO_2 Eq.)

The burning of garbage and non-hazardous solids, referred to as municipal solid waste (MSW), as well as the burning of hazardous waste, is usually performed to recover energy from the waste materials. 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 accounted for under the Land-Use Change and Forestry chapter. Several components of MSW, such as plastics, synthetic rubber, synthetic fibers, and carbon black, are of fossil fuel origin, and are included as sources of CO_2 emissions.

Natural Gas Flaring (5.3 Tg CO_2 Eq.)

The flaring of natural gas from oil wells results in the release of CO_2 emissions. Natural gas is flared from both on-shore and off-shore oil wells to relieve rising pressure or to dispose of small quantities of gas that are not commercially marketable. In 2002, flaring accounted for approximately 0.1 percent of U.S. CO_2 emissions.

Biomass Combustion (207.1 Tg CO_2 Eq.)

Biomass refers to organically-based carbon fuels (as opposed to fossil-based). Biomass in the form of fuel wood and wood waste was used primarily in the industrial sector, while the transportation sector was the predominant user of biomass-based fuels, such as ethanol from corn and woody crops.

Although these fuels do emit CO_2, in the long run the CO_2 emitted from biomass 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 in the estimates for Land-Use Change and Forestry. As a result, CO_2 emissions from biomass combustion have been estimated separately from fossil fuel-based emissions and are not included in the U.S. totals.

The consumption of wood biomass in the industrial, residential, electric power, and commercial sectors accounted for 68, 17, 7, and 2 percent of gross CO_2 emissions from biomass combustion, respectively. Ethanol consumption in the transportation sector accounted for the remaining 6 percent.

Industrial Processes

Emissions are produced as a by-product of many non-energy-related activities. For example, industrial processes can chemically transform raw materials, which often release waste gases such as CO_2. The processes that emit CO_2 include iron and steel production, cement manufacture, ammonia manufacturing and urea application, lime manufacture, limestone and dolomite use, soda ash manufacture and consumption, aluminum production, titanium dioxide production, phosphoric acid production, ferroalloy production, and CO_2 consumption. Carbon dioxide emissions from these sources were approximately 146.5 Tg CO_2 Eq. in 2002, accounting for about 3 percent of total CO_2 emissions.

Iron and Steel Production (54.4 Tg CO_2 Eq.)

Pig iron is the product of combining iron oxide (i.e., iron ore) and sinter with metallurgical coke in a blast furnace. The pig iron production process, as well as the thermal processes used to create sinter and metallurgical coke result in the emission of CO_2. Some of the pig iron is transformed into steel using a variety of specialized steel making furnaces that allow the emission of additional CO_2. The majority of CO_2 emissions from the iron and steel processes come from the production of coke for use in pig iron creation, with smaller amounts evolving from the removal of carbon from pig iron used to produce steel.

Cement Manufacture (42.0 Tg CO_2 Eq.)

Clinker is an intermediate product in the formation of finished Portland and masonry cement. Heating calcium carbonate ($CaCO_3$) in a cement kiln forms lime and CO_2. The lime combines with other materials to produce clinker, and the CO_2 is released into the atmosphere.

Ammonia Manufacture and Urea Application (17.7 Tg CO_2 Eq.)

In the United States, roughly 98 percent of synthetic ammonia is produced by catalytic steam reforming of natural gas, and the remainder is produced using naphtha (i.e., a petroleum fraction) or the electrolysis of brine at chlorine plants (EPA 1997). The two fossil fuel-based reactions produce carbon monoxide and hydrogen gas. This carbon monoxide is transformed into CO_2 in the presence of a catalyst. The CO_2 is generally released into the atmosphere, but some of the CO_2, together with ammonia, is used as a raw material in the production of urea [$CO(NH_2)_2$], which is a type of nitrogenous fertilizer. The carbon in the urea that is produced and assumed to be subsequently applied to agricultural land as a nitrogenous fertilizer is ultimately released into the environment as CO_2.

Lime Manufacture (12.3 Tg CO_2 Eq.)

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

Limestone and Dolomite Use (5.8 Tg CO_2 Eq.)

Limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)$) are basic raw materials used in a wide variety of industries, including construction, agriculture, chemical, and metallurgy. 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 (4.1 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.

Aluminum Production (4.2 Tg CO_2 Eq.)

Carbon dioxide is emitted when alumina (aluminum oxide, Al_2O_3) is reduced to aluminum. The reduction of the alumina occurs through electrolysis in a molten bath of natural or synthetic cryolite. The reduction cells contain a carbon lining that serves as the cathode. Carbon is also contained in the anode, which can be a carbon mass of paste, coke briquettes, or prebaked carbon blocks from petroleum coke. During reduction, some of this carbon is oxidized and released to the atmosphere as CO_2.

Titanium Dioxide Production (2.0 Tg CO_2 Eq.)

Titanium dioxide (TiO_2) is a metal oxide manufactured from titanium ore, and is principally used as a pigment. It is used in white paint and as a pigment in the manufacture of white paper, foods, and other products. Two processes, the chloride process and the sulfate process, are used for making TiO_2. Carbon dioxide is emitted from the chloride process, which uses petroleum coke and chlorine as raw materials.

Phosphoric Acid Production (1.3 Tg CO_2 Eq.)

Phosphoric acid is a basic raw material in the production of phosphate-based fertilizers. The phosphate rock consumed in the United States originates from both domestic mines, located primarily in Florida, North Carolina, Idaho, and Utah, and foreign mining operations in Morocco. The primary use of this material is as a basic component of a series of chemical reactions that lead to the production of phosphoric acid, as well as the by-products CO_2 and phosphogypsum.

Ferroalloy Production (1.3 Tg CO_2 Eq.)

Carbon dioxide is emitted from the production of several ferroalloys. Ferroalloys are composites of iron and other elements such as silicon, manganese, and chromium. When incorporated in alloy steels, ferroalloys are used to alter the material properties of the steel. Ferroalloy emissions have been decreasing since 1999, due to decreases in production. Overall, from 1990 ferroalloy emissions have decreased 12 percent.

Carbon Dioxide Consumption (1.3 Tg CO_2 Eq.)

Many segments of the economy consume CO_2, including food processing, beverage manufacturing, chemical processing, and a host of industrial and other miscellaneous applications. Carbon dioxide may be produced as a by-product from the production of certain chemicals (e.g., ammonia), from select natural gas wells, or by separating it from crude oil and natural gas. 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 terrestrial biosphere through land use, changes in land-use, and land management practices, they also alter the natural carbon fluxes between biomass, soils, and the atmosphere. Forest management practices, tree planting in urban areas, the management of agricultural soils, and landfilling of yard trimmings have resulted in a net uptake (sequestration) of carbon in the United States, which offset about 10 percent of total U.S. gross CO_2 emissions in 2002. Forests (including vegetation, soils, and harvested wood) accounted for approximately 87 percent of total 2002 sequestration, urban trees accounted for 8 percent, agricultural soils (including mineral and organic soils and the application of lime) accounted for 3 percent, and landfilled yard trimmings accounted for 1 percent of the total sequestration in 2002. The net forest sequestration is a result of net forest growth and increasing forest area, as well as a net accumulation of carbon stocks in harvested wood pools. The net sequestration in urban forests is a result of net tree growth in these areas. In agricultural soils, mineral soils account for a net carbon sink that is approximately one and a third times larger than the sum of emissions from organic soils and liming. The mineral soil carbon sequestration is largely due to conversion of cropland to permanent pastures and hay production, a reduction in summer fallow areas in semi-arid areas, an increase in the adoption of conservation tillage practices, and an increase in the amounts of organic fertilizers (i.e., manure and sewage sludge) applied to agriculture lands. The landfilled yard trimmings net sequestration is due to the long-term accumulation of yard trimming carbon in landfills.

Methane Emissions

According to the IPCC, CH_4 is more than 20 times as effective as CO_2 at trapping heat in the atmosphere. Over the last two hundred and fifty years, the concentration of CH_4 in the atmosphere increased by 150 percent (IPCC 2001).

Experts believe that over half of this atmospheric increase was due to emissions from anthropogenic sources, such as landfills, natural gas and petroleum systems, agricultural activities, coal mining, wastewater treatment, stationary and mobile combustion, and certain industrial processes (see Figure ES-11 and Table ES-7).

Figure ES-11: 2002 Sources of CH_4

Table ES-7: U.S. Sources of CH_4 Emissions (Tg CO_2 Eq.)

Source	**1990**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Landfills	210.0	208.8	203.4	196.6	197.8	199.3	193.2	193.0
Natural Gas Systems	122.0	127.4	126.1	124.5	120.9	125.7	124.9	121.8
Enteric Fermentation	117.9	120.5	118.3	116.7	116.6	115.7	114.3	114.4
Coal Mining	81.9	63.2	62.6	62.8	58.9	56.2	55.6	52.2
Manure Management	31.0	34.6	36.3	38.8	38.6	38.0	38.8	39.5
Wastewater Treatment	24.1	26.9	27.4	27.7	28.2	28.4	28.1	28.7
Petroleum Systems	28.9	25.6	25.5	25.0	23.7	23.5	23.5	23.2
Stationary Sources	8.2	8.7	7.7	7.2	7.4	7.7	7.2	6.8
Rice Cultivation	7.1	7.0	7.5	7.9	8.3	7.5	7.6	6.8
Mobile Sources	5.0	4.8	4.7	4.5	4.5	4.4	4.3	4.2
Abandoned Coal Mines	3.4	6.0	5.6	4.8	4.4	4.4	4.2	4.1
Petrochemical Production	1.2	1.6	1.6	1.7	1.7	1.7	1.4	1.5
Iron and Steel Production	1.3	1.3	1.3	1.2	1.2	1.2	1.1	1.0
Field Burning of Agricultural Residues	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.7
Silicon Carbide Production	+	+	+	+	+	+	+	+
*International Bunker Fuels**	*0.2*	*0.1*	*0.1*	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*
Total*	**642.6**	**637.0**	**628.8**	**620.1**	**613.0**	**614.4**	**605.1**	**598.1**

+ 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.

Landfills (193.0 Tg CO_2 Eq.)

Landfills are the largest anthropogenic source of CH_4 emissions in the United States, accounting for approximately 32 percent of total CH_4 emissions in 2002. In an environment where the oxygen content is low or zero, anaerobic bacteria can decompose organic materials, such as yard waste, household waste, food waste, and paper, resulting in the generation of CH_4 and biogenic CO_2. Site-specific factors, such as waste composition, moisture, and landfill size, influence the level of methane generation.

Methane emissions from U.S. landfills have decreased by 8 percent since 1990. The generally declining emission estimates are a result of two offsetting trends: (1) the amount of municipal solid waste in landfills contributing to CH_4 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. Additionally, 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.

Natural Gas and Petroleum Systems (145.0 Tg CO_2 Eq.)

Methane is the major component of natural gas. Fugitive emissions of CH_4 occur throughout the production, processing, transmission, and distribution of natural gas. 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 2002, CH_4 emissions from U.S. natural gas systems accounted for approximately 20 percent of U.S. CH_4 emissions.

Petroleum is often found in the same geological structures as natural gas, and the two are often retrieved together. Crude oil is saturated with many lighter hydrocarbons, including methane. When the oil is brought to the surface and processed, many of the dissolved lighter hydrocarbons (as well as water) are removed through a series of high-pressure and low-pressure separators. The remaining hydrocarbons in the oil are emitted at various points along the system. Methane emissions from the components of petroleum systems generally occur as a result of system leaks, disruptions, and routine maintenance. In 2002, emissions from petroleum systems were just under 4 percent of U.S. CH_4 emissions.

Enteric Fermentation (114.4 Tg CO_2 Eq.)

During animal digestion, CH_4 is produced through the process of enteric fermentation, in which microbes residing in animal digestive systems break down food. Ruminants, which include cattle, buffalo, sheep, and goats, have the highest CH_4 emissions among all animal types because they have a rumen, or large fore-stomach, in which CH_4-producing fermentation occurs. Non-ruminant domestic animals, such as pigs and horses, have much lower CH_4 emissions. In 2002, enteric fermentation was the source of about 19 percent of U.S. CH_4 emissions, and more than 71 percent of the CH_4 emissions from agriculture. From 1990 to 2002, emissions from this source decreased by 3 percent. Emissions from enteric fermentation have been generally decreasing since 1995, primarily due to declining dairy cow and beef cattle populations as a result of improved efficiency in milk and beef production.

Coal Mining (52.2 Tg CO_2 Eq.)

Produced millions of years ago during the formation of coal, CH_4 trapped within coal seams and surrounding rock strata is released when the coal is mined. The quantity of CH_4 released to the atmosphere during coal mining operations depends primarily upon the type of coal and the method and rate of mining.

Methane from surface mines is emitted directly to the atmosphere as the rock strata overlying the coal seam are removed. Because CH_4 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, CH_4-recovery systems may supplement these ventilation systems. Recovery of CH_4 in the United States has increased in recent years. During 2002, coal mining activities emitted 9 percent of U.S. CH_4 emissions. From 1990 to 2002, emissions from this source decreased by 36 percent due to increased use of the CH_4 collected by mine degasification systems and a general shift toward surface mining.

Manure Management (39.5 Tg CO_2 Eq.)

The decomposition of organic animal waste in an anaerobic environment produces CH_4. The most important factor affecting the amount of CH_4 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 CH_4, whereas solid waste management approaches produce little or no CH_4. Higher temperatures and moist climatic conditions also promote CH_4 production.

Emissions from manure management were about 7 percent of U.S. CH_4 emissions in 2002 and 24 percent of the CH_4 emissions from the agriculture sector. From 1990 to 2002, emissions from this source increased by 27 percent. 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.

Wastewater Treatment (28.7 Tg CO_2 Eq.)

Wastewater from domestic sources (i.e., municipal sewage) and industrial sources is treated to remove soluble organic matter, suspended solids, pathogenic organisms and chemical contaminants. Soluble organic matter is generally removed using biological processes in which microorganisms consume the organic matter for maintenance and growth. Microorganisms can biodegrade soluble organic material in wastewater under aerobic or anaerobic conditions, with the latter condition producing CH_4. During collection and treatment, wastewater may be accidentally or deliberately managed under anaerobic conditions. In addition, the sludge may be further biodegraded under aerobic or anaerobic conditions. Untreated wastewater may also produce CH_4 if contained under anaerobic conditions. In 2002, wastewater treatment was the source of approximately 5 percent of U.S. CH_4 emissions.

Stationary and Mobile Combustion (11.1 Tg CO_2 Eq.)

In 2002, stationary and mobile combustion were responsible for CH_4 emissions of 6.8 and 4.2 Tg CO_2 Eq., respectively. The majority of CH_4 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 CH_4 emitted from mobile combustion.

Rice Cultivation (6.8 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 CH_4 to the atmosphere, primarily through the rice plants. In 2002, rice cultivation was the source of 1 percent of U.S. CH_4 emissions, and about 4 percent of U.S. CH_4 emissions from agriculture. Emission estimates from this source have decreased about 4 percent since 1990.

Abandoned Coal Mines (4.1 Tg CO_2 Eq.)

Coal mining activities result in the emission of CH_4 into the atmosphere. However, the closure of a coal mine does not correspond with an immediate cessation in the release of emissions. Following an initial decline, abandoned mines can liberate CH_4 at a near-steady rate over an extended period of time, or, if flooded, produce gas for only a few years. In 2002, the emissions from abandoned coal mines constituted less than 1 percent of U.S. CH_4 emissions.

Petrochemical and Silicon Carbide Production (1.5 Tg CO_2 Eq.)

Small amounts of CH_4 are released during the production of five petrochemicals: carbon black, ethylene, ethylene dichloride, styrene, and methanol. These production processes resulted in emissions of 1.5 Tg CO_2 Eq. in 2002. Methane is also emitted from the production of silicon carbide, a material used as an industrial abrasive. In 2002, silicon carbide production resulted in emissions of less than 0.1 Tg CO_2 Eq.

Iron and Steel Production (1.0 Tg CO_2 Eq.)

Pig iron is the product of combining iron oxide (i.e., iron ore) and sinter with metallurgical coke in a blast furnace. The pig iron production process, as well as the thermal processes used to create sinter and metallurgical coke result in the emission of CH_4. In 2002, iron and steel production resulted in 1.0 Tg CO_2 Eq. of CH_4 emissions with the majority of the emissions coming from the pig iron production process.

Field Burning of Agricultural Residues (0.7 Tg CO_2 Eq.)

Burning crop residue releases a number of greenhouse gases, including CH_4. Because field burning is not a common debris clearing method used in the United States, it was responsible for only 0.1 percent of U.S. CH_4 emissions in 2002.

Nitrous Oxide Emissions

Nitrous oxide (N_2O) is produced by biological processes that occur in soil and water and by a variety of anthropogenic activities in the agricultural, energy-related, industrial, and waste management fields. While total N_2O emissions are much lower than CO_2 emissions, N_2O is approximately 300 times more powerful than CO_2 at trapping heat in the atmosphere. Since 1750, the atmospheric concentration of N_2O has risen by approximately 16 percent (IPCC 2001). The main anthropogenic activities producing N_2O in the United States are agricultural soil management, fuel combustion in motor vehicles, manure management, nitric acid production, human sewage, and stationary fuel combustion (see Figure ES-12 and Table ES-8).

Figure ES-12: 2002 Sources of N_2O

Table ES-8: U.S. Sources of Nitrous Oxide Emissions (Tg CO_2 Eq.)

Source	1990	1996	1997	1998	1999	2000	2001	2002
Agricultural Soil Management	262.8	288.1	293.2	294.2	292.1	289.7	288.6	287.3
Mobile Sources	50.7	60.7	60.3	59.6	58.6	57.4	55.0	52.9
Manure Management	16.2	17.0	17.3	17.3	17.4	17.7	18.0	17.8
Nitric Acid	17.8	20.7	21.2	20.9	20.1	19.6	15.9	16.7
Human Sewage	12.8	14.2	14.4	14.7	15.2	15.3	15.4	15.6
Stationary Sources	12.6	13.8	13.9	13.7	13.8	14.3	13.8	13.9
Adipic Acid	15.2	17.0	10.3	6.0	5.5	6.0	4.9	5.9
N_2O Product Usage	4.3	4.5	4.8	4.8	4.8	4.8	4.8	4.8
Field Burning of Agricultural Residues	0.4	0.4	0.4	0.5	0.4	0.5	0.5	0.4
Waste Combustion	0.4	0.4	0.4	0.3	0.3	0.4	0.4	0.4
*International Bunker Fuels**	*1.0*	*0.9*	*1.0*	*1.0*	*0.9*	*0.9*	*0.9*	*0.8*
Total*	**393.1**	**436.8**	**436.2**	**432.0**	**428.3**	**425.7**	**417.2**	**415.8**

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

Agricultural Soil Management (287.3 Tg CO_2 Eq.)

Nitrous oxide 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 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 and forages; 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 or deposited on soils as fertilizer, livestock manure, and sewage sludge.

In 2002, agricultural soil management accounted for 69 percent of U.S. N_2O emissions. From 1990 to 2002, emissions from this source increased by 9 percent as fertilizer consumption, manure production, and production of nitrogen-fixing and other crops rose.

Stationary and Mobile Combustion (66.8 Tg CO_2 Eq.)

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

In 2002, N_2O emissions from mobile combustion were 13 percent of U.S. N_2O emissions, while stationary combustion accounted for 3 percent. From 1990 to 2002, combined N_2O emissions from stationary and mobile combustion increased by 6 percent, primarily due to increased rates of N_2O generation in highway vehicles.

Manure Management (17.8 Tg CO_2 Eq.)

Nitrous oxide is produced as part of microbial nitrification and denitrification processes in managed and unmanaged manure. Unmanaged manure is addressed under the discussion of agricultural soil management. Total N_2O emissions from managed manure systems in 2002 accounted for 4 percent of U.S. N_2O emissions. From 1990 to 2002, emissions from this source category increased by 10 percent, primarily due to increases in swine and poultry populations over the same time period.

Nitric Acid Production (16.7 Tg CO_2 Eq.)

Nitric acid production is an 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 2002, N_2O emissions from nitric acid production accounted for 4 percent of U.S. N_2O emissions. From 1990 to 2002, emissions from this source category decreased by 6 percent with the trend in the time series closely tracking the changes in production.

Human Sewage (Domestic Wastewater) (15.6 Tg CO_2 Eq.)

Domestic human sewage is usually mixed with other household wastewater, which includes shower drains, sink drains, washing machine effluent, etc., and transported by a collection system to either a direct discharge, an on-site or decentralized or centralized wastewater treatment system. After processing, treated effluent may be discharged to a receiving water environment (e.g., river, lake, estuary, etc.), applied to soils, or disposed of below the surface. Nitrous oxide may be generated during both nitrification and denitrification of the nitrogen present, usually in the form of urea, ammonia, and proteins. Emissions of N_2O from treated human sewage discharged into aquatic environments accounted for 4 percent of U.S. N_2O emissions in 2002. From 1990 to 2002, emissions from this source category increased by 22 percent.

Adipic Acid Production (5.9 Tg CO_2 Eq.)

Most 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 2002, U.S. adipic acid plants emitted 1 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 61 percent since 1990.

N_2O from Product Usage (4.8 Tg CO2 Eq.)

Nitrous oxide is used in carrier gases with oxygen to administer more potent inhalation anesthetics for general anesthesia and as an anesthetic in various dental and veterinary applications. As such, it is used to treat short-term pain, for sedation in minor elective surgeries and as an induction anesthetic. The second main use of N_2O is as a propellant in pressure and aerosol products, the largest application being pressure-packaged whipped cream. In 2002, N_2O emissions from product usage constituted approximately 1 percent of U.S. N_2O emissions. From 1990 to 2002, emissions from this source category increased by 11 percent.

Field Burning of Agricultural Residues (0.4 Tg CO_2 Eq.)

Large quantities of agricultural crop residues are produced by farming activities, some of which is disposed by burning in the field. Field burning of crop residues is a source of N_2O, which is released during combustion. Because field burning is not a common method of agricultural residue disposal in the United States, emissions from this source are minor, representing 0.1 percent of U.S. N_2O emissions.

Waste Combustion (0.4 Tg CO_2 Eq.)

Combustion is used to manage about 7 to 17 percent of the municipal solid wastes (MSW) generated in the United States. Almost all combustion of MSW in the United States occurs at waste-to-energy facilities where energy is recovered. Most of the organic materials in MSW are of biogenic origin (e.g., paper, yard trimmings), with some components, such as plastics, synthetic rubber, and synthetic fibers, of fossil origin, which together accounted for emissions of 0.1 percent of U.S. N_2O emissions in 2002.

HFC, PFC, and SF_6 Emissions

Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are families 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. HFCs and PFCs do not deplete the stratospheric ozone layer, and are therefore acceptable alternatives under 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 once emitted. Sulfur hexafluoride is the most potent greenhouse gas the IPCC has evaluated.

Other emissive sources of these gases include HCFC-22 production, electrical transmission and distribution systems, semiconductor manufacturing, aluminum production, and magnesium production and processing. Figure ES-13 and Table ES-9 present emission estimates for HFCs, PFCs, and SF_6, which totaled 138.6 Tg CO_2 Eq. in 2002.

Figure ES-13: 2002 Sources of HFCs, PFCs, and SF_6

Table ES-9: Emissions of HFCs, PFCs, and SF_6 (Tg CO_2 Eq.)

Source	**1990**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Substitution of Ozone Depleting Substances	0.3	35.0	46.4	56.6	66.0	75.3	83.6	92.0
HCFC-22 Production	35.0	31.1	30.0	40.2	30.4	29.8	19.8	19.8
Electrical Transmission and Distribution	37.6	27.7	24.3	17.7	16.4	15.9	15.6	14.8
Semiconductor Manufacture	2.9	5.5	6.3	7.1	7.2	6.3	4.5	4.4
Aluminum Production	18.1	12.5	11.0	9.0	8.9	8.9	4.0	5.2
Magnesium Production and Processing	5.4	6.5	6.3	5.8	6.0	3.2	2.5	2.4
Total	**99.4**	**118.3**	**124.4**	**136.5**	**134.9**	**139.3**	**130.0**	**138.6**

Note: Totals may not sum due to independent rounding.

Substitution of Ozone Depleting Substances (92.0 Tg CO_2 Eq.)

The use and subsequent emissions of HFCs and PFCs as substitutes for ozone depleting substances (ODSs) have increased from small amounts in 1990 to account for 66 percent of aggregate HFC, PFC, and SF_6 emissions. This increase was in large part the result of efforts to phase-out chlorofluorocarbons (CFCs) and other ODSs in the United States, especially the introduction of HFC-134a as a CFC substitute in refrigeration and air-conditioning applications. In the short term, this trend is expected to continue, and will likely accelerate in the next decade as hydrochlorofluorocarbons (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 and the introduction of alternative gases and technologies, however, may help to offset this anticipated increase in emissions.

HCFC-22 Production (19.8 Tg CO_2 Eq.)

HFC-23 is a by-product of the production of HCFC-22. Emissions from this source have decreased by 43 percent since 1990. The HFC-23 emission rate (i.e., the amount of HFC-23 emitted per kilogram of HCFC-22 manufactured) has declined significantly since 1990, although production has been increasing.

Electrical Transmission and Distribution Systems (14.8 Tg CO_2 Eq.)

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 decreased by 61 percent since 1990, primarily due to higher SF_6 prices and industrial efforts to reduce emissions.

Semiconductor Manufacturing (4.4 Tg CO_2 Eq.)

The semiconductor industry uses combinations of HFCs, PFCs, SF_6, and other gases for plasma etching and to clean chemical vapor deposition tools. Emissions from this source category have increased with the growth in the semiconductor industry and the rising intricacy of chip designs. However, the growth rate in emissions has slowed since 1997, and emissions actually declined between 1999 and 2002. This later reduction is due to the implementation of PFC emission reduction methods, such as process optimization.

Aluminum Production (5.2 Tg CO_2 Eq.)

During the production of primary aluminum CF_4 and C_2F_6 are emitted as intermittent by-products of the smelting process. These PFCs are formed when fluorine from the cryolite bath combines with carbon from the electrolyte anode. Emissions from aluminum production have decreased by 71 percent between 1990 and 2002 due to emission reduction efforts by the industry and falling domestic aluminum production.

Magnesium Production (2.4 Tg CO_2 Eq.)

Sulfur hexafluoride is also used as a protective cover gas for the casting of molten magnesium. Emissions from primary magnesium production and magnesium casting have decreased by 55 percent since 1990. Emissions have decreased since 1999; due to a decrease in the quantity of magnesium die cast and the closure of a U.S. primary magnesium production facility.

Box ES-2: Emissions of Ozone Depleting Substances

Manmade halogenated compounds were first emitted into the atmosphere in significant quantities during the 20th century. This family of man-made compounds includes CFCs, halons, methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). These substances have a variety of industrial applications, including refrigeration, air conditioning, foam blowing, solvent cleaning, sterilization, fire extinguishing, agricultural fumigation and sterilization, coatings, paints, and aerosols.

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

Recognizing the harmful effects of these compounds on the ozone layer, in 1987 many countries ratified 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 UNFCCC reporting guidelines do not include reporting instructions for estimating emissions of ODSs because they are tracked under the *Montreal Protocol*. Nevertheless, estimates for several Class I and Class II ODSs are provided in Table ES-10 for informational purposes. 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 the destruction of ozone—also a greenhouse gas— 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-10: Emissions of Ozone Depleting Substances (Gg)

Compound	1990	1996	1997	1998	1999	2000	2001	2002
Class I								
CFC-11	28.6	8.2	7.8	7.2	6.6	16.1	15.8	15.4
CFC-12	155.5	83.6	72.9	60.2	50.7	43.0	35.1	28.6
CFC-113	59.4	+	+	+	+	+	+	+
CFC-114	5.1	0.5	0.6	0.5	+	+	+	+
CFC-115	4.5	2.9	2.4	1.8	1.6	1.5	1.4	1.3
Carbon Tetrachloride	4.3	22.2	22.6	23.1	23.5	24.0	24.5	25.0
Methyl Chloroform	222.5	8.7	+	+	+	+	+	+
Halon-1211	+	+	+	+	+	+	+	+
Halon-1301	+	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Class II								
HCFC-22	37.1	55.3	59.1	62.8	65.9	73.7	76.3	78.0
HCFC-123	+	1.3	1.5	1.8	2.0	2.2	2.3	2.5
HCFC-124	+	3.4	3.9	4.3	4.3	4.6	4.4	4.2
HCFC-141b	1.1	5.7	6.3	6.9	7.6	7.7	7.6	7.1
HCFC-142b	2.2	3.4	3.7	4.1	4.4	4.8	5.1	5.5
HCFC-225ca/cb	+	+	+	+	+	+	+	+

Source: EPA, Office of Atmospheric Programs

\+ Does not exceed 0.05 Gg

[END BOX]

ES.4. Other Information

Ambient Air Pollutant Emissions – TO BE UPDATED

In the United States, carbon monoxide (CO), nitrogen oxides (NO$_x$), nonmethane volatile organic compounds (NMVOCs), and sulfur dioxide (SO$_2$) are referred to as "ambient air pollutants," as termed in the Clean Air Act. These 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$_2$O). NMVOCs—which include hundreds of organic compounds that participate in atmospheric chemical reactions (i.e., propane, butane, xylene, toluene, ethane and many others)—are emitted primarily from transportation, industrial processes, and non-industrial consumption of organic solvents. In the United States, SO$_2$ is primarily emitted from coal combustion for electric power generation and the metals industry.

Ambient air pollutants are regulated under the Clean Air Act in an effort to protect human health and the environment. These gases also indirectly affect the global climate by either acting as short-lived greenhouse gases or reacting with other chemical compounds in the atmosphere to form compounds that are greenhouse gases. Unlike the other ambient air pollutants, sulfur-containing compounds emitted into the atmosphere affect the Earth's radiative budget negatively; therefore, it is discussed separately.

One important indirect climate change effect of NMVOCs and NO$_x$ is their role as precursors for tropospheric ozone formation. They can also alter the atmospheric lifetimes of other greenhouse gases. Another example of ambient air pollutant formation into greenhouse gases is carbon monoxide's interaction 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 ambient air pollutants (EPA 2003).[12] Table ES-11 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.

Table ES-11: Emissions of NO_x, CO, NMVOCs, and SO_2 (Gg) – TO BE UPDATED

Gas/Activity	**1990**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
NO_x	**23,037**	**22,360**	**22,289**	**21,961**	**21,341**	**20,917**	**20,141**	**20,141**
Stationary Fossil Fuel Combustion	9,884	9,540	9,578	9,419	8,716	8,226	7,826	7,826
Mobile Fossil Fuel Combustion	12,134	11,714	11,768	11,592	11,582	11,395	11,254	11,254
Oil and Gas Activities	139	126	130	130	113	115	117	117
Waste Combustion	82	135	140	145	142	149	149	149
Industrial Processes	769	808	634	635	748	992	755	755
Solvent Use	1	3	3	3	3	3	3	3
Field Burning of Agricultural Residues	28	32	34	35	34	35	35	35
Waste	0	3	3	3	3	3	3	3
CO	**130,575**	**104,063**	**101,132**	**98,976**	**95,464**	**93,965**	**100,653**	**100,653**
Stationary Fossil Fuel Combustion	4,999	3,935	3,927	3,927	4,941	4,163	4,169	4,169
Mobile Fossil Fuel Combustion	119,482	93,409	90,284	87,940	84,574	83,680	90,268	90,268
Oil and Gas Activities	302	321	333	332	152	152	153	153
Waste Combustion	978	2,628	2,668	2,826	2,833	2,914	2,916	2,916
Industrial Processes	4,124	3,016	3,153	3,163	2,145	2,214	2,327	2,327
Solvent Use	4	1	1	1	46	45	44	44
Field Burning of Agricultural Residues	685	747	761	781	760	784	762	762
Waste	1	5	5	5	14	14	14	14
NMVOCs	**20,937**	**17,184**	**16,994**	**16,403**	**16,245**	**15,418**	**15,148**	**15,148**
Stationary Fossil Fuel Combustion	912	1,018	1,016	1,016	1,312	1,088	1,087	1,087
Mobile Fossil Fuel Combustion	10,933	8,306	7,928	7,742	7,658	7,230	6,800	6,800
Oil and Gas Activities	555	433	442	440	376	348	357	357
Waste Combustion	222	304	313	326	326	332	333	333
Industrial Processes	2,426	1,997	2,038	2,047	1,890	1,845	1,829	1,829
Solvent Use	5,217	4,969	5,100	4,671	4,533	4,422	4,584	4,584
Field Burning of Agricultural Residues	NA	NA	NA	NA	NA	NA	NA	NA
Waste	673	158	157	161	151	153	158	158
SO_2	**20,936**	**16,682**	**17,091**	**17,189**	**16,013**	**14,802**	**14,324**	**14,324**
Stationary Fossil Fuel Combustion	18,407	14,746	15,104	15,191	14,073	12,883	12,367	12,367
Mobile Fossil Fuel Combustion	793	649	659	665	701	632	636	636
Oil and Gas Activities	390	304	312	310	275	279	281	281
Waste Combustion	39	29	29	30	29	29	30	30
Industrial Processes	1,306	953	985	991	933	977	1,008	1,008
Solvent Use	0	1	1	1	1	1	1	1

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[12] NO_x and CO emission estimates from field burning of agricultural residues were estimated separately, and therefore not taken from EPA (2003).

Field Burning of Agricultural Residues	NA		NA	NA	NA	NA	NA	NA	NA
Waste	0		1	1	1	1	1	1	1

Source: (EPA 2003) except for estimates from field burning of agricultural residues.
+ Does not exceed 0.5 Gg
NA (Not Available)
Note: Totals may not sum due to independent rounding.

[BEGIN BOX]

Box ES-3: Sources and Effects of Sulfur Dioxide TO BE UPDATED

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 radiation from the sun back to space, thereby reducing the radiation reaching the Earth's surface; (2) affect cloud formation; and (3) affect atmospheric chemical composition (e.g., by providing surfaces for heterogeneous chemical reactions). The indirect effect of sulfur-derived aerosols on radiative forcing can be considered in two parts. The first indirect effect is the aerosols' tendency to decrease water droplet size and increase water droplet concentration in the atmosphere. The second indirect effect is the tendency of the reduction in cloud droplet size to affect precipitation by increasing cloud lifetime and thickness. Although still highly uncertain, the radiative forcing estimates from both the first and the second indirect effect are believed to be negative, as is the combined radiative forcing of the two (IPCC 2001). 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 regional haze, 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.

Electricity generation is the largest anthropogenic source of SO_2 emissions in the United States, accounting for 69 percent in 2001. Coal combustion contributes nearly all of those emissions (approximately 92 percent). Sulfur dioxide emissions have decreased in recent years, primarily as a result of electric power generators switching from high sulfur to low sulfur coal and installing flue gas desulfurization equipment.

[END BOX]

Emissions by Economic Sector

Throughout this report, emission estimates are grouped into six sectors (i.e., chapters) defined by the IPCC: Energy, Industrial Processes, Solvent Use, Agriculture, Land-Use Change and Forestry, and Waste. While it is important to use this characterization for consistency with UNFCCC reporting guidelines, it is also useful to allocate emissions into more commonly used sectoral categories. This section reports emissions by the following economic sectors: Residential, Commercial, Industry, Transportation, Electricity Generation, and Agriculture, and U.S. Territories. Table ES-12 summarizes emissions from each of these sectors. Figure ES-14 shows the trend in emissions by sector from 1990 to 2002.

Figure ES-14: Emissions Allocated to Economic Sectors

Table ES-12: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (Tg CO_2 Eq.)

Sector	**1990**		**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Electricity Generation	1,852.3		2,050.5	2,115.9	2,196.9	2,206.7	2,309.1	2,265.5	2,286.8

Transportation	1,513.4	1,683.7	1,698.6	1,732.9	1,794.7	1,844.8	1,827.0	1,861.4
Industry	1,437.5	1,493.2	1,495.5	1,454.7	1,414.1	1,418.7	1,353.4	1,331.5
Agriculture	482.8	520.8	532.6	534.3	534.7	520.7	519.3	519.8
Commercial	472.2	497.4	496.7	477.2	484.9	505.1	492.2	500.4
Residential	345.6	403.8	385.1	352.4	373.6	394.0	381.7	387.7
U.S. Territories	33.7	41.3	42.6	42.6	43.7	45.9	45.0	46.5
Total	**6,137.4**	**6,690.6**	**6,767.0**	**6,791.1**	**6,852.5**	**7,038.4**	**6,884.0**	**6,934.0**
Land-Use Change and Forestry	(957.9)	(1,055.2)	(821.0)	(705.8)	(675.8)	(690.2)	(689.7)	(690.7)
Net Emissions (Sources and Sinks)	**5,179.6**	**5,635.4**	**5,946.1**	**6,085.3**	**6,176.7**	**6,348.3**	**6,194.3**	**6,243.3**

Note: Totals may not sum. Emissions include CO_2, CH_4, HFCs, PFCs, and SF_6.
See Table 9-1 for more detailed data.

Using this categorization, emissions from electricity generation accounted for the largest portion (33 percent) of U.S. greenhouse gas emissions in 2002. Transportation activities, in aggregate, accounted for the second largest portion (27 percent). Emissions from industry accounted for 19 percent of U.S. greenhouse gas emissions in 2002. In contrast to electricity generation and transportation, emissions from industry have declined over the past decade, as structural changes have occurred in the U.S. economy (i.e., shifts from a manufacturing based to a service-based economy), fuel switching has occurred, and efficiency improvements have been made. The remaining 21 percent of U.S. greenhouse gas emissions were contributed by the residential, agriculture, and commercial economic sectors, plus emissions from U.S. Territories. Residences accounted for about 6 percent, and primarily consisted of CO_2 emissions from fossil fuel combustion. Activities related to agriculture accounted for roughly 7 percent of U.S. emissions; these emissions were dominated by N_2O emissions from agricultural soils instead of CO_2 from fossil fuel combustion. The commercial sector accounted for about 7 percent of emissions, while U.S. territories accounted for 1 percent.

Carbon dioxide was also emitted and sequestered by a variety of activities related to forest management practices, tree planting in urban areas, the management of agricultural soils, and landfilling of yard trimmings.

Electricity is ultimately consumed in the economic sectors described above. Table ES-13 presents greenhouse gas emissions from economic sectors with emissions related to electricity generation distributed into end-use categories (i.e., emissions from electricity generation are allocated to the economic sectors in which the electricity is consumed). To distribute electricity emissions among end-use sectors, emissions from the source categories assigned to electricity generation were allocated to the residential, commercial, industry, transportation, and agriculture economic sectors according to retail sales of electricity.[13] These source categories include CO_2 from fossil fuel combustion and the use of limestone and dolomite for flue gas desulfurization, CO_2 and N_2O from waste combustion, CH_4 and N_2O from stationary sources, and SF_6 from electrical transmission and distribution systems.

When emissions from electricity are distributed among these sectors, industry accounts for the largest share of U.S. greenhouse gas emissions (30 percent) in 2002. Emissions from the residential and commercial sectors also increase substantially due to their relatively large share of electricity consumption (e.g., lighting, appliances, etc.). Transportation activities remain the second largest contributor to emissions. In all sectors except agriculture, CO_2 accounts for more than 75 percent of greenhouse gas emissions, primarily from the combustion of fossil fuels. Figure ES-15 shows the trend in these emissions by sector from 1990 to 2002.

Table ES-13: U.S Greenhouse Gas Emissions by Economic Sector and Gas with Electricity-Related Emissions Distributed (Tg CO_2 Eq.)

Sector	**1990**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**

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[13] Emissions were not distributed to U.S. territories, since the electricity generation sector only includes emissions related to the generation of electricity in the 50 states and the District of Columbia.

Industry	2,070.6	2,212.0	2,237.7	2,210.7	2,179.6	2,198.1	2,063.7	2,047.4
Transportation	1,516.5	1,686.7	1,701.6	1,736.0	1,797.9	1,848.1	1,830.4	1,864.5
Commercial	1,021.5	1,094.7	1,138.8	1,149.6	1,166.0	1,229.3	1,232.9	1,234.3
Residential	951.1	1,063.5	1,058.0	1,057.3	1,080.0	1,139.0	1,125.6	1,158.1
Agriculture	543.9	592.5	588.3	594.8	585.3	577.9	586.3	583.1
U.S. Territories	33.7	41.3	42.6	42.6	43.7	45.9	45.0	46.5
Total	**6,137.4**	**6,690.6**	**6,767.0**	**6,791.1**	**6,852.5**	**7,038.4**	**6,884.0**	**6,934.0**
Land-Use Change and Forestry	(957.9)	(1,055.2)	(821.0)	(705.8)	(675.8)	(690.2)	(689.7)	(690.7)
Net Emissions (Sources and Sinks)	**5,179.6**	**5,635.4**	**5,946.1**	**6,085.3**	**6,176.7**	**6,348.3**	**6,194.3**	**6,243.3**

See Table 9-3 for more detailed data.

Figure ES-15: Emissions with Electricity Distributed to Economic Sectors

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Box ES-4: Recent Trends in Various U.S. Greenhouse Gas Emissions-Related Data

Total emissions can be compared to other economic and social indices to highlight changes over time. These comparisons include: 1) emissions per unit of aggregate energy consumption, because energy-related activities are the largest sources of emissions; 2) emissions per unit of fossil fuel consumption, because almost all energy-related emissions involve the combustion of fossil fuels; 3) emissions per unit of electricity consumption, because the electric power industry—utilities and nonutilities combined—was the largest source of U.S. greenhouse gas emissions in 2002; 4) emissions per unit of total gross domestic product as a measure of national economic activity; or 5) emissions per capita.

Table ES-14 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 1.0 percent since 1990. This rate is slower than that for total energy or fossil fuel consumption and much slower than that for either electricity consumption or overall gross domestic product. Total U.S. greenhouse gas emissions have also grown more slowly than national population since 1990 (see Figure ES-16). 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-14: Recent Trends in Various U.S. Data (Index 1990 = 100) and Global Atmospheric CO_2 Concentration

Variable	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Growth Rate[f]
Greenhouse Gas Emissions[a]	99	101	103	105	106	109	110	111	112	115	112	113	**1.0%**
Energy Consumption[b]	100	101	103	105	108	111	112	112	114	117	114	115	**1.2%**
Fossil Fuel Consumption[b]	100	102	104	105	107	110	112	112	113	117	115	116	**1.3%**
Electricity Consumption[b]	102	102	106	109	112	115	117	121	124	128	126	129	**2.2%**
GDP[c]	100	103	106	110	113	117	122	127	133	138	139	142	**3.0%**
Population[d]	101	103	104	105	107	108	109	111	112	113	114	116	**1.2%**
Atmospheric CO_2 Concentration[e]	100	101	101	101	102	102	103	104	104	104	105	105	**0.4%**

[a] GWP weighted values

[b] Energy content weighted values (EIA 2003)

[c] Gross Domestic Product in chained 2000 dollars (BEA 2004)

[d] (U.S. Census Bureau 2003)

[e] Mauna Loa Observatory, Hawaii (Keeling and Whorf 2003)

[f] Average annual growth rate

Figure ES-16: U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product

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Quality Assurance and Quality Control (QA/QC)

The United States seeks to continually improve the quality, transparency and credibilty of the Inventory of U.S. Greenhouse Gas Emissions and Sinks. To assist in these efforts, the United States recently implemented a systematic approach to QA/QC. While QA/QC has always been an integral part of the U.S. national system for Inventory development, the procedures followed for the current inventory have been formalized in accordance with the QA/QC Plan and the UNFCCC reporting guidelines.

Uncertainty in and Limitations of Emission Estimates

While the current U.S. emissions inventory provides a solid foundation for the development of a more detailed and comprehensive national inventory, there are uncertainties associated with the emission estimates. Some of the current estimates, such as those for CO_2 emissions from energy-related activities and cement processing, are considered to have low uncertainties. For some other categories of emissions, however, a lack of data or an incomplete understanding of how emissions are generated increases the uncertainty associated with the estimates presented. Acquiring a better understanding of the uncertainty associated with inventory estimates is an important step in helping to prioritize future work and improve the overall quality of the Inventory. Recognizing the benefit of conducting an uncertainty analysis, the UNFCCC reporting guidelines follow the recommendations of the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (hereafter referred to as the IPCC Good Practice Guidance) and require that countries provide single point estimates for many source and sink categories.

Currently, a qualitative discussion of uncertainty is presented for all source and sink categories. Within the discussion of each emission source, specific factors affecting the uncertainty surrounding the estimates are discussed. Most sources also contain a quantitative uncertainty assessment, in accordance with the new UNFCCC reporting guidelines.

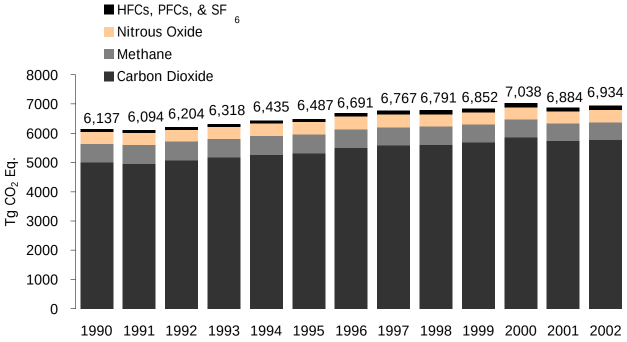

Figure ES-1: U.S. GHG Emissions by Gas

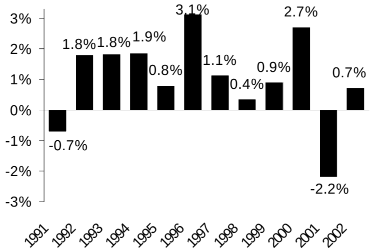

Figure ES-2: Annual Percent Change in U.S. GHG Emissions

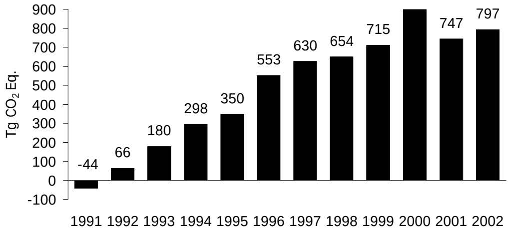

Figure ES-3: Absolute Change in U.S. Greenhouse Gas Emissions Since 1990

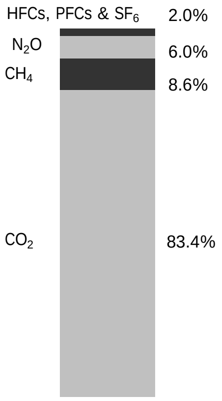

Figure ES-4: 2002 Greenhouse Gas Emissions by Gas

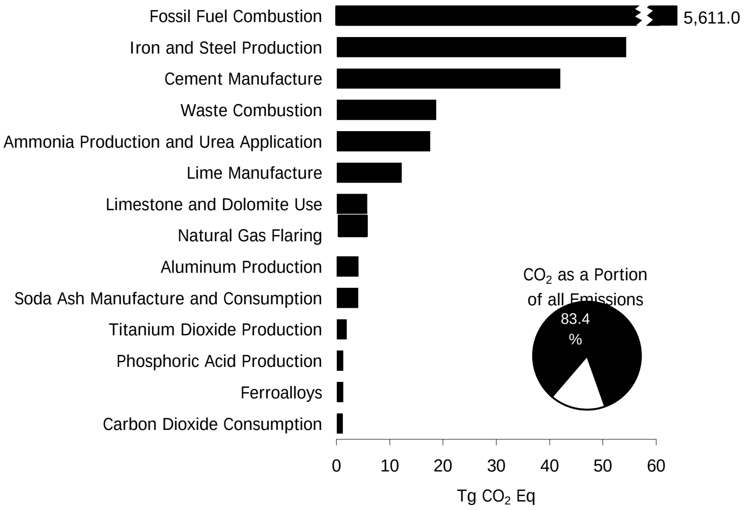

Figure ES-5: 2002 Sources of CO$_2$

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Figure ES- 6: U.S. Fossil Carbon Flows for 2002

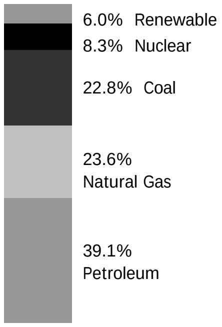

Figure ES-7: 2002 U.S. Energy Consumption by Energy Source

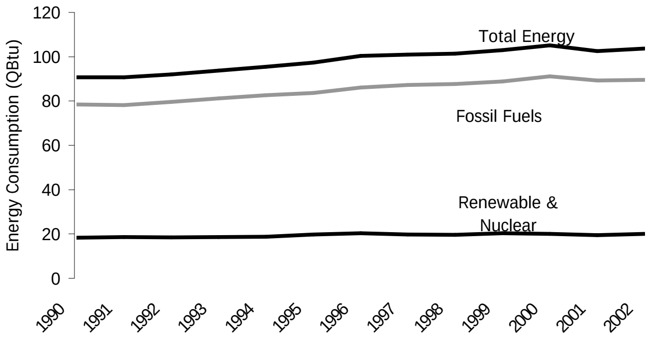

Figure ES-8:   U.S. Energy Consumption (Quadrillion Btu)
Note: Expressed as gross calorific values.

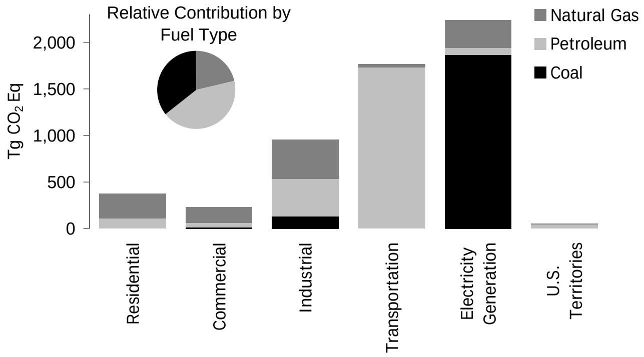

Figure ES-9: 2002 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type
Note: Utilities also includes emissions of less than 1 Tg CO_2 Eq. from geothermal based electricity generation

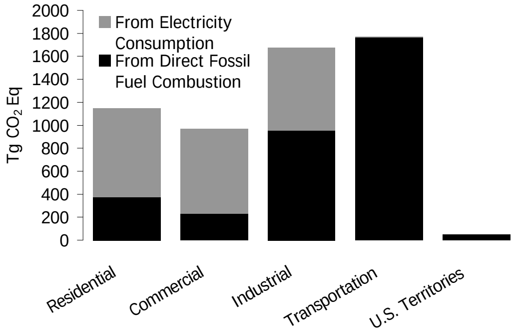

Figure ES-10: 2002 End-Use Sector Emissions of CO_2 from Fossil Fuel Combustion

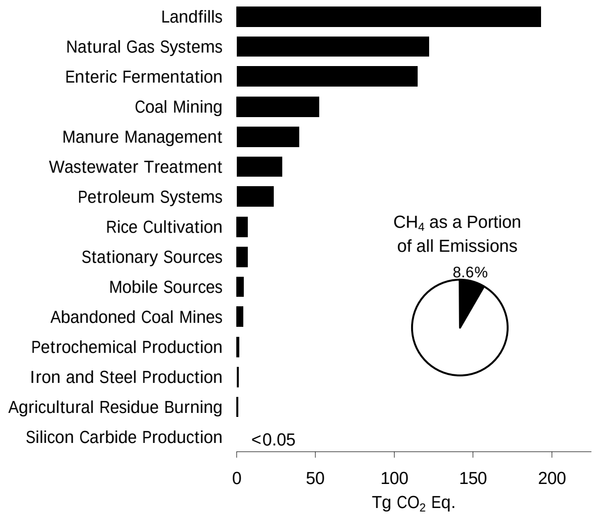

Figure ES-11: 2002 Sources of CH_4

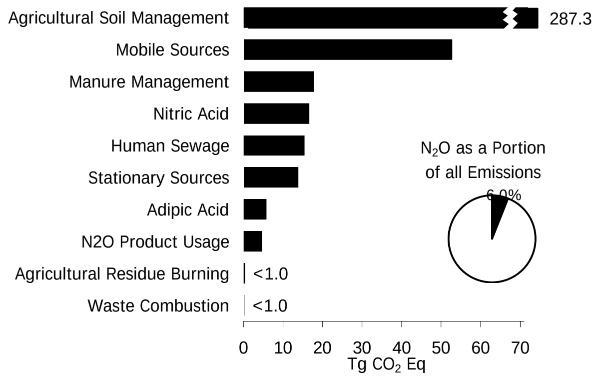

Figure ES-12: 2002 Sources of N_2O