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Emissions of Greenhouse Gases in the United States 2005

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Preface

Title XVI, Section 1605(a) of the Energy Policy Act of 1992 (enacted October 24, 1992) provides:

> *Not later than one year after the date of the enactment of this Act, the Secretary, through the Energy Information Administration, shall develop, based on data available to, and obtained by, the Energy Information Administration, an inventory of the national aggregate emissions of each greenhouse gas for each calendar year of the baseline period of 1987 through 1990. The Administrator of the Energy Information Administration shall annually update and analyze such inventory using available data. This subsection does not provide any new data collection authority.*

The first report in this series, *Emissions of Greenhouse Gases 1985-1990*, was published in September 1993. This report—the fourteenth annual report—presents the Energy Information Administration's latest estimates of emissions for carbon dioxide, methane, nitrous oxide, and other greenhouse gases. Most of these estimates are based on activity data and applied emissions factors and not on measured or metered emissions. A limited number of emissions estimates, such as for methane from coal mine ventilation, are obtained through direct measurement.

For this report, data on coal and natural gas consumption and electricity sales and losses by sector were obtained from the Energy Information Administration's (EIA's) October 2006 *Monthly Energy Review*. Additional detailed information on petroleum consumption was obtained from unpublished material in support of the *Monthly Energy Review*. Electric power sector emissions were obtained from data underlying EIA's *Electric Power Annual*. In keeping with current international practice, this report presents data on greenhouse gas emissions in million metric tons carbon dioxide equivalent. The data can be converted to carbon equivalent units by multiplying times 12/44.

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U.S. Anthropogenic Emissions of Greenhouse Gases, 1990-2005

	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Million Metric Tons)	7,147.2
Change Compared to 2004 (Million Metric Tons)	42.7
Change from 2004 *(Percent)*	*0.6%*
Change Compared to 1990 (Million Metric Tons)	1,034.4
Change from 1990 *(Percent)*	*16.9%*
Average Annual Increase, 1990-2005 *(Percent)*	*1.0%*

This report, in accordance with Section 1605(a) of the Energy Policy Act of 1992, provides estimates of U.S. emissions of greenhouse gases.[1] Table ES1 shows trends in emissions of the principal greenhouse gases, measured in million metric tons of native gas. Throughout the remainder of the report, emissions are given in carbon dioxide equivalents, which put the emissions of each gas in comparable terms of their global warming potentials (GWPs) relative to that of carbon dioxide.[2] As shown in Table ES2, U.S. emissions of greenhouse gases in 2005 totaled 7,147.2 million metric tons carbon dioxide equivalent ($MMTCO_2e$), 0.6 percent more than in 2004 (7,104.6 $MMTCO_2e$). The modest increase in total greenhouse gas emissions in 2005 is attributable mainly to below-average growth in emissions of carbon dioxide (0.3 percent). There were larger increases in emissions of nitrous oxide (1.9 percent) and methane (0.9 percent), but collectively these two gases make up only about 14 percent of total U.S. greenhouse gas emissions. Emissions of high-GWP gases—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—increased by 7.2 percent, but their share of the total is only 2.2 percent. The U.S. economy grew by 3.2 percent in 2005. Consequently, U.S. greenhouse gas intensity (greenhouse gas emissions per unit of real economic output) was 2.5 percent lower in 2005 than in 2004. From 1990 to 2005, U.S. greenhouse gas intensity declined by 25 percent, or by an average of 1.9 percent per year.

U.S. greenhouse gas emissions in 2005 were 17 percent higher than the 1990 emissions level of 6,112.8 $MMTCO_2e$—an average annual increase of 1.0 percent over the period. Since 1990, U.S. emissions have increased more slowly than the average annual growth in population (1.2 percent), primary energy consumption (1.1 percent), electric power generation (1.9 percent), or gross domestic product (3.0 percent). While the annual growth rate in carbon dioxide emissions since 1990 (1.2 percent) has closely tracked annual growth in population and energy consumption, the average annual rate of growth in total greenhouse gas emissions has been lower (1.0 percent) because of reductions in methane emissions and relatively slow annual growth in nitrous oxide emissions (0.6 percent) since 1990.

Table ES1. Summary of Estimated U.S. Emissions of Greenhouse Gases, 1990, 1995, and 1998-2005
(Million Metric Tons of Gas)

Gas	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Carbon Dioxide	4,990.6	5,308.5	5,594.0	5,673.9	5,853.4	5,767.0	5,814.7	5,875.3	5,988.7	6,008.6
Methane	30.5	29.2	27.4	26.8	26.6	26.0	26.1	26.2	26.4	26.6
Nitrous Oxide	1.1	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.2	1.2
HFCs, PFCs, and SF_6	M	M	M	M	M	M	M	M	M	M

P = preliminary data.

M = mixture of gases. These gases cannot be summed in native units. See Table ES2 for estimated totals in carbon dioxide equivalent.

Note: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005).

Source: Estimates presented in this report.

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[1] Most of the estimates in this report are based on activity data and estimated emissions factors, not on measured or metered emissions.

[2] See "Units for Measuring Greenhouse Gases" on page x, and Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

During 2005, approximately 83 percent of total U.S. greenhouse gas emissions consisted of carbon dioxide from the combustion and nonfuel use of fossil fuels (Figure ES1), such as coal, petroleum, and natural gas (after adjustments for U.S. Territories and international bunker fuels). U.S. emissions trends are driven largely by trends in fossil energy consumption. In recent years, national energy consumption, like emissions, has grown relatively slowly, with year-to-year deviations from trend growth caused by weather-related phenomena, fluctuations in business cycles, changes in the fuel mix for electric power generation, and developments in domestic and international energy markets.

Other 2005 U.S. greenhouse gas emissions include carbon dioxide from non-combustion sources (1.5 percent of total U.S. greenhouse gas emissions), methane (8.6 percent), nitrous oxide (5.1 percent), and other gases (2.2 percent). Methane and nitrous oxide emissions are caused by the biological decomposition of various waste streams and fertilizer; fugitive emissions from chemical processes; fossil fuel production, transmission, and combustion; and many smaller sources. The other gases include HFCs, used primarily as refrigerants; PFCs, released as fugitive emissions from aluminum smelting and used in semiconductor manufacture; and SF_6, used as an insulator in utility-scale electrical equipment.

Table ES2. U.S. Emissions of Greenhouse Gases, Based on Global Warming Potential, 1990, 1995, and 1998-2005
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Carbon Dioxide	4,990.6	5,308.5	5,594.0	5,673.9	5,853.4	5,767.0	5,814.7	5,875.3	5,988.7	6,008.6
Methane.	701.7	672.5	629.8	616.5	611.2	597.7	600.2	602.2	606.5	611.9
Nitrous Oxide.	333.5	357.7	348.8	346.8	342.8	337.9	333.6	332.9	359.9	366.6
HFCs, PFCs, and SF_6 . .	87.1	94.9	134.3	133.9	138.0	128.5	137.8	136.6	149.5	160.2
Total	**6,112.8**	**6,433.5**	**6,707.0**	**6,771.1**	**6,945.4**	**6,831.0**	**6,886.3**	**6,946.9**	**7,104.6**	**7,147.2**

P = preliminary data.

Note: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005).

Units for Measuring Greenhouse Gases

Emissions data are reported here in metric units, as favored by the international scientific community. Metric tons are relatively intuitive for users of English measurement units, because 1 metric ton is only about 10 percent heavier than 1 English short ton.

Table ES1 shows emissions of greenhouse gases in terms of the full molecular weights of the native gases. In Table ES2, and subsequently throughout this report, emissions of carbon dioxide and other greenhouse gases are given in carbon dioxide equivalents. In the case of carbon dioxide, emissions denominated in the molecular weight of the gas or in carbon dioxide equivalents are the same. Carbon dioxide equivalent data can be converted to carbon equivalents by multiplying by 12/44.

Emissions of other greenhouse gases (such as methane) can also be measured in carbon dioxide equivalent units by multiplying their emissions (in metric tons) by their global warming potentials (GWPs). Carbon dioxide equivalents are the amount of carbon dioxide by weight emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another radiatively active gas.

Carbon dioxide equivalents are computed by multiplying the weight of the gas being measured (for example, methane) by its estimated GWP (which is 23 for methane). GWPs are discussed in Chapter 1 and summarized in Table 4 on page 6. In 2001, the IPCC Working Group I released its Third Assessment Report, *Climate Change 2001: The Scientific Basis*. Among other things, the Third Assessment Report updated a number of the GWP estimates that appeared in the IPCC's Second Assessment Report. The GWPs published in the Third Assessment Report were used for the calculation of carbon dioxide equivalent emissions for this report. Generally, the level of total U.S. carbon dioxide equivalent emissions is 0.6 percent higher when the GWPs from the Third Assessment Report are used; however, the trends in growth of greenhouse gas emissions are similar for the two sets of GWP values. GWPs from the Second Assessment Report still are used for comparisons among countries.

[a] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

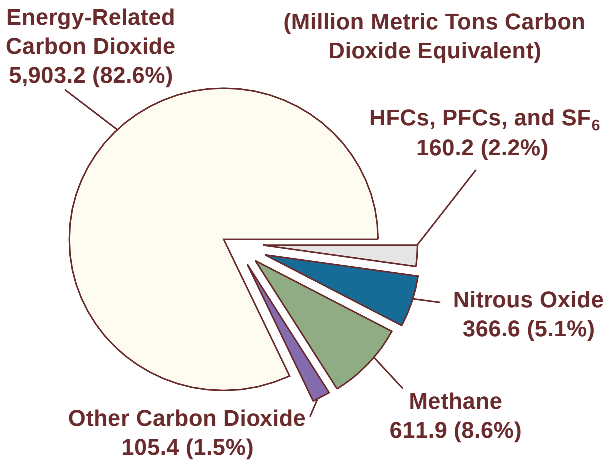
[b] Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change* (Cambridge, UK: Cambridge University Press, 1996).

Carbon Dioxide

The preliminary estimate of U.S. carbon dioxide emissions from both energy consumption and industrial processes in 2005 is 6,008.6 million metric tons (MMT), which is 0.3 percent higher than in 2004 (5,988.7 MMT) and accounts for 84 percent of total U.S. greenhouse gas emissions (see Table ES3 for a breakdown of U.S. carbon dioxide emissions by source). U.S. carbon dioxide emissions have grown by an average of 1.2 percent annually since 1990. Although short-term changes in carbon dioxide emissions can result from temporary variations in weather, power generation fuel mixes, and the economy, growth in carbon dioxide emissions in the longer term results largely from population- and income-driven increases in energy use, as well as consumer choices of energy-using equipment. The "carbon intensity" of energy use (carbon dioxide emissions per unit of energy consumed) can also influence the trend of growth in energy-related carbon dioxide emissions.

Figure ES2 shows recent trends in some common indexes used to measure the carbon intensity of the U.S. economy. Carbon dioxide emissions per unit of gross domestic product (GDP) have continued to fall relative to 1990; by 2005, this measure was 23 percent lower than

Figure ES1. U.S. Greenhouse Gas Emissions by Gas, 2005



Source: Tables ES2 and ES3.

Table ES3. U.S. Carbon Dioxide Emissions from Energy and Industry, 1990, 1995, and 1998-2005
(Million Metric Tons Carbon Dioxide)

Fuel Type or Process	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Energy Use by Sector										
Residential	953.7	1,030.7	1,088.1	1,111.3	1,171.9	1,161.1	1,186.4	1,214.0	1,213.9	1,253.8
Commercial	780.7	841.1	935.7	947.7	1,006.4	1,014.2	1,009.4	1,020.3	1,034.1	1,050.6
Industrial	1,683.6	1,728.6	1,782.3	1,770.5	1,778.0	1,702.8	1,684.8	1,688.0	1,736.0	1,682.3
Transportation	1,566.8	1,665.3	1,761.8	1,810.0	1,854.0	1,831.7	1,871.7	1,878.2	1,939.2	1,958.6
Energy Subtotal	**4,984.8**	**5,265.8**	**5,567.8**	**5,639.5**	**5,810.2**	**5,709.8**	**5,752.2**	**5,800.5**	**5,923.2**	**5,945.3**
Nonfuel Use Emissions[a]	**98.1**	**104.7**	**118.6**	**124.1**	**110.0**	**104.9**	**105.4**	**103.5**	**111.7**	**106.4**
Nonfuel Use Sequestration	**251.2**	**286.4**	**314.7**	**325.8**	**308.1**	**293.7**	**293.8**	**289.5**	**311.1**	**300.9**
Adjustments to Energy										
U.S. Territories (+)	31.1	38.2	41.0	40.4	42.2	53.6	52.3	56.8	60.0	58.6
Military Bunker Fuels (-)	13.6	8.9	10.0	9.8	7.8	8.2	8.1	9.2	10.1	10.1
International Bunker Fuels (-)	100.1	91.9	104.9	97.4	93.5	89.6	81.2	75.0	90.1	90.6
Bunker Fuels Subtotal (-)	*113.7*	*100.8*	*114.9*	*107.2*	*101.3*	*97.8*	*89.3*	*84.2*	*100.2*	*100.7*
Total Energy Adjustments	**-82.6**	**-62.6**	**-73.9**	**-66.8**	**-59.1**	**-44.1**	**-37.0**	**-27.5**	**-40.2**	**-42.1**
Adjusted Energy Subtotal	**4,902.3**	**5,203.2**	**5,494.0**	**5,572.7**	**5,751.1**	**5,665.7**	**5,715.2**	**5,773.0**	**5,883.0**	**5,903.2**
Other Sources										
Natural Gas Flaring	9.1	17.2	6.2	6.7	5.5	5.9	6.0	5.9	5.9	5.9
Carbon Dioxide in Natural Gas	14.0	16.7	18.0	17.8	18.2	18.6	17.9	18.1	17.8	17.3
Cement Production	33.3	36.9	39.3	40.1	41.3	41.5	43.0	43.2	45.7	45.9
Other Industrial	26.8	28.4	29.7	29.3	29.4	27.4	26.4	27.6	28.5	28.1
Waste Combustion	5.1	6.2	6.9	7.2	7.9	8.0	6.2	7.5	7.7	8.3
Total Other Sources	**88.3**	**105.3**	**100.1**	**101.2**	**102.3**	**101.3**	**99.5**	**102.3**	**105.7**	**105.4**
Total	**4,990.6**	**5,308.5**	**5,594.0**	**5,673.9**	**5,853.4**	**5,767.0**	**5,814.7**	**5,875.3**	**5,988.7**	**6,008.6**

[a] Emissions from nonfuel use are included in the sectoral totals above.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding. Adjusted energy total includes U.S. Territories.

Sources: EIA estimates presented in this report.

in 1990. Carbon dioxide emissions per capita, however, were 1.0 percent above 1990 levels in 2005. Population growth and other factors resulted in increased aggregate carbon dioxide emissions per year from 1990 through 2005 (a total increase of 20 percent). Carbon dioxide emissions per unit of net electricity generation in 2005 were 0.9 percent higher than in 2004.

Energy Consumption

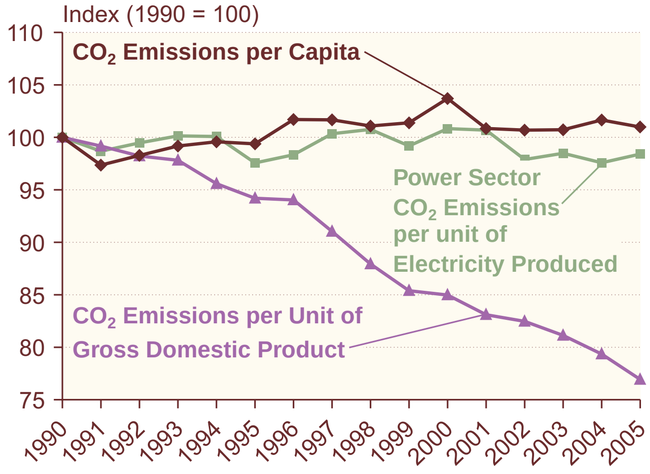
The consumption of energy in the form of fossil fuel combustion is the largest single contributor to anthropogenic greenhouse gas emissions in the United States and the world. Of total 2005 U.S. carbon dioxide emissions (adjusting for U.S. Territories and bunker fuels), 98 percent, or 5,903.2 MMT, resulted from the combustion of fossil fuels—0.3 percent more than in 2004.

The Energy Information Administration (EIA) divides energy consumption into four general end-use categories: residential, commercial, industrial, and transportation. Emissions from electricity generators, which provide electricity to the end-use sectors, are allocated in proportion to the electricity consumed in, and losses allocated to, each sector. Figure ES3 illustrates trends in carbon dioxide emissions by energy consumption sector. Average annual growth rates in carbon dioxide emissions by sector during the 1990-2005 period were 2.0 percent for the commercial sector, 1.8 percent for the residential sector, and 1.5 percent for the transportation sector. For the industrial sector, carbon dioxide emissions have grown in some years and fallen in others; industrial emissions in 2005 were slightly below their 1990 level.

Carbon dioxide emissions from the transportation sector are the largest source of energy-related carbon dioxide emissions. At 1,958.6 MMT, the transportation sector accounted for 33 percent of total U.S. energy-related carbon dioxide emissions in 2005. Transportation sector emissions increased by 1.0 percent in 2005 relative to the 2004 level of 1,939.2 MMT. Almost all (98 percent) of transportation sector carbon dioxide emissions result from the consumption of petroleum products: motor gasoline, 1,170.5 MMT (60 percent of total transportation sector emissions in 2005); middle distillates (diesel fuel), 434.1 MMT (22 percent); jet fuel, 243.8 MMT (12 percent); and residual oil (heavy fuel oil, largely for maritime use), 64.1 MMT (3.1 percent). The growth in transportation-related carbon dioxide emissions in 2005 included increases in emissions from the use of jet fuel (6.5 MMT), residual fuel oil (6.4 MMT), and diesel fuel (4.5 MMT).

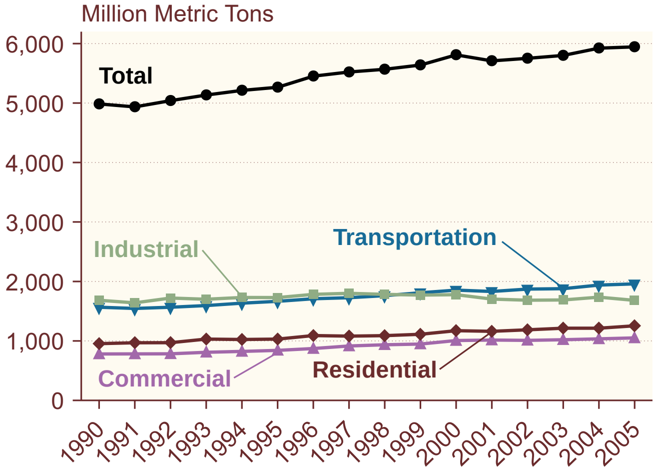
Industrial sector carbon dioxide emissions, at 1,682.3 MMT, accounted for 28 percent of total U.S. energy-related carbon dioxide emissions in 2005. The 2005 emissions level represents a 3.1-percent decrease from 2004 emissions of 1,736.0 MMT. Although industrial production rose by 3.2 percent in 2005, total industrial emissions fell, because three of the most energy-intensive industries experienced downturns in 2005: primary metals (down 2.7 percent), chemicals (down 6.9 percent), and petroleum (down 7.5 percent). In terms of fuel shares, electricity consumption was responsible for 39 percent of total industrial sector carbon dioxide emissions (662.8 MMT), natural gas for 24 percent (399.7 MMT), petroleum for 26 percent (431.2 MMT), and coal for 11 percent (184.5 MMT). Carbon dioxide emissions attributable to industrial sector energy consumption in 2005 were 0.1 percent (1.3 MMT) lower than in 1990.

Figure ES2. Carbon Dioxide Emissions Intensity of U.S. Gross Domestic Product, Population, and Electricity Production, 1990-2005



Sources: Estimates presented in this report.

Figure ES3. U.S. Carbon Dioxide Emissions from Energy Use by Sector, 1990-2005



Note: Sectoral emissions include both direct emissions and emissions attributable to purchased electricity.

Sources: Estimates presented in this report.

At 1,253.8 MMT, residential carbon dioxide emissions represented 21 percent of U.S. energy-related carbon dioxide emissions in 2005. The 2005 residential emissions were 3.3 percent higher than the 2004 level of 1,213.9 MMT. The residential sector's pro-rated share of electric power sector carbon dioxide emissions, 885.7 MMT, accounted for more than two-thirds of all emissions in the residential sector.[3] Natural gas accounted for 21 percent (261.7 MMT) and petroleum (mainly distillate fuel oil) represented 8.4 percent (105.3 MMT). Since 1990, when residential sector carbon dioxide emission totaled 953.7 MMT, the growth in residential carbon dioxide emissions has averaged 1.8 percent per year.

Commercial sector carbon dioxide emissions accounted for about 18 percent of total energy-related carbon dioxide emissions in 2005, at 1,050.6 MMT, of which 78 percent (821.1 MMT) was the sector's pro-rated share of electricity-related emissions. Natural gas contributed 16 percent (166.3 MMT) and petroleum 5.3 percent (55.4 MMT). Commercial sector carbon dioxide emissions increased by 1.6 percent from the 2004 level of 1,034.1 MMT. Since 1990, carbon dioxide emissions in the commercial sector have increased on average by 2.0 percent per year, the largest growth of any end-use sector. Commercial sector carbon dioxide emissions have risen by 269.9 MMT since 1990, accounting for 28 percent of the total increase in U.S. energy-related carbon dioxide emissions.

Carbon dioxide emissions from the U.S. electric power sector increased by 2.8 percent (65.6 MMT), from 2,309.4 MMT in 2004 to 2,375.0 MMT in 2005. Carbon dioxide emissions from the electric power sector have grown by 32 percent since 1990, while total carbon dioxide emissions from all energy-related sources have grown by 19 percent. Carbon dioxide emissions from the electric power sector represented 40 percent of total U.S. energy-related carbon dioxide emissions in 2005; however, as noted above, in calculating emissions from the end-use sectors EIA distributes electric power sector emissions to the four sectors in proportion to their respective shares of total electricity purchases. Therefore, electric power emissions are already included in the sectoral totals. By fuel, emissions from natural-gas-fired generation increased by 7.7 percent, emissions from coal-fired generation increased by 2.1 percent, and emissions from petroleum-fired generation increased by 2.3 percent in 2005 from their 2004 levels (see box on page xiv for allocation of all greenhouse gases to EIA's end-use sectors).

Nonfuel Uses of Energy Inputs

Nonfuel uses of fossil fuels, principally petroleum, both emit carbon dioxide and sequester carbon over their life cycles. In 2005, nonfuel uses of fossil fuels resulted in emissions of 106.4 MMT carbon dioxide, a 4.7-percent decrease from the 2004 level of 111.7 MMT. Emissions from nonfuel uses of energy fuels are included in the unadjusted energy consumption subtotals in Table ES3.

On the sequestration side of the ledger, nonfuel uses of fossil fuels also resulted in carbon sequestration equal to 300.9 $MMTCO_2e$ in 2005, a 3.3-percent decrease from the 2004 level of 311.1 $MMTCO_2e$. The major fossil fuel products that emit and sequester carbon include liquefied petroleum gas (LPG) and feedstocks for plastics and other petrochemicals. Asphalt and road oils are a major source of sequestration, but they do not emit carbon dioxide. It is estimated that, of the amount of carbon sequestered in the form of plastic, about 11.1 $MMTCO_2e$ was emitted as carbon dioxide from the burning of the plastic components of municipal solid waste to produce electricity in 2005. The 2004 estimate of 19.4 $MMTCO_2e$ is used in this report as an estimate for total 2005 emissions of carbon dioxide from the burning of wastes. The U.S. Environmental Protection Agency (EPA) estimates total emissions from waste burning, and its 2005 value was not available at the time this report was published.

Adjustments to Energy Consumption

Total U.S. carbon dioxide emissions and the estimates of energy consumption on which they are based correspond to EIA's coverage of energy consumption, including the 50 States and the District of Columbia. Under the United Nations Framework Convention on Climate Change (UNFCCC), however, the United States is also responsible for counting emissions emanating from its Territories, and their emissions are added to the U.S. total. Conversely, because the IPCC definition of energy consumption excludes international bunker fuels from the statistics of all countries, emissions from international bunker fuels are subtracted from the U.S. total. Military bunker fuels are also subtracted, because they are also excluded by the IPCC from national emissions totals. On net, these adjustments resulted in the subtraction of 42.1 MMT from total U.S. carbon dioxide emissions related to energy consumption (5,945.3 MMT), resulting in an adjusted total of 5,903.2 MMT for

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[3] Sectoral (residential, commercial, and industrial) energy-related carbon dioxide emissions include the share of total electric power sector carbon dioxide emissions that can be attributed to each end-use sector. The share is based on the percentage of total electricity sales purchased by the sector and losses attributed to the sector. (For values used to calculate sectoral shares, see Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035, Tables 2.2, 2.3, 2.4, and 2.5, web site www.eia.doe.gov/emeu/mer/consump.html.) All carbon dioxide emissions associated with industrial or commercial enterprises whose primary business is not the production of electricity are allocated to the sectors in which they occur.

Greenhouse Gas Emissions in the U.S. Economy

The diagram on page xv illustrates the flow of U.S. greenhouse gas emissions in 2005, from their sources to their distribution across the U.S. end-use sectors. The left side shows gases and quantities; the right side shows their distribution by sector. The center of the diagram indicates the split between emissions from direct fuel combustion and electricity conversion. Adjustments indicated at the top of the diagram for U.S. territories and international bunker fuels correspond to greenhouse gas reporting requirements developed by the UNFCCC.

CO_2. CO_2 emission sources include energy-related emissions (primarily from fossil fuel combustion) and emissions from industrial processes. The energy subtotal (5,945 $MMTCO_2e$) includes petroleum, coal, and natural gas consumption and smaller amounts from renewable sources, including municipal solid waste and geothermal power generation. The energy subtotal also includes emissions from nonfuel uses of fossil fuels, mainly as inputs to other products. Industrial process emissions (105 $MMTCO_2e$) include cement manufacture, limestone and dolomite calcination, soda ash manufacture and consumption, carbon dioxide manufacture, and aluminum production. The sum of the energy subtotal and industrial processes equals unadjusted CO_2 emissions (6,051 $MMTCO_2e$). The energy component of unadjusted emissions can be divided into direct fuel use (3,570 $MMTCO_2e$) and fuel converted to electricity (2,375 $MMTCO_2e$).

Non-CO_2 Gases. Methane (612 $MMTCO_2e$) and nitrous oxide (367 $MMTCO_2e$) sources include emissions related to energy, agriculture, waste management, and industrial processes. Other gases (160 $MMTCO_2e$) include HFCs, PFCs, and SF_6. These gases have a variety of uses in the U.S. economy, including refrigerants, insulators, solvents, and aerosols; as etching, cleaning, and firefighting agents; and as cover gases in various manufacturing processes.

Adjustments. In keeping with the UNFCCC, CO_2 emissions from U.S. Territories (59 $MMTCO_2e$) are added to the U.S. total, and CO_2 emissions from fuels used for international transport (both oceangoing vessels and airplanes) (101 $MMTCO_2e$) are subtracted to derive total U.S. greenhouse gas emissions (7,147 $MMTCO_2e$).

Emissions by End-Use Sector. CO_2 emissions by end-use sectors are based on EIA's estimates of energy consumption (direct fuel use and purchased electricity) by sector and on the attribution of industrial process emissions by sector. CO_2 emissions from purchased electricity are allocated to the end-use sectors based on their shares of total electricity sales. Non-CO_2 gases are allocated by direct emissions in those sectors plus emissions in the electric power sector that can be attributed to the end-use sectors based on electricity sales.

Residential emissions (1,284 $MMTCO_2e$) include energy-related CO_2 emissions (1,266 $MMTCO_2e$); and non-CO_2 emissions (18 $MMTCO_2e$). The non-CO_2 sources include direct methane and nitrous oxide emissions from direct fuel use. Non-CO_2 indirect emissions attributable to purchased electricity, including methane and nitrous oxide emissions from electric power generation and SF_6 emissions related to electricity transmission and distribution, are also included.

Emissions in the commercial sector (1,301 $MMTCO_2e$) include both energy-related CO_2 emissions (1,061 $MMTCO_2e$) and non-CO_2 emissions (240 $MMTCO_2e$). The non-CO_2 emissions include direct emissions from landfills, wastewater treatment plants, commercial refrigerants, and stationary combustion emissions of methane and nitrous oxide. Non-CO_2 indirect emissions attributable to purchased electricity, including methane and nitrous oxide emissions from electric power generation and SF_6 emissions related to electricity transmission and distribution, are also included.

Industrial emissions (2,562 $MMTCO_2e$) include CO_2 emissions (1,804 $MMTCO_2e$)—which can be broken down between combustion (1,699 $MMTCO_2e$) and process emissions (105 $MMTCO_2e$)—and non-CO_2 emissions (757 $MMTCO_2e$). The non-CO_2 direct emissions include emissions from agriculture (methane and nitrous oxide), coal mines (methane), petroleum and natural gas pipelines (methane), industrial process emissions (methane, nitrous oxide, HFCs, PFCs and SF_6), and direct stationary combustion emissions of methane and nitrous oxide. Non-CO_2 indirect emissions attributable to purchased electricity, including methane and nitrous oxide emissions from electric power generation and SF_6 emissions related to electricity transmission and distribution, are also included.

Transportation emissions (2,000 $MMTCO_2e$) include energy-related CO_2 emissions from mobile source combustion (1,877 $MMTCO_2e$); and non-CO_2 emissions (123 $MMTCO_2e$). The non-CO_2 emissions include methane and nitrous oxide emissions from mobile source combustion and HFC emissions from the use of refrigerants for mobile source air-conditioning units.

(continued on page xv)

Greenhouse Gas Emissions in the U.S. Economy (Continued)

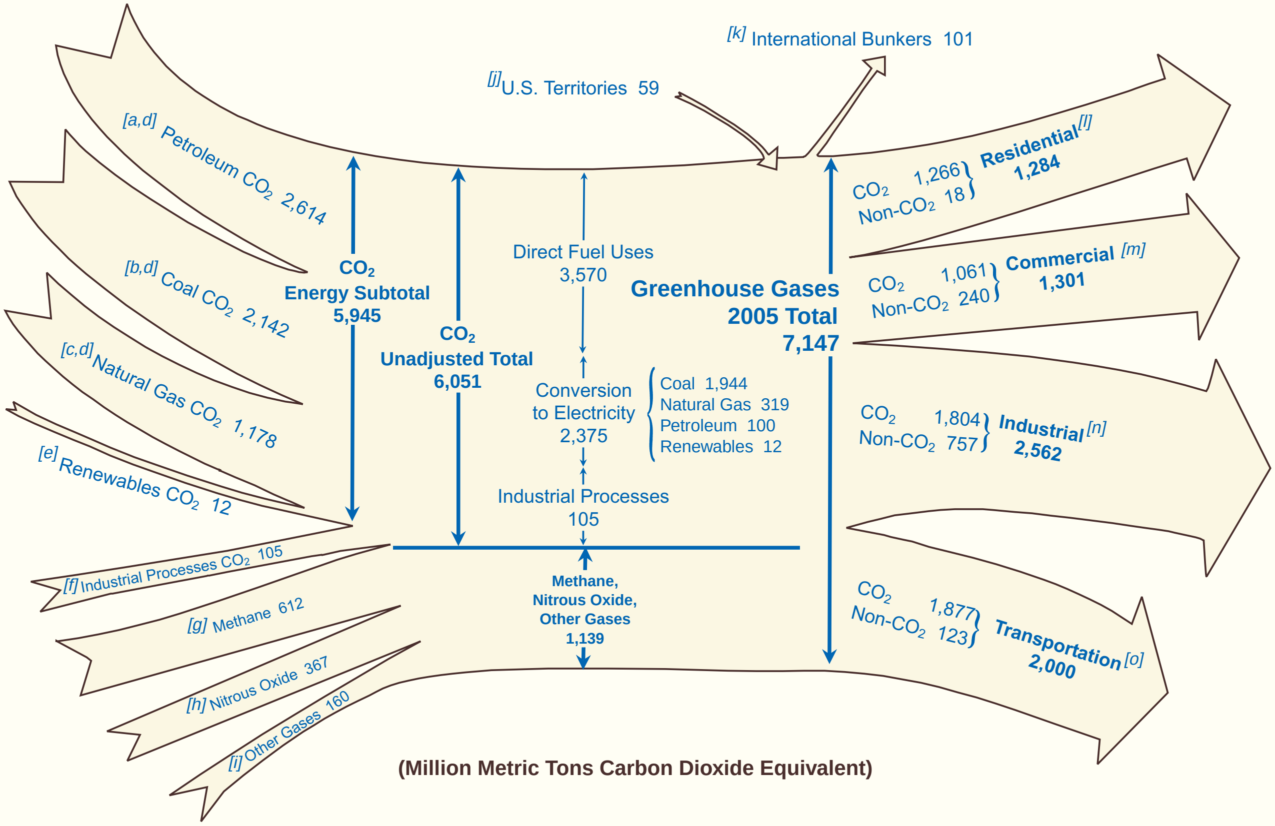


Diagram Notes

[*a*] CO_2 emissions related to petroleum consumption (includes 88.0 $MMTCO_2$ of non-fuel-related emissions).

[*b*] CO_2 emissions related to coal consumption (includes 0.5 $MMTCO_2$ of non-fuel-related emissions).

[*c*] CO_2 emissions related to natural gas consumption (includes 18.0 $MMTCO_2$ of non-fuel-related emissions).

[*d*] Excludes carbon sequestered in nonfuel fossil products.

[*e*] CO_2 emissions from the plastics portion of municipal solid waste (11.1 $MMTCO_2$) combusted for electricity generation and very small amounts (0.4 $MMTCO_2$) of geothermal-related emissions.

[*f*] Includes mainly direct process emissions. Some combustion emissions are included from waste combustion outside the electric power sector and flaring of non-marketed natural gas.

[*g*] Includes methane emissions related to energy, agriculture, waste management, and industrial processes.

[*h*] Includes nitrous oxide emissions related to agriculture, energy, industrial processes, and waste management.

[*i*] Includes hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

[*j*] Includes only energy-related CO_2 emissions from fossil fuels.

[*k*] Includes vessel bunkers and jet fuel consumed for international travel. Under the UNFCCC, these emissions are not included in country emission inventories.

[*l*] Direct stationary combustion emissions of methane and nitrous oxide plus indirect power sector emissions of methane, nitrous oxide, and other greenhouse gases.

[*m*] Direct stationary combustion emissions of methane and nitrous oxide plus indirect power sector emissions of methane, nitrous oxide, and other greenhouse gases. Additional direct emissions include emissions from landfills, wastewater treatment, and commercial refrigerants.

[*n*] Direct stationary combustion emissions of methane and nitrous oxide plus indirect power sector emissions of methane, nitrous oxide, and other greenhouse gases. In addition, all agricultural emissions are included in the industrial sector as well as direct process emissions of methane, nitrous oxide, and the other gases.

[*o*] Direct mobile combustion emissions of methane and nitrous oxide. Also, emissions related to transportation refrigerants are included.

Source: Estimates presented in this report. CO_2 emissions by end-use sector are based on EIA's estimates of energy consumption by sector and on industrial process emissions. CO_2 emissions from the electric power sector are allocated to the end-use sectors based on electricity sales to the sector. Non-CO_2 emissions by end-use sector are allocated by direct emissions in those sectors plus indirect emissions from the electric power sector allocated by electricity sales. Data are preliminary. Totals may not equal sum of components due to independent rounding.

(continued on page xvi)

energy-related carbon dioxide emissions in 2005 (Table ES3).

Energy-related carbon dioxide emissions for the U.S. Territories are added as an adjustment, in keeping with IPCC guidelines for national emissions inventories. The Territories included are Puerto Rico, the U.S. Virgin Islands, American Samoa, Guam, the U.S. Pacific Islands, and Wake Island. Most of these emissions are from petroleum products; however, Puerto Rico and the Virgin Islands consume coal in addition to petroleum products. Total energy-related carbon dioxide emissions from the U.S. Territories in 2005 are estimated at 58.6 MMT (Table ES3).

Greenhouse Gas Emissions in the U.S. Economy (Continued)

Distribution of Total U.S. Greenhouse Gas Emissions by End-Use Sector, 2005

Greenhouse Gas and Source	Sector				
	Residential	Commercial	Industrial	Transportation	Total
Carbon Dioxide	Million Metric Tons Carbon Dioxide Equivalent				
Energy-Related	1,266.1	1,060.9	1,699.0	1,877.2	**5,903.2**
Industrial Processes	—	—	105.4	—	**105.4**
Total CO_2	**1,266.1**	**1,060.9**	**1,804.4**	**1,877.2**	**6,008.6**
Methane					
Energy					
Coal Mining	—	—	65.5	—	**65.5**
Natural Gas Systems	—	—	154.0	—	**154.0**
Petroleum Systems	—	—	21.1	—	**21.1**
Stationary Combustion	8.8	0.1	0.5	—	**9.4**
Stationary Combustion: Electricity	0.1	0.1	0.1	—	**0.3**
Mobile Sources	—	—	—	4.5	**4.5**
Waste Management					
Landfills	—	155.7	—	—	**155.7**
Wastewater Treatment	—	15.8	—	—	**15.8**
Industrial Processes	—	—	2.5	—	**2.5**
Agricultural Sources					
Enteric Fermentation	—	—	115.6	—	**115.6**
Animal Waste	—	—	55.3	—	**55.3**
Rice Cultivation	—	—	10.9	—	**10.9**
Crop Residue Burning	—	—	1.2	—	**1.2**
Total Methane	**8.9**	**171.7**	**426.8**	**4.5**	**611.9**
Nitrous Oxide					
Agriculture					
Nitrogen Fertilization of Soils	—	—	218.1	—	**218.1**
Solid Waste of Animals	—	—	61.2	—	**61.2**
Crop Residue Burning	—	—	0.6	—	**0.6**
Energy Use					
Mobile Combustion	—	—	—	52.6	**52.6**
Stationary Combustion	0.9	0.4	4.2	—	**5.4**
Stationary Combustion: Electricity	3.4	3.2	2.6	—	**9.2**
Industrial Sources	—	—	13.2	—	**13.2**
Waste Management					
Human Sewage in Wastewater	—	5.8	—	—	**5.8**
Waste Combustion	—	—	—	—	**0.0**
Waste Combustion: Electricity	0.1	0.1	0.1	—	**0.3**
Total Nitrous Oxide	**4.5**	**9.5**	**300.0**	**52.6**	**366.5**
Hydrofluorocarbons					
HFC-23	—	—	17.3	—	**17.3**
HFC-32	—	0.4	—	—	**0.4**
HFC-125	—	22.1	—	—	**22.1**
HFC-134a	—	—	—	66.1	**66.1**
HFC-143a	—	23.0	—	—	**23.0**
HFC-236fa	—	2.9	—	—	**2.9**
Total HFCs	**0.0**	**48.4**	**17.3**	**66.1**	**131.8**
Perfluorocarbons					
CF_4	—	—	3.2	—	**3.2**
C_2F_6	—	—	3.0	—	**3.0**
NF_3, C_3F_8, and C_4F_8	—	—	0.5	—	**0.5**
Total PFCs	**0.0**	**0.0**	**6.7**	**0.0**	**6.7**
Other HFCs, PFCs/PFPEs	**—**	**6.1**	**—**	**—**	**6.1**
Sulfur Hexafluoride					
SF_6: Utility	4.6	4.2	3.4	—	**12.3**
SF_6: Other	—	—	3.4	—	**3.4**
Total SF_6	**4.6**	**4.2**	**6.8**	**0.0**	**15.6**
Total Non-CO_2	**17.9**	**240.0**	**757.4**	**123.2**	**1,138.5**
Total Emissions	**1,284.0**	**1,301.0**	**2,561.8**	**2,000.3**	**7,147.2**

In 2005, approximately 100.7 MMT carbon dioxide was emitted in total from international bunker fuels, including 90.6 MMT attributable to civilian consumption of bunker fuels and 10.1 MMT from military use.[4] In Table ES3, total emissions from international bunker fuels are included as a negative adjustment to U.S. energy-related carbon dioxide emissions. Just over two-thirds of the carbon dioxide emissions associated with international bunker fuels comes from the combustion of jet fuels; residual and distillate fuels account for the other one-third, with most of that coming from residual fuel.

Other Carbon Dioxide Emissions

In addition to carbon dioxide emissions from fossil fuel combustion and use, a total of 105.4 MMT was emitted from other sources in 2005 (Table ES3). Cement manufacture (45.9 MMT) and industrial sources (28.1 MMT) accounted for nearly three-fourths of the total carbon dioxide emissions from other sources. Energy sector components in the other emissions category included the stripping of carbon dioxide from natural gas (17.3 MMT) and natural gas flaring (5.9 MMT). An additional 8.3 MMT carbon dioxide is estimated to have been released from the burning of wastes other than municipal solid waste in the electric power sector.

Methane

U.S. anthropogenic methane emissions totaled 611.9 MMTCO$_2$e[5] (26.6 million metric tons of methane) in 2005, representing 8.6 percent of total U.S. greenhouse gas emissions. Methane emissions in 2005 were 0.9 percent (5.3 MMTCO$_2$e) higher than the 2004 level of 606.5 MMTCO$_2$e (Table ES4). The increase is attributable primarily to increases in methane emissions from landfills (6.9 MMTCO$_2$e) and, to a lesser extent, emissions associated with animal husbandry. Those increases were offset to some degree by a decrease in methane emissions from coal mines (1.8 MMTCO$_2$e) and a small decrease in emissions from the cultivation of crops. Despite the 0.9-percent increase in 2005, methane emissions still were 89.8 MMTCO$_2$e (13 percent) below their 1990 level of 701.7 MMTCO$_2$e.

Methane emissions come from four source categories, three major and one minor. The major sources are energy, agriculture, and waste management, and the

Table ES4. U.S. Methane Emissions from Anthropogenic Sources, 1990, 1995, and 1998-2005
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Energy Sources										
Coal Mining	97.7	83.8	75.6	71.5	68.1	68.0	64.1	64.2	67.3	65.5
Natural Gas Systems	128.9	137.6	143.9	144.2	151.0	147.0	154.0	153.2	154.7	154.0
Petroleum Systems	29.9	26.9	25.5	24.0	23.8	23.7	23.5	23.3	22.3	21.1
Stationary Combustion	12.9	11.8	8.9	9.3	10.0	8.7	8.9	9.3	9.5	9.7
Mobile Sources	5.6	4.8	4.7	4.6	4.6	4.5	4.4	4.2	4.4	4.5
Total Energy Sources	**275.0**	**264.9**	**258.6**	**253.7**	**257.5**	**251.9**	**255.0**	**254.1**	**258.3**	**254.9**
Waste Management										
Landfills	237.3	204.9	170.9	162.4	155.4	147.8	146.7	148.7	148.8	155.7
Wastewater Treatment	13.2	14.2	14.7	14.8	15.0	15.2	15.3	15.5	15.6	15.8
Total Waste Management	**250.6**	**219.1**	**185.6**	**177.2**	**170.3**	**162.9**	**162.0**	**164.2**	**164.5**	**171.5**
Agricultural Sources										
Enteric Fermentation	119.6	124.4	117.2	117.3	116.3	115.1	115.8	116.1	114.2	115.6
Animal Waste	43.5	49.9	53.6	52.7	52.8	53.3	53.7	54.2	54.7	55.3
Rice Cultivation	9.3	10.2	10.7	11.5	10.2	10.7	10.2	9.8	10.9	10.9
Crop Residue Burning	1.0	1.0	1.1	1.1	1.1	1.1	1.0	1.2	1.3	1.2
Total Agricultural Sources	**173.4**	**185.4**	**182.6**	**182.5**	**180.4**	**180.3**	**180.7**	**181.3**	**181.1**	**183.0**
Industrial Processes	**2.7**	**3.0**	**3.1**	**3.1**	**2.9**	**2.5**	**2.6**	**2.6**	**2.7**	**2.5**
Total	**701.7**	**672.5**	**629.8**	**616.5**	**611.2**	**597.7**	**600.2**	**602.2**	**606.5**	**611.9**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates presented in this report. Emissions calculations based on Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.83-4.84, web site www.ipcc.ch/pub/guide.htm; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[4] Data for 2005 military bunker fuels were not available at the time of publication. It should also be noted that only bunker fuels purchased in the United States are subject to adjustment.

[5] Based on an estimated GWP of 23 for methane.

minor source is industrial processes. The three major sources accounted for 42, 30, and 28 percent, respectively, of total 2005 U.S. emissions of methane. Trends in the major sources of anthropogenic methane emissions since 1990 are illustrated in Figure ES4.

Energy Sources

Total U.S. energy consumption fell by 0.3 percent from 2004 to 2005; and methane emissions from energy sources (coal mining, natural gas systems, petroleum systems, stationary combustion, and mobile source combustion) in 2005, at 254.9 MMTCO$_2$e, were 1.3 percent below the 2004 level of 258.3 MMTCO$_2$e. Methane emissions from energy sources have fallen by 7.3 percent since 1990.

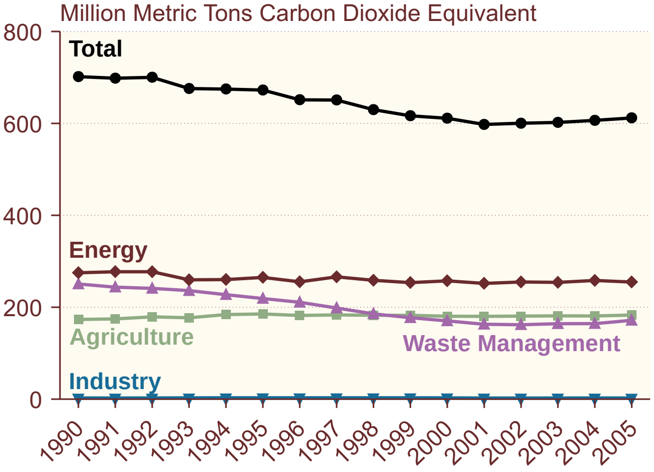
Agricultural Sources

Methane emissions from agricultural sources, at 183.0 MMTCO$_2$e, represented 30 percent of total U.S. anthropogenic methane emissions in 2005. Emissions increased by 1.0 percent (1.9 MMTCO$_2$e) in 2005 relative to 2004. Increases greater than 1 percent in emissions from enteric fermentation in domesticated animals and from animal waste were offset to some extent by decreases in emissions from rice cultivation and burning of crop residues. Of the total 2005 methane emissions from agricultural sources, 93 percent (170.9 MMTCO$_2$e) resulted from livestock management, of which 68 percent (115.6 MMTCO$_2$e) was from enteric fermentation and the remainder (55.3 MMTCO$_2$e) was from anaerobic decomposition of livestock wastes. Methane emissions from rice cultivation (10.9 MMTCO$_2$e) and crop residue burning (1.2 MMTCO$_2$e) together represented about 6.6 percent of total methane emissions from agricultural sources in 2005, which have increased by 5.5 percent since 1990.

Waste Management

Methane emissions from waste management, which at 171.5 MMTCO$_2$e accounted for 28 percent of U.S. anthropogenic methane emissions in 2005, were 4.3 percent above the 2004 level of 164.5 MMTCO$_2$e. Landfills—the largest single source of U.S. anthropogenic methane emissions—represented 91 percent (155.7 MMTCO$_2$e) of total U.S. methane emissions from waste management in 2005. The remainder of 2005 methane emissions from waste management (15.8 MMTCO$_2$e) was associated with domestic wastewater treatment. Methane emissions from waste management have fallen by 32 percent (79.1 MMTCO$_2$e) from their 1990 level of 250.6 MMTCO$_2$e, due largely to increased methane recovery at landfills, which increased to 122.5 MMTCO$_2$e in 2005 from 21.7 MMTCO$_2$e in 1990. Even at these higher methane recovery levels, however, waste management emissions, after bottoming out in 2002, increased in both 2004 and 2005.

Figure ES4. U.S. Emissions of Methane by Source, 1990-2005



Source: Estimates presented in this report.

Industrial Processes

Methane emissions from industrial processes totaled 2.5 MMTCO$_2$e in 2005, including 1.5 MMTCO$_2$e from chemical manufacturing and 1.0 MMTCO$_2$e from iron and steel production. The 2005 total was 7.7 percent below the 2004 total of 2.7 MMTCO$_2$e. Since 1990, growth in methane emissions from chemical production has been more than offset by reductions in emissions from iron and steel production, leaving the 2005 total for industrial process emissions 8.4 percent below the total for 1990.

Nitrous Oxide

Estimated U.S. anthropogenic emissions of nitrous oxide in 2005 totaled 366.6 MMTCO$_2$e, or 1.2 MMT nitrous oxide. Nitrous oxide emissions represented 5.1 percent of total U.S. greenhouse gas emissions in 2005 and were 1.9 percent (6.7 MMTCO$_2$e) above the 2004 level of 359.9 MMTCO$_2$e. Most of the increase from 2004 can be attributed to increased emissions from agricultural sources, which rose by 7.0 MMTCO$_2$e in 2005. Emissions from waste management contributed about 1 percent to the total growth from 2004 to 2005, whereas emissions from industrial sources were 5.3 percent lower in 2005 than in 2004 (Table ES5 and Figure ES5).

Agriculture

Agricultural sources, at 279.9 MMTCO$_2$e, accounted for 76 percent of total U.S. nitrous oxide emissions in 2005. Agricultural emissions in 2005 were 2.6 percent above the 2004 total of 272.9 MMTCO$_2$e, primarily as the result of an increase of 2.9 percent (6.2 MMTCO$_2$e) in emissions from the nitrogen fertilization of agricultural soils. Emissions from nitrogen fertilization, at 218.1 MMTCO$_2$e, accounted for 60 percent of nitrous oxide emissions from agriculture in 2005. Emissions from the solid waste of domesticated animals, at 61.2 MMTCO$_2$e, made up 22 percent of agricultural nitrous oxide emissions in 2005, and burning of crop residues produced another 0.6 MMTCO$_2$e. Total U.S. emissions of nitrous oxide from agriculture sources have increased by 12.3 percent since 1990.

Energy Use

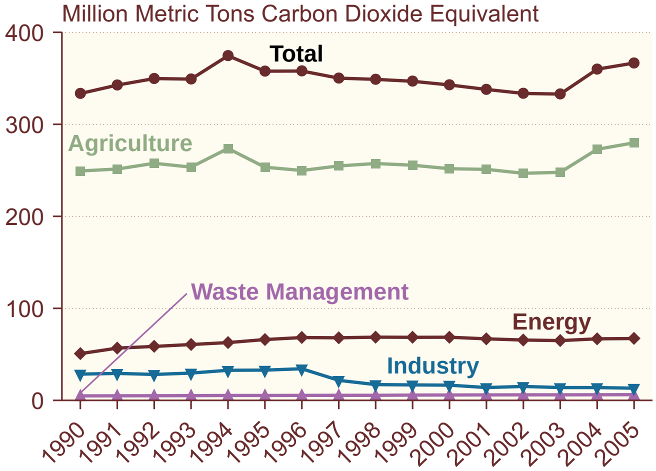
U.S. nitrous oxide emissions associated with fossil fuel combustion in 2005 were 67.3 MMTCO$_2$e, or 18 percent of total nitrous oxide emissions. Most of the energy-related emissions of nitrous oxide in 2005 (78 percent or 52.6 MMTCO$_2$e) were from mobile sources, principally, motor vehicles equipped with catalytic converters. The remainder (22 percent or 14.7 MMTCO$_2$e) was from stationary source combustion of fossil fuels. Nitrous oxide emissions from energy sources have increased by 32 percent since 1990.

Industrial Processes and Waste Management

Industrial processes and waste management facilities were responsible for 3.6 percent and 1.6 percent, respectively, of total U.S. nitrous oxide emissions in 2005. Industrial process emissions in 2005 (13.2 MMTCO$_2$e) were 5.3 percent below the 2004 level of 14.0 MMTCO$_2$e. Industrial process emissions have fallen by 54 percent since 1990 due to decreases in nitrous oxide emissions from the manufacture of adipic acid.

Nitrous oxide emissions from waste management facilities in 2005 (6.2 MMTCO$_2$e) increased by 1.1 percent from the 2004 level of 6.1 MMTCO$_2$e. Most of the 2005 emissions (5.8 MMTCO$_2$e) were from human sewage in wastewater and the remainder from waste combustion. Nitrous oxide emissions from waste management facilities have increased by 26 percent since 1990.

Figure ES5. U.S. Emissions of Nitrous Oxide by Source, 1990-2005



Source: Estimates presented in this report.

Table ES5. Estimated U.S. Emissions of Nitrous Oxide, 1990, 1995, and 1998-2005
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Agriculture										
Nitrogen Fertilization of Soils	186.9	187.3	194.0	192.7	189.4	189.1	185.1	186.6	211.9	218.1
Solid Waste of Domesticated Animals	61.9	65.6	62.8	62.3	61.8	61.4	61.1	60.7	60.3	61.2
Crop Residue Burning	0.5	0.5	0.6	0.5	0.6	0.6	0.5	0.5	0.6	0.6
Subtotal	**249.3**	**253.4**	**257.4**	**255.6**	**251.8**	**251.1**	**246.8**	**247.8**	**272.9**	**279.9**
Energy Use										
Mobile Combustion	37.4	52.2	54.3	54.0	53.6	52.4	51.2	50.5	52.0	52.6
Stationary Combustion	13.3	13.9	14.4	14.6	15.0	14.5	14.3	14.5	14.8	14.7
Subtotal	**50.8**	**66.1**	**68.7**	**68.6**	**68.6**	**66.9**	**65.6**	**65.0**	**66.9**	**67.3**
Industrial Sources	**28.6**	**32.9**	**17.2**	**16.8**	**16.6**	**14.0**	**15.2**	**14.0**	**14.0**	**13.2**
Waste Management										
Human Sewage in Wastewater	4.6	5.1	5.3	5.5	5.6	5.6	5.7	5.7	5.8	5.8
Waste Combustion	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Subtotal	**4.9**	**5.4**	**5.5**	**5.8**	**5.8**	**6.0**	**6.0**	**6.1**	**6.1**	**6.2**
Total	**333.5**	**357.7**	**348.8**	**346.8**	**342.8**	**337.9**	**333.6**	**332.9**	**359.9**	**366.6**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Estimates presented in this report. Emissions calculations based on Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.81-4.94, web site www.ipcc.ch/pub/guide.htm; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

Other Gases: Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride

HFCs, PFCs, and SF_6 are three classes of high-GWP gases that accounted for 2.2 percent of total U.S. greenhouse gas emissions in 2005. At 160.2 $MMTCO_2e$, their emissions were 7.2 percent higher than in 2004 (149.5 $MMTCO_2e$). The increase in emissions of the high-GWP gases from 2004 to 2005 resulted largely from an 8.9-percent increase in HFC emissions, which more than offset decreases in emissions of PFCs (5.2 percent lower than in 2004) and SF_6 (2.1 percent lower) (Table ES6).

At 131.8 $MMTCO_2e$, emissions of HFCs made up the majority of U.S. emissions of high-GWP greenhouse gases, followed by SF_6 at 15.7 $MMTCO_2e$ and PFCs at 6.7 $MMTCO_2e$. Another group of high-GWP gases, consisting of other HFCs, other PFCs, and perfluoropolyethers (PFPEs), includes HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and a variety of PFCs and PFPEs. They are grouped together in this report to protect confidential data. In 2005, their combined emissions totaled 6.1 $MMTCO_2e$. Emissions of the gases in this group in 2005 were 13 percent higher than in 2004 and an order of magnitude higher than in 1990, when they totaled less than 0.4 $MMTCO_2e$. Since 1990, HFC emissions from U.S. sources have increased by 265 percent, PFC emissions have fallen by 67 percent, and SF_6 emissions have fallen by 49 percent.

Emissions of the high-GWP gases specified in the Kyoto Protocol are very small (at most a few thousand metric tons). On the other hand, some of the gases (including PFCs and SF_6) have atmospheric lifetimes measured in the thousands of years, and consequently they are potent greenhouse gases with GWPs thousands of times higher than that of carbon dioxide per unit of molecular weight. Some of the commercially produced HFCs (134a, 152a, 4310mee, and 227ea), which are used as replacements for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), have shorter atmospheric lifetimes, ranging from 1 to 33 years.

Land-Use Change and Forestry

Forest lands in the United States are net absorbers of carbon dioxide from the atmosphere, primarily as a result

Table ES6. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990, 1995, and 1998-2005
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Hydrofluorocarbons										
HFC-23	36.1	28.1	41.6	31.7	30.9	20.6	20.6	12.9	16.3	17.3
HFC-32	0.0	0.0	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4
HFC-125	0.0	4.4	10.7	12.1	13.6	14.9	16.3	17.9	19.8	22.1
HFC-134a	0.0	17.7	35.2	40.2	45.4	49.7	53.5	56.8	61.6	66.1
HFC-143a	0.0	0.9	5.9	7.5	9.3	11.4	13.8	16.5	19.5	23.0
HFC-236fa	0.0	0.0	0.6	1.3	2.0	2.6	3.2	3.5	3.5	2.9
Total HFCs	**36.1**	**51.0**	**94.2**	**93.1**	**101.5**	**99.4**	**107.6**	**107.8**	**121.1**	**131.8**
Perfluorocarbons										
CF_4	14.6	10.0	8.4	8.3	8.4	3.8	5.0	3.8	3.2	3.2
C_2F_6	5.4	5.4	5.8	5.8	4.9	3.3	3.8	3.3	3.4	3.0
NF_3	*	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3
C_3F_8	*	*	*	*	0.1	0.1	0.1	0.1	*	*
C_4F_8	*	*	*	*	*	*	0.1	0.1	0.1	0.1
Total PFCs	**20.0**	**15.5**	**14.2**	**14.2**	**13.6**	**7.3**	**9.2**	**7.6**	**7.0**	**6.7**
Other HFCs, PFCs/PFPEs	**0.4**	**2.1**	**4.9**	**5.0**	**4.9**	**4.7**	**4.7**	**4.7**	**5.4**	**6.1**
Sulfur Hexafluoride	**30.7**	**26.3**	**21.0**	**21.6**	**18.1**	**17.1**	**16.3**	**16.4**	**16.0**	**15.7**
Total Emissions	**87.1**	**94.9**	**134.3**	**133.9**	**138.0**	**128.5**	**137.8**	**136.6**	**149.5**	**160.2**

*Less than 50,000 metric tons carbon dioxide equivalent.

P = preliminary data.

Notes: Other HFCs, PFCs/PFPEs include HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and a variety of PFCs and perfluoropolyethers (PFPEs). They are grouped together to protect confidential data. Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, September 2005).

of the reversal of the extensive deforestation that occurred in the United States during the late 19th and early 20th centuries. Since then, millions of acres of formerly cultivated land have been abandoned and have returned to forest, with the regrowth of forests sequestering carbon on a large scale. The process is steadily diminishing, however, because the rate at which forests absorb carbon slows as the trees mature, and because the rate of reforestation has slowed.

The EPA estimates annual U.S. carbon sequestration from land-use change and forestry in 2004 at 780.1 MMTCO$_2$e,[6] representing an offset of 11 percent of total 2004 U.S. greenhouse gas emissions (7,104.6 MMTCO$_2$e). In 1990, carbon sequestration attributable to land use and forestry was 910.4 MMTCO$_2$e, or 15 percent of total 1990 U.S. greenhouse gas emissions (6,112.8 MMTCO$_2$e).[7] The EPA's 2004 estimates for carbon sequestration from land-use change and forestry include 637.2 MMTCO$_2$e from forested land, 88.0 MMTCO$_2$e from urban trees, 9.3 MMTCO$_2$e from landfilled yard trimmings and food scraps, and 45.6 MMTCO$_2$e from all other sources, including net emissions of 7.3 MMTCO$_2$e from grassland soil stocks (Table ES7).

Uncertainty in Emissions Estimates

The emissions numbers presented in this report are, for the most part, estimates based on estimated activity data and estimated emission factors. As such, they have an element of uncertainty, given that the activity data and emission factors on which the emission estimates are based also have a range of possible values. The activity data and emission factors can themselves be characterized by systematic biases and/or random errors. In 2000, EIA employed a Monte Carlo analysis to estimate the range of uncertainty, at a 95-percent confidence level, around estimated emissions of carbon dioxide, methane, and nitrous oxide (HFCs, PFCs, and SF$_6$ were not part of the analysis).[8]

The Monte Carlo simulations revealed that uncertainty varies by type of gas. There is less uncertainty around the simulated mean for carbon dioxide (-1.4 percent to +1.3 percent) than for methane (-15.6 percent to 16.0 percent) or nitrous oxide (-53.5 percent to +54.2 percent). The simulations also showed that the uncertainty around the simulated mean of total greenhouse gas

Table ES7. Net Carbon Dioxide Sequestration from U.S. Land-Use Change and Forestry, 1990 and 1998-2004
(Million Metric Tons Carbon Dioxide Equivalent)

Component	1990	1998	1999	2000	2001	2002	2003	2004
Forest Land Remaining Forest Land: Changes in Forest Carbon Stocks	773.4	618.8	637.9	631.0	634.0	634.6	635.8	637.2
Cropland Remaining Cropland: Changes in Agricultural Soil Carbon Stocks and Liming Emissions	33.1	24.6	24.6	26.1	27.8	27.5	28.7	28.9
Land Converted to Cropland: Changes in Agricultural Soil Carbon Stocks	-1.5	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Grassland Remaining Grassland: Changes in Agricultural Soil Carbon Stocks	4.5	-7.5	-7.5	-7.4	-7.4	-7.4	-7.3	-7.3
Land Converted to Grassland: Changes in Agricultural Soil Carbon Stocks	17.6	21.1	21.1	21.1	21.1	21.1	21.1	21.1
Settlements Remaining Settlements	83.2	84.2	86.8	85.9	89.7	89.9	93.8	97.3
Urban Trees	*58.7*	*73.3*	*77.0*	*77.0*	*80.7*	*80.7*	*84.3*	*88.0*
Landfilled Yard Trimmings and Food Scraps	*24.5*	*10.9*	*9.8*	*8.9*	*9.0*	*9.3*	*9.4*	*9.3*
Total Net Flux	**910.4**	**744.0**	**765.7**	**759.5**	**768.0**	**768.6**	**774.8**	**780.1**

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

Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

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[6] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*, EPA 430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html. Estimates for carbon sequestration in 2005 are not yet available.

[7] EIA does not include sequestration from land-use change and forestry as part of its annual emissions inventory.

[8] Energy Information Administration, *Documentation for Estimation of Greenhouse Gases in the United States 2004*, DOE/EIA-0638(2004) (Washington, DC, November 2006), Chapter 8, web site www.eia.doe.gov/oiaf/1605/ggrpt/documentation/pdf/0638(2004).pdf.

emissions (excluding HFCs, PFCs, and SF_6) is -4.4 percent to +4.6 percent.

The certainty of emissions data varies by category and by source. For example, methane emissions from existing underground coal mines are relatively certain. In general, however, the estimates for carbon dioxide emissions are more certain than the estimates for other gases. It is likely that the estimate of total U.S. carbon dioxide emissions is accurate to within 5 percent. For methane emissions, most of the estimates are much more uncertain, with a level of uncertainty that may exceed 30 percent. Estimates of methane emissions may also understate actual emissions as a result of the exclusion of sources that are unknown or difficult to quantify. For example, EIA does not include sources such as abandoned coal mines and industrial wastewater. Nitrous oxide emissions estimates are much less certain than those for carbon dioxide or methane emissions, in part because nitrous oxide emissions have been studied far less than emissions of the other greenhouse gases and in part because the largest apparent sources of nitrous oxide emissions are area sources that result from biological activity, which makes for emissions that are highly variable and hard to measure or characterize. The uncertainty for nitrous oxide emissions may exceed 100 percent.

1. U.S. Emissions of Greenhouse Gases: Background and Context

About This Report

The Energy Policy Act of 1992 requires the Energy Information Administration (EIA) to prepare an inventory of aggregate U.S. national emissions of greenhouse gases for the period 1987-1990, with annual updates thereafter. This report contains data from the thirteenth annual inventory update, covering national emissions over the period 1990-2004, with preliminary estimates of emissions for 2005.

EIA continually reviews its methods for estimating emissions of greenhouse gases. As better methods and information become available, EIA revises both current and historical emissions estimates (see "What's New").

This introductory chapter provides background information on U.S. greenhouse gases in a global context, the greenhouse effect and global climate change, and recent domestic and international developments to address climate change. Chapters 2 through 4 cover emissions of carbon dioxide, methane, and nitrous oxide, respectively. Chapter 5 focuses on emissions of gases with high global warming potentials (GWPs), including hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Chapter 6 describes potential sequestration and emissions of greenhouse gases as a result of land-use changes.

What's New

Carbon Dioxide

In preparing for this year's report, it was determined that EIA had been miscounting an adjustment to ethanol consumption. The corrected value for ethanol consumption increases the value for carbon dioxide emissions resulting from the consumption of motor gasoline; however, the trend remains the same.

Methane

In calculating methane emissions from landfills, EIA uses estimates of municipal solid waste (MSW) generated and MSW landfilled, published by *Biocycle* magazine. In its April 2006 issue, *Biocycle* reported estimates of MSW generated in 2002 and 2004 that were more than 20 percent below its previously published estimates. The reason for the revisions is that *Biocycle* now excludes certain non-MSW materials (such as construction and demolition debris and industrial waste) from its MSW generation estimates.

To ensure that EIA's estimates of methane emissions from landfills are consistent over the entire 1990-2005 time frame, waste generation estimates for the years 1989 through 2004 have been adjusted downward, based on the implied downward revision of the *Biocycle* data most recently reported for 2002 and 2004. EIA assumed a constant ratio of actual MSW generation to reported MSW generation for the period 1989 through 2004 and adjusted the estimates of waste generation—and methane emissions from landfills—for those years downward, to ensure that all the earlier estimates (1990-2004) are consistent with *Biocycle*'s new method.

Other Gases: Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride

Difluoromethane (HFC-32). In this annual edition of EIA's greenhouse gas emissions inventory, data on hydrofluorocarbon (HFC) emissions for the first time include emissions of HFC-32, which increasingly is being used to replace HCFC-22 in refrigerant blends. Its inclusion in the inventory, based on data from the U.S. Environmental Protection Agency (EPA), adds 0.4 million metric tons carbon dioxide equivalent (MMTCO$_2$e) to EIA's estimate of total greenhouse gas emissions in 2005.

Electricity Transmission and Distribution. Changes in the calculations of emissions from electricity transmission and distribution resulted in an average annual increase in estimated SF$_6$ emissions from electric power systems of 0.1 to 0.6 million metric tons carbon dioxide equivalent (MMTCO$_2$e) for the 1990-2003 period.[1]

Magnesium Production and Processing. Emissions estimates from the EPA have been revised to reflect more accurate data on emission factors for sand casting activities and updated historical secondary production data from the U.S. Geological Survey (USGS). The changes resulted in a decrease in estimated SF$_6$ emissions

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[1] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-05-003 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

from magnesium production and processing of 0.1 $MMTCO_2e$ (5 percent) for 2002.[2]

Substitution of Ozone-Depleting Substances. The EPA has updated assumptions for its Vintaging Model pertaining to trends in chemical substitutions, market size and growth rates, and amounts used. The changes resulted in an average annual net decrease in estimated HFC and PFC emissions of 2.0 $MMTCO_2e$ (3 percent) for the 1990-2003 period.[3]

Aluminum Production. The EPA has revised smelter-specific emissions factors and aluminum production levels to reflect recently reported data on smelter operating parameters. The changes resulted in an average annual increase of less than 0.5 $MMTCO_2e$ (0.4 percent) for the 1990-2003 period.[4]

Land-Use Issues

This year's report includes separate estimates for carbon stocks in three new land-use categories: land converted to cropland, grassland remaining grassland, and land converted to grassland. In last year's report, carbon stocks in these categories were not reported separately but were included in the category of cropland remaining cropland.

U.S. Emissions in a Global Perspective

This report estimates that U.S. energy-related carbon dioxide emissions in 2003 (including nonfuel uses of fossil fuels) totaled 5,800 million metric tons ($MMTCO_2$). To put U.S. emissions in a global perspective, total energy-related carbon dioxide emissions for the world in 2003 are estimated at 25,033 $MMTCO_2$, making U.S. emissions about 23 percent of the world total (Table 1).[5] Emissions for the mature economies of countries that are members of the Organization for Economic Cooperation and Development (OECD)—including OECD North America, OECD Europe, Japan, and Australia/New Zealand—in 2003 are estimated at 13,155 $MMTCO_2$, or about 53 percent of the world total. The remaining 47 percent of worldwide energy-related carbon dioxide emissions in 2003 (11,878 $MMTCO_2$) is attributed to the transitional and developing economies of countries that are not OECD members. Emissions for the transitional economies of non-OECD Europe and Eurasia (including Russia and the other countries of the former Soviet Union) are estimated at 2,725 $MMTCO_2$.

U.S. energy-related carbon dioxide emissions are projected to increase at an average annual rate of 1.3 percent from 2003 to 2030, while emissions from the non-OECD economies are projected to grow by 3.0 percent per year.[6] As a result, the U.S. share of world carbon dioxide emissions is projected to fall to 19 percent in 2030 (8,115 $MMTCO_2$ out of a global total of 43,676 $MMTCO_2$).

The Greenhouse Effect and Global Climate Change

The Earth is warmed by radiant energy from the Sun. Over time, the amount of energy transmitted to the Earth's surface is equal to the amount of energy re-radiated back into space in the form of infrared radiation, and the temperature of the Earth's surface stays roughly constant; however, the temperature of the Earth is strongly influenced by the existence, density, and composition of its atmosphere. Many gases in the Earth's atmosphere absorb infrared radiation re-radiated from the surface, trapping heat in the lower atmosphere. Without the natural greenhouse effect, it is likely that the average temperature of the Earth's surface would be on the order of -19º Celsius, rather than the +14º Celsius actually observed.[7] The gases that help trap the Sun's heat close to the Earth's surface are referred to as "greenhouse gases." All greenhouse gases absorb infrared radiation (heat) at particular wavelengths.

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[2] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-05-003 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2006.html.

[3] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-05-003 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2006.html.

[4] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-05-003 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2006.html.

[5] Energy Information Administration, *International Energy Outlook 2006*, DOE/EIA-0484(2006) (Washington, DC, June 2006). The historical estimates and projections of U.S. energy-related carbon dioxide emissions have been revised; emissions estimates for the rest of the world have not yet been revised from those published in the *International Energy Outlook 2006*. Emissions of gases other than energy-related carbon dioxide are difficult to estimate for the world's transitional and developing economies; however, emissions related to fossil fuel consumption are likely to make up 80 to 85 percent of total greenhouse gas emissions.

[6] Energy Information Administration, *International Energy Outlook 2006*, DOE/EIA-0484(2006) (Washington, DC, June 2006), Table A10, p. 93.

[7] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), pp. 89-90. See also web site www.ipcc.ch.

The most important greenhouse gases are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and several high-GWP gases, such as HFCs, perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Water vapor is by far the most common, with an atmospheric concentration of nearly 1 percent, compared with less than 0.04 percent for carbon dioxide. The effect of human activity on global water vapor concentrations is considered negligible, however, and anthropogenic (human-made) emissions of water vapor are not factored into national greenhouse gas emission inventories for the purposes of meeting the requirements of the United Nations Framework Convention on Climate Change (UNFCCC) or the Kyoto Protocol.[8] Concentrations of other greenhouse gases, such as methane and nitrous oxide, are a fraction of that for carbon dioxide (Table 2).

Table 1. World Energy-Related Carbon Dioxide Emissions by Region, 1990-2030
(Million Metric Tons Carbon Dioxide)

Region/Country	History[a]			Projections[a]					Average Annual Percent Change, 2003-2030
	1990	2002	2003	2010	2015	2020	2025	2030	
OECD									
OECD North America	**5,759**	**6,691**	**6,801**	**7,505**	**7,997**	**8,513**	**9,096**	**9,735**	**1.3**
United States[b]	4,985	5,752	5,800	6,365	6,718	7,119	7,587	8,115	1.3
Canada	474	570	596	683	753	799	839	873	1.4
Mexico	300	369	405	457	526	595	670	747	2.3
OECD Europe	**4,089**	**4,203**	**4,264**	**4,474**	**4,632**	**4,741**	**4,909**	**5,123**	**0.7**
OECD Asia	**1,536**	**2,063**	**2,090**	**2,269**	**2,390**	**2,455**	**2,540**	**2,638**	**0.9**
Japan	1,011	1,191	1,206	1,200	1,228	1,218	1,214	1,219	0.0
South Korea	234	462	470	608	675	723	781	843	2.2
Australia/New Zealand	291	410	415	462	487	515	545	576	1.2
Total OECD	**11,384**	**12,957**	**13,155**	**14,248**	**15,019**	**15,709**	**16,545**	**17,496**	**1.1**
Non-OECD									
Non-OECD Europe and Eurasia	**4,193**	**2,634**	**2,725**	**3,113**	**3,444**	**3,758**	**4,047**	**4,352**	**1.7**
Russia	2,334	1,546	1,606	1,799	1,949	2,117	2,246	2,374	1.5
Other	1,859	1,088	1,118	1,314	1,495	1,641	1,801	1,978	2.1
Non-OECD Asia	**3,626**	**5,733**	**6,072**	**9,079**	**10,753**	**12,407**	**14,113**	**15,984**	**3.6**
China	2,241	3,273	3,541	5,857	7,000	8,159	9,349	10,716	4.2
India	578	1,011	1,023	1,369	1,592	1,799	2,008	2,205	2.9
Other Non-OECD Asia	807	1,449	1,508	1,853	2,161	2,449	2,756	3,062	2.7
Middle East	**704**	**1,152**	**1,182**	**1,463**	**1,647**	**1,811**	**1,987**	**2,177**	**2.3**
Africa	**649**	**850**	**893**	**1,188**	**1,363**	**1,477**	**1,593**	**1,733**	**2.5**
Central and South America	**673**	**993**	**1,006**	**1,270**	**1,436**	**1,586**	**1,758**	**1,933**	**2.4**
Brazil	220	347	348	423	469	508	559	610	2.1
Other Central/South America	453	645	659	847	967	1,078	1,199	1,323	2.6
Total Non-OECD	**9,846**	**11,362**	**11,878**	**16,113**	**18,643**	**21,039**	**23,500**	**26,180**	**3.0**
Total World	**21,230**	**24,319**	**25,033**	**30,361**	**33,662**	**36,748**	**40,045**	**43,676**	**2.1**

[a] Values adjusted for nonfuel sequestration.

[b] Includes the 50 States and the District of Columbia.

Note: The U.S. numbers include carbon dioxide emissions attributable to renewable energy sources.

Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2003* (May-July 2005), web site www.eia.doe.gov/iea/; and data presented in this report. **Projections:** EIA, *Annual Energy Outlook 2006*, DOE/EIA-0383(2006) (Washington, DC, February, 2006), Table 1, web site www.eia.doe.gov/oiaf/aeo; and *International Energy Outlook 2006*, DOE/EIA-0484(2006) (Washington, DC, June 2006), Table A10.

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[8] The UNFCCC, which “entered into force” in 1994, called on Annex I countries defined in the Convention, including the United States, to return their greenhouse gas emissions to 1990 levels by the year 2000. The Kyoto Protocol, adopted in December 1997, set quantified greenhouse gas emissions targets for Annex I countries for the 2008 to 2012 commitment period that are collectively about 5 percent lower than the 1990 emissions of those countries. The United States, at UNFCCC negotiations in Bonn, Germany, in July 2001, indicated that it considered the Kyoto Protocol to be flawed and stated that it had no plans to ratify the Protocol. The Kyoto Protocol entered into force in February 2005, 3 months after signatory countries accounting for 61 percent of total 1990 Annex I carbon dioxide emissions had ratified the agreement.

Scientists recognized in the early 1960s that concentrations of carbon dioxide in the Earth's atmosphere were increasing every year. Subsequently, they discovered that atmospheric concentrations of methane, nitrous oxide, and many high-GWP greenhouse gas chemicals also were rising. Because current concentrations of greenhouse gases keep the Earth at its present temperature, scientists began to postulate that increasing concentrations of greenhouse gases would make the Earth warmer.

In computer-based simulation models, rising concentrations of greenhouse gases nearly always produce an increase in the average temperature of the Earth. Rising temperatures may, in turn, produce changes in weather and in the level of the oceans that might prove disruptive to current patterns of land use and human settlement, as well as to existing ecosystems. To date, however, it has proven difficult to disentangle the human impact on climate from normal temporal and spatial variations in temperature on both a global scale and geologic timeframe. The most recent report of the Intergovernmental Panel on Climate Change (IPCC), an international assemblage of scientists commissioned by the United Nations to assess the scientific, technical, and socioeconomic information relevant for the understanding of the risk of human-induced climate change, estimates that the global average surface temperature has increased by 0.6 ± 0.2° Celsius since the late 19th century.[9] The IPCC goes on to conclude that: "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."[10]

Greenhouse Gas Sources and Sinks

Most greenhouse gases have both natural and human-made emission sources, and there are significant natural mechanisms (land-based or ocean-based "sinks") for removing them from the atmosphere; however, increased levels of anthropogenic emissions have pushed the total level of greenhouse gas emissions (both natural and anthropogenic) above their natural absorption rates. The positive imbalance between emissions and absorption has resulted in the continuing growth in atmospheric concentrations of these gases. Table 3 illustrates the relationship between anthropogenic and natural emissions and absorption of the principal greenhouse gases on an annual average basis during the 1990s.

Relative Forcing Effects of Various Gases

The ability of a greenhouse gas to affect global temperatures depends not only on its radiative or heat-trapping properties but also on its lifetime or stability in the atmosphere. Because the radiative properties and lifetimes of greenhouse gases vary greatly, comparable increases in the concentrations of different greenhouse gases can have vastly different heat-trapping effects. The cumulative effect (radiative forcing—measured in watts per square meter) can vary substantially from the marginal impact of a gas. For example, among the "Kyoto gases," carbon dioxide is the most prominent in terms of emissions, atmospheric concentration, and radiative forcing (1.46 watts per square meter), but it is among the least effective as a greenhouse gas in terms of the marginal

Table 2. Global Atmospheric Concentrations of Selected Greenhouse Gases

Item	Carbon Dioxide	Methane	Nitrous Oxide	Sulfur Hexafluoride	Perfluoro-methane
	(parts per million)			(parts per trillion)	
Pre-industrial (1750) Atmospheric Concentration	278	0.700	0.270	0	40
1998 Atmospheric Concentration	365	1.745	0.314	4.2	80
Average Annual Change, 1990-1999	1.5[a]	0.007[a]	0.0008	0.2	1.0
Atmospheric Lifetime (Years)	50–200[b]	12[c]	114[c]	3,200	>50,000

[a] The rate has fluctuated between 0.9 and 2.8 parts per million per year for CO_2 and between 0 and 0.013 parts per million per year for methane over the 1990-1999 period.

[b] No single lifetime can be defined for CO_2 because uptake rates differ for different removal processes.

[c] This lifetime has been defined as an "adjustment time" that takes into account the indirect effect of the gas on its own residence time.

Source: Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), pp. 38 and 244.

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[9] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 26.

[10] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 10.

impact of each additional gram of gas added to the atmosphere. Other compounds, on a gram-per-gram basis, appear to have much greater marginal effects.

There has been extensive study of the relative effectiveness of various greenhouse gases in trapping the Earth's heat. Such research has led to the development of the concept of a "global warming potential," or GWP. The GWP is intended to illustrate the relative impacts on global warming of an additional unit of a given gas relative to carbon dioxide over a specific time horizon. The IPCC has conducted an extensive research program aimed at summarizing the effects of various greenhouse gases through a set of GWPs. The results of that work were originally released in 1995 in an IPCC report, *Climate Change 1994*,[11] and subsequently updated in *Climate Change 1995*[12] and *Climate Change 2001*.[13]

The calculation of a GWP is based on the radiative efficiency (heat-absorbing ability) of the gas relative to the radiative efficiency of the reference gas (carbon dioxide), as well as the removal process (or decay rate) for the gas relative to the reference gas over a specified time horizon. Table 4 summarizes the consensus results of the most recent studies by scientists working on behalf of the IPCC, showing estimates of atmospheric lifetimes and global warming potentials across various time scales. For the purposes of calculating "CO_2 equivalent" units for this report, 100-year GWPs are used.

Current U.S. Climate Change Initiatives

Federal Initiatives

The Bush Administration is pursuing a broad range of strategies to address the issues of global climate change through the implementation of multiple new initiatives. Details of these initiatives were initially provided on February 14, 2002, when the President announced the Global Climate Change Initiative. This initiative sets a national goal for the United States to reduce its greenhouse gas intensity (total greenhouse gas emissions per unit of gross domestic product [GDP]) by 18 percent between 2002 and 2012 through voluntary measures.

To meet this goal and encourage the development of strategies and technologies that can be used to limit greenhouse gas emissions both at home and abroad, the

Table 3. Global Natural and Anthropogenic Sources and Absorption of Greenhouse Gases in the 1990s

Gas	Sources			Absorption	Annual Increase in Gas in the Atmosphere
	Natural	Human-Made	Total		
Carbon Dioxide (Million Metric Tons of Gas)[a]	770,000	23,100	793,100	781,400	11,700
Methane (Million Metric Tons of Gas)[b]	239	359	598	576	22
Nitrous Oxide (Million Metric Tons of Gas)[c]	9.5	6.9	16.4	12.6	3.8

[a] Carbon dioxide natural source and absorption of 770,000 million metric tons carbon dioxide, based on balanced flux of 40,000 million metric tons between land and atmosphere and 330,000 million metric tons between oceans and atmosphere, from Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), Figure 3.1, p. 188. Human-made emissions of 23,100 million metric tons and distribution of those emissions (atmospheric absorption 11,700 million metric tons, ocean absorption 6,200 million metric tons, and land absorption 5,100 million metric tons), taken from Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 39.

[b] Methane total sources, absorption, and annual atmospheric increases from Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), Table 4.2, p. 250. Distinction between natural and human-made sources based on the assumption that 60 percent of total sources are anthropogenic, from Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 248.

[c] Nitrous oxide total and human-made sources, absorption, and atmospheric increases from Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), Table 4.4, p. 252. Nitrous oxide natural sources (9.5 million metric tons of gas) derived by subtracting human-made sources from total sources.

Source: Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

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[11] Intergovernmental Panel on Climate Change, *Climate Change 1994: Radiative Forcing of Climate Change* (Cambridge, UK: Cambridge University Press, 1995).

[12] Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change* (Cambridge, UK: Cambridge University Press, 1996).

[13] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

Administration has implemented a number of related initiatives, including the following:[14]

- **Climate Change Technology Program (CCTP):** The CCTP is a multi-agency program to accelerate the development and deployment of key technologies that can achieve substantial reductions in greenhouse gas emissions. The program's most recent Strategic Plan was released in September 2006.[15] The CCTP coordinates and prioritizes the Federal Government's portfolio of investments in climate-related technology research, development, demonstration, and deployment (RDD&D), which totals about $3 billion for 2006. It also takes a century-long look at the nature of the climate change challenge and the potential for technological solutions across a range of uncertainties. The technologies outlined in the 2006 Strategic Plan include hydrogen, biorefining, clean coal, carbon sequestration, and nuclear fission and fusion, among others.

- **Climate Change Science Program (CCSP):** The CCSP was launched in February 2002 as a collaborative interagency program under a new cabinet-level organization designed to improve the government-wide management of climate science and climate-related technology development. The core mission of the CCSP is to apply the best possible scientific knowledge to help manage climate variability and global climate change. The CCSP incorporates and integrates the U.S. Global Change Research Program (USGCRP) with the Administration's U.S. Climate Change Research Initiative (CCRI).

The USGCRP was established by the Global Change Research Act of 1990 to enhance understanding of natural and human-induced changes in the Earth's global environmental system; to monitor, understand, and predict global change; and to provide a sound scientific basis for national and international decisionmaking. The CCRI builds on the USGCRP, with a focus on accelerating progress over a 5-year period on the most important issues and uncertainties in climate science, enhancing climate observation systems, and improving the integration of scientific knowledge into policy and management decisions and evaluation of management strategies and choices. The CCSP Strategic Plan calls for a series of more than 20 synthesis and assessment reports. The most recent, Synthesis Product 2.2, was released on September 19, 2006, for public review and comment and is scheduled for completion in the first quarter of 2007.[16]

Table 4. Numerical Estimates of Global Warming Potentials Compared With Carbon Dioxide
(Kilogram of Gas per Kilogram of Carbon Dioxide)

Gas	Lifetime (Years)	Direct Effect for Time Horizons of		
		20 Years	100 Years	500 Years
Carbon Dioxide	5 – 200[a]	1	1	1
Methane	12	62	23	7
Nitrous Oxide	114	275	296	156
HFCs, PFCs, and Sulfur Hexafluoride				
HFC-23	260	9,400	12,000	10,000
HFC-125	29	5,900	3,400	1,100
HFC-134a	13.8	3,300	1,300	400
HFC-152a	1.4	410	120	37
HFC-227ea	33	5,600	3,500	1,100
Perfluoromethane (CF_4)	50,000	3,900	5,700	8,900
Perfluoroethane (C_2F_6)	10,000	8,000	11,900	18,000
Sulfur Hexafluoride (SF_6)	3,200	15,100	22,200	32,400

[a]No single lifetime can be defined for carbon dioxide due to different rates of uptake by different removal processes.

Note: The typical uncertainty for global warming potentials is estimated by the Intergovernmental Panel on Climate Change at ±35 percent.

Source: Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), pp. 38 and 388-389.

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[14] See "White House Reviews Action on Global Climate Change," Office of the Press Secretary, The White House, updated by the Council on Environmental Quality (September 22, 2004), web site www.whitehouse.gov/ceq/global-change.html#5.

[15] U.S. Climate Change Technology Program, *U.S. Climate Change Technology Program Strategic Plan, 2006* (Washington, DC, September 20, 2006), web site www.climatetechnology.gov.

[16] U.S. Climate Change Science Program, *The First State of the Carbon Cycle Report (SOCCR): North American Carbon Budget and Implications for the Global Carbon Cycle*, Draft for Public Review (September 2006), web site www.climatescience.gov/Library/sap/sap2-2/default.htm.

- **International Cooperation:** The United States is engaged in international efforts on climate change, both through multilateral and bilateral activities. Multilaterally, the United States is the largest donor to activities under the UNFCCC and the IPCC. Since 2001, the United States has launched bilateral partnerships with numerous countries on issues ranging from climate change science, to energy and sequestration technologies, to policy approaches.
    - **Asia-Pacific Partnership on Clean Development and Climate:** In June 2005, the United States launched a new international effort, the Asia-Pacific Partnership on Clean Development and Climate, which involves the United States, Australia, China, India, Japan, and South Korea. The partnership will collaborate to promote the development, diffusion, deployment, and transfer of existing and emerging cost-effective, cleaner technologies and practices. Areas for collaboration may include energy efficiency, clean coal, integrated gasification combined cycle, liquefied natural gas, carbon capture and storage, combined heat and power, methane capture and use, civilian nuclear power, geothermal power, rural/village energy systems, advanced transportation, building and home construction and operation, bioenergy, agriculture and forestry, hydropower, wind power, solar power, and other renewables.[17]
    - **Methane to Markets Partnership:** In July 2004, the United States announced the Methane to Markets Partnership. The partnership is an international initiative that advances cost-effective, near-term methane recovery and use as a clean energy source. Its goal is to reduce global methane emissions in order to enhance economic growth, strengthen energy security, improve air quality, improve industrial safety, and reduce emissions of greenhouse gases. Participating countries include Argentina, Australia, Brazil, Canada, China, Colombia, Ecuador, Germany, India, Italy, Japan, Mexico, Nigeria, Republic of Korea, Russia, Ukraine, United Kingdom, and the United States. The United States will commit up to $53 million to the partnership through 2009 for work with the private sector on sharing and expanding the use of profitable technologies to capture methane emissions that are now wasted in the course of industrial processes and use them as a new energy source.[18]
- **Near-Term Greenhouse Gas Reduction Initiatives:** The Federal Government administers a wide array of voluntary, regulatory, and incentive-based programs on energy efficiency, agricultural practices, and greenhouse gas reductions. Major initiatives announced by the Bush Administration include:
    - **Climate VISION Partnership:** In February 2003, President Bush announced that 12 major industrial sectors and the membership of the Business Roundtable had committed to work with the EPA and three Federal departments (Energy, Transportation, and Agriculture) to reduce greenhouse gas emissions in the next decade. Participating industries include electric utilities; petroleum refiners and natural gas producers; automobile, iron and steel, chemical, and magnesium manufacturers; forest and paper producers; railroads; and the cement, mining, aluminum, lime, and semiconductor industries. In May 2005, the Industrial Minerals Association–North America joined the list of participating industries.

      On February 14, 2006, the Climate VISION partners held a workshop to hear from industry sectors on activities they have undertaken to reduce energy usage and greenhouse gas emissions intensity. The purpose of the workshop was to provide an opportunity for current and prospective industry partners to share experiences and lessons learned through case studies and to explore new opportunities for collaboration.[19]
    - **Climate Leaders:** Climate Leaders, established by the EPA in February 2002, is a voluntary partnership that encourages companies to establish and meet clearly defined targets for greenhouse gas emission reductions. Climate Leaders Partners represent a variety of sectors, from heavy manufacturing to banking and retail. As of October 2006, the program had 103 Partners, 59 of which had publicly announced greenhouse gas emission reduction goals. The rest were in the process of completing emissions inventories before setting their reduction goals. (In January 2006, the EPA announced that 5 Partners had achieved their initial reduction goals.) The EPA estimates that emissions reductions by Climate Leaders Partners will prevent emissions equivalent to more than 9 million metric tons of carbon per year—enough to offset annual emissions from more than 6 million cars.[20]

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[17] U.S. Department of State, *Vision Statement of Australia, China, India, Japan, the Republic of Korea, and the U.S. for a New Asia-Pacific Partnership on Clean Development and Climate* (Washington, DC, July 28, 2005), web site www.state.gov/g/oes/rls/fs/50335.htm.

[18] U.S. Environmental Protection Agency, “Methane to Markets,” web site www.methanetomarkets.org.

[19] Climate Vision, “Climate VISION Partners Highlight Success Stories,” web site www.climatevision.gov/events_climate.html.

[20] U.S. Environmental Protection Agency, “Climate Leaders Fact Sheet” (Washington, DC, September 2006), web site www.epa.gov/climateleaders/docs/partnership_fact_sheet.doc.

Trends in U.S. Carbon Intensity and Total Greenhouse Gas Intensity

From 2004 to 2005, the greenhouse gas intensity of the U.S. economy fell from 664 to 647 metric tons per million 2000 dollars of GDP (2.5 percent), continuing a trend of decreases in both carbon intensity (see figure at right) and total greenhouse gas intensity. As shown in the table below, declines in carbon intensity by decade have ranged from a low of 3.3 percent in the 1960s to 25.6 percent in the 1980s. From 1990 to 2005, total U.S. greenhouse gas intensity fell by 24.7 percent, at an average rate of 1.9 percent per year.

Historical Growth Rates for U.S. Carbon Intensity

	Overall Change in Intensity (Percent)		Average Annual Change in Intensity (Percent)	
Decade	Carbon Dioxide	Total GHG	Carbon Dioxide	Total GHG
History				
1950-1960	-12.9	—	-1.4	—
1960-1970	-3.3	—	-0.3	—
1970-1980	-17.8	—	-1.9	—
1980-1990	-25.6	—	-2.7	—
1990-2000	-15.0	-17.7	-1.6	-1.9

Source: Energy Information Administration, *Annual Energy Review 2005*, DOE/EIA-0384(2005) (Washington, DC, August 2006), and estimates presented in historical carbon dioxide emissions data series.

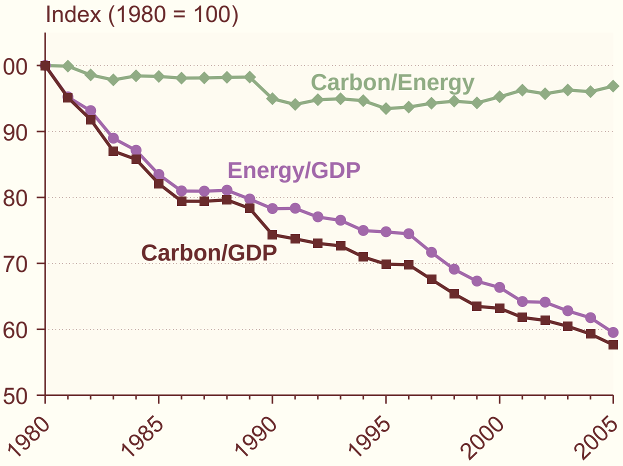
The carbon intensity and greenhouse gas intensity of the U.S. economy move in lockstep, because carbon dioxide emissions make up most of the total for U.S. greenhouse gas emissions. Energy-related carbon dioxide emissions represent approximately 80 percent of total U.S. greenhouse gas emissions. As such, trends in energy-related carbon dioxide emissions have a significant impact on trends in total greenhouse gas emissions. Historical trends in U.S. carbon intensity (energy-related carbon dioxide emissions per unit of economic output) are described below.

The carbon intensity of the economy can largely be decomposed into two basic elements: (1) energy intensity, defined as the amount of energy consumed per dollar of economic activity; and (2) carbon intensity of energy supply, defined as the amount of carbon emitted per unit of energy. As illustrated by the formulas below, the multiplication of the two elements produces a numerical value for U.S. carbon intensity, defined as the amount of carbon dioxide emitted per dollar of economic activity:

Energy Intensity x *Carbon Intensity of Energy Supply =*
Carbon Intensity of the Economy ,

or, algebraically,

Intensity Ratios: Carbon/GDP, Carbon/Energy, and Energy/GDP



Source: Historical carbon dioxide emissions data series.

(Energy/GDP) x *(Carbon Emissions/Energy) =*
(Carbon Emissions/GDP) .

Components of Energy Intensity. Since World War II the U.S. economy has been moving away from traditional "smokestack" industries toward more service-based or information-based enterprises. This has meant that over the second half of the 20th century economic growth was less tied to growth in energy demand than it was during the period of industrialization in the 19th and early 20th century. Other factors contributing to decreases in energy intensity include:

- Improvements in the energy efficiency of industrial equipment as new materials and methods improved performance in terms of energy inputs versus outputs
- Increased efficiency of transportation equipment as lighter materials and more efficient engines entered the marketplace
- Improvements in commercial and residential lighting, refrigeration, and heating and cooling equipment
- Developments in new electricity generating technologies, such as combined-cycle turbines.

Further reductions in energy intensity, which are projected to continue, will among other things promote deeper reductions in U.S. carbon intensity.

Components of the Carbon Intensity of Energy Supply. Changes in the carbon intensity of energy supply have been less dramatic than changes in energy

(continued on page 9)

Trends in U.S. Carbon Intensity and Total Greenhouse Gas Intensity (Continued)

intensity. There was a slow but steady decline from 1980 until about the mid-1990s, after which it has remained relatively unchanged. The primary reason for the decline has been the development of nuclear power, which is carbon-free and therefore weights the fuel mix toward lower carbon intensity. Other factors that can decrease the carbon intensity of the energy supply include:

- Development of new renewable resources, such as wind power, for electricity generation
- Substitution of natural gas for coal and oil in power generation
- Transportation fuels with a higher biogenic component, such as ethanol.

- **Voluntary Reporting of Greenhouse Gases Program:** As part of the Climate Change Initiative, announced by President Bush on February 14, 2002, the U.S. Department of Energy (DOE) has developed new reporting guidelines to improve and expand the Voluntary Reporting of Greenhouse Gases Program administered by EIA. The current program has in excess of 200 participating companies, whose emissions represent approximately 13 percent of total U.S. greenhouse gas emissions.[21] The primary goal of the DOE effort is to create a credible and transparent program for the reporting of real reductions that support the national greenhouse gas intensity goal laid out in the President's Global Climate Change Initiative.

  On April 21, 2006,[22] DOE issued final General and Technical Guidelines for the revised Voluntary Reporting of Greenhouse Gases Program, which became effective on June 1, 2006. EIA is currently in the process of developing new reporting forms and instructions, with the goal of finalizing the forms by end of calendar year 2006.[23] New electronic reporting software is also in development, and the new program is intended to be operational in mid-2007.

California State Initiative

California Assembly Bill 32, "California Global Warming Solutions Act of 2006," which was signed into law by Governor Arnold Schwarzenegger on September 27, 2006,[24] calls for a 25-percent reduction in the State's carbon dioxide emissions by 2020. The first major controls, for the industrial sector, are scheduled to take effect in 2012. The plan grants the California Air Resources Board lead authority for establishing how much industry groups contribute to global warming pollution, assigning emission targets, and setting noncompliance penalties. It sets a 2009 date for establishing how the system will work and then allows 3 years for the State's industries to prepare for the 2012 startup of mandatory emissions reductions.[25]

International Developments in Global Climate Change

The primary international agreement addressing climate change is the UNFCCC, which opened for signature at the "Earth Summit" in Rio de Janeiro, Brazil, in June 1992 and entered into force in March 1994.[26] The agreement currently has 185 signatories, including the United States. The objective of the Framework Convention is stated as follows:

> *The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.*[27]

The Framework Convention divided its signatories into three groups: the countries listed in Annex I; Annex II,

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[21] Energy Information Administration, "Voluntary Reporting of Greenhouse Gases Program" (September 2006), web site www.eia.doe.gov/oiaf/1605/frntvrgg.html.

[22] U.S. Department of Energy, "Guidelines for Voluntary Greenhouse Gas Reporting: Final Rule," *Federal Register*, Vol. 77, p. 20784 (April 21, 2006), web site www.pi.energy.gov/pdf/library/April21FRwithFinalGG.pdf.

[23] Energy Information Administration, "Revised Reporting Form and Instructions" (September 2006), web site www.eia.doe.gov/oiaf/1605/Forms.html.

[24] M. Finnegan and M. Lifsher, "State's Greenhouse Gas Bill Signed," *Los Angeles Times* (September 27, 2006).

[25] F. Barringer, "Officials Reach California Deal To Cut Emissions," *New York Times* (August 31, 2006).

[26] The Framework Convention was "adopted" by a vote of the conference of the parties on May 9th, while the signatures and ratifications of member states flowed in over a period of years. The treaty "entered into force" in 1994. For a discussion of the development of the Convention, see D. Bodanzky, "Prologue to the Climate Convention," in I. Mintzer and J.A. Leonard (eds.), *Negotiating Climate Change: The Inside Story of the Rio Convention* (Cambridge, UK: Cambridge University Press, 1994), pp. 49-66.

[27] The official text of the Framework Convention can be found at web site http://unfccc.int/essential_background/convention/background/items/2853.php.

which comprises the Annex I countries minus the countries with economies in transition; and non-Annex I countries, which include countries that ratified or acceded to the UNFCCC but are not included in Annex I. The Annex I countries include the 24 original members of the OECD (including the United States), the European Union, and 14 countries with economies in transition (Russia, Ukraine, and Eastern Europe).[28]

The Convention requires all parties to undertake "policies and measures" to limit emissions of greenhouse gases, and to provide national inventories of emissions of greenhouse gases (Article 4.1a and b). Annex I parties are further required to take actions "with the aim of returning . . . to their 1990 levels these anthropogenic emissions of carbon dioxide and other greenhouse gases" (Article 4.2a and b). The signatories subsequently agreed that Annex I parties should provide annual inventories of greenhouse gas emissions.

The Kyoto Protocol

The Kyoto Protocol to the UNFCCC, negotiated in December 1997, is a set of quantified greenhouse gas emissions targets for Annex I countries, which collectively are about 5 percent lower than the 1990 emissions of those countries taken as a group.[29] Developing country signatories do not have quantified targets.[30] The conditions for ratification of the Kyoto Protocol were met in November 2004, following formal acceptance by the Russian Parliament and President Putin's signing of the ratifying legislation. Those actions brought the number of ratifying countries to 118, with Annex I countries representing 61.2 percent of total Annex I carbon dioxide emissions in 1990. As of September 28, 2006, 166 states or "regional economic integrating organizations" had ratified the Protocol, which entered into force in February 2005. While the United States is a party to the Framework Convention, it is not a party to the Kyoto Protocol.

Recent and Upcoming Conferences of the Parties and Other International Events

Since the negotiation of the Kyoto Protocol in 1997, much of the work done at periodic (usually annual) meetings of the UNFCCC Conference of the Parties (COP) has been focused on filling in details related to the operation of the UNFCCC, the Protocol, and their respective mechanisms.

COP-11 and MOP-1

Canada hosted the first Meeting of the Parties to the Kyoto Protocol (MOP-1) in conjunction with the eleventh meeting of the Conference of Parties to the Framework Convention (COP-11). The meetings were held in Montreal, Canada, from November 28 to December 9, 2005.[31] Two key outcomes emerged from the meetings. In MOP-1, the parties finalized the Kyoto Protocol "rulebook," strengthened the Protocol's Clean Development Mechanism (CDM), and agreed to begin negotiations on binding requirements for developing countries. In COP-11, agreement was reached on opening a non-binding dialogue on long-term cooperation among the parties to meet the goals of the UNFCCC.[32]

COP-12 and MOP-2

Kenya will host the second Meeting of the Parties to the Kyoto Protocol (COP/MOP-2), in conjunction with the twelfth session of the Conference of the Parties to the Climate Change Convention (COP-12) in Nairobi, Kenya, from November 6 to November 17, 2006.

G8 Summit in St. Petersburg, Russia

In a communiqué on global energy security,[33] the leaders of the G8 nations[34] meeting in St. Petersburg, Russia, July 16-19, 2006, summarized their position on climate change and sustainable development, including the following:

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[28] The Annex I nations include Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom, and the United States of America. Turkey has not ratified the Framework Convention. Turkey will be placed in a different situation from that of other Annex I parties when it becomes a Party to the Convention. Kazakhstan has announced its intention to be bound by Annex I commitments, but is not formally classified as an Annex I party. Kazakhstan was, however, considered an Annex I party when the Kyoto Protocol entered into force in February 2005. Turkey acceded to the Convention in May 2004.

[29] The text of the Kyoto Protocol can also be found at web site www.unfccc.de/index.html.

[30] For details on the Kyoto Protocol, see archived editions of this report, web site www.eia.doe.gov/oiaf/1605/1605aold.html.

[31] Earlier COP sessions are described in previous editions of this report. See web site www.eia.doe.gov/oiaf/1605/1605aold.html.

[32] Pew Center on Global Climate Change, "COP 11 and COP/MOP 1 Montreal," web site www.pewclimate.org/what_s_being_done/in_the_world/cop11.

[33] Official Website of the G8 Presidency of the Russian Federation in 2006, "Global Energy Security" (July 16, 2006), web site http://en.g8russia.ru/docs/11.html.

[34] The G8 nations include the Russian Federation, France, United States, United Kingdom, Japan, Germany, Canada, and Italy.

- "We reaffirm our intention to deliver on commitments made in Gleneagles[35] in order to meet our shared and multiple objectives of reducing greenhouse gas emissions . . . ."
- "We also affirm our commitment to the UNFCCC's ultimate objective of stabilizing greenhouse gas concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system."
- "Those of us committed to making the Kyoto Protocol a success underline the importance we attach to it, view Clean Development Mechanism and the Joint Implementation Mechanism as central elements of this, and look forward to the process to develop it further."
- "We welcome the progress made at the XI Conference of the Parties to the UNFCCC (Montreal, December 2005) where we committed to engage in a dialogue on long-term cooperative action to address climate change by enhancing implementation of the convention . . . ."
- "We reaffirm the importance of the work of the Intergovernmental Panel on Climate Change (IPCC) and look forward to its 2007 report."
- "We welcome the progress made by the World Bank and the IEA on developing a framework for clean energy and sustainable development and on identifying alternative energy scenarios and strategies to support and implement elements of the Gleneagles Plan of Action."
- "We welcome the progress made at the first meeting of the Gleneagles Dialogue on Climate Change, Clean Energy and Sustainable Development, held on 1 November last year. We look forward to the next Ministerial meeting in Mexico in October 2006, where we will continue to identify opportunities for greater collaboration to tackle climate change . . . ."

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[35] The Gleneagles Dialogue on Climate Change was announced at G8 Meetings held in Gleneagles, Scotland, in July 2005. For details, see Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005), web site www.eia.doe.gov/oiaf/1605/1605aold.html.

2. Carbon Dioxide Emissions

Overview

U.S. Anthropogenic Carbon Dioxide Emissions, 1990-2005

	Carbon Dioxide	Carbon Equivalent
Estimated 2005 Emissions (Million Metric Tons)	6,008.6	1,638.7
Change Compared to 2004 (Million Metric Tons)	19.9	5.4
Change from 2004 *(Percent)*	*0.3%*	*0.3%*
Change Compared to 1990 (Million Metric Tons)	1,018.0	277.6
Change from 1990 *(Percent)*	*20.4%*	*20.4%*
Average Annual Increase, 1990-2005 *(Percent)*	*1.2%*	*1.2%*

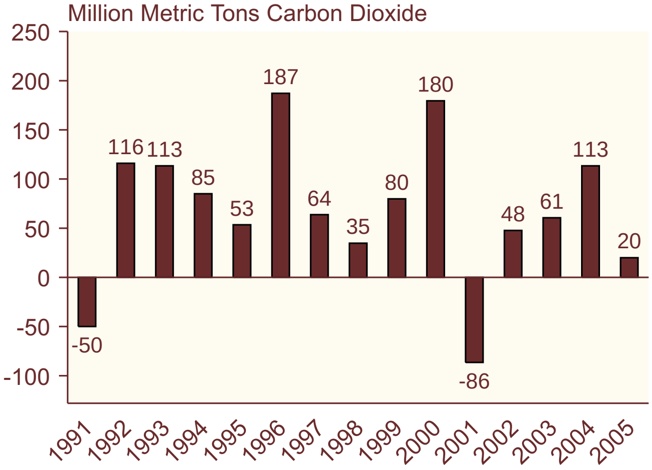
Carbon dioxide emissions in the United States and its Territories were 6,008.6 million metric tons (MMT) in 2005, 19.9 MMT (0.3 percent) more than in 2004 (Table 5). The slow growth in emissions from 2004 to 2005 can be attributed mainly to higher energy prices that suppressed demand, low or negative growth in several energy-intensive industries, and weather-related disruptions in the energy infrastructure along the Gulf Coast. As a result, while the economy grew by 3.2 percent, energy consumption fell by 0.3 percent. The 0.3-percent growth in total U.S. carbon dioxide emissions from 2004 to 2005 followed an increase of 1.9 percent, or 113.4 MMT, from 2003 to 2004 (Figure 1). Since 1990, total U.S. carbon dioxide emissions have increased by an average of about 1.2 percent per year.

Carbon dioxide emissions represent about 84 percent of total U.S. greenhouse gas emissions. In the United States, most carbon dioxide (98 percent) is emitted as a result of the combustion of fossil fuels; consequently, carbon dioxide emissions and energy use are highly correlated. (The remaining 2 percent of carbon dioxide emissions comes from a variety of other industrial sources.) Historically, economic growth, the weather, the carbon and energy intensity of the economy, and movements in energy prices have caused year-to-year fluctuations in energy consumption and resulting carbon dioxide emissions.

In both the residential and commercial sectors, 2005 energy-related carbon dioxide emissions were higher than 2004 levels (Table 6). In the residential sector, emissions of carbon dioxide increased by 3.3 percent, from 1,213.9 MMT in 2004 to 1,253.8 MMT in 2005. In the commercial sector, carbon dioxide emissions increased by 1.6 percent, from 1,034.1 MMT in 2004 to 1,050.6 MMT in 2005. There was little change in heating degree-days from 2004 to 2005, but cooling degree-days increased by 13.5 percent. Thus, higher demand for electricity—especially for air conditioning—was largely responsible for the increase in emissions from both sectors.

Industrial production rose by 3.2 percent in 2005, but industrial emissions of carbon dioxide declined by 3.1 percent, from 1,736.0 MMT in 2004 to 1,682.3 MMT in 2005 (Table 6). Trends in industrial emissions are driven in part by growth patterns in the six most energy-intensive manufacturing industries, which account for about two-thirds of total industrial emissions of carbon dioxide. Paper manufacturing, at 5.6 percent, was the only one of the six that grew at a rate greater than the overall gross domestic product (GDP) growth rate of 3.2 percent. (The paper industry is energy-intensive but uses a high proportion of biogenic material and, therefore, has the lowest carbon intensity among the six energy-intensive industries.) Two others grew by less

Figure 1. Annual Change in U.S. Carbon Dioxide Emissions, 1990-2005



Source: Estimates presented in this chapter.

than overall GDP (food by 2.3 percent and nonmetallic minerals by 1.6 percent), and for three output fell (primary metals by 2.7 percent, chemicals by 6.9 percent, and petroleum by 7.5 percent).

Estimates for 2005 indicate that carbon dioxide emissions in the transportation sector increased by 1.0 percent, from 1,939.2 MMT in 2004 to 1,958.6 MMT in 2005 (Table 6)—less than the 1.5-percent average annual growth in transportation emissions since 1990.

While net generation of electricity increased by 2.0 percent from 2004 to 2005, carbon dioxide emissions from the electric power sector increased by 2.8 percent, from 2,309.4 MMT in 2004 to 2,375.0 MMT in 2005 (Table 6). Accordingly, the overall carbon intensity of U.S. electricity production increased by about 0.9 percent. The higher carbon intensity resulted from an increase in the use of fossil fuels to generate electricity. In addition, generation from "non-carbon" nuclear and renewable fuels fell by 10.6 billion kilowatthours (1.0 percent).[36]

In this report, the electric power sector is defined as all utilities, nonutilities, and combined heat and power (CHP) facilities whose primary business is the production of electric power. Carbon dioxide emissions from generators that produce electric power as part of an industrial or commercial operation—that is, businesses that produce electricity primarily for their own use—are not included in the electric power sector total but are assigned to the industrial or commercial sector according to the classification of the business. In addition, the emissions totals reported above for the energy end-use sectors (residential, commercial, industrial, and transportation) include their shares of total electric power sector emissions.

Nonfuel uses of fossil fuels, principally petroleum, both emit and sequester carbon dioxide over their life cycles. In 2005, carbon dioxide emissions from nonfuel uses of fossil fuels totaled 106.4 MMT, a 4.7-percent decrease from the 2004 total of 111.7 MMT (Table 5). Nonfuel uses of fossil fuels also resulted in carbon sequestration equal to 300.9 million metric tons carbon dioxide equivalent ($MMTCO_2e$) in 2005, a 3.3-percent decrease from the 2004 level of 311.1 $MMTCO_2e$.[37] The major fossil fuel products that emit and sequester carbon include liquefied petroleum gas (LPG) and feedstocks for plastics and other petrochemicals. Asphalt and road oils are a major source of sequestration, but they do not emit carbon dioxide. It is estimated that, of the amount of carbon dioxide sequestered in the form of plastic, about 11.1 MMT was emitted as carbon dioxide from the burning of the plastic components of municipal solid waste to produce electricity in 2005.

Emissions of carbon dioxide from other sources—including cement production, industrial processes, waste combustion, carbon dioxide in natural gas, and gas flaring—decreased by 0.2 percent, from 105.7 MMT in 2004 to 105.4 MMT in 2005 (Table 5).

Energy Consumption

Energy End-Use Sector Sources of U.S. Carbon Dioxide Emissions, 1990-2005

Sector	Million Metric Tons Carbon Dioxide 1990	 2005	*Percent Change* 1990-2005	 2004-2005
Residential	953.7	1,253.8	*31.5%*	*3.3%*
Commercial	780.7	1,050.6	*34.6%*	*1.6%*
Industrial	1,683.6	1,682.3	*-0.1%*	*-3.1%*
Transportation	1,566.8	1,958.6	*25.0%*	*1.0%*

Note: Electric power sector emissions are distributed across sectors.

The consumption of energy in the form of fossil fuel combustion is the largest single contributor to greenhouse gas emissions in the United States and the world. Of total 2005 U.S. carbon dioxide emissions (adjusting for U.S. Territories and bunker fuels), about 98 percent, or 5,903.2 MMT carbon dioxide, resulted from the combustion of fossil fuels. This figure represents an increase of 20.2 MMT from 2004 levels.

In the short term, year-to-year changes in energy consumption and carbon dioxide emissions tend to be dominated by weather, economic fluctuations, and movements in energy prices. Over longer time spans, changes in energy consumption and emissions are also influenced by other factors, such as population shifts and energy consumers' choice of fuels, appliances, and capital equipment (e.g., vehicles, aircraft, and industrial plant and equipment). The energy-consuming capital stock of the United States—cars and trucks, airplanes, heating and cooling plants in homes and businesses, steel mills, aluminum smelters, cement plants, and petroleum refineries—changes slowly from one year to

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[36] Included as non-carbon renewable fuels are hydropower, wood, solar, and wind. Both geothermal power and waste combustion produce some carbon dioxide emissions. Wood-fired generation is considered carbon-neutral so long as it does not lead to deforestation.

[37] Unlike emissions of carbon that occur in the form of carbon dioxide, carbon is sequestered in combination with other chemicals. Therefore, carbon sequestration is estimated in carbon dioxide equivalent units, rather than simply as carbon dioxide.

the next, because capital stock usually is retired only when it begins to break down or becomes obsolete.

The Energy Information Administration (EIA) divides energy consumption into four general end-use categories: residential, commercial, industrial, and transportation. Emissions from electricity generators, which provide electricity to the end-use sectors, are allocated in proportion to the electricity consumed in, and losses allocated to, each sector (Table 6).

Residential Sector

At 1,253.8 MMT, residential carbon dioxide emissions represented 21 percent of U.S. energy-related carbon dioxide emissions in 2005. The residential sector's pro-rated share of electric power sector emissions, 885.7 MMT, accounts for 71 percent of all emissions in the residential sector (Table 7).[38] Natural gas accounted for 21 percent (261.7 MMT), and petroleum (mainly distillate fuel oil) represented 8.4 percent (105.3 MMT). Since 1990, residential electricity-related emissions have grown by 2.5 percent annually. Emissions from the direct combustion of fuels, primarily natural gas, in the residential sector have grown by 0.5 percent annually since 1990.

Total carbon dioxide emissions from the residential sector increased by 3.3 percent in 2005. Year-to-year, residential sector emissions are strongly influenced by weather. While heating degree-days were about the same in 2004 and 2005, a warmer summer in 2005 meant that cooling degree-days were up by 13.5 percent,[39] and the resulting increase in demand for air conditioning contributed to the growth in residential carbon dioxide emissions.

Since 1990, the growth in carbon dioxide emissions attributable to the residential sector has averaged 1.8 percent per year. Residential sector emissions in 2005 were 300.1 MMT higher than in 1990, representing 31 percent of the total increase in unadjusted U.S. energy-related carbon dioxide emissions since 1990. Long-term trends in residential carbon dioxide emissions are strongly influenced by demographic factors, living space attributes, and building shell and appliance efficiency choices. For example, the movement of population into warmer climates tends to increase summer air conditioning consumption and promote the use of electric heat pumps, which increases emissions from electricity use (although the increase could be offset by a reduction in emissions from heating fuel combustion). Growth in the number of households, resulting from increasing population and immigration, also contributes to more residential energy consumption.

Commercial Sector

Commercial sector carbon dioxide emissions, at 1,050.6 MMT, accounted for about 18 percent of total energy-related carbon dioxide emissions in 2005, of which 78 percent (821.1 MMT) is the sector's pro-rated share of electricity-related emissions (Table 8). Natural gas contributes 16 percent and petroleum 5 percent of the sector's emissions.

Commercial sector emissions largely have their origin in the lighting, space heating, and space cooling requirements of commercial structures, such as office buildings, shopping malls, schools, hospitals, and restaurants. Lighting is a significantly more important component of energy demand in the commercial sector (approximately 20 percent of total demand in 2004) than it is in the residential sector (approximately 12 percent of total demand in 2004). Heating and cooling demand accounted for approximately 40 percent of energy demand in the residential sector in 2004, and about 18 percent in the commercial sector.[40] Thus, commercial sector emissions are affected less by the weather than are residential sector emissions. In the longer run, because commercial activity is a factor of the larger economy, emissions from the commercial sector are more affected by economic trends and less affected by population growth than are emissions from the residential sector.

Emissions attributable to the commercial sector's pro-rated share of electricity consumption increased by 2.6 percent in 2005, and emissions from the direct combustion of fuels (dominated by natural gas, as in the residential sector) decreased by 2.0 percent. Overall, carbon dioxide emissions related to commercial sector activity increased by 1.6 percent—from 1,034.1 to 1,050.6 MMT—between 2004 and 2005 (Table 8). Since 1990, commercial emissions growth has averaged 2.0 percent per year, the largest growth of any end-use sector. Commercial sector carbon dioxide emissions have risen by

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[38] Sectoral (residential, commercial, and industrial) energy-related carbon dioxide emissions include the share of total electric power sector carbon dioxide emissions that can be attributed to each end-use sector. The share is based on the percentage of total electricity sales purchased by the sector and losses attributed to the sector. (For values used to calculate sectoral shares, see Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035, Tables 2.2, 2.3, 2.4, and 2.5, web site www.eia.doe.gov/emeu/mer/consump.html.) All carbon dioxide emissions associated with industrial or commercial enterprises whose primary business is not the production of electricity are allocated to the sectors in which they occur.

[39] Energy Information Administration, *Short-Term Energy Outlook* (Washington, DC, July 2006), Appendix A, Table A2, p. 2, web site www.eia.doe.gov/emeu/steo/pub/pdf/a2tab.pdf.

[40] Energy Information Administration, *Annual Energy Outlook 2006*, DOE/EIA-0383(2006) (Washington, DC, February 2006), Table A5, web site www.eia.doe.gov/oiaf/aeo/excel/aeo_base.xls.

269.9 MMT since 1990, accounting for 28 percent of the total increase in U.S. unadjusted energy-related carbon dioxide emissions.

Industrial Sector

Industrial sector emissions, at 1,682.3 MMT carbon dioxide, accounted for 28 percent of total U.S. energy-related carbon dioxide emissions in 2005. In terms of fuel shares, electricity consumption was responsible for 39 percent of total industrial sector emissions (662.8 MMT), natural gas for 24 percent (399.7 MMT), petroleum for 26 percent (431.2 MMT), and coal for 11 percent (184.5 MMT).

Estimated 2005 energy-related carbon dioxide emissions in the industrial sector, at 1,682.3 MMT (Table 9), were 3.1 percent lower than the 2004 emissions level of 1,736.0 MMT. Carbon dioxide emissions attributable to industrial sector energy consumption, while fluctuating from year to year, have decreased slightly since 1990. Total energy-related industrial emissions in 2005 were 0.1 percent (1.3 MMT) lower than in 1990, despite a much larger economy.

A contributing factor to the negative growth in industrial sector carbon dioxide emissions is the erosion of the older energy-intensive (and specifically coal-intensive) industrial base. For example, coke plants consumed 38.9 million short tons of coal in 1990, as compared with 23.4 million short tons in 2005. Other industrial coal consumption declined from 76.3 million short tons in 1990 to 60.8 million short tons in 2005. Also, the share of manufacturing activity represented by less energy-intensive industries, such as computer chip and electronic component manufacturing, has increased while the share represented by energy-intensive industries has fallen.

Transportation Sector

Carbon dioxide emissions from the transportation sector, at 1,958.6 MMT, accounted for 33 percent of total U.S. energy-related carbon dioxide emissions in 2005. Almost all (98 percent) of transportation sector emissions result from the consumption of petroleum products: motor gasoline, at 60 percent of total transportation sector emissions; middle distillates (diesel fuel) at 22 percent; jet fuel at 12 percent of the total; and residual oil (i.e., heavy fuel oil, largely for maritime use) at 3.3 percent of the sector's total emissions. Motor gasoline is used primarily in automobiles and light trucks, and middle distillates are used in heavy trucks, locomotives, and ships.

Emissions attributable to the transportation sector increased by 1.0 percent in 2005, from 1,939.2 MMT carbon dioxide in 2004 to 1,958.6 MMT in 2005 (Table 10). The fuel-use patterns and related emissions sources in the transportation sector are different from those in the other end-use sectors. By far the largest single source of emissions, motor gasoline, at 1,170.5 MMT carbon dioxide, increased by 0.1 percent. Emissions from motor gasoline were partially offset by a 13.7-percent increase in the consumption of ethanol (about 2 percent of the market). Carbon dioxide emissions from ethanol consumption are considered to be zero, because the carbon in the fuel is derived primarily from corn, and it is assumed that an equivalent amount of carbon will be sequestered during the corn-growing season. (See the box on page 20 for a discussion of the net emissions benefits of ethanol consumption.)

Since 1990, carbon dioxide emissions related to the transportation sector have increased at an average annual rate of 1.5 percent. The growth since 1990 has meant that transportation emissions have increased by 391.8 MMT, representing 41 percent of the growth in unadjusted energy-related carbon dioxide emissions from all sectors. Transportation is the largest contributing end-use sector to total emissions.

Electric Power Sector

Electric Power Sector Carbon Dioxide Emissions by Fuel Input, 1990-2005

	Million Metric Tons Carbon Dioxide		*Percent Change*	
Fuel	1990	2005	1990-2005	2004-2005
Petroleum	100.9	100.3	*-0.6%*	*2.3%*
Natural Gas	176.9	318.9	*80.3%*	*7.7%*
Coal	1,519.1	1,944.2	*28.0%*	*2.1%*
Total	1,803.1	2,375.0	*31.7%*	*2.8%*

The data in Table 11 represent estimates of carbon dioxide emissions for the electric power sector. These emissions when taken as a whole account for 40 percent of total U.S. energy-related carbon dioxide emissions; in calculating sector-specific emissions, electric power sector emissions are distributed to the end-use sectors. The electric power sector includes traditional regulated utilities, as well as independent power producers whose primary business is the generation and sale of electricity. The industrial sector and, to a much lesser extent, the commercial sector also include establishments that generate electricity; however, their primary business is not electricity generation, and so their electricity-related emissions are included in the totals for those sectors, not in the electric power sector.

Energy-Related Carbon Dioxide Emissions in Manufacturing

Manufacturing is the single largest source of energy-related carbon dioxide emissions in the U.S. industrial sector, which also includes agriculture, forestry, fisheries, mining, and construction. The manufacturing subsector accounted for about 84 percent of energy-related carbon dioxide emissions and 90 percent of energy consumption in the industrial sector in 2002. The table below shows estimates of energy-related carbon dioxide emissions from manufacturing in 2002, based on end-use energy consumption statistics from EIA's Manufacturing Energy Consumption Survey (MECS), which surveys more than 15,000 manufacturing plants every 4 years. The most recent MECS data available are from the 2002 survey. The table on page 18 shows estimates of manufacturing emissions by fuel, based on statistics from the 1991, 1998, and 2002 surveys.

The 1991 MECS reported energy consumption (for fuel and nonfuel purposes) that yielded carbon dioxide emissions from the manufacturing subsector as a whole totaling 1,251.4 million metric tons. The corresponding estimate for 2002 is 1,401.2 million metric tons—an increase of 149.8 million metric tons, representing an average increase of 1.0 percent per year. Over the same interval, the demand for manufacturing products (as measured by gross output[a]) increased by 1.3 percent per year. Therefore, the overall carbon intensity of U.S. manufacturing, measured as metric tons of carbon dioxide emitted per million chained 2000 dollars of gross output, was 420.4 in 1991 but had dropped to 358.4 by 2002, representing an average decrease of 1.4 percent per year.

The *overall carbon intensity* of the U.S. manufacturing subsector is the ratio of its total carbon dioxide emissions (C) to manufacturing output (Y), as measured by the gross output (in chained 2000 dollars). That ratio (C/Y) can be calculated as the product of the subsector's aggregate *carbon intensity of energy supply*—carbon dioxide emissions (C) per unit of energy consumed (E)—and its *energy intensity*—energy consumed (E) per unit of gross output (Y). That is:

$$C/Y = (C/E) \times (E/Y) \quad .$$

For the manufacturing subsector as a whole, energy intensity (the ratio E/Y) is a function primarily of the energy intensities of different production groups and their contributions to the total gross output mix in the subsector. The subsector's carbon intensity of energy supply (the ratio C/E) is determined primarily by the mix of energy fuel inputs and the mix of fuel and nonfuel (sequestering) uses of the inputs. Thus, the overall carbon intensity of manufacturing (C/Y) is a combination of the energy intensity of manufacturing gross output and the carbon intensity of the energy consumed to meet manufacturing energy demand.[b]

The manufacturing E/Y ratio fell by 1.2 percent per year from 1991 to 2002; however, the reduction was largely the result of a structural shift (i.e., a change in relative market shares in the subsector). The energy intensity for the "other manufacturing" category declined by 1.6 percent per year, and at the same time its gross output grew by 3.2 percent per year, from

(continued on page 18)

Carbon Dioxide Emissions from Manufacturing by Industry Group, 2002

Industry Group	NAICS[a] Code	Carbon Dioxide Emissions (Million Metric Tons)	Share of Total Manufacturing Emissions (Percent)	Carbon Intensity of Energy Supply (Million Metric Tons per Quadrillion Btu of Energy Consumed)
Petroleum	324	304.8	21.8	43.2
Chemicals	325	311.0	22.2	41.5
Metals	331	212.8	15.2	68.7
Paper	322	102.4	7.3	36.5
Minerals	327	91.1	6.5	68.1
Other Manufacturing		379.0	27.0	54.6
Total		**1,401.2**	**100.0**	**49.5**

[a] North American Industry Classification System. For emissions by 6-digit NAICS categories, see web site www.eia.doe.gov/oiaf/1605/ggrpt/pdf/industry_mecs.pdf.

Sources: Energy Information Administration, Form EIA-846, "Manufacturing Energy Consumption Survey," and Form EIA-810, "Monthly Refinery Report" (2002).

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[a] Consists of sales, or receipts, and other operating income, plus commodity taxes and changes in inventories.

[b] The ratios presented here are estimated as aggregations of several manufacturing industries. Specifically, 22 manufacturing industry groups were aggregated into 6 groups for calculations of industry-specified E/Y and C/Y ratios. Therefore, quantifying influences on the change in overall carbon intensity is valuable to extent that these groupings represent changes in the U.S. manufacturing sector. It should be noted, however, that these ratios are based on survey data that are subject to sampling errors and other uncertainties.

Energy-Related Carbon Dioxide Emissions in Manufacturing (Continued)

Carbon Dioxide Emissions from Manufacturing by Fuel, 1991, 1998, and 2002

Fuel Type	NAICS[a] Code					Other Mfg.	Total
	324	325	331	322	327		
1991							
Carbon Dioxide Emissions (Million Metric Tons)							
Petroleum	149.9	42.1	3.4	13.6	6.4	14.1	**229.6**
Natural Gas	44.2	102.3	37.4	29.1	20.1	73.4	**306.6**
Coal	1.4	25.2	83.2	28.3	27.9	27.2	**193.2**
Electricity	19.8	83.1	94.3	38.0	19.8	192.7	**447.8**
Other	61.0	9.7	3.0	0.2	0.0	0.5	**74.3**
Total	**276.3**	**262.4**	**221.3**	**109.2**	**74.3**	**307.8**	**1,251.4**
Share of Total Gross Output (Percent)	7.1	12.4	4.4	5.1	2.4	68.6	**100.0**
Share of Total Energy Use (Percent)	24.8	23.3	13.2	11.9	4.5	22.3	**100.0**
Share of Total Carbon Dioxide Emissions (Percent)	22.1	21.0	17.7	8.7	5.9	24.6	**100.0**
1998							
Carbon Dioxide Emissions (Million Metric Tons)							
Petroleum	174.8	56.5	3.6	15.1	6.7	13.4	**270.1**
Natural Gas	53.2	127.7	47.9	31.1	23.4	91.5	**374.9**
Coal	0.0	26.9	94.3	25.8	27.7	23.7	**198.3**
Electricity	22.9	103.2	101.8	45.6	24.4	263.7	**561.6**
Other	69.5	4.9	3.4	0.8	0.7	1.6	**80.9**
Total	**320.4**	**319.2**	**251.0**	**118.4**	**82.9**	**393.9**	**1,485.8**
Share of Total Gross Output (Percent)	5.7	11.0	4.2	4.2	2.4	72.5	**100.0**
Share of Total Energy Use (Percent)	25.2	24.0	7.4	10.8	4.1	28.5	**100.0**
Share of Total Carbon Dioxide Emissions (Percent)	21.6	21.5	16.9	8.0	5.6	26.5	**100.0**
2002							
Carbon Dioxide Emissions (Million Metric Tons)							
Petroleum	153.9	70.2	2.4	10.0	11.4	9.6	**257.6**
Natural Gas	46.4	106.2	37.2	26.6	22.3	87.3	**325.9**
Coal	19.3	32.8	72.4	22.5	30.1	25.6	**202.8**
Electricity	24.6	99.4	93.8	42.4	26.8	253.7	**540.7**
Other	60.8	2.4	7.0	0.8	0.4	2.8	**74.2**
Total	**304.8**	**311.0**	**212.8**	**102.4**	**91.1**	**379.0**	**1,401.2**
Share of Total Gross Output (Percent)	5.9	10.5	3.6	3.9	2.2	73.9	**100.0**
Share of Total Energy Use (Percent)	24.9	26.5	10.9	8.4	4.7	24.5	**100.0**
Share of Total Carbon Dioxide Emissions (Percent)	21.8	22.2	15.2	7.3	6.5	27.0	**100.0**

[a] North American Industry Classification System: 324, petroleum products; 325, chemicals; 331, primary metals; 322, paper; 327, nonmetallic minerals (includes stone, clay, and glass).

Notes: Totals may not equal sum of components due to independent rounding. To calculate intensity and consumption values, electricity was calculated as primary electricity: 10,436 Btu per kilowatthour for 1991, 10,197 for 1998, and 10,173 for 2002. These conversion factors represent the average energy input to the generation process for fossil-fired utility plants in the United States. See Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(2003/09) (Washington, DC, September 2003), Table A6.

Sources: Energy Information Administration, Form EIA-846, “Manufacturing Energy Consumption Survey,” and Form EIA-810, “Monthly Refinery Report” (1991, 1998, and 2002); and U.S. Department of Commerce, Bureau of Economic Analysis, Industry Economics Division.

(continued on page 19)

Energy-Related Carbon Dioxide Emissions in Manufacturing (Continued)

$2.0 trillion in 1991 to $2.9 trillion in 2002 (in chained 2000 dollars), as newer, less energy-intensive industries accounted for an increasing share of manufacturing activity. In 1991 the four most energy-intensive industries (petroleum, chemicals, primary metals, and paper) accounted for 29.0 percent of total manufacturing gross output, but by 2002 their share had fallen to 23.9 percent. For three of the six manufacturing categories, energy intensity increased from 1991 to 2002 (petroleum by 0.4 percent per year, chemicals 1.5 percent, and nonmetallic minerals 0.1 percent). For paper, primary metals, and other manufacturing, energy intensity declined by 0.4 percent, 0.9 percent, and 1.6 percent per year, respectively.

The mix and quantity of energy fuels consumed by manufacturers (for both fuel and nonfuel uses) affect the subsector's aggregate carbon intensity of energy supply. Overall, manufacturing industries had *C/E* ratios equal to 50.9 million metric tons carbon dioxide equivalent per quadrillion Btu in 1991 and 49.5 million metric tons carbon dioxide equivalent per quadrillion Btu in 2002; however, the carbon dioxide factors of the various industries differed markedly.

The petroleum and chemical industries both transform some energy products into products that sequester carbon, such as petrochemical feedstocks, asphalt, and plastics. Because of that use, both the petroleum and chemical industries have lower aggregate *C/E* ratios than the manufacturing average (45.3 and 43.2 million metric tons carbon dioxide equivalent per quadrillion Btu for the petroleum industry and 45.8 and 41.5 for the chemicals industry in 1991 and 2002, respectively).

The paper industry makes extensive use of wood byproducts as an energy source. Carbon dioxide emissions from wood consumption are considered to be zero, because the carbon that is emitted has been sequestered recently, and the regrowing of trees will again sequester an equivalent amount of carbon dioxide. Consequently, the paper industry has a relatively low *C/E* ratio, at 37.4 and 36.5 million metric tons carbon dioxide equivalent per quadrillion Btu in 1991 and 2002, respectively. In contrast, the primary metals industry, which uses large amounts of coal and other carbon-intensive fuels (e.g., electricity), has a high *C/E* ratio: 68.2 in 1991 and 68.7 in 2002.

Between 1998 and 2002, manufacturing industries had decreases in carbon dioxide emissions associated with their use of electricity (20.9 million metric tons) and natural gas (49.0 million metric tons). Even so, electricity use continues to account for the largest share of manufacturers' energy-related carbon dioxide emissions: 37.8 percent (561.6 million metric tons) in 1998 and 38.6 percent (540.7 million metric tons) in 2002.

As a result of the above changes in energy intensity, in combination with the structural shift in the subsector, the overall manufacturing energy intensity (*E/Y*) declined by 1.2 percent per year from 1991 to 2002. When the influence of the structural shift is removed, however, decomposition analysis suggests that the aggregate energy intensity of the manufacturing sector is virtually unchanged.[c]

Changes in Key Measures of Carbon Intensity in Manufacturing, 1991-2002

Industry Group	NAICS[a] Code	1991			2002			Annual Percent Change, 1991-2002		
		E/Y	*C/E*	*C/Y*	*E/Y*	*C/E*	*C/Y*	*E/Y*	*C/E*	*C/Y*
Petroleum	324	29	45.3	1,310.6	30	43.2	1,312.2	0.4	-0.4	0.0
Chemicals	325	15	45.8	708.0	18	41.5	758.0	1.5	-0.9	0.6
Metals	331	25	68.2	1,688.3	22	68.7	1,532.2	-0.9	0.1	-0.9
Paper	322	19	37.4	717.9	18	36.5	668.2	-0.4	-0.2	-0.6
Minerals	327	15	67.8	1,048.2	16	68.1	1,058.7	0.1	0.0	0.1
Other Manufacturing		3	56.1	150.8	2	58.3	131.2	-1.6	-0.3	-1.3
Total		**8**	**50.9**	**420.4**	**7**	**49.5**	**358.4**	**-1.2**	**-0.3**	**-1.4**
Total Without Structural Shift		**8**	**NA**	**NA**	**8**	**NA**	**NA**	**-0.1**	**NA**	**NA**

[a] North American Industry Classification System.

Notes: *E/Y* = energy consumed (thousand Btu) per chained 2000 dollar value of gross output. *C/E* = million metric tons carbon dioxide emitted per quadrillion Btu of energy consumed. *C/Y* = metric tons carbon dioxide emitted per million chained 2000 dollars of gross output. NA = not applicable. Annual percent change for *E/Y* is not statistically significant.

Sources: Energy Information Administration, Form EIA-846, "Manufacturing Energy Consumption Survey," and Form EIA-810, "Monthly Refinery Report" (1991 and 2002).

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[c] There are several approaches that, based on index number theory, can be used to decompose aggregate values. The values reported here are based on a discrete approximation of the Divisia integral index.

Preliminary estimates indicate that carbon dioxide emissions from the electric power sector increased by 2.8 percent (65.6 MMT), from 2,309.4 MMT in 2004 to 2,375.0 MMT in 2005 (Table 11). Emissions from natural-gas-fired generation increased by 7.7 percent, from coal-fired generation by 2.1 percent, and from petroleum-fired generation by 2.3 percent. Carbon dioxide emissions from the electric power sector have grown by 32 percent since 1990, while total unadjusted energy-related carbon dioxide emissions have grown by 19 percent. Of the total growth in energy-related carbon dioxide emissions from 1990 to 2005, 60 percent can be attributed to growth in electric power sector emissions.

Nonfuel Use of Energy Inputs

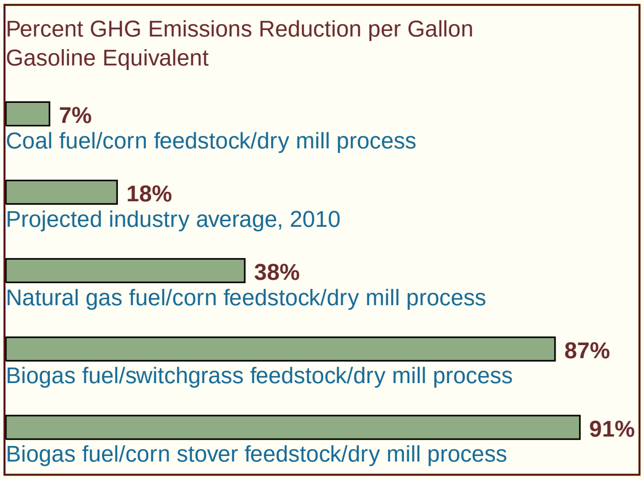
Nonfuel uses of energy fuels, principally petroleum products, both emit and sequester carbon dioxide over their life cycles. In 2005, nonfuel uses of fossil fuels resulted in emissions of 106.4 MMT carbon dioxide, a decrease of 5.2 MMT (4.7 percent) from the 2004 level of 111.7 MMT (Table 12). Carbon dioxide emissions from nonfuel uses, which represent about 2 percent of total U.S. carbon dioxide emissions, have grown by an average of 0.5 percent annually from their 1990 level of 98.1 MMT. Emissions from nonfuel uses of petroleum products in 2005 were 82.4 MMT in the industrial sector and

Ethanol and Greenhouse Gas Emissions

Because the carbon in biogenic material is part of the natural carbon cycle, using ethanol in place of gasoline has the potential to reduce greenhouse gas (GHG) emissions. The nature of the impacts could vary greatly, however, depending on the fuels, feedstocks, and processes used to produce the ethanol.

For this report, Argonne National Laboratory produced a life-cycle ("well to wheels") comparison of GHG emissions for conventional motor gasoline and ethanol per gallon of fuel consumed, on a Btu equivalent basis. As shown in the figure below, there is substantial variation in the potential GHG savings for ethanol as compared with motor gasoline. The analysis, based on the near future (2010), compared an outcome based on the current industry average with what could be technically feasible for 2010. Key inputs for the analysis included: corn yield (bushels per acre); nitrogen fertilizer application rate (pounds per acre); nitrogen fertilizer production (Btu per pound); corn ethanol conversion rate (gallons per bushel); ethanol conversion process (Btu per gallon); total energy use (Btu per gallon); and coproduct energy credits (Btu per gallon).

Potential Reductions in Greenhouse Gas Emissions Resulting from U.S. Ethanol Use, 2010



Source: Argonne National Laboratory, GREET Model runs (transmitted on October 4, 2006).

Among the simulations performed, the smallest savings in GHG emissions when ethanol is used are 7 percent (for an ethanol plant using coal as the input fuel, corn as the energy crop feedstock, and a dry mill production process). The comparison based on the projected industry average for ethanol production in 2010[b] shows savings in GHG emissions of about 18 percent. When a dry mill process is assumed with 100 percent natural gas as the input fuel and corn as the energy crop, the potential savings are about 38 percent.

The higher GHG emissions savings are estimated to occur when the input fuel is renewable and the energy crop is cellulosic rather than corn. With a biogas fuel input and switchgrass as the energy crop, the potential savings are estimated at about 87 percent; with corn stover as the energy crop, the savings are estimated to be more than 90 percent.

The intent of this analysis was not to weigh in on a particular position with regard to the feasibility of the scenarios examined. It is clear, however, that input assumptions are significant in any examination of the potential for GHG emissions savings from the use of ethanol as a transportation fuel. The analysis examined neither economic feasibility nor issues of scale-up to meet a targeted market share, and the future technologies and crop inputs assumed in the analysis remain untested on a national scale.

[a] The industry average in 2010 is projected to be 30 percent wet and 70 percent dry process, with an input fuel mix of 72 percent natural gas, 18 percent coal, and 10 percent electricity for a dry mill plant and a fuel mix of 60 percent natural gas and 40 percent coal for a wet mill plant.

5.6 MMT in the transportation sector. Within the industrial petroleum products category, the leading carbon dioxide emission sources were petrochemical feedstocks at 38.0 MMT and LPG at 18.3 MMT. Nonfuel uses of natural gas resulted in emissions of 18.0 MMT carbon dioxide in 2005.

In 2005, carbon sequestration through nonfuel uses of fossil fuels totaled 300.9 MMTCO$_2$e (Table 13). The vast majority was sequestered in petroleum-based products, including 276.1 MMTCO$_2$e in the industrial sector and 5.6 MMTCO$_2$e in the transportation sector sequestered through the use of petroleum-based lubricants. Smaller amounts of carbon were sequestered in natural-gas-based products (17.7 MMTCO$_2$e) and coal-based products (1.5 MMTCO$_2$e). The main products that sequester carbon include asphalt and road oil (100.0 MMTCO$_2$e), LPG (73.4 MMTCO$_2$e), and feedstocks for plastics and other petrochemicals (64.2 MMTCO$_2$e). The amount sequestered in 2005 was 3.3 percent less than in 2004, when 311.1 MMTCO$_2$e was sequestered. Since 1990, the annual sequestration of carbon in this manner has increased by 49.7 MMTCO$_2$e or 20 percent. This translates to an average annual growth rate of 1.2 percent.

Adjustments to Energy Consumption

Total energy consumption and the carbon dioxide emissions upon which they are based correspond to EIA's coverage of energy consumption, which includes the 50 States and the District of Columbia. Under the United Nations Framework Convention on Climate Change (UNFCCC), however, the United States is also responsible for counting emissions emanating from its Territories, and their emissions are added to the U.S. total. Conversely, because the Intergovernmental Panel on Climate Change (IPCC) definition of energy consumption excludes international bunker fuels from the statistics of all countries, emissions from international bunker fuels are subtracted from the U.S. total. Additionally, military bunker fuels are subtracted because they are also excluded by the IPCC from the national total. These sources and subtractions are enumerated and described as "adjustments to energy."

U.S. Territories

Energy-related carbon dioxide emissions for the U.S. Territories are added as an adjustment in keeping with IPCC guidelines for national emissions inventories. The Territories included are Puerto Rico, the U.S. Virgin Islands, American Samoa, Guam, the U.S. Pacific Islands, and Wake Island. Most of these emissions are from petroleum products; however, Puerto Rico and the Virgin Islands consume coal in addition to petroleum products. For 2005, total energy-related carbon dioxide emissions from the U.S. Territories are estimated at 58.6 MMT (Table 5).

International Bunker Fuels

In keeping with the IPCC guidelines for estimating national greenhouse gas emissions, carbon dioxide emissions from international bunker fuels are subtracted from the estimate of total U.S. energy-related emissions of carbon dioxide. Purchases of distillate and residual fuels by foreign-bound ships at U.S. seaports, as well as jet fuel purchases by international air carriers at U.S. airports, form the basis of the estimate for bunker fuels. Additionally, U.S. military operations for which fuel was originally purchased in the United States but consumed in international waters or airspace are subtracted from the total, because they are also considered international bunker fuels under this definition.

For 2004, the carbon dioxide emissions estimate for military bunker fuels was 10.1 MMT.[41] In 2005, approximately 100.7 MMT carbon dioxide was emitted in total from international bunker fuels, including 90.6 MMT attributed to civilian consumption of bunker fuels. The total amount is subtracted from the U.S. total in Table 5. Just over one-half of the carbon dioxide emissions associated with international bunker fuels comes from the combustion of jet fuels; residual and distillate fuels account for the other half, with most coming from residual fuel.

Other Carbon Dioxide Emissions

Energy Production

In addition to emissions resulting from fossil energy consumed, oil and gas production leads to emissions of carbon dioxide from sources other than the combustion of those marketed fossil fuels. The two energy production sources estimated for this report are:

- Flared natural gas (gas burned at the production site), which is flared either because the cost of bringing the gas to market is prohibitive or because the gas is of insufficient quality to sell
- Carbon dioxide scrubbed from natural gas to improve its heat content and quality and subsequently vented to the atmosphere.

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[41] Data for 2005 military bunker fuels were not available at the time of publication. It should also be noted that only bunker fuels purchased in the United States are subject to adjustment.

U.S. Carbon Dioxide Emissions from Other Sources, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide)	105.4
Change Compared to 2004 (Million Metric Tons Carbon Dioxide)	-0.2
Change from 2004 *(Percent)*	*-0.2%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide)	17.1
Change from 1990 *(Percent)*	*19.4%*

Because many States require flaring of natural gas, EIA assumes that all gas reported under the category "Vented and Flared" is actually flared and therefore should be counted as carbon dioxide emissions rather than methane emissions. In 2005, about 5.9 MMT carbon dioxide was emitted in this way (Table 5).

By computing the difference between the estimated carbon dioxide content of raw gas and the carbon dioxide content of pipeline gas, the amount of carbon dioxide that has been removed (scrubbed) in order to improve the heat content and quality of natural gas can be calculated. This amount was about 17.3 MMT in 2005 (Table 5).

Information on energy production sources that are excluded from this report because of insufficient data is available in Energy Information Administration, *Documentation for Emissions of Greenhouse Gases in the United States 2004*.[42]

Industrial Process Emissions

Industrial emissions of carbon dioxide not caused by the combustion of fossil fuels accounted for 1.2 percent (74.0 MMT) of total U.S. carbon dioxide emissions in 2005 (Table 14). Process-related emissions from industrial sources depend largely on the level of activity in the construction industries and on production at oil and gas wells. These sources include limestone and dolomite calcination, soda ash manufacture and consumption, carbon dioxide manufacture, cement manufacture, and aluminum production.

Estimated industrial process emissions of carbon dioxide in 2005 totaled 74.0 MMT, 13.9 MMT (23 percent) higher than in 1990 and 0.3 MMT (0.3 percent) lower than in 2004 (Table 14). Of the total estimate for carbon dioxide emissions from industrial processes in 2005, 62 percent is attributed to cement manufacture. When calcium carbonate is heated (calcined) in a kiln, it is converted to lime and carbon dioxide. The lime is combined with other materials to produce clinker (an intermediate product from which cement is made), and the carbon dioxide is released to the atmosphere. In 2005, the United States produced an estimated 97.4 million metric tons of cement,[43] resulting in the direct release of 45.9 MMT into the atmosphere. This calculation is independent of the carbon dioxide released by the combustion of energy fuels consumed in making cement. The estimate for 2005 represents an increase in carbon dioxide emissions of 12.5 MMT (38 percent) compared with 1990 and an increase of about 0.2 MMT (0.4 percent) compared with 2004.

Collectively, in 2005, industrial processes other than cement manufacture emitted 28.1 MMT carbon dioxide. Limestone manufacture and consumption emitted 18.3 MMT, soda ash manufacture 3.9 MMT, aluminum manufacture 3.7 MMT, carbon dioxide manufacture 1.6 MMT, and soda ash consumption 0.6 MMT.

Waste Combustion

Waste that is combusted contains, on average, a portion that is composed of plastics, synthetic rubber, synthetic fibers, and carbon black. The carbon in these plastics has normally been accounted for as sequestered carbon, as reported in Table 13; however, according to the IPCC, emissions from the plastics contained in municipal solid waste must be counted in total national emissions inventories. The U.S. Environmental Protection Agency (EPA) estimates that plastics and other non-biogenic materials in combusted waste produced emissions of about 19.4 MMT carbon dioxide in 2004 (about 11.1 MMT from grid-connected power generation).[44] The EPA's 2004 value is used in this report as an estimate for 2005. The difference between the estimated total and EIA's estimate for the electric power sector is reported in Table 5. For 2005, the difference is 8.3 MMT carbon dioxide.

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[42] Energy Information Administration, *Documentation for Emissions of Greenhouse Gases in the United States 2004,* DOE/EIA-0638(2004) (Washington, DC, November 2006), web site www.eia.doe.gov/oiaf/1605/ggrpt/documentation/pdf/0638(2004).pdf. See also Energy Information Administration, *Documentation for Emissions of Greenhouse Gases in the United States 2005* (to be published).

[43] U.S. Department of the Interior, U.S. Geological Service, "Cement," *Mineral Commodity Summary*, web site http://minerals.usgs.gov/minerals/pubs/commodity/cement/cemenmcs06.pdf.

[44] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-05-003 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

Table 5. U.S. Carbon Dioxide Emissions from Energy and Industry, 1990, 1995, and 1998-2005
(Million Metric Tons Carbon Dioxide)

Fuel Type or Process	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Energy Consumption										
Petroleum	2,169.6	2,192.1	2,345.6	2,413.3	2,443.0	2,461.7	2,457.7	2,499.7	2,597.9	2,614.0
Coal	1,781.8	1,878.7	2,022.3	2,023.5	2,119.2	2,051.2	2,054.0	2,092.5	2,115.5	2,141.7
Natural Gas	1,027.2	1,184.6	1,189.3	1,191.9	1,237.6	1,185.7	1,227.5	1,196.5	1,198.4	1,178.1
Renewables[a]	6.2	10.4	10.6	10.8	10.5	11.1	13.0	11.7	11.4	11.5
Energy Subtotal	**4,984.8**	**5,265.8**	**5,567.8**	**5,639.5**	**5,810.2**	**5,709.8**	**5,752.2**	**5,800.5**	**5,923.2**	**5,945.3**
Nonfuel Use Emissions[b]	**98.1**	**104.7**	**118.6**	**124.1**	**110.0**	**104.9**	**105.4**	**103.5**	**111.7**	**106.4**
Nonfuel Use Sequestration[c]	**251.2**	**286.4**	**314.7**	**325.8**	**308.1**	**293.7**	**293.8**	**289.5**	**311.1**	**300.9**
Adjustments to Energy										
U.S. Territories (+)	31.1	38.2	41.0	40.4	42.2	53.6	52.3	56.8	60.0	58.6
Military Bunker Fuels (-)	13.6	8.9	10.0	9.8	7.8	8.2	8.1	9.2	10.1	10.1
International Bunker Fuels (-)	100.1	91.9	104.9	97.4	93.5	89.6	81.2	75.0	90.1	90.6
Total Energy Adjustments	**-82.6**	**-62.6**	**-73.9**	**-66.8**	**-59.1**	**-44.1**	**-37.0**	**-27.5**	**-40.2**	**-42.1**
Adjusted Energy Subtotal	**4,902.3**	**5,203.2**	**5,494.0**	**5,572.7**	**5,751.1**	**5,665.7**	**5,715.2**	**5,773.0**	**5,883.0**	**5,903.2**
Other Sources										
Natural Gas Flaring	9.1	17.2	6.2	6.7	5.5	5.9	6.0	5.9	5.9	5.9
Carbon Dioxide in Natural Gas	14.0	16.7	18.0	17.8	18.2	18.6	17.9	18.1	17.8	17.3
Cement Production	33.3	36.9	39.3	40.1	41.3	41.5	43.0	43.2	45.7	45.9
Other Industrial	26.8	28.4	29.7	29.3	29.4	27.4	26.4	27.6	28.5	28.1
Waste Combustion	5.1	6.2	6.9	7.2	7.9	8.0	6.2	7.5	7.7	8.3
Total Other Sources	**88.3**	**105.3**	**100.1**	**101.2**	**102.3**	**101.3**	**99.5**	**102.3**	**105.7**	**105.4**
Total	**4,990.6**	**5,308.5**	**5,594.0**	**5,673.9**	**5,853.4**	**5,767.0**	**5,814.7**	**5,875.3**	**5,988.7**	**6,008.6**

[a] Includes emissions from electricity generation using municipal solid waste and geothermal energy.

[b] Emissions from nonfuel use are included in the fuel categories above. See Table 12 for details by fuel category.

[c] See Table 13 for details by fuel.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding. Adjusted energy total includes U.S. Territories.

Sources: EIA estimates presented in this chapter.

Table 6. U.S. Carbon Dioxide Emissions from Energy Consumption by End-Use Sector, 1990, 1995, and 1998-2005

(Million Metric Tons Carbon Dioxide)

End-Use Sector	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Residential	953.7	1,030.7	1,088.1	1,111.3	1,171.9	1,161.1	1,186.4	1,214.0	1,213.9	1,253.8
Commercial	780.7	841.1	935.7	947.7	1,006.4	1,014.2	1,009.4	1,020.3	1,034.1	1,050.6
Industrial	1,683.6	1,728.6	1,782.3	1,770.5	1,778.0	1,702.8	1,684.7	1,688.0	1,736.0	1,682.3
Transportation	1,566.8	1,665.3	1,761.8	1,810.0	1,854.0	1,831.7	1,871.7	1,878.2	1,939.2	1,958.6
Total[a]	**4,984.8**	**5,265.8**	**5,567.8**	**5,639.5**	**5,810.2**	**5,709.8**	**5,752.2**	**5,800.5**	**5,923.2**	**5,945.3**
Electric Power	1,803.1	1,936.8	2,164.9	2,175.8	2,279.3	2,240.2	2,250.0	2,277.4	2,309.4	2,375.0

P = preliminary data.

[a] Includes emissions from nonfuel uses of fossil fuels. See Table 12 for details by fuel category.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding. Electric power sector emissions are distributed across the end-use sectors. Emissions allocated to sectors are unadjusted. Adjustments are made to total emissions only (Table 5).

Sources: EIA estimates presented in this chapter.

Table 7. U.S. Carbon Dioxide Emissions from Residential Sector Energy Consumption, 1990, 1995, and 1998-2005

(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Petroleum										
Liquefied Petroleum Gas	22.6	25.1	26.9	33.1	34.9	33.2	33.6	34.9	32.9	31.2
Distillate Fuel	70.8	65.5	55.9	59.9	65.5	65.8	62.3	65.5	66.9	67.5
Kerosene	4.6	5.3	7.8	8.0	6.8	6.8	4.3	5.0	6.1	6.6
Petroleum Subtotal	**98.0**	**95.9**	**90.5**	**101.0**	**107.2**	**105.8**	**100.2**	**105.5**	**105.9**	**105.3**
Coal	2.9	1.6	1.2	1.3	1.0	1.0	1.1	1.2	1.3	0.9
Natural Gas	238.6	263.1	246.6	256.4	269.2	259.0	263.7	276.1	264.8	261.7
Electricity[a]	614.2	670.0	749.8	752.6	794.4	795.3	821.4	831.2	841.9	885.7
Total	**953.7**	**1,030.7**	**1,088.1**	**1,111.3**	**1,171.9**	**1,161.1**	**1,186.4**	**1,214.0**	**1,213.9**	**1,253.8**

[a] Share of total electric power sector carbon dioxide emissions weighted by sales to the residential sector.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates presented in this chapter.

Table 8. U.S. Carbon Dioxide Emissions from Commercial Sector Energy Consumption, 1990, 1995, and 1998-2005

(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Petroleum										
Motor Gasoline	7.8	1.3	2.7	2.0	3.1	2.6	3.2	4.2	3.4	3.4
Liquefied Petroleum Gas	4.0	4.4	4.7	5.8	6.2	5.9	5.9	6.2	5.8	5.5
Distillate Fuel	38.8	34.7	31.1	31.8	35.6	36.8	32.2	34.9	34.1	34.4
Residual Fuel	17.9	11.0	6.6	5.7	7.1	5.4	6.2	8.7	9.6	10.5
Kerosene	0.8	1.6	2.2	1.9	2.1	2.2	1.1	1.3	1.5	1.6
Petroleum Subtotal	**69.4**	**53.0**	**47.4**	**47.2**	**54.1**	**53.0**	**48.7**	**55.3**	**54.3**	**55.4**
Coal	11.6	11.0	9.5	9.6	8.1	8.3	8.3	7.8	9.5	7.8
Natural Gas	142.4	164.5	163.6	165.3	171.8	164.3	170.2	175.8	170.3	166.3
Electricity[a]	557.2	612.6	715.2	725.5	772.4	788.5	782.3	781.4	799.9	821.1
Total	**780.7**	**841.1**	**935.7**	**947.7**	**1,006.4**	**1,014.2**	**1,009.4**	**1,020.3**	**1,034.1**	**1,050.6**

[a] Share of total electric power sector carbon dioxide emissions weighted by sales to the commercial sector.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates presented in this chapter.

Table 9. U.S. Carbon Dioxide Emissions from Industrial Sector Energy Consumption, 1990, 1995, and 1998-2005

(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Petroleum										
Motor Gasoline	13.0	14.1	14.0	10.6	10.5	20.7	21.7	22.7	26.1	26.2
Liquefied Petroleum Gas	39.9	46.4	40.3	49.3	57.9	50.1	55.8	51.4	56.8	54.4
Distillate Fuel	83.1	81.6	87.3	85.5	86.5	93.7	86.8	81.9	87.5	89.1
Residual Fuel	30.3	24.2	15.7	14.0	16.6	13.6	13.1	15.5	17.7	19.7
Asphalt and Road Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lubricants	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kerosene	0.9	1.1	1.6	0.9	1.1	1.7	1.0	1.7	2.0	2.2
Petroleum Coke	81.2	79.6	97.6	109.0	87.6	97.2	94.8	91.6	107.2	102.5
Other Petroleum	125.1	112.1	123.6	128.0	115.5	130.0	127.3	137.3	139.8	137.1
Petroleum Subtotal	**373.5**	**359.1**	**380.1**	**397.3**	**375.7**	**407.0**	**400.5**	**402.2**	**437.3**	**431.2**
Coal	**247.7**	**223.6**	**203.1**	**198.6**	**207.5**	**201.4**	**185.2**	**187.3**	**188.1**	**184.5**
Coal Coke Net Imports	**0.5**	**5.7**	**7.4**	**6.5**	**6.1**	**2.7**	**5.7**	**4.7**	**12.8**	**4.1**
Natural Gas	**433.5**	**489.4**	**495.0**	**473.6**	**479.7**	**438.8**	**450.7**	**433.5**	**434.9**	**399.7**
Electricity[a]	**628.5**	**650.9**	**696.6**	**694.5**	**708.9**	**652.9**	**642.7**	**660.4**	**662.9**	**662.8**
Total[b]	**1,683.6**	**1,728.6**	**1,782.3**	**1,770.5**	**1,778.0**	**1,702.8**	**1,684.7**	**1,688.0**	**1,736.0**	**1,682.3**

[a] Share of total electric power sector carbon dioxide emissions weighted by sales to the industrial sector.

[b] Includes emissions from nonfuel uses of fossil fuels. See Table 12 for details by fuel category.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005).Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates presented in this chapter.

Table 10. U.S. Carbon Dioxide Emissions from Transportation Sector Energy Consumption, 1990, 1995, and 1998-2005

(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Petroleum										
Motor Gasoline	952.1	1,019.4	1,076.8	1,104.0	1,110.7	1,115.8	1,144.2	1,147.9	1,169.0	1,170.5
Liquefied Petroleum Gas	1.3	1.0	1.0	0.8	0.7	0.8	0.8	1.0	1.1	1.1
Jet Fuel	220.4	219.9	235.6	242.9	251.2	240.4	234.4	229.1	237.4	243.8
Distillate Fuel	265.1	303.8	348.4	362.2	374.0	383.2	390.5	410.3	429.6	434.1
Residual Fuel	79.3	71.0	52.6	51.9	69.2	45.7	52.8	44.5	57.7	64.1
Lubricants[a]	6.5	6.2	6.6	6.7	6.6	6.0	6.0	5.5	5.6	5.6
Aviation Gasoline	3.1	2.7	2.4	2.7	2.5	2.4	2.3	2.1	2.1	2.4
Petroleum Subtotal	**1,527.7**	**1,624.0**	**1,723.4**	**1,771.2**	**1,815.0**	**1,794.3**	**1,831.0**	**1,840.5**	**1,902.5**	**1,921.7**
Coal	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Natural Gas	**35.9**	**38.2**	**35.1**	**35.6**	**35.5**	**33.9**	**37.1**	**33.3**	**32.1**	**31.5**
Electricity[b]	**3.2**	**3.2**	**3.3**	**3.2**	**3.6**	**3.5**	**3.6**	**4.5**	**4.6**	**5.4**
Total	**1,566.8**	**1,665.3**	**1,761.8**	**1,810.0**	**1,854.0**	**1,831.7**	**1,871.7**	**1,878.2**	**1,939.2**	**1,958.6**

[a] Includes emissions from nonfuel uses of fossil fuels. See Table 12 for details by fuel category.

[b] Share of total electric power sector carbon dioxide emissions weighted by sales to the transportation sector.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates presented in this chapter.

Table 11. U.S. Carbon Dioxide Emissions from Electric Power Sector Energy Consumption, 1990, 1995, and 1998-2005

(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Petroleum										
Heavy Fuel Oil	91.0	44.6	82.7	75.7	68.8	79.3	51.7	68.3	69.1	69.1
Light Fuel Oil	7.0	7.8	9.8	10.1	12.6	12.4	9.2	11.6	8.0	8.3
Petroleum Coke	2.9	7.7	11.7	10.7	9.5	10.0	16.4	16.4	20.9	22.9
Petroleum Subtotal[a]	**100.9**	**60.1**	**104.1**	**96.5**	**90.9**	**101.6**	**77.4**	**96.3**	**98.0**	**100.3**
Coal	**1,519.1**	**1,636.8**	**1,801.1**	**1,807.6**	**1,896.6**	**1,837.8**	**1,853.7**	**1,891.5**	**1,903.7**	**1,944.2**
Natural Gas	**176.9**	**229.4**	**249.1**	**260.9**	**281.4**	**289.6**	**305.9**	**277.9**	**296.2**	**318.9**
Municipal Solid Waste	**5.8**	**10.0**	**10.2**	**10.4**	**10.1**	**10.8**	**12.6**	**11.3**	**11.1**	**11.1**
Geothermal	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.3**	**0.4**	**0.4**	**0.4**	**0.4**
Total	**1,803.1**	**1,936.8**	**2,164.9**	**2,175.8**	**2,279.3**	**2,240.2**	**2,250.0**	**2,277.4**	**2,309.4**	**2,375.0**

P = preliminary data.

[a] Includes small amounts of other petroleum liquids, such as jet fuel and waste oil.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Emissions for total fuel consumption are allocated to end-use sectors in proportion to electricity sales. Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates presented in this chapter.

Table 12. U.S. Carbon Dioxide Emissions from Nonfuel Use of Energy Fuels, 1990, 1995, and 1998-2005
(Million Metric Tons Carbon Dioxide)

End Use and Type	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Industrial										
Petroleum										
Liquefied Petroleum Gases	14.8	19.5	21.5	22.4	20.4	19.1	19.9	19.0	19.3	18.3
Distillate Fuel	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Residual Fuel	1.8	2.0	2.2	2.2	2.2	2.2	1.7	1.7	1.7	1.7
Asphalt and Road Oil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lubricants	6.8	6.5	7.0	7.1	7.0	6.4	6.3	5.8	5.9	5.9
Other *(Subtotal)*	*51.2*	*51.5*	*60.6*	*66.2*	*53.7*	*51.4*	*52.7*	*52.5*	*60.2*	*56.1*
Pentanes Plus	1.1	4.0	2.7	3.5	3.1	2.7	2.3	2.2	2.3	2.0
Petrochemical Feed	33.3	35.7	39.3	37.8	36.4	32.6	33.2	36.2	41.4	38.0
Petroleum Coke	9.0	6.7	10.8	14.4	7.1	10.5	9.7	8.3	12.9	11.6
Special Naphtha	7.8	5.2	7.8	10.6	7.1	5.7	7.5	5.9	3.7	4.6
Waxes and Miscellaneous	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Petroleum Subtotal	*74.9*	*79.9*	*91.7*	*98.3*	*83.8*	*79.5*	*81.0*	*79.5*	*87.6*	*82.4*
Coal	0.5	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
Natural Gas	16.2	17.9	19.7	18.5	19.0	18.8	18.0	18.0	18.0	18.0
Industrial Subtotal	***91.6***	***98.5***	***112.0***	***117.4***	***103.4***	***98.9***	***99.5***	***98.0***	***106.1***	***100.9***
Transportation										
Lubricants	6.5	6.2	6.6	6.7	6.6	6.0	6.0	5.5	5.6	5.6
Total	**98.1**	**104.7**	**118.6**	**124.1**	**110.0**	**104.9**	**105.4**	**103.5**	**111.7**	**106.4**

P = preliminary data.

Notes: Emissions from nonfuel use of energy fuels are included in the energy consumption tables in this chapter. Data in this table are revised from unpublished data used to produce the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates presented in this chapter.

Table 13. U.S. Carbon Sequestered by Nonfuel Use of Energy Fuels, 1990, 1995, and 1998-2005
(Million Metric Tons Carbon Dioxide Equivalent)

End Use and Type	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Industrial										
Petroleum										
Liquefied Petroleum Gases	59.3	78.5	86.4	89.9	82.1	76.7	79.9	76.3	77.7	73.4
Distillate Fuel	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Residual Fuel	1.9	2.1	2.2	2.2	2.2	2.2	1.7	1.7	1.7	1.7
Asphalt and Road Oil	88.5	89.1	95.5	100.1	96.4	95.0	93.7	92.2	98.6	100.0
Lubricants	6.9	6.6	7.1	7.2	7.0	6.5	6.4	5.9	6.0	5.9
Other *(Subtotal)*	*72.0*	*83.0*	*92.7*	*94.9*	*88.7*	*83.9*	*86.4*	*88.1*	*101.9*	*94.6*
Pentanes Plus	4.4	16.2	10.9	14.0	12.7	10.8	9.2	9.0	9.1	8.0
Petrochemical Feed	46.0	50.0	59.1	55.5	57.7	50.7	55.1	59.2	69.2	64.2
Petroleum Coke	9.1	6.8	10.9	14.5	7.2	10.6	9.8	8.3	13.0	11.7
Special Naphtha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Waxes and Miscellaneous	12.5	10.1	11.8	10.9	11.2	11.8	12.2	11.5	10.6	10.6
Petroleum Subtotal	*228.8*	*259.6*	*284.3*	*294.8*	*277.0*	*264.7*	*268.6*	*264.7*	*286.3*	*276.1*
Coal	1.4	2.1	1.8	1.8	1.8	1.7	1.5	1.5	1.5	1.5
Natural Gas	14.4	18.4	21.9	22.5	22.6	21.2	17.7	17.7	17.7	17.7
Industrial Subtotal	***244.7***	***280.1***	***308.0***	***319.1***	***301.4***	***287.6***	***287.8***	***283.9***	***305.5***	***295.3***
Transportation										
Lubricants	6.5	6.2	6.7	6.8	6.7	6.1	6.0	5.6	5.6	5.6
Total	**251.2**	**286.4**	**314.7**	**325.8**	**308.1**	**293.7**	**293.8**	**289.5**	**311.1**	**300.9**

P = preliminary data.

Notes: Emissions from nonfuel use of energy fuels are included in the energy consumption tables in this chapter. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates presented in this chapter.

Table 14. U.S. Carbon Dioxide Emissions from Industrial Processes, 1990, 1995, and 1998-2005

(Million Metric Tons Carbon Dioxide)

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Cement Manufacture										
Clinker Production	32.6	36.1	38.4	39.2	40.4	40.5	42.0	42.2	44.7	44.9
Masonry Cement	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cement Kiln Dust	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9
Cement Subtotal	**33.3**	**36.9**	**39.3**	**40.1**	**41.3**	**41.5**	**43.0**	**43.2**	**45.7**	**45.9**
Other Industrial										
Limestone Consumption										
Lime Manufacture	12.4	14.5	15.8	15.5	15.4	14.8	14.1	15.1	15.7	15.7
Iron Smelting	1.7	1.2	1.1	1.0	1.1	1.0	0.9	0.9	1.0	0.7
Steelmaking	0.3	0.5	0.4	0.3	0.5	0.6	0.5	0.4	0.4	*
Copper Refining	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Glass Manufacture	0.1	0.3	0.0	0.2	0.2	0.1	0.1	0.2	0.2	0.2
Flue Gas Desulfurization	0.7	0.9	1.0	1.1	1.2	1.4	1.4	1.3	1.4	1.5
Dolomite Manufacture	0.5	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Limestone Subtotal	***15.9***	***17.8***	***18.7***	***18.3***	***18.6***	***18.1***	***17.1***	***18.0***	***18.9***	***18.3***
Soda Ash Manufacture	3.4	3.8	3.8	3.7	3.6	3.6	3.5	3.6	3.8	3.9
Soda Ash Consumption										
Glass Manufacture	0.1	0.3	*	0.2	0.2	0.1	0.1	0.2	0.2	0.2
Flue Gas Desulfurization	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Sodium Silicate	0.2	0.3	0.3	0.2	0.2	0.3	0.2	0.3	0.3	0.3
Sodium Tripolyphosphate	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Soda Ash Subtotal	***0.5***	***0.8***	***0.5***	***0.6***	***0.6***	***0.5***	***0.4***	***0.6***	***0.6***	***0.6***
Carbon Dioxide Manufacture	0.9	1.0	1.2	1.2	1.3	1.3	1.4	1.5	1.5	1.6
Aluminum Manufacture	5.9	4.9	5.4	5.5	5.4	3.9	4.0	4.0	3.7	3.7
Shale Oil Production	0.2	*	*	*	*	*	*	*	*	*
Other Industrial Subtotal	**26.8**	**28.4**	**29.7**	**29.3**	**29.4**	**27.4**	**26.4**	**27.6**	**28.5**	**28.1**
Total	**60.1**	**65.3**	**69.0**	**69.4**	**70.7**	**68.9**	**69.4**	**70.8**	**74.2**	**74.0**

*Less than 50,000 metric tons carbon dioxide.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates presented in this chapter.

3. Methane Emissions

Overview

U.S. Anthropogenic Methane Emissions, 1990-2005

	Methane	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Million Metric Tons)	26.6	611.9
Change Compared to 2004 (Million Metric Tons)	0.2	5.3
Change from 2004 *(Percent)*	*0.9%*	*0.9%*
Change Compared to 1990 (Million Metric Tons)	-3.9	-89.8
Change from 1990 *(Percent)*	*-12.8%*	*-12.8%*

U.S. anthropogenic methane emissions in 2005 totaled 611.9 million metric tons carbon dioxide equivalent (MMTCO$_2$e),[45] or 26.6 million metric tons of methane, representing 8.6 percent of total U.S. greenhouse gas emissions. U.S. methane emissions in 2005 were 0.9 percent (5.3 MMTCO$_2$e) higher than their 2004 level of 606.5 MMTCO$_2$e (Table 15), primarily as a result of an increase in emissions from waste management (landfills and wastewater treatment plants) and smaller increases in emissions associated with agriculture (ruminant animals and animal waste), which together more than offset declines in emissions from energy sources.[46]

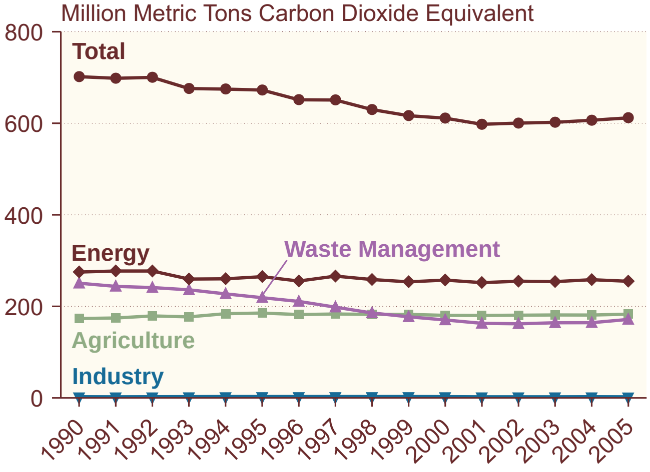
U.S. emissions of methane in 2005 were 12.8 percent (89.8 MMTCO$_2$e) below their 1990 level of 701.7 MMTCO$_2$e (Figure 2). In addition to a reduction of 81.6 MMTCO$_2$e (34 percent) in methane emissions from landfills since 1990, there was also a decrease of 32.2 MMTCO$_2$e (33 percent) in methane emissions from coal mines over the same period. The decline in emissions from coal mining was the result of a 173-percent increase in methane recovery from coal mines and a shift in production away from gassy mines. Methane emissions have decreased on average by 0.9 percent per year since 1990.

Principal Sources of U.S. Anthropogenic Methane Emissions, 1990-2005

	Million Metric Tons CO$_2$e		*Percent Change*	
Source	1990	2005	1990-2005	2004-2005
Energy	275.0	254.9	*-7.3%*	*-1.3%*
Waste Management	250.6	171.5	*-31.6%*	*4.3%*
Agriculture	173.4	183.0	*5.5%*	*1.0%*
Industrial Processes	2.7	2.5	*-8.4%*	*-7.7%*

Estimates of U.S. methane emissions have been revised to reflect a new methodology for estimating municipal solid waste (MSW) generated and landfilled. As a result, the estimate of total methane emissions in 1990 in this report is 19.4 MMTCO$_2$e lower than in previous reports. The downward revision grows over the time series, to

Figure 2. U.S. Emissions of Methane by Source, 1990-2005



Source: Estimates presented in this chapter.

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[45] Based on an estimated global warming potential factor of 23 for methane. For an expanded discussion of global warming potentials, see Chapter 1, pages 5-6.

[46] Recent research findings suggest that vegetation may emit methane under aerobic conditions. The proper allocation of such emissions to anthropogenic and nonanthropogenic pools remains to be determined. See the text box in Chapter 6, page 73, for discussion.

29.4 $MMTCO_2e$ in 2003, and is 33.7 $MMTCO_2e$ in 2004. Methane emission estimates generally are much more uncertain than carbon dioxide emission estimates. Methane emissions usually are accidental or incidental to biological processes and may not be metered in any systematic way.[47] Thus, methane emission estimates often must rely on proxy measurements.

Estimated U.S. anthropogenic methane emissions for 2005 are based on incomplete data for several key sources; thus, the overall estimate is likely to be revised. Because emissions from three of these sources—coal mining, natural gas systems, and landfills—represented more than three-fifths of all U.S. methane emissions, comparisons between 2004 and 2005 numbers are more likely to be valid in terms of their direction than their magnitude. For example, because 2005 data on waste generation are not yet available, waste generation has been estimated from a simple regression equation with economic output as the independent variable. Less critical but still important data are also unavailable for natural gas systems, such as miles of gas transmission and distribution pipeline.

Energy Sources

U.S. methane emissions from energy sources in 2005 are estimated at 254.9 $MMTCO_2e$, equivalent to 42 percent of total methane emissions. The 2005 emission level is 1.3 percent below the 2004 level of 258.3 $MMTCO_2e$. Total methane emissions from energy sources in 2005 were 20.1 $MMTCO_2e$ below their 1990 level of 275.0 $MMTCO_2e$.

The drop in methane emissions from energy sources since 1990 can be traced primarily to an overall reduction in emissions from coal mines and secondarily to lower emissions from petroleum systems and stationary combustion. Methane emissions from coal mines dropped by 33 percent (32.2 $MMTCO_2e$) between 1990 and 2005. This decline resulted partly from the increased capture and use of methane from coal mine degasification systems and a shift in production away from some of the Nation's gassiest underground mines in Central Appalachia. Also, between 1990 and 2005, the share of coal production represented by underground mines declined from 41 percent to 33 percent. Methane emissions from underground mines tend to be higher than emissions from surface mines per ton of coal mined, because coal mined from the surface has been subjected to lower pressures, and methane in the seams of surface mines has had earlier opportunities to migrate to the surface through cracks and fissures.

Methane emissions from petroleum systems dropped from 29.9 $MMTCO_2e$ in 1990 to 21.1 $MMTCO_2e$ in 2005. Decreases of 3.2 $MMTCO_2e$ and 1.1 $MMTCO_2e$ in estimated methane emissions from stationary and mobile source combustion, respectively, made smaller contributions to the overall drop in emissions from energy sources between 1990 and 2005. Together, the declines in emissions from coal mining, petroleum systems, and stationary and mobile combustion more than compensated for the increase of 25.1 $MMTCO_2e$ in emissions from natural gas systems, attributed to increasing U.S. consumption of natural gas between 1990 and 2005.

Coal Mining

U.S. Methane Emissions from Coal Mining, 1990-2005

	Methane	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Million Metric Tons)	2.8	65.5
Change Compared to 2004 (Million Metric Tons)	-0.1	-1.8
Change from 2004 *(Percent)*	*-2.7%*	*-2.7%*
Change Compared to 1990 (Million Metric Tons)	-1.4	-32.2
Change from 1990 *(Percent)*	*-32.9%*	*-32.9%*

The preliminary estimate of methane emissions from coal mines for 2005 is 65.5 $MMTCO_2e$ (Table 16), a decrease of 2.7 percent (1.8 $MMTCO_2e$) from the 2004 level of 67.3 $MMTCO_2e$. Despite a record level of coal production in 2005 to meet escalating demand—attributed to continued economic expansion and warm summer weather[48]—emissions were lower primarily as the result of a decrease in emissions from ventilation and degasification systems in the Nation's gassiest underground coal mines. Together, emissions from ventilation

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[47] Wherever possible, estimates of methane emissions are based on measured data. In some cases, however, measured data are incomplete or unavailable. In the absence of measured data, emissions are indexed to some known activity data, such as coal production or natural gas throughput, and multiplied by an emissions factor derived from a small sample of the relevant emissions source or through laboratory experiments. For a more detailed discussion of where measured data were used and how emissions factors were developed, see Energy Information Administration, *Documentation for Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0638(2004) (Washington, DC, November 2006), web site www.eia.doe.gov/oiaf/1605/ggrpt/documentation/pdf/0638(2004).pdf; and Energy Information Administration, *Documentation for Emissions of Greenhouse Gases in the United States 2005* (to be published).

[48] Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(2006/07) (Washington, DC, July 2006), Table 7.3a, "Consumption of Combustible Fuels for Electricity Generation: Total (All Sectors)," web site www.eia.doe.gov/emeu/mer.

and degasification systems in gassy mines totaled 56.0 $MMTCO_2e$ in 2005, more than 22 $MMTCO_2e$ lower than in 1990 and lower than in any subsequent year.

Methane emissions from coal mines have dropped by 33 percent, from 97.7 $MMTCO_2e$ in 1990 to 65.5 $MMTCO_2e$ in 2005. The decline is attributed to three important trends: (1) methane recovery from active coal mines for use as an energy resource increased from 6.1 $MMTCO_2e$ in 1990 to about 16.7 $MMTCO_2e$ in 2005; (2) methane emissions from degasification systems were reduced by nearly 7.3 $MMTCO_2e$, from 28.9 $MMTCO_2e$ in 1990 to 21.6 $MMTCO_2e$ in 2005; and (3) decreases in coal production from gassy mines, combined with enhanced methane recovery though degasification, caused methane emissions from ventilation systems at gassy mines to drop by about 15.3 $MMTCO_2e$, from 48.9 $MMTCO_2e$ in 1990 to 33.6 $MMTCO_2e$ in 2005 (Table 16).[49]

Abandoned coal mines represent a significant source of additional emissions that has not been incorporated into the overall estimate of methane emissions in this report because of uncertainties associated with the data. The text box on page 33 provides a discussion of those uncertainties and the potential magnitude of additional emissions.

Natural Gas Systems

U.S. Methane Emissions from Natural Gas Systems, 1990-2005

	Methane	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Million Metric Tons)	6.7	154.0
Change Compared to 2004 (Million Metric Tons)	*	-0.7
Change from 2004 *(Percent)*	*-0.5%*	*-0.5%*
Change Compared to 1990 (Million Metric Tons)	1.1	25.1
Change from 1990 *(Percent)*	*19.5%*	*19.5%*

*Less than 0.05 million metric tons.

At 154.0 $MMTCO_2e$, 2005 estimated methane emissions from natural gas systems were down by 0.5 percent from the 154.7 $MMTCO_2e$ emitted in 2004 (Table 17). The 2005 estimate is preliminary, however, because pipeline data for 2005 have not been finalized as of the publication of this report. The estimated 2005 emissions level is 19 percent (25.1 $MMTCO_2e$) above the 1990 level (128.9 $MMTCO_2e$), with more than three-fifths of the increase attributable to increased mileage of transmission and distribution pipelines and almost two-fifths attributable to increases in natural gas production.[50]

Petroleum Systems

U.S. Methane Emissions from Petroleum Systems, 1990-2005

	Methane	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Million Metric Tons)	0.9	21.1
Change Compared to 2004 (Million Metric Tons)	-0.1	-1.2
Change from 2004 *(Percent)*	*-5.3%*	*-5.3%*
Change Compared to 1990 (Million Metric Tons)	-0.4	-8.8
Change from 1990 *(Percent)*	*-29.5%*	*-29.5%*

Methane emissions from petroleum systems in 2005 are estimated at 21.1 $MMTCO_2e$, 5.3 percent below their 2004 level and 29 percent (8.8 $MMTCO_2e$) below the 1990 level of 29.9 $MMTCO_2e$. The decline in emissions from this source is almost exclusively due to a 30-percent reduction in domestic oil production from 1990 to 2005. Approximately 96 percent (20.2 $MMTCO_2e$) of all U.S. emissions from petroleum systems occur during oil exploration and production (Table 18). A much smaller portion of methane emissions from petroleum systems can be traced to refineries (0.6 $MMTCO_2e$) and transportation of crude oil (0.2 $MMTCO_2e$).

Stationary Combustion

U.S. methane emissions from stationary combustion in 2005 were 9.7 $MMTCO_2e$, up by 1.8 percent from their 2004 level of 9.5 $MMTCO_2e$ but still 25 percent below

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[49] EIA obtains data on methane released and recovered from pre-mining degasification from the U.S. Environmental Protection Agency (EPA).

[50] The EPA estimates that companies participating in the Natural Gas STAR program together avoided emissions of 34.7 $MMTCO_2e$ of methane from the natural gas system in 2005 (Table 17). Program participants report annually on emissions reductions achieved through such activities as equipment replacement, enhanced inspection and maintenance, and improved operations management. Participating companies may either use their own techniques to estimate reductions achieved or employ default values developed by the EPA and the Gas Technology Institute (formerly the Gas Research Institute).

U.S. Methane Emissions from Stationary Combustion, 1990-2005

	Methane	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Million Metric Tons)	0.4	9.7
Change Compared to 2004 (Million Metric Tons)	*	0.2
Change from 2004 *(Percent)*	*1.8%*	*1.8%*
Change Compared to 1990 (Million Metric Tons)	-0.1	-3.2
Change from 1990 *(Percent)*	*-24.9%*	*-24.9%*

*Less than 0.05 million metric tons.

U.S. Methane Emissions from Mobile Sources, 1990-2005

	Methane	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Million Metric Tons)	0.2	4.5
Change Compared to 2004 (Million Metric Tons)	*	0.1
Change from 2004 *(Percent)*	*2.9%*	*2.9%*
Change Compared to 1990 (Million Metric Tons)	*	-1.1
Change from 1990 *(Percent)*	*-19.4%*	*-19.4%*

*Less than 0.05 million metric tons.

their 1990 level of 12.9 MMTCO$_2$e (Table 19). Residential wood consumption typically accounts for about 88 percent of methane emissions from stationary combustion. Methane emissions are the result of incomplete combustion, and residential woodstoves and fireplaces provide much less efficient combustion than industrial or utility boilers. Estimates of emissions from residential wood combustion have fallen by 28 percent, from 11.8 MMTCO$_2$e in 1990 to 8.5 MMTCO$_2$e in 2005, although these estimates are very uncertain.[51]

The universe of wood consumers is large and heterogeneous, and the Energy Information Administration (EIA) collects data on residential wood consumption only at 4-year intervals in its Residential Energy Consumption Survey (RECS). The most recently published EIA data on residential wood consumption are from the 2001 RECS.[52]

Mobile Combustion

Estimated U.S. methane emissions from mobile combustion in 2005 were 4.5 MMTCO$_2$e, up by 2.9 percent from the 2004 level but 19 percent lower than the 1990 level of 5.6 MMTCO$_2$e (Table 20). Methane emissions from passenger cars have declined since 1990 as older vehicles with catalytic converters that are less efficient at destroying methane have been taken off the road. Estimates of methane emissions from mobile sources have been revised downward in the last three annual editions of this report, reflecting a change in the source of data for vehicle miles traveled and a related adjustment in the emission factors for light-duty trucks.[53]

Waste Management

Methane emissions from waste management, at 171.5 MMTCO$_2$e, accounted for 28 percent of U.S. anthropogenic methane emissions in 2005 (Figure 2). Emissions from this source have fallen by 32 percent (79.1 MMTCO$_2$e) from their 1990 level of 250.6 MMTCO$_2$e. Landfills represent 91 percent (155.7 MMTCO$_2$e) of the methane emissions from waste management in 2005, and they are the largest single source of U.S. anthropogenic methane emissions (Table 15). The remainder of emissions from waste management (15.8 MMTCO$_2$e) is associated with domestic wastewater treatment. Estimated emissions from waste management would increase if sufficient information were available to develop a reliable estimate of emissions from industrial wastewater treatment.

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[51] For further details see Energy Information Administration, *Documentation for Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0638(2004) (Washington, DC, November 2006), web site www.eia.doe.gov/oiaf/1605/ggrpt/documentation/pdf/0638(2004).pdf; and Energy Information Administration, *Documentation for Emissions of Greenhouse Gases in the United States 2005* (to be published).

[52] Energy Information Administration, Residential Energy Consumption Survey, web site www.eia.doe.gov/emeu/recs/recs2001/publicuse2001.html. Updated data on residential wood consumption for calendar year 2004 will be available from the 2005 RECS in spring 2007.

[53] For a more detailed discussion of the revisions in estimation methods for mobile sources, see Energy Information Administration, *Documentation for Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0638(2004) (Washington, DC, November 2006), web site www.eia.doe.gov/oiaf/1605/ggrpt/documentation/pdf/0638(2004).pdf; and Energy Information Administration, *Documentation for Emissions of Greenhouse Gases in the United States 2005* (to be published).

Methane Emissions from Abandoned Coal Mines

Thousands of coal mines in the United States have been closed and abandoned during the past 100 years. The U.S. Department of Labor's Mine Safety and Health Administration (MSHA) estimates that since 1980 more than 7,500 coal mines have been abandoned, and many continue to emit methane. In an April 2004 report,[a] the U.S. Environmental Protection Agency (EPA) estimated that methane emissions from abandoned coal mines ranged between 3.0 $MMTCO_2e$ and 4.6 $MMTCO_2e$ in 1990, and between 4.6 $MMTCO_2e$ and 6.4 $MMTCO_2e$ in 2002. More recently, the EPA estimated methane emissions of 7.1 $MMTCO_2e$ from abandoned underground coal mines in 2004, up from 6.0 $MMTCO_2e$ in 1990 but down from a peak of 8.7 $MMTCO_2e$ in 2000 due to a decline in the number of gassy mines being abandoned.[b] Because access to abandoned mines is limited and a systematic measurement program at those sites would be time-intensive and costly, the EPA estimates rely on actual emissions data from when the mines were operating and assume a decline function in emissions based on mine and coal-seam characteristics.

The most important variable in determining the amount of methane emissions from an abandoned mine is its post-mining status—whether the mine has been sealed, flooded, or continues to be vented. Sealed and flooded mines have much lower rates of emissions than vented mines. Another variable deemed important is whether the mine was gassy (emitting more than 100,000 cubic feet per day) when it was operating. Gassy mines are estimated to emit 98 percent of all methane emissions from operating coal mines, and the EPA assumes that abandoned mines which had been gassy when operating represent a similarly predominant portion of emissions from abandoned mines. The EPA's 2004 study thus focuses on abandoned mines that had been gassy prior to closure. Of the 438 gassy mines abandoned since 1972, the EPA has data on the status (i.e., whether the mines were sealed, flooded, or continue to be vented) of 263 or 60 percent of them. From those data, the EPA calculates percentage shares of emissions by status, then assumes that the same shares apply to mines for which it does not have data.

For abandoned mines that have been vented, the EPA derives an emissions decline curve based on three primary factors: adsorption isotherms by coal basin, coal permeability estimates, and estimates of pressure at abandonment. For mines that are flooded, the EPA assumes a decline curve equation based on measurements taken from eight abandoned mines in two basins. The EPA treats sealed mines similarly to those vented, adjusting the initial emissions rate and length of time for emissions to dissipate, given the slower release rate from sealed vents.

The EPA sought to calibrate its estimation methodology to field measurements, but restricted access precluded measurement at all but seven mines. Although results from those mines suggested the general accuracy of the estimation method, the methodology had not yet been validated when this report was being prepared. EIA expects the new method to be included in the 2006 IPCC *Guidelines for National Greenhouse Gas Inventories* and anticipates the inclusion of estimates for this source in future annual reports.

[a] U.S. Environmental Protection Agency, Coalbed Methane Outreach Program, *Methane Emissions from Abandoned Coal Mines in the United States: Emission Inventory Methodology and 1990-2002 Emissions Estimates* (Washington, DC, April 2004), web site www.epa.gov/cmop/pdf/amm_final_report.pdf.

[b] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

EIA's estimates of methane emissions from landfills include emissions from both MSW landfills and industrial landfills. Estimated methane emissions from industrial landfills, based on a methodology developed by the EPA, represent 7 percent of emissions from MSW landfills.[54]

In calculating methane emissions from landfills, EIA uses estimates of MSW generated and MSW landfilled, published by *Biocycle* magazine.[55] In its April 2006 issue, *Biocycle* reported estimates of MSW generated in 2002 and 2004 that were more than 20 percent below its previously published estimates. The reason for the revisions is that *Biocycle* now excludes certain non-MSW materials (such as construction and demolition debris and industrial waste) from its MSW generation estimates.

To ensure that EIA's estimates of methane emissions from landfills are consistent over the entire 1990-2005 time frame, waste generation estimates for the years 1989 through 2004 have been adjusted downward, based on the implied downward revision of the *Biocycle*

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[54] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[55] *Biocycle*, "The State of Garbage in America" (various years).

data most recently reported for 2002 and 2004. EIA assumed a constant ratio of actual MSW generation to reported MSW generation for the period 1989 through 2004 and adjusted the estimates of waste generation—and methane emissions from landfills—for those years downward, to ensure that all the earlier estimates (1990-2004) are consistent with *Biocycle*'s new method. The change results in a decrease of roughly 20 percent in the estimated volumes of waste generated and landfilled across all years.

Landfills

U.S. Methane Emissions from Landfills, 1990-2005

	Methane	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Million Metric Tons)	6.8	155.7
Change Compared to 2004 (Million Metric Tons)	0.3	6.9
Change from 2004 *(Percent)*	*4.6%*	*4.6%*
Change Compared to 1990 (Million Metric Tons)	-3.5	-81.6
Change from 1990 *(Percent)*	*-34.4%*	*-34.4%*

Due to increased levels of waste disposed in landfills, estimated methane emissions from landfills rose to 155.7 $MMTCO_2e$ in 2005, 4.6 percent (6.9 $MMTCO_2e$) above the 2004 level of 148.8 $MMTCO_2e$ but still 34 percent (81.6 $MMTCO_2e$) below the 1990 level of 237.3 $MMTCO_2e$ (Table 21). The decrease in methane emissions (about one-third since 1990) is directly attributable to an increase of 100.8 $MMTCO_2e$ in methane captured at landfills that otherwise would have been emitted to the atmosphere. Of the 122.5 $MMTCO_2e$ of methane believed to have been captured from this source in 2005, 64.9 $MMTCO_2e$ was recovered for energy use, and 57.5 $MMTCO_2e$ was recovered and flared. In 2005, methane recovery for energy increasingly took the form of direct use of medium-Btu gas in industrial boilers. The acceleration of this practice was driven by higher natural gas prices, which made landfill gas more competitive.[56]

Estimates of methane recovered for energy are drawn from data collected by the U.S. Environmental Protection Agency's (EPA's) Landfill Methane Outreach Program[57] and EIA's Voluntary Reporting of Greenhouse Gas Emissions and Reductions Program. Estimates of methane recovered and flared are based on data collected from flaring equipment vendors, in conjunction with data reported on Form EIA-1605.[58] There is less uncertainty in the estimate of methane recovered and used for energy, which has a market value; however, it is likely that estimates of methane flared are subject to error due to a lack of comprehensive industry data.

The rapid growth in methane recovery has been aided by a combination of regulatory and tax policy. The Federal Section 29 (of the Internal Revenue Code) tax credit for alternative energy sources, added to the tax code as part of the Crude Oil Windfall Profits Act of 1980, provided a subsidy roughly equivalent to 1 cent per kilowatthour for electricity generated from landfill gas; however, the tax credit expired on June 30, 1998. As part of the American Jobs Creation Act of 2004, a tax credit for electricity generation using landfill gas was added to Section 45 of the Internal Revenue Code. The credit was augmented under the Energy Policy Act of 2005, which extended the credit period—previously 5 years from the original date of service—to 10 years from the original date of service. To be eligible for the credit, a landfill gas-to-energy project must be placed in service between October 22, 2004, and December 31, 2007. Those facilities that qualify are eligible for a 5-year tax credit valued at 0.9 cent per kilowatthour.

Increases in methane recovery have also resulted from the implementation of the EPA's New Source Performance Standards and Emission Guidelines. The regulations require all landfills with more than 2.5 million metric tons of waste in place and annual emissions of nonmethane organic compounds (NMOCs) exceeding 50 metric tons to collect and burn their landfill gas, either by flaring or for use as an energy source.

Domestic and Commercial Wastewater Treatment

With the U.S. population growing by only about 1 percent per year, methane emissions from domestic and commercial wastewater treatment are estimated to have grown by 1.0 percent between 2004 and 2005 to 15.8 $MMTCO_2e$—about 19 percent above the 1990 level of

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[56] Personal communication with Brian Guzzone, U.S. Environmental Protection Agency, Landfill Methane Outreach Program.

[57] U.S. Environmental Protection Agency, Landfill Methane Outreach Program, web site www.epa.gov/lmop.

[58] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http:// yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2006.html; and Energy Information Administration, Voluntary Reporting of Greenhouse Gases database, web site www.eia.doe.gov/oiaf/1605/database.html.

13.2 MMTCO$_2$e (Table 15). Methane emissions from industrial wastewater treatment are discussed in the text box on page 36.

U.S. Methane Emissions from Domestic and Commercial Wastewater Treatment, 1990-2005

	Methane	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Million Metric Tons)	0.7	15.8
Change Compared to 2004 (Million Metric Tons)	*	0.2
Change from 2004 *(Percent)*	*1.0%*	*1.0%*
Change Compared to 1990 (Million Metric Tons)	0.1	2.5
Change from 1990 *(Percent)*	*19.2%*	*19.2%*

*Less than 0.05 million metric tons.

Methane emissions from domestic and commercial wastewater treatment are a function of the share of organic matter in the wastewater stream and the conditions under which it decomposes. Wastewater may be treated aerobically or anaerobically. Because aerobic decomposition does not yield methane, whereas anaerobic decomposition does, the method of treatment is a critical determinant of emissions; however, there is little information available on wastewater treatment methods. Data on flaring or energy recovery from methane generated by wastewater are also sparse. EIA believes that emissions from this source are relatively small, representing less than 3 percent of all U.S. methane emissions in 2005. Thus, emissions are estimated using a default per-capita emissions factor and U.S. population data.

Agricultural Sources

Estimated methane emissions from agricultural sources, at 183.0 MMTCO$_2$e in 2005, represent 30 percent of total U.S. anthropogenic methane emissions (Table 15). Agricultural methane emissions increased by 1.0 percent (1.9 MMTCO$_2$e) from 2004 to 2005, as emissions increases from enteric fermentation and animal waste management more than offset small decreases in emissions from rice cultivation and crop residue burning. Of total estimated methane emissions from agricultural activities, 93 percent (170.9 MMTCO$_2$e) results from livestock management, of which 68 percent (115.6 MMTCO$_2$e) can be traced to enteric fermentation in ruminant animals and the remainder (55.3 MMTCO$_2$e) to anaerobic decomposition of livestock wastes. A small portion of U.S. agricultural methane emissions result from crop residue burning and wetland rice cultivation.

Enteric Fermentation in Domesticated Animals

U.S. Methane Emissions from Enteric Fermentation in Domesticated Animals, 1990-2005

	Methane	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Million Metric Tons)	5.0	115.6
Change Compared to 2004 (Million Metric Tons)	0.1	1.4
Change from 2004 *(Percent)*	*1.2%*	*1.2%*
Change Compared to 1990 (Million Metric Tons)	-0.2	-4.1
Change from 1990 *(Percent)*	*-3.4%*	*-3.4%*

In 2005, estimated methane emissions from enteric fermentation in domesticated animals rose by 1.2 percent to 115.6 MMTCO$_2$e (Table 22). Because 95 percent (110.0 MMTCO$_2$e) of all emissions from enteric fermentation is attributable to cattle, trends in emissions correlate with trends in cattle populations. Between 2004 and 2005, cattle populations grew by 1.1 percent, with small gains in all population categories. Estimated methane emissions from enteric fermentation in 2005 are 3.4 percent below their 1990 level of 119.6 MMTCO$_2$e.

Solid Waste of Domesticated Animals

Estimated methane emissions from the solid waste of domesticated animals increased from 54.7 MMTCO$_2$e in 2004 to 55.3 MMTCO$_2$e in 2005 (Table 23). The increase reinforced a larger trend over the past decade: in 2005, emissions from the solid waste of domesticated animals were 11.8 MMTCO$_2$e above their 1990 level of 43.5 MMTCO$_2$e, an increase of 27 percent. Between 1990 and 2005, there was a shift in livestock management to larger facilities, which are believed to be more likely to manage waste using liquid systems that tend to promote methane generation.[59]

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[59] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), p. 6-7, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

U.S. Methane Emissions from Solid Waste of Domesticated Animals, 1990-2005

	Methane	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Million Metric Tons)	2.4	55.3
Change Compared to 2004 (Million Metric Tons)	*	0.6
Change from 2004 *(Percent)*	*1.1%*	*1.1%*
Change Compared to 1990 (Million Metric Tons)	0.5	11.8
Change from 1990 *(Percent)*	*27.2%*	*27.2%*

*Less than 0.05 million metric tons.

Rice Cultivation

Estimated methane emissions from U.S. rice cultivation in 2005, at 10.9 $MMTCO_2e$, were nearly unchanged from their 2004 level (Table 15). The total acreage of rice harvested was 0.9 percent higher in 2005 than in 2004, but the increase was centered in Arkansas and Mississippi—two States where the length of the harvesting season is slightly lower than average.[60] Methane emissions from rice cultivation in 2005 were 17 percent (1.6 $MMTCO_2e$) higher than in 1990.

Burning of Crop Residues

Crop residue burning, the smallest contributor to U.S. methane emissions, represents less than 1 percent of total U.S. methane emissions. Estimated 2005 methane emissions from the burning of crop residues were 1.2 MMTCO2e, down by 3.8 percent from 2004 but still 23 percent above their 1990 level of 1.0 MMTCO2e (Table 15). The decrease from 2004 to 2005 is attributable to a decline in U.S. crop production.

Methane Emissions from Industrial Wastewater Treatment

When wastewater containing large amounts of organic material is treated through anaerobic decomposition, methane is emitted. The best estimate of those emissions would be based on a systematic measurement of all point sources; however, the number and diversity of U.S. industrial wastewater sources make such an approach unaffordable and impractical. As an alternative, methane emissions from industrial wastewater treatment are calculated by the following equation:

$$M = P \times O \times COD \times A \times EF \quad ,$$

where M = methane emissions, P = product output, O = wastewater outflow per unit of product output, COD = organic loading in outflow, A = percentage of outflow treated anaerobically, and EF = emissions factor for anaerobically treated outflow.

The Intergovernmental Panel on Climate Change (IPCC), in its *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*,[a] provides default data for wastewater generation and *COD* on an industry-specific basis. The default data, often based on one or two literature sources, are assumed to have an uncertainty range of minus 50 percent to plus 100 percent (although no justification for the range is provided). The IPCC also provides a single default factor of 0.25 kilograms methane per kilogram of *COD*, premised on a general approximation of the theoretical maximum for this emission factor, and identifies an uncertainty of plus or minus 30 percent for this estimate.

There are currently no specific U.S. data that could be used to improve on the IPCC defaults, and the uncertainties make it impossible for the Energy Information Administration (EIA) to provide a reliable estimate of emissions from this source. It can, however, be noted that—depending on the extent to which industrial wastewater from such industries as meat and poultry processing, pulp and paper manufacturing, and vegetable, fruit, and juice processing (which is likely to have a high content of organic material) is treated anaerobically—excluding the resulting methane emissions from the U.S. emissions total will tend to produce an underestimate. The U.S. Environmental Protection Agency estimates that U.S. methane emissions from industrial wastewater treatment could be as high as 16.9 $MMTCO_2e$ in 2004.[b] EIA anticipates that additional methodological guidance and data will be forthcoming in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories that will support emissions estimates for this source in subsequent annual reports.

[a] Intergovernmental Panel On Climate Change, *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (Montreal, Canada, May 2000), web site www.ipcc-nggip.iges.or.jp/public/gp/english/.

[b] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

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[60] U.S. Department of Agriculture, National Agricultural Statistics Service, *Crop Production—Annual Summary* (Washington, DC, various years), web site http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bban.

Industrial Processes

U.S. Methane Emissions from Industrial Processes, 1990-2005

	Methane	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Million Metric Tons)	0.1	2.5
Change Compared to 2004 (Million Metric Tons)	*	-0.2
Change from 2004 *(Percent)*	*-7.7%*	*-7.7%*
Change Compared to 1990 (Million Metric Tons)	*	-0.2
Change from 1990 *(Percent)*	*-8.4%*	*-8.4%*

*Less than 0.05 million metric tons.

Chemical Production

The preliminary estimate of methane emissions from U.S. chemical production in 2005 is 1.5 MMTCO$_2$e, down by 6.1 percent from the 2004 level of 1.6 MMTCO$_2$e. The decrease from 2004 levels is attributable to declining production of ethylene, ethylene dichloride, methanol, and styrene. Methane emissions from chemical production in 2005 were 18 percent above their 1990 level of 1.3 MMTCO$_2$e (Table 24).[61]

Iron and Steel Production

With production of pig iron reaching a 2-decade low in 2005,[62] methane emissions from iron and steel production dropped to an estimated 1.0 MMTCO$_2$e in 2005, a 10-percent decrease from 2004 levels and 32 percent below their 1990 level of 1.4 MMTCO$_2$e (Table 24).

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[61] Personal communication with Kevin Swift, American Chemistry Council (July 2006).

[62] American Iron and Steel Institute, *Annual Statistical Report*, Tables 26, 31, and 32 (Washington, DC, various years).

Table 15. U.S. Methane Emissions from Anthropogenic Sources, 1990, 1995, and 1998-2005

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Million Metric Tons Carbon Dioxide Equivalent										
Energy Sources										
Coal Mining	97.7	83.8	75.6	71.5	68.1	68.0	64.1	64.2	67.3	65.5
Natural Gas Systems	128.9	137.6	143.9	144.2	151.0	147.0	154.0	153.2	154.7	154.0
Petroleum Systems	29.9	26.9	25.5	24.0	23.8	23.7	23.5	23.3	22.3	21.1
Stationary Combustion	12.9	11.8	8.9	9.3	10.0	8.7	8.9	9.3	9.5	9.7
Mobile Sources	5.6	4.8	4.7	4.6	4.6	4.5	4.4	4.2	4.4	4.5
Total Energy Sources	**275.0**	**264.9**	**258.6**	**253.7**	**257.5**	**251.9**	**255.0**	**254.1**	**258.3**	**254.9**
Waste Management										
Landfills	237.3	204.9	170.9	162.4	155.4	147.8	146.7	148.7	148.8	155.7
Wastewater Treatment	13.2	14.2	14.7	14.8	15.0	15.2	15.3	15.5	15.6	15.8
Total Waste Management	**250.6**	**219.1**	**185.6**	**177.2**	**170.3**	**162.9**	**162.0**	**164.2**	**164.5**	**171.5**
Agricultural Sources										
Enteric Fermentation	119.6	124.4	117.2	117.3	116.3	115.1	115.8	116.1	114.2	115.6
Animal Waste	43.5	49.9	53.6	52.7	52.8	53.3	53.7	54.2	54.7	55.3
Rice Cultivation	9.3	10.2	10.7	11.5	10.2	10.7	10.2	9.8	10.9	10.9
Crop Residue Burning	1.0	1.0	1.1	1.1	1.1	1.1	1.0	1.2	1.3	1.2
Total Agricultural Sources	**173.4**	**185.4**	**182.6**	**182.5**	**180.4**	**180.3**	**180.7**	**181.3**	**181.1**	**183.0**
Industrial Processes	**2.7**	**3.0**	**3.1**	**3.1**	**2.9**	**2.5**	**2.6**	**2.6**	**2.7**	**2.5**
Total	**701.7**	**672.5**	**629.8**	**616.5**	**611.2**	**597.7**	**600.2**	**602.2**	**606.5**	**611.9**
Million Metric Tons Methane										
Energy Sources										
Coal Mining	4.25	3.64	3.29	3.11	2.96	2.96	2.79	2.79	2.93	2.85
Natural Gas Systems	5.60	5.98	6.26	6.27	6.57	6.39	6.70	6.66	6.73	6.70
Petroleum Systems	1.30	1.17	1.11	1.04	1.03	1.03	1.02	1.01	0.97	0.92
Stationary Combustion	0.56	0.51	0.39	0.41	0.43	0.38	0.39	0.41	0.41	0.42
Mobile Sources	0.24	0.21	0.20	0.20	0.20	0.20	0.19	0.18	0.19	0.20
Total Energy Sources	**11.96**	**11.52**	**11.24**	**11.03**	**11.20**	**10.95**	**11.09**	**11.05**	**11.23**	**11.08**
Waste Management										
Landfills	10.32	8.91	7.43	7.06	6.75	6.42	6.38	6.47	6.47	6.77
Wastewater Treatment	0.58	0.62	0.64	0.65	0.65	0.66	0.67	0.67	0.68	0.69
Total Waste Management	**10.89**	**9.53**	**8.07**	**7.70**	**7.41**	**7.08**	**7.04**	**7.14**	**7.15**	**7.46**
Agricultural Sources										
Enteric Fermentation	5.20	5.41	5.09	5.10	5.06	5.00	5.03	5.05	4.97	5.02
Animal Waste	1.89	2.17	2.33	2.29	2.29	2.32	2.33	2.36	2.38	2.41
Rice Cultivation	0.40	0.44	0.47	0.50	0.44	0.47	0.45	0.43	0.47	0.47
Crop Residue Burning	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.05
Total Agricultural Sources	**7.54**	**8.06**	**7.94**	**7.94**	**7.85**	**7.84**	**7.86**	**7.88**	**7.88**	**7.96**
Industrial Processes	**0.12**	**0.13**	**0.13**	**0.13**	**0.13**	**0.11**	**0.11**	**0.11**	**0.12**	**0.11**
Total	**30.51**	**29.24**	**27.38**	**26.80**	**26.57**	**25.99**	**26.10**	**26.18**	**26.37**	**26.60**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2004*. Emissions calculations based on Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.83-4.84, web site www.ipcc.ch/pub/guide.htm; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

Table 16. U.S. Methane Emissions from Coal Mining and Post-Mining Activities, 1990, 1995, and 1998-2005

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Million Metric Tons Carbon Dioxide Equivalent										
Surface Mining										
Mining	9.8	10.3	11.4	11.5	11.4	12.1	12.0	11.7	12.1	12.4
Post-Mining	0.9	0.9	1.0	1.0	1.0	1.1	1.0	1.0	1.1	1.1
Subtotal	*10.7*	*11.2*	*12.4*	*12.5*	*12.4*	*13.2*	*13.0*	*12.7*	*13.1*	*13.5*
Underground Mining										
Ventilation (Gassy Mines)[a]	48.9	43.9	41.5	40.6	38.3	37.2	34.7	33.4	36.3	33.6
Ventilation (Nongassy Mines)	0.6	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8
Degasification Systems	28.9	27.8	21.8	17.5	19.8	21.7	22.3	22.1	21.9	21.6
Post-Mining	14.7	13.7	14.5	13.6	12.9	13.2	12.4	12.2	12.7	12.8
Methane Recovery for Energy (-)	6.1	13.6	15.5	13.6	16.2	18.0	19.0	16.9	17.5	16.7
Subtotal	*87.0*	*72.5*	*63.2*	*58.9*	*55.7*	*54.9*	*51.1*	*51.5*	*54.2*	*52.1*
Net Emissions	**97.7**	**83.8**	**75.6**	**71.5**	**68.1**	**68.0**	**64.1**	**64.2**	**67.3**	**65.5**
Million Metric Tons Methane										
Surface Mining										
Mining	0.43	0.45	0.49	0.50	0.49	0.53	0.52	0.51	0.53	0.54
Post-Mining	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.05	0.05
Subtotal	*0.46*	*0.49*	*0.54*	*0.54*	*0.54*	*0.57*	*0.57*	*0.55*	*0.57*	*0.59*
Underground Mining										
Ventilation (Gassy Mines)[a]	2.13	1.91	1.80	1.76	1.67	1.62	1.51	1.45	1.58	1.46
Ventilation (Nongassy Mines)	0.03	0.03	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.03
Degasification Systems	1.26	1.21	0.95	0.76	0.86	0.94	0.97	0.96	0.95	0.94
Post-Mining	0.64	0.60	0.63	0.59	0.56	0.57	0.54	0.53	0.55	0.55
Methane Recovery for Energy (-)	0.26	0.59	0.67	0.59	0.70	0.78	0.83	0.74	0.76	0.72
Subtotal	*3.78*	*3.15*	*2.75*	*2.56*	*2.42*	*2.38*	*2.22*	*2.24*	*2.36*	*2.26*
Net Emissions	**4.25**	**3.64**	**3.29**	**3.11**	**2.96**	**2.96**	**2.79**	**2.79**	**2.93**	**2.85**

[a] A “gassy” mine is an underground mine with ventilation emissions of 100,000 cubic feet of methane or more per day, as measured by the U.S. Mine Safety and Health Administration.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2004.* Coal production numbers from Energy Information Administration, *Coal Production*, DOE/EIA-0118 (Washington, DC, various years), and *Coal Industry Annual*, DOE/EIA-0584 (Washington, DC, various years). Methane recovery rates from U.S. Environmental Protection Agency, Office of Air and Radiation, Non-CO_2 Gases and Sequestration Branch, Coalbed Methane Outreach Program. Ventilation data for 1985, 1988, and 1990 provided by G. Finfinger, U.S. Department of the Interior, Bureau of Mines, Pittsburgh Research Center. Ventilation data for all other years provided by U.S. Environmental Protection Agency, Office of Air and Radiation, Non-CO_2 Gases and Sequestration Branch, Coalbed Methane Outreach Program.

Table 17. U.S. Methane Emissions from Natural Gas Systems, 1990, 1995, and 1998-2005

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Million Metric Tons Carbon Dioxide Equivalent										
Production	33.8	36.1	38.4	37.3	39.9	42.0	42.4	42.9	43.5	43.1
Natural Gas Processing	14.9	16.5	16.0	16.1	16.4	16.0	15.5	14.4	14.8	14.5
Transmission and Storage	48.3	49.3	51.0	52.8	55.4	49.0	55.6	54.7	53.7	53.8
Distribution	32.0	35.7	38.5	38.0	39.3	40.0	40.5	41.2	42.6	42.6
Total	**128.9**	**137.6**	**143.9**	**144.2**	**151.0**	**147.0**	**154.0**	**153.2**	**154.7**	**154.0**
Natural Gas STAR Reductions	0.3	5.0	10.4	12.2	14.7	18.2	22.4	24.2	29.2	34.7
Million Metric Tons Methane										
Production	1.47	1.57	1.67	1.62	1.73	1.83	1.84	1.87	1.89	1.87
Natural Gas Processing	0.65	0.72	0.69	0.70	0.71	0.69	0.67	0.63	0.65	0.63
Transmission and Storage	2.10	2.14	2.22	2.30	2.41	2.13	2.42	2.38	2.34	2.34
Distribution	1.39	1.55	1.67	1.65	1.71	1.74	1.76	1.79	1.85	1.85
Total	**5.60**	**5.98**	**6.26**	**6.27**	**6.57**	**6.39**	**6.70**	**6.66**	**6.73**	**6.70**
Natural Gas STAR Reductions	0.01	0.22	0.45	0.53	0.64	0.79	0.97	1.05	1.27	1.51

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding. Data for Natural Gas STAR reductions are estimates provided by the EPA, based on annual submissions to the EPA by companies participating in the program, which report activities undertaken to avoid methane emissions from natural gas and petroleum systems.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2004*; National Risk Management Research Laboratory, *Methane Emissions From the Natural Gas Industry*, Vol. 2, Technical Report, GRI-94/0257.1 and EPA-600-R-96-08 (Research Triangle Park, NC, June 1996), Appendix A; American Gas Association, *Gas Facts* (various years); Energy Information Administration, *Natural Gas Annual,* DOE/EIA-0131 (various years); Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(2005/07) (Washington, DC, July 2005); and Energy Information Administration, *Petroleum Supply Annual*, DOE/EIA-0340 (Washington, DC, various years).

Table 18. U.S. Methane Emissions from Petroleum Systems, 1990, 1995, and 1998-2005

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Million Metric Tons Carbon Dioxide Equivalent										
Refineries	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Exploration and Production	29.0	26.1	24.7	23.2	22.9	22.9	22.6	22.4	21.4	20.2
Crude Oil Transportation	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total	**29.9**	**26.9**	**25.5**	**24.0**	**23.8**	**23.7**	**23.5**	**23.3**	**22.3**	**21.1**
Million Metric Tons Methane										
Refineries	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Exploration and Production	1.26	1.13	1.07	1.01	1.00	0.99	0.98	0.97	0.93	0.88
Crude Oil Transportation	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	**1.30**	**1.17**	**1.11**	**1.04**	**1.03**	**1.03**	**1.02**	**1.01**	**0.97**	**0.92**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2004*; U.S. Environmental Protection Agency, Office of Air and Radiation, *Draft Estimates of Methane Emissions from the U.S. Oil Industry* (Draft Report, Washington, DC); Energy Information Administration, *Petroleum Supply Annual*, DOE/EIA-0340 (Washington, DC, various years); and *Oil and Gas Journal*, Worldwide Refining Issue and Pipeline Economics Issue (various years).

Table 19. U.S. Methane Emissions from Stationary Combustion Sources, 1990, 1995, and 1998-2005

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
	Thousand Metric Tons Carbon Dioxide Equivalent									
Residential										
Coal	*	*	*	*	*	*	*	*	*	*
Fuel Oil[a]	113	105	89	96	105	105	99	105	107	108
Natural Gas	100	110	103	107	113	108	111	116	111	110
LPG	10	11	12	14	15	14	14	14	14	14
Wood	11,763	10,546	7,707	8,112	8,721	7,504	7,707	8,112	8,315	8,518
Total	**11,986**	**10,772**	**7,911**	**8,329**	**8,953**	**7,731**	**7,932**	**8,347**	**8,547**	**8,749**
Commercial										
Coal	29	27	23	24	20	21	21	19	23	23
Fuel Oil[a]	16	12	9	9	10	10	9	11	11	12
Natural Gas	71	83	82	83	86	83	86	87	85	83
LPG	2	2	2	3	3	3	3	2	3	2
Wood	4	5	4	5	5	5	5	5	5	3
Total	**122**	**128**	**121**	**122**	**124**	**120**	**123**	**124**	**127**	**124**
Industrial										
Coal	150	136	123	121	125	122	112	113	114	109
Fuel Oil[a]	32	27	20	18	21	18	17	19	21	23
Natural Gas	263	298	303	291	295	270	274	264	265	242
LPG	51	64	65	71	72	65	70	67	69	65
Wood	89	102	99	100	101	89	86	84	91	89
Total	**585**	**626**	**610**	**601**	**613**	**564**	**559**	**547**	**560**	**528**
Electric Power										
Coal	225	242	267	268	281	273	275	280	282	288
Fuel Oil[a]	18	10	16	14	17	17	11	14	14	14
Natural Gas	7	10	10	11	12	12	13	12	12	13
Wood	1	*	*	*	*	*	*	*	*	*
Total	**251**	**262**	**293**	**293**	**309**	**302**	**298**	**306**	**309**	**315**
Total All Sectors										
Coal	405	405	413	412	426	416	408	412	419	420
Fuel Oil[a]	179	154	134	137	152	150	137	149	154	157
Natural Gas	441	500	499	492	505	473	484	479	474	449
LPG	62	77	78	88	90	82	87	83	86	81
Wood	11,857	10,652	7,810	8,217	8,826	7,597	7,797	8,201	8,411	8,610
Total	**12,944**	**11,788**	**8,934**	**9,346**	**9,999**	**8,717**	**8,912**	**9,324**	**9,542**	**9,716**

*Less than 500 metric tons carbon dioxide equivalent.

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

P = preliminary data.

See notes and sources at end of table.

Table 19. U.S. Methane Emissions from Stationary Combustion Sources, 1990, 1995, and 1998-2005 (Continued)

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
					Thousand Metric Tons Methane					
Residential										
Coal	*	*	*	*	*	*	*	*	*	*
Fuel Oil[a]	5	5	4	4	5	5	4	5	5	5
Natural Gas	4	5	4	5	5	5	5	5	5	5
LPG	*	*	1	1	1	1	1	1	1	1
Wood	511	459	335	353	379	326	335	353	362	370
Total	**521**	**468**	**344**	**362**	**389**	**336**	**345**	**363**	**372**	**380**
Commercial										
Coal	1	1	1	1	1	1	1	1	1	1
Fuel Oil[a]	1	1	*	*	*	*	*	*	*	1
Natural Gas	3	4	4	4	4	4	4	4	4	4
LPG	*	*	*	*	*	*	*	*	*	*
Wood	*	*	*	*	*	*	*	*	*	*
Total	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**6**
Industrial										
Coal	7	6	5	5	5	5	5	5	5	5
Fuel Oil[a]	1	1	1	1	1	1	1	1	1	1
Natural Gas	11	13	13	13	13	12	12	11	12	11
LPG	2	3	3	3	3	3	3	3	3	3
Wood	4	4	4	4	4	4	4	4	4	4
Total	**25**	**27**	**27**	**26**	**27**	**25**	**24**	**24**	**24**	**23**
Electric Power										
Coal	10	11	12	12	12	12	12	12	12	13
Fuel Oil[a]	1	*	1	1	1	1	*	1	1	1
Natural Gas	*	*	*	*	1	1	1	1	1	1
Wood	*	*	*	*	*	*	*	*	*	*
Total	**11**	**11**	**13**	**13**	**13**	**13**	**13**	**13**	**13**	**14**
Total All Sectors										
Coal	18	18	18	18	19	18	18	18	18	18
Fuel Oil[a]	8	7	6	6	7	7	6	6	7	7
Natural Gas	19	22	22	21	22	21	21	21	21	20
LPG	3	3	3	4	4	4	4	4	4	4
Wood	516	463	340	357	384	330	339	357	366	374
Total	**563**	**513**	**388**	**406**	**435**	**379**	**387**	**405**	**415**	**422**

*Less than 500 metric tons methane.

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

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2004*; U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources*, AP 42, Fifth Edition (Washington, DC, January 1995), web site www.epa.gov/ttn/chief/ap42; Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), web site www.ipcc.ch/pub/guide.htm; Energy Information Administration, *State Energy Data Report*, DOE/EIA-0214 (Washington, DC, various years); Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(2005/07) (Washington, DC, July 2005); and Energy Information Administration, *Annual Energy Review*, DOE/EIA-0384 (Washington, DC, various years).

Table 20. U.S. Methane Emissions from Mobile Sources, 1990, 1995, and 1998-2005

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Thousand Metric Tons Carbon Dioxide Equivalent										
Motor Vehicles										
Passenger Cars	3,284	2,234	2,018	1,991	1,955	1,912	1,841	1,708	1,695	1,661
Buses	21	24	26	28	28	26	25	25	25	25
Motorcycles	92	94	99	102	101	93	92	92	97	97
Light-Duty Trucks	1,402	1,630	1,686	1,651	1,625	1,595	1,578	1,541	1,640	1,695
Other Trucks	271	330	363	375	380	387	397	403	419	419
Total	**5,070**	**4,311**	**4,192**	**4,148**	**4,089**	**4,013**	**3,934**	**3,769**	**3,875**	**3,897**
Other Transport	515	510	460	481	505	476	469	421	500	604
Total Transport	**5,585**	**4,820**	**4,653**	**4,628**	**4,594**	**4,489**	**4,403**	**4,190**	**4,375**	**4,500**
Thousand Metric Tons Methane										
Motor Vehicles										
Passenger Cars	143	97	88	87	85	83	80	74	74	72
Buses	1	1	1	1	1	1	1	1	1	1
Motorcycles	4	4	4	4	4	4	4	4	4	4
Light-Duty Trucks	61	71	73	72	71	69	69	67	71	74
Other Trucks	12	14	16	16	17	17	17	18	18	18
Total	**220**	**187**	**182**	**180**	**178**	**174**	**171**	**164**	**168**	**169**
Other Transport	22	22	20	21	22	21	20	18	22	26
Total Transport	**243**	**210**	**202**	**201**	**200**	**195**	**191**	**182**	**190**	**196**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2004*. For passenger cars and light-duty trucks, 1990-2000 vehicle miles traveled (VMT) data are based on 2002 data on vehicle stocks provided by R.L. & Polk Co., with VMT modified by Oak Ridge National Laboratory (ORNL), *Transportation Energy Data Book: Edition 23* (Oak Ridge, TN, October 2003), Chapter 7. 1996-2000 data were further adjusted using fleet data and survival curves for the population of aging vehicles. For years after 2000, emissions data are based on fleet data, econometrically modeled VMT, and survival curves for the population of aging vehicles. Calculations for buses, motorcycles, and other trucks are based on VMT from Federal Highway Administration, U.S. Department of Transportation, *Federal Highway Statistics*, Table VM-1 (various years). Vehicle emissions coefficients are from Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 1.65-1.75, web site www.ipcc.ch/pub/guide.htm. Fuel consumption data for non-highway sources are from Energy Information Administration, *Fuel Oil and Kerosene Sales*, DOE/EIA-0535 (Washington, DC, various years); Energy Information Administration, *Petroleum Supply Annual*, DOE/EIA-0340 (Washington, DC, various years), and ORNL, *Transportation Energy Data Book: Edition 23* (Oak Ridge, TN, October 2003), Chapter 9, web site www-cta.ornl.gov/data/chapter9.html.

Table 21. U.S. Methane Emissions from Landfills, 1990, 1995, and 1998-2005

Type	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Million Metric Tons Carbon Dioxide Equivalent										
Gross Emissions from MSW Landfills	172.3	169.8	167.1	166.3	166.2	166.5	169.2	173.6	179.0	185.0
Emissions from Industrial Landfills	16.9	16.5	16.0	15.8	15.9	16.0	16.3	16.8	17.5	18.2
Methane Recovered for Energy (-)	15.6	22.6	37.5	41.7	46.4	51.7	54.5	58.1	61.6	64.9
Methane Assumed Flared (-)	6.0	24.6	35.5	36.7	40.6	44.6	47.9	50.6	57.5	57.5
Net Emissions	**237.3**	**204.9**	**170.9**	**162.4**	**155.4**	**147.8**	**146.7**	**148.7**	**148.8**	**155.7**
Million Metric Tons Methane										
Gross Emissions from MSW Landfills	10.52	10.25	9.91	9.78	9.85	9.92	10.12	10.46	10.89	11.30
Emissions from Industrial Landfills	0.74	0.72	0.69	0.68	0.69	0.69	0.71	0.73	0.76	0.79
Methane Recovered for Energy (-)	0.68	0.98	1.63	1.81	2.02	2.25	2.37	2.52	2.68	2.82
Methane Assumed Flared (-)	0.26	1.07	1.55	1.60	1.77	1.94	2.08	2.20	2.50	2.50
Net Emissions	**10.32**	**8.91**	**7.43**	**7.06**	**6.75**	**6.42**	**6.38**	**6.47**	**6.47**	**6.77**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2004*. Municipal solid waste landfilled in 2002 from "Nationwide Survey: The State of Garbage in America," *Biocycle* (January 2004). Municipal solid waste generated and landfilled in previous years from "Nationwide Survey: The State of Garbage in America," *Biocycle* (various years), adjusted on the basis of residential demolitions, to reflect exclusion of construction and demolition waste as in the 2002 data. Municipal waste landfilled in 2003 based on 2002 estimate, scaled to annual economic growth. Emissions calculations based on S.A. Thorneloe et al., "Estimate of Methane Emissions from U.S. Landfills," Prepared for the U.S. Environmental Protection Agency, Office of Research and Development (April 1994), and D. Augenstein, "The Greenhouse Effect and U.S. Landfill Methane," *Global Environment Change* (December 1992), pp. 311-328. Methane recovered and flared from U.S. Environmental Protection Agency, Landfill Methane Outreach Program, web site www.epa.gov/lmop/. Emissions from industrial landfills estimated at 7 percent of methane emissions from municipal solid waste landfills, based on U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

Table 22. U.S. Methane Emissions from Enteric Fermentation in Domesticated Animals, 1990, 1995, and 1998-2005

Animal Type	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Million Metric Tons Carbon Dioxide Equivalent										
Cattle	113.6	118.7	111.5	111.8	110.9	109.7	110.3	110.8	108.9	110.0
Swine	1.6	1.8	1.9	1.9	1.8	1.8	1.9	1.9	1.9	1.9
Sheep	2.1	1.6	1.4	1.3	1.3	1.3	1.2	1.1	1.1	1.1
Goats	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.3
Horses	2.1	2.1	2.2	2.1	2.2	2.2	2.2	2.2	2.2	2.2
Total	**119.6**	**124.4**	**117.2**	**117.3**	**116.3**	**115.1**	**115.8**	**116.1**	**114.2**	**115.6**
Million Metric Tons Methane										
Cattle	4.94	5.16	4.85	4.86	4.82	4.77	4.80	4.82	4.73	4.78
Swine	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Sheep	0.09	0.07	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05
Goats	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Horses	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10
Total	**5.20**	**5.41**	**5.09**	**5.10**	**5.06**	**5.00**	**5.03**	**5.05**	**4.97**	**5.02**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2004*. Cattle, sheep, and pig population data provided by the U.S. Department of Agriculture, National Agricultural Statistics Service, Livestock, Dairy and Poultry Service. Goat and horse population figures extrapolated from U.S. Department of Commerce, Bureau of the Census, *Census of Agriculture*, 1982, 1987, 1992, and 1997. Emissions calculations based on U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html; and P.J. Crutzen, I. Aselmann, and W.S. Seiler, "Methane Production by Domestic Animals, Wild Ruminants, Other Herbivorous Fauna, and Humans," *Tellus*, Vol. 38B (1986), pp. 271-284.

Table 23. U.S. Methane Emissions from the Solid Waste of Domesticated Animals, 1990, 1995, and 1998-2005

Animal Type	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Thousand Metric Tons Carbon Dioxide Equivalent										
Cattle										
Beef Cattle	4,037	4,838	4,592	4,547	4,496	4,470	4,454	4,433	4,406	4,455
Dairy Cattle	12,717	15,236	16,970	17,092	17,430	17,746	18,014	18,185	18,267	18,544
Swine										
Market Swine	19,222	21,368	23,366	22,522	22,368	22,627	22,724	23,165	23,522	23,713
Breeding Swine	3,502	3,788	3,739	3,488	3,507	3,470	3,390	3,362	3,340	3,364
Poultry										
Layers	1,663	1,814	1,913	1,979	2,016	2,052	2,076	2,082	2,114	2,132
Broilers	1,590	2,158	2,298	2,372	2,255	2,284	2,339	2,312	2,379	2,415
Other Animals										
Sheep	115	34	29	28	27	27	25	24	24	24
Goats	16	15	12	11	11	12	10	10	10	23
Horses	624	631	644	636	645	652	652	652	652	652
Total	**43,486**	**49,883**	**53,563**	**52,676**	**52,756**	**53,340**	**53,684**	**54,225**	**54,715**	**55,320**
Thousand Metric Tons Methane										
Cattle										
Beef Cattle	176	210	200	198	195	194	194	193	192	194
Dairy Cattle	553	662	738	743	758	772	783	791	794	806
Swine										
Market Swine	836	929	1,016	979	973	984	988	1,007	1,023	1,031
Breeding Swine	152	165	163	152	152	151	147	146	145	146
Poultry										
Layers	72	79	83	86	88	89	90	91	92	93
Broilers	69	94	100	103	98	99	102	101	103	105
Other Animals										
Sheep	5	1	1	1	1	1	1	1	1	1
Goats	1	1	1	*	*	1	*	*	*	1
Horses	27	27	28	28	28	28	28	28	28	28
Total	**1,891**	**2,169**	**2,329**	**2,290**	**2,294**	**2,319**	**2,334**	**2,358**	**2,379**	**2,405**

*Less than 500 metric tons methane.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2004*. Population data for horses and goats extrapolated from U.S. Department of Commerce, Bureau of the Census, *Census of Agriculture*, 1982, 1987, 1992, and 1997. Population data for all other animals from U.S. Department of Agriculture, National Agricultural Statistics Service, Livestock, Dairy and Poultry Branch. Typical animal sizes from U.S. Environmental Protection Agency, Office of Air and Radiation, *Anthropogenic Methane Emissions in the United States: Estimates for 1990, Report to Congress* (Washington, DC, April 1993), p. 6-8; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, Table M-2, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/Resource CenterPublicationsGHGEmissionsUSEmissionsInventory2006.html. Cattle sizes adjusted by annual slaughter weight from U.S. Department of Agriculture, National Agricultural Statistics Service, Livestock, Dairy and Poultry Branch. Maximum methane production, and waste management systems used from L.M. Safley, M.E. Casada, et al., *Global Methane Emissions from Livestock and Poultry Manure* (Washington, DC: U.S. Environmental Protection Agency, February 1992), pp. 24-27; U.S. Environmental Protection Agency, *Cost Methodology Report for Beef and Dairy Animal Feeding Operations*, EPA-821-R-01-019 (Washington, DC, January 2001), pp.1-13–1-14; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), Table M-2. General methane conversion factors from Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), p. 4.25, web site www.ipcc.ch/pub/guide.htm. State methane conversion factors for dairy cattle from U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-1998*, EPA-236-R-00-001 (Washington, DC, April 2001); and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-003 (Washington, DC, April 2004), Table M-4.

Table 24. U.S. Methane Emissions from Industrial Processes, 1990, 1995, and 1998-2005

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Thousand Metric Tons Carbon Dioxide Equivalent										
Chemical Production										
Ethylene	380	488	540	578	521	470	493	479	535	500
Ethylene Dichloride	58	72	82	91	82	78	78	83	101	94
Styrene	335	475	477	499	452	357	415	437	456	427
Methanol	174	225	262	254	203	142	137	132	123	97
Carbon Black	331	386	407	415	384	363	386	386	386	386
Total	**1,277**	**1,646**	**1,767**	**1,837**	**1,643**	**1,410**	**1,509**	**1,518**	**1,602**	**1,504**
Iron and Steel Production										
Coke[a]	251	201	163	148	155	130	132	120	108	100
Sinter	141	144	125	127	124	106	104	103	93	96
Pig Iron	1,028	1,053	998	958	991	872	833	841	875	770
Total	**1,420**	**1,399**	**1,286**	**1,233**	**1,271**	**1,108**	**1,068**	**1,065**	**1,076**	**967**
Total Industrial Processes	**2,697**	**3,044**	**3,053**	**3,070**	**2,914**	**2,518**	**2,577**	**2,582**	**2,678**	**2,471**
Thousand Metric Tons Methane										
Chemical Production										
Ethylene	17	21	23	25	23	20	21	21	23	22
Ethylene Dichloride	3	3	4	4	4	3	3	4	4	4
Styrene	15	21	21	22	20	16	18	19	20	19
Methanol	8	10	11	11	9	6	6	6	5	4
Carbon Black	14	17	18	18	17	16	17	17	17	17
Total	**56**	**72**	**77**	**80**	**71**	**61**	**66**	**66**	**70**	**65**
Iron and Steel Production										
Coke[a]	11	9	7	6	7	6	6	5	5	4
Sinter	6	6	5	6	5	5	5	4	4	4
Pig Iron	45	46	43	42	43	38	36	37	38	33
Total	**62**	**61**	**56**	**54**	**55**	**48**	**46**	**46**	**47**	**42**
Total Industrial Processes	**117**	**132**	**133**	**133**	**127**	**109**	**112**	**112**	**116**	**107**

[a] Based on total U.S. production of metallurgical coke, including non-iron and steel uses.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2004*; American Iron and Steel Institute, *Annual Statistical Report* (Washington, DC, various years); American Chemical Council (formerly the Chemical Manufacturers Association), *U.S. Chemical Industry Statistical Handbook* (Washington, DC, various years); and Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), p. 2.23, web site www.ipcc/pub/guide.htm.

4. Nitrous Oxide Emissions

Overview

U.S. Anthropogenic Nitrous Oxide Emissions, 1990-2005

	Nitrous Oxide	Carbon Dioxide Equivalent
Estimated 2005 Emissions (Thousand Metric Tons)	1,238.4	366,560
Change Compared to 2004 (Thousand Metric Tons)	22.6	6,686
Change from 2004 *(Percent)*	*1.9%*	*1.9%*
Change Compared to 1990 (Thousand Metric Tons)	111.7	33,061
Change from 1990 *(Percent)*	*9.9%*	*9.9%*

Estimated U.S. anthropogenic nitrous oxide emissions totaled 1.2 million metric tons in 2005, or 366.6 million metric tons carbon dioxide equivalent (MMTCO$_2$e), 1.9 percent more than in 2004 and 9.9 percent above 1990 levels (Table 25). The 2005 total for nitrous oxide emissions represents 5.1 percent of all U.S. greenhouse gas emissions for the year. Most of the increase in U.S. nitrous oxide emissions for 2005 can be attributed to emissions from agricultural sources, which increased by 7.0 MMTCO$_2$e.

A downward trend in U.S. nitrous oxide emissions that began in 1995, after emissions of nitrous oxide peaked at 374.5 MMTCO$_2$e in 1994, ended in 2003. Over the past 2 years, nitrous oxide emissions have increased. In 2004, annual U.S. emissions of nitrous oxide (359.9 MMTCO$_2$e) were higher than their 1990 level (333.5 MMTCO$_2$e) for the first time since 2001, and in 2005 they were only 2.1 percent below their 1994 peak value.

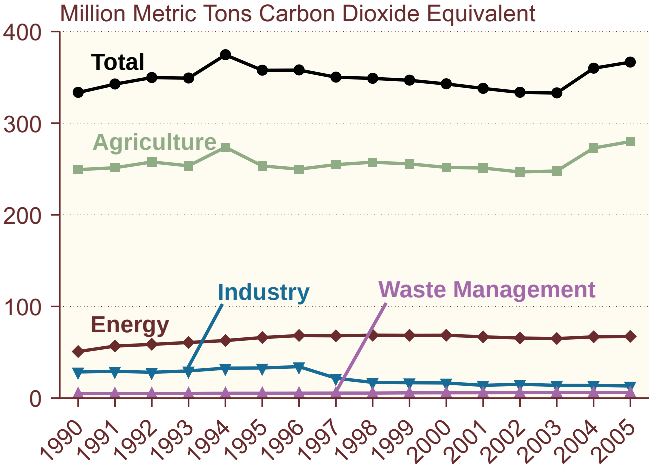
Sources of U.S. nitrous oxide emissions include energy use, agriculture, waste management, and industrial processes. The largest component of U.S. anthropogenic nitrous oxide emissions is emissions from agricultural activities, at 279.9 MMTCO$_2$e or 76 percent of total nitrous oxide emissions in 2005. Nitrogen fertilization of agricultural soils represents 78 percent of emissions from agricultural activities. Most of the remainder (22 percent) is from the handling of animal waste in managed systems. Small quantities of nitrous oxide (0.2 percent of nitrous oxide emissions from agricultural activities) are also released from the burning of crop residues. Estimated emissions of nitrous oxide from agricultural sources in 2005 were 2.6 percent above 2004 levels and 12 percent above 1990 levels (Figure 3).

The second-largest source of anthropogenic nitrous oxide emissions is energy consumption, which includes mobile source combustion from passenger cars, buses, motorcycles, and trucks; and stationary source combustion from commercial, residential, industrial, and electric power sector energy use. Energy use was responsible for 67.3 MMTCO$_2$e of nitrous oxide emissions in 2005 (18 percent of total U.S. nitrous oxide emissions). The 2005 level of emissions from energy sources

Sources of U.S. Anthropogenic Nitrous Oxide Emissions, 1990-2005

	Million Metric Tons CO$_2$e		*Percent Change*	
Source	1990	2005	1990-2005	2004-2005
Agriculture	249.3	279.9	*12.3%*	*2.6%*
Energy	50.8	67.3	*32.5%*	*0.6%*
Industrial Processes	28.6	13.2	*-53.6%*	*-5.3%*
Waste Management	4.9	6.2	*26.3%*	*1.1%*

Figure 3. U.S. Emissions of Nitrous Oxide by Source, 1990-2005



Source: Estimates presented in this chapter.

is 0.6 percent higher than the 2004 level and 33 percent higher than in 1990.

Industrial production of adipic and nitric acid, which releases nitrous oxide as a byproduct, accounted for emissions of 13.2 MMTCO$_2$e in 2005 (3.6 percent of total U.S. nitrous oxide emissions), 5.3 percent lower than the 2004 level and 54 percent lower than in 1990. The large decline in emissions of nitrous oxide from adipic acid production since 1990 is a result of the continuing utilization of emissions control technology at three of the four adipic acid plants operating in the United States.

Nitrous oxide emissions from activities related to waste management in 2005 totaled 6.2 MMTCO$_2$e, or 1.7 percent of all U.S. anthropogenic nitrous oxide emissions (Table 25). During 2005, emissions from human sewage in wastewater accounted for 94 percent of estimated nitrous oxide emissions from this source, and the remainder was associated with waste combustion.

Agriculture

U.S. Nitrous Oxide Emissions from Agriculture, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	279.9
Change Compared to 2004 (Million Metric Tons Carbon Dioxide Equivalent)	7.0
Change from 2004 *(Percent)*	*2.6%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	30.6
Change from 1990 *(Percent)*	*12.3%*

Nitrous oxide emissions from agricultural activities increased by 7.0 MMTCO$_2$e (2.6 percent) in 2005 to a total of 279.9 MMTCO$_2$e, compared with 272.9 MMTCO$_2$e in 2004. Since 1990, nitrous oxide emissions from agricultural activities have increased by 12.3 percent. Agricultural activities were responsible for 76 percent of U.S. nitrous oxide emissions in 2005, smaller than the 86-percent share that agricultural practices contribute to nitrous oxide emissions globally.[63] Nitrous oxide emissions from agricultural activities represent 3.9 percent of total U.S. greenhouse gas emissions.

Nitrogen fertilization of agricultural soils accounted for 78 percent of U.S. agricultural emissions of nitrous oxide in 2005. Nearly all the remaining agricultural emissions (22 percent) can be traced to the management of the solid waste of domesticated animals. The disposal of crop residues by burning also produces nitrous oxide that is released into the atmosphere; however, the amount is relatively minor, at 0.6 MMTCO$_2$e or 0.2 percent of total U.S. emissions of nitrous oxide from agricultural sources in 2005.

Nitrogen Fertilization of Agricultural Soils

EIA estimates that 218.1 MMTCO$_2$e of nitrous oxide was released into the atmosphere as a result of direct and indirect emissions associated with fertilization practices in 2005 (Table 26). Estimated emissions increased by 2.9 percent compared with 2004 levels and were 16.7 percent higher than in 1990.

Nitrogen uptake and nitrous oxide emissions occur naturally as a result of nitrification and denitrification processes in soil and crops, generally through bacterial action. When nitrogen compounds are added to the soil, bacterial action is stimulated, and emissions generally increase, unless the application precisely matches plant uptake and soil capture.[64] Nitrogen may be added to the soil by synthetic or organic fertilizers, nitrogen-fixing crops, and crop residues. Nitrogen-rich soils, called “histosols,” may also stimulate emissions. Direct emissions in 2005 (171.0 MMTCO$_2$e) represented 78 percent of total emissions from nitrogen fertilization, with the primary components including the biological fixation of nitrogen in crops (70.7 MMTCO$_2$e), nitrogen fertilizers (58.6 MMTCO$_2$e), and crop residues (37.3 MMTCO$_2$e).

Indirect emissions from nitrogen fertilization result from adding excess nitrogen to the soil, which in turn enriches ground and surface waters, such as rivers and streams, and results in emissions of nitrous oxide. This source is referred to as “soil leaching.” Additional indirect emissions occur from “atmospheric deposition,” in which soils emit other nitrogen compounds that react to form nitrous oxide in the atmosphere. Indirect emissions in 2005 (47.1 MMTCO$_2$e) represented 22 percent of total emissions from nitrogen fertilization, with soil leaching accounting for 40.0 MMTCO$_2$e and atmospheric deposition totaling 7.1 MMTCO$_2$e.

There are significant uncertainties associated with estimating the amount of emissions produced by adding nitrogen to agricultural soils. Models used to estimate

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[63] U.S. Environmental Protection Agency, web site www.epa.gov/nonco2/econ-inv/international.html.

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

the amount are based on limited sources of experimental data.[65] The uncertainty increases when moving from emissions associated with animal manure to soil mineralization and atmospheric deposition, where both estimating the amount of emissions and segmenting anthropogenic from biogenic sources become increasingly difficult.

Solid Waste of Domesticated Animals

Estimated 2005 nitrous oxide emissions from animal waste management were 61.2 $MMTCO_2e$, up by 1.4 percent from 2004 levels but 1.2 percent lower than 1990 levels (Table 27), making animal waste management the second-largest U.S. agricultural source of nitrous oxide emissions, after nitrogen fertilization of soils. Nitrous oxide emissions from animal waste are dominated by emissions from cattle waste, which in 2005 accounted for 92 percent of emissions from the solid waste of domesticated animals (a total of 56.4 $MMTCO_2e$ in 2005).

Nitrous oxide is released as part of the microbial denitrification of animal manure. The total volume of nitrous oxide emissions is a function of animal size and manure production, the amount of nitrogen in the animal waste, and the method of managing the animal waste. Waste managed by a solid storage or pasture range method may emit 20 times more nitrous oxide per unit of nitrogen content than does waste managed in anaerobic lagoon and liquid systems. Generally, solid waste from feedlot beef cattle is managed with the solid storage or pasture range method, accounting for the majority of nitrous oxide emissions. Solid waste from swine is generally managed in anaerobic lagoons and other liquid systems. Anaerobic digestion yields methane emissions but only negligible amounts of nitrous oxide. Thus, changes in estimated emissions result primarily from changes in cattle populations. For example, beef cattle populations grew during the first half of the 1990s, leading to higher emissions through 1995, but then declined slowly through 2004, lowering emissions to below 1990 levels. In 2005, U.S. cattle populations increased slightly from their 2004 level.

Crop Residue Burning

In 2005, estimated emissions of nitrous oxide from crop residue burning were 0.6 $MMTCO_2e$, 3.0 percent below the 2004 level (Table 25). The decrease is attributable to a nearly across-the-board decrease in U.S. crop production. Emissions from this source remain very small, at 0.2 percent of all U.S. nitrous oxide emissions. When crop residues are burned, the incomplete combustion of agricultural waste results in the production of nitrous oxide, as well as methane (discussed in Chapter 3).

Energy Use

U.S. Nitrous Oxide Emissions from Energy, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	67.3
Change Compared to 2004 (Million Metric Tons Carbon Dioxide Equivalent)	0.4
Change from 2004 *(Percent)*	*0.6%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	16.5
Change from 1990 *(Percent)*	*32.5%*

The energy use category includes nitrous oxide emissions from both mobile and stationary sources as byproducts of fuel combustion. Estimated 2005 energy-related emissions were 67.3 $MMTCO_2e$, or 18 percent of total U.S. anthropogenic nitrous oxide emissions (Table 25). Emissions from energy use are dominated by mobile combustion (78 percent of nitrous oxide emissions from energy use in 2005).

Mobile Combustion

Nitrous oxide emissions from mobile source combustion in 2005 were 52.6 $MMTCO_2e$, an increase of 1.0 percent from the 2004 level of 52.0 $MMTCO_2e$ (Table 28). In addition to emissions from passenger cars and light-duty trucks, emissions from air, rail, and marine transportation and from farm and construction equipment are also included in the estimates. Motor vehicles, however, are the predominant source, accounting for 92 percent of nitrous oxide emissions from mobile combustion.

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

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[65] Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.87-4.100, web site www.ipcc-nggip.iges.or.jp/public/gl/invs6.htm.

probably vary with engine size. Thus, emissions also depend on the "mix" of vehicle age and type on the road.

Nitrous oxide emissions from mobile sources grew rapidly from 1990 to 1996 due to increasing motor vehicle use, the shifting composition of the light-duty vehicle fleet toward light trucks that have lower fuel economy and higher per-mile emission factors, and the gradual replacement of low emitting pre-1983 vehicles that did not use catalytic converters with higher emitting post-1983 vehicles that do use catalytic converters. This growth moderated between 1996 and 1999 due to the introduction of more advanced, lower-emitting catalytic converters. After peaking in 1999, U.S. emissions of nitrous oxide from mobile sources declined slowly through 2002, as vehicle turnover led to a fleet dominated by the more advanced catalytic converters. Since 2002, emissions have increased as both the number of motor vehicles on U.S. roadways and emissions from other mobile sources have grown.

Stationary Combustion

In 2005, estimated nitrous oxide emissions from stationary combustion sources were 14.7 $MMTCO_2e$, 1.1 percent (0.2 $MMTCO_2e$) lower than in 2004 and 9.9 percent (1.3 $MMTCO_2e$) higher than in 1990 (Table 29). The increase in emissions from this source from 1990 to 2005 can be attributed principally to coal-fired combustion systems. Nitrous oxide emissions from coal-fired combustion systems increased by 19 percent over the period, from 8.0 $MMTCO_2e$ in 1990 to 9.5 $MMTCO_2e$ in 2005.

Coal-fired combustion systems produced 65 percent of the 2005 emissions of nitrous oxide from stationary combustion. Other fuels—including fuel oil (2.3 $MMTCO_2e$), wood (2.2 $MMTCO_2e$), and natural gas (0.6 $MMTCO_2e$)—accounted for the balance. During combustion, nitrous oxide is produced as a result of chemical interactions between nitrogen oxides (mostly NO_2) and other combustion products. With most conventional stationary combustion systems, high temperatures destroy almost all nitrous oxide, limiting the quantity that escapes; therefore, emissions from these systems typically are low.

Industrial Sources

Emissions of nitrous oxide from industrial sources were 13.2 $MMTCO_2e$ in 2005, a decrease of 0.7 $MMTCO_2e$ (5.3 percent) from 2004 and a decrease of 15.3 $MMTCO_2e$ (54 percent) since 1990. Nitrous oxide is emitted as a byproduct of certain chemical production processes. Table 30 provides estimates of emissions from the production of adipic acid and nitric acid, the two principal known sources.

Nitric Acid Production

The 6.3 million metric tons of nitric acid manufactured in 2005[66] resulted in estimated nitrous oxide emissions of 10.3 $MMTCO_2e$ (Table 30). This estimate was 5.6 percent lower than 2004 levels and 12 percent lower than 1990 levels. The emissions factor used to estimate nitrous oxide emissions from the production of nitric acid was based on measurements at a single DuPont plant, which indicated an emissions factor of 2 to 9 grams of nitrous oxide emitted per kilogram of nitric acid manufactured, suggesting a significant range of uncertainty.[67] Nitric acid, a primary ingredient in fertilizers, usually is manufactured by oxidizing ammonia (NH_3) with a platinum catalyst. Nitrous oxide emissions are a direct result of the oxidation.

Adipic Acid Production

Emissions from adipic acid production in 2005 were 2.9 $MMTCO_2e$, 4.2 percent lower than in 2004. Nitrous oxide emissions from this source in 2005 were 83 percent (13.9 $MMTCO_2e$) lower than in 1990.

Adipic acid is a fine white powder that is used primarily in the manufacture of nylon fibers and plastics, such as carpet yarn, clothing, and tire cord. Other uses of adipic acid include production of plasticizer for polyvinyl chloride and polyurethane resins, lubricants, insecticides, and dyes. In the United States, three companies, which

U.S. Nitrous Oxide Emissions from Industrial Sources, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	13.2
Change Compared to 2004 (Million Metric Tons Carbon Dioxide Equivalent)	-0.7
Change from 2004 *(Percent)*	*-5.3%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	-15.3
Change from 1990 *(Percent)*	*-53.6%*

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[66] U.S. Department of Commerce, Bureau of Census, *Current Industrial Reports: Fertilizer Materials and Related Products, Fourth Quarter 2005*, MQ325B(05)-4 (Washington, DC, March 2006), Table 1, web site www.census.gov/industry/1/mq325b054.pdf.

[67] Intergovernmental Panel on Climate Change, *IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, Vol. 3 (Paris, France, 1997), Table 2-7, web site www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch2ref1.pdf.

operate four plants, manufacture adipic acid by oxidizing a ketone-alcohol mixture with nitric acid. Nitrous oxide is an intrinsic byproduct of this chemical reaction. For every metric ton of adipic acid produced, 0.3 metric ton of nitrous oxide is created.[68] Emissions from adipic acid manufacture grew by 23 percent from 1990 to 1996, reaching 20.7 MMTCO$_2$e before dropping sharply to 7.8 MMTCO$_2$e in 1997.

Before 1997, two of the four plants that manufacture adipic acid controlled emissions by thermally decomposing the nitrous oxide. This technique eliminates 98 percent of potential nitrous oxide emissions from the process.[69] During the first quarter of 1997, a third plant installed emissions controls, increasing the share of adipic acid production employing emissions abatement controls from 74 percent in 1996 to 92 percent in 1997. In 1998, with emissions controls in place for the full year, 97 percent of emissions from U.S. adipic acid production were controlled.[70]

Estimated emissions of nitrous oxide from uncontrolled adipic acid production decreased from 19.6 MMTCO$_2$e in 1996 to 2.0 MMTCO$_2$e in 1998 and remained fairly stable through 2002, before dropping to 1.4 MMTCO$_2$e per year in 2003 (Table 30). Emissions of nitrous oxide from controlled plants have remained relatively constant from 1998 through 2005, in a range of 1.4 to 1.6 MMTCO$_2$e. With the share of adipic acid production employing abatement controls now at 98 percent, future changes in nitrous oxide emissions from this source are expected to result primarily from changes in plant production levels in response to market demand.

Waste Management

Nitrous oxide emissions from waste management in 2005 are estimated at 6.2 MMTCO$_2$e, or 1.7 percent of all U.S. anthropogenic nitrous oxide emissions (Table 25). During 2005, emissions from human sewage in wastewater were responsible for 94 percent of the estimated emissions from this source, and the remainder was associated with waste combustion. Estimated emissions from waste management increased by 1.1 percent from 2004 to 2005 and by 26 percent from 1990 to 2005. Because of the lack of reliable data and an effective estimation method, no estimate of emissions from industrial wastewater was calculated, leaving estimated emissions from waste management lower than they otherwise would be had a viable estimation method been available.

Human Sewage in Wastewater

In 2005, nitrous oxide emissions from wastewater were 5.8 MMTCO$_2$e, a 1.0-percent increase from 2004 levels and a 27-percent increase from the 1990 level (Table 25). Estimates of nitrous oxide emissions from human waste are scaled to population size and per capita protein intake. U.S. population has grown by 19 percent since 1990.[71] U.S. per capita protein intake rose steadily from 1990 to 1999, then declined from 2000 to 2002. U.S. per capita protein intake in 2002 was 6.5 percent above the 1990 level.[72]

Nitrous oxide is emitted from wastewater that contains nitrogen-based organic materials, such as those found in human or animal waste. Two natural processes—nitrification and denitrification—combine to produce nitrous oxide. Nitrification, an aerobic process, converts ammonia into nitrate; denitrification, an anaerobic process, converts nitrate to nitrous oxide. Factors that influence the amount of nitrous oxide generated from wastewater include temperature, acidity, biochemical oxygen demand (BOD),[73] and nitrogen concentration.

U.S. Nitrous Oxide Emissions from Waste Management, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	6.2
Change Compared to 2004 (Million Metric Tons Carbon Dioxide Equivalent)	0.1
Change from 2004 *(Percent)*	*1.1%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	1.3
Change from 1990 *(Percent)*	*26.3%*

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

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

[70] R.A. Reimer, R.A. Parrett, and C.S. Slaten, "Abatement of N_2O Emissions Produced in Adipic Acid," in *Proceedings of the Fifth International Workshop on Nitrous Oxide Emissions* (Tsukuba, Japan, July 1992).

[71] U.S. Census Bureau, web site www.census.gov. For 1990 population, see www.census.gov/population/cen2000/phc-t1/tab04.xls; for 2005 population estimate, see www.census.gov/popest/states/tables/NST-EST2005-01.xls.

[72] Data on protein intake are taken from the United Nations Food and Agriculture Organization (FAO), statistical databases, web site www.fao.org/statistics/yearbook/vol_1_1/site_en.asp?page=consumption.

[73] Biochemical oxygen demand (BOD) is a measure of the organic content of wastewater that is subject to decomposition.

Waste Combustion

In 2005, estimated nitrous oxide emissions from waste combustion were 0.3 MMTCO$_2$e, up by 2.8 percent from the 2004 level and 15 percent above the 1990 level. Data on the amount of waste generated in the United States in 2005 were not available in time for this report; therefore, EIA scaled the 2005 estimate for waste combustion to the growth in U.S. gross domestic product. The share of waste burned is estimated to have remained nearly stable between 1998 and 2005, but the total volume of waste generated is estimated to have risen steadily. The total volume of waste generated in the United States increased by 79 percent from 1990 to 2005; however, the share of waste burned in 2005 was just 7.4 percent, compared with 12 percent in 1990.[74]

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[74] *Biocycle*, “The State of Garbage in America” (April 2006).

Table 25. Estimated U.S. Emissions of Nitrous Oxide, 1990, 1995, and 1998-2005

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Million Metric Tons Carbon Dioxide Equivalent										
Agriculture										
Nitrogen Fertilization of Soils	186.9	187.3	194.0	192.7	189.4	189.1	185.1	186.6	211.9	218.1
Solid Waste of Domesticated Animals	61.9	65.6	62.8	62.3	61.8	61.4	61.1	60.7	60.3	61.2
Crop Residue Burning	0.5	0.5	0.6	0.5	0.6	0.6	0.5	0.5	0.6	0.6
Subtotal	**249.3**	**253.4**	**257.4**	**255.6**	**251.8**	**251.1**	**246.8**	**247.8**	**272.9**	**279.9**
Energy Use										
Mobile Combustion	37.4	52.2	54.3	54.0	53.6	52.4	51.2	50.5	52.0	52.6
Stationary Combustion	13.3	13.9	14.4	14.6	15.0	14.5	14.3	14.5	14.8	14.7
Subtotal	**50.8**	**66.1**	**68.7**	**68.6**	**68.6**	**66.9**	**65.6**	**65.0**	**66.9**	**67.3**
Industrial Sources	**28.6**	**32.9**	**17.2**	**16.8**	**16.6**	**14.0**	**15.2**	**14.0**	**14.0**	**13.2**
Waste Management										
Human Sewage in Wastewater	4.6	5.1	5.3	5.5	5.6	5.6	5.7	5.7	5.8	5.8
Waste Combustion	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Subtotal	**4.9**	**5.4**	**5.5**	**5.8**	**5.8**	**6.0**	**6.0**	**6.1**	**6.1**	**6.2**
Total	**333.5**	**357.7**	**348.8**	**346.8**	**342.8**	**337.9**	**333.6**	**332.9**	**359.9**	**366.6**
Thousand Metric Tons Nitrous Oxide										
Agriculture										
Nitrogen Fertilization of Soils	631	633	655	651	640	639	625	630	716	737
Solid Waste of Domesticated Animals	209	222	212	211	209	207	207	205	204	207
Crop Residue Burning	2	2	2	2	2	2	2	2	2	2
Subtotal	**842**	**856**	**869**	**864**	**851**	**848**	**834**	**837**	**922**	**946**
Energy Use										
Mobile Combustion	126	176	183	183	181	177	173	170	176	178
Stationary Combustion	45	47	49	49	51	49	48	49	50	50
Subtotal	**172**	**223**	**232**	**232**	**232**	**226**	**222**	**220**	**226**	**227**
Industrial Sources	**96**	**111**	**58**	**57**	**56**	**47**	**51**	**47**	**47**	**45**
Waste Management										
Human Sewage in Wastewater	16	17	18	19	19	19	19	19	20	20
Waste Combustion	1	1	1	1	1	1	1	1	1	1
Subtotal	**17**	**18**	**19**	**20**	**20**	**20**	**20**	**20**	**21**	**21**
Total	**1,127**	**1,208**	**1,178**	**1,172**	**1,158**	**1,141**	**1,127**	**1,125**	**1,216**	**1,238**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Estimates presented in this chapter. Emissions calculations based on Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.81-4.94, web site www.ipcc.ch/pub/guide.htm; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenter PublicationsGHGEmissionsUSEmissionsInventory2006.html.

Table 26. U.S. Nitrous Oxide Emissions from Nitrogen Fertilization of Agricultural Soils, 1990, 1995, and 1998-2005

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
					Million Metric Tons Carbon Dioxide Equivalent					
Direct Emissions										
Biological Fixation in Crops	58.6	62.1	68.7	68.2	67.9	69.5	65.3	62.5	71.0	70.7
Nitrogen Fertilizers	53.1	51.2	47.5	47.7	45.6	44.4	45.6	48.0	54.3	58.6
Crop Residues	28.2	28.1	34.8	33.8	34.6	34.7	32.9	32.8	38.5	37.3
Soil Mineralization	3.0	3.1	3.1	3.1	3.1	3.1	3.1	3.2	3.2	3.2
Animal Manure	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Sewage Sludge	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.4	0.4
Total Direct Emissions	**144.1**	**145.9**	**155.5**	**154.1**	**152.4**	**153.0**	**148.2**	**147.7**	**168.2**	**171.0**
Indirect Emissions										
Soil Leaching	36.3	35.2	32.6	32.8	31.3	30.6	31.4	33.0	37.1	40.0
Atmospheric Deposition	6.5	6.3	5.8	5.8	5.6	5.5	5.6	5.9	6.6	7.1
Total Indirect Emissions	**42.8**	**41.4**	**38.5**	**38.6**	**36.9**	**36.0**	**37.0**	**38.8**	**43.7**	**47.1**
Total	**186.9**	**187.3**	**194.0**	**192.7**	**189.4**	**189.1**	**185.1**	**186.6**	**211.9**	**218.1**
					Thousand Metric Tons Nitrous Oxide					
Direct Emissions										
Biological Fixation in Crops	198	210	232	230	229	235	221	211	240	239
Nitrogen Fertilizers	179	173	161	161	154	150	154	162	183	198
Crop Residues	95	95	118	114	117	117	111	111	130	126
Soil Mineralization	10	10	10	10	11	11	11	11	11	11
Animal Manure	4	5	4	4	4	4	4	4	4	4
Sewage Sludge	1	1	1	1	1	1	1	1	1	1
Total Direct Emissions	**487**	**493**	**525**	**521**	**515**	**517**	**501**	**499**	**568**	**578**
Indirect Emissions										
Soil Leaching	123	119	110	111	106	103	106	111	125	135
Atmospheric Deposition	22	21	20	20	19	18	19	20	22	24
Total Indirect Emissions	**144**	**140**	**130**	**130**	**125**	**122**	**125**	**131**	**148**	**159**
Total	**631**	**633**	**655**	**651**	**640**	**639**	**625**	**630**	**716**	**737**

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Estimates presented in this chapter. Emissions coefficients from Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), pp. 4.89-4.107, web site www.ipcc.ch/pub/guide.htm. Total nitrogen content of U.S. commercial fertilizer consumption—1988-1994, Tennessee Valley Authority; 1995-2002, Association of American Plant Food Control Officials, *Commercial Fertilizers* (Washington, DC, various years). Manure application based on cattle population data provided by the U.S. Department of Agriculture, National Agricultural Statistics Service, web sites www.usda.gov/nass/pubs/histdata.htm and www.nass.usda.gov/ipedb/. Typical animal sizes from U.S. Environmental Protection Agency, Office of Air and Radiation, *Anthropogenic Methane Emissions in the United States: Estimates for 1990* (Washington, DC, April 1993), p. 6-8. Manure production and waste management systems used from L.M. Safley, M.E. Casada et al., *Global Methane Emissions From Livestock and Poultry Manure* (Washington, DC, February 1992), and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

Table 27. U.S. Nitrous Oxide Emissions from Solid Waste of Domesticated Animals, 1990, 1995, and 1998-2005

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Million Metric Tons Carbon Dioxide Equivalent										
Cattle	57.5	61.1	58.3	57.9	57.4	56.9	56.7	56.3	55.8	56.4
Swine	1.5	1.6	1.7	1.6	1.6	1.6	1.6	1.7	1.7	1.7
Poultry	0.9	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4
Horses	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Sheep	1.0	0.8	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5
Goats	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.4
Total	**61.9**	**65.6**	**62.8**	**62.3**	**61.8**	**61.4**	**61.1**	**60.7**	**60.3**	**61.2**
Thousand Metric Tons Nitrous Oxide										
Cattle	194	206	197	195	194	192	192	190	189	191
Swine	5	5	6	6	5	6	6	6	6	6
Poultry	3	4	4	4	4	4	4	4	5	5
Horses	2	2	2	2	2	2	2	2	2	2
Sheep	3	3	2	2	2	2	2	2	2	2
Goats	1	1	1	1	1	1	1	1	1	1
Total	**209**	**222**	**212**	**211**	**209**	**207**	**207**	**205**	**204**	**207**

P = preliminary data.

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

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

Table 28. U.S. Nitrous Oxide Emissions from Mobile Combustion, 1990, 1995, and 1998-2005

Item	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Million Metric Tons Carbon Dioxide Equivalent										
Motor Vehicles										
Passenger Cars	21.6	29.2	29.3	28.9	28.3	27.4	26.1	25.1	25.0	24.5
Light-Duty Trucks	10.4	17.2	19.0	18.9	18.9	18.8	18.9	19.2	20.5	21.2
Other Trucks	1.7	2.1	2.3	2.4	2.4	2.5	2.6	2.6	2.7	2.7
Buses	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Motorcycles	*	*	*	*	*	*	*	*	*	*
Subtotal	**33.9**	**48.6**	**50.7**	**50.3**	**49.7**	**48.8**	**47.7**	**47.1**	**48.3**	**48.5**
Other Mobile Sources	**3.6**	**3.6**	**3.5**	**3.7**	**3.9**	**3.6**	**3.6**	**3.4**	**3.7**	**4.1**
Total	**37.4**	**52.2**	**54.3**	**54.0**	**53.6**	**52.4**	**51.2**	**50.5**	**52.0**	**52.6**
Thousand Metric Tons Nitrous Oxide										
Motor Vehicles										
Passenger Cars	73	98	99	98	96	92	88	85	85	83
Light-Duty Trucks	*	*	*	*	*	*	*	*	*	*
Other Trucks	*	*	*	*	*	*	*	*	*	*
Buses	35	58	64	64	64	64	64	65	69	72
Motorcycles	6	7	8	8	8	8	9	9	9	9
Subtotal	**114**	**164**	**171**	**170**	**168**	**165**	**161**	**159**	**163**	**164**
Other Mobile Sources	**12**	**12**	**12**	**12**	**13**	**12**	**12**	**11**	**13**	**14**
Total	**126**	**176**	**183**	**183**	**181**	**177**	**173**	**170**	**176**	**178**

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

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

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

Table 29. U.S. Nitrous Oxide Emissions from Stationary Combustion, 1990, 1995, and 1998-2005

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
					Thousand Metric Tons Carbon Dioxide Equivalent					
Residential										
Coal	13	7	5	6	4	5	5	5	6	5
Fuel Oil[a]	251	247	235	263	279	275	261	268	277	274
Natural Gas	128	142	133	138	145	139	143	149	143	142
Wood	676	606	443	466	501	431	443	466	478	489
Total	**1,068**	**1,002**	**815**	**873**	**929**	**850**	**852**	**888**	**903**	**911**
Commercial										
Coal	52	48	42	42	36	38	38	34	42	42
Fuel Oil[a]	170	131	118	118	135	132	122	134	135	138
Natural Gas	77	89	88	89	92	89	92	93	92	89
Wood	77	84	75	78	83	78	80	83	82	82
Total	**375**	**352**	**323**	**328**	**346**	**337**	**332**	**344**	**351**	**351**
Industrial										
Coal	1,129	1,020	925	905	940	913	841	851	853	818
Fuel Oil[a]	1,606	1,668	1,680	1,743	1,690	1,694	1,644	1,655	1,750	1,701
Natural Gas	242	274	279	268	271	248	252	243	244	224
Wood	1,680	1,924	1,867	1,887	1,906	1,681	1,626	1,588	1,719	1,442
Total	**4,657**	**4,886**	**4,752**	**4,803**	**4,807**	**4,536**	**4,363**	**4,336**	**4,566**	**4,185**
Electric Power										
Coal	6,770	7,278	8,008	8,034	8,426	8,205	8,244	8,411	8,446	8,635
Fuel Oil[a]	228	135	233	216	204	229	216	215	213	216
Natural Gas	94	123	133	140	151	153	164	150	156	165
Wood	150	146	160	161	156	147	175	195	192	196
Total	**7,242**	**7,682**	**8,534**	**8,551**	**8,937**	**8,733**	**8,799**	**8,971**	**9,008**	**9,212**
Total All Sectors										
Coal	**7,963**	**8,354**	**8,980**	**8,987**	**9,406**	**9,161**	**9,128**	**9,301**	**9,347**	**9,501**
Fuel Oil[a]	**2,256**	**2,180**	**2,266**	**2,341**	**2,308**	**2,330**	**2,242**	**2,272**	**2,375**	**2,329**
Natural Gas	**541**	**627**	**633**	**634**	**659**	**629**	**651**	**635**	**634**	**621**
Wood	**2,583**	**2,760**	**2,544**	**2,592**	**2,646**	**2,337**	**2,324**	**2,331**	**2,471**	**2,209**
Total	**13,343**	**13,921**	**14,424**	**14,554**	**15,020**	**14,457**	**14,346**	**14,539**	**14,827**	**14,659**

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

P = preliminary data. See notes and sources at end of table.

Table 29. U.S. Nitrous Oxide Emissions from Stationary Combustion, 1990, 1995, and 1998-2005 (Continued)

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
	Thousand Metric Tons Nitrous Oxide									
Residential										
Coal	*	*	*	*	*	*	*	*	*	*
Fuel Oil[a]	1	1	1	1	1	1	1	1	1	1
Natural Gas	*	*	*	*	*	*	*	1	*	*
Wood	2	2	1	2	2	1	1	2	2	2
Subtotal	**4**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Commercial										
Coal	*	*	*	*	*	*	*	*	*	*
Fuel Oil[a]	1	*	*	*	*	*	*	*	*	*
Natural Gas	*	*	*	*	*	*	*	*	*	*
Wood	*	*	*	*	*	*	*	*	*	*
Subtotal	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Industrial										
Coal	4	3	3	3	3	3	3	3	3	3
Fuel Oil[a]	5	6	6	6	6	6	6	6	6	6
Natural Gas	1	1	1	1	1	1	1	1	1	1
Wood	6	7	6	6	6	6	5	5	6	5
Subtotal	**16**	**17**	**16**	**16**	**16**	**15**	**15**	**15**	**15**	**14**
Electric Power										
Coal	23	25	27	27	28	28	28	28	29	29
Fuel Oil[a]	1	*	1	1	1	1	1	1	1	1
Natural Gas	*	*	*	*	1	1	1	1	1	1
Wood	1	*	1	1	1	*	1	1	1	1
Total	**24**	**26**	**29**	**29**	**30**	**30**	**30**	**30**	**30**	**31**
Total All Sectors										
Coal	**27**	**28**	**30**	**30**	**32**	**31**	**31**	**31**	**32**	**32**
Fuel Oil[a]	**8**	**7**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**8**
Natural Gas	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
Wood	**9**	**9**	**9**	**9**	**9**	**8**	**8**	**8**	**8**	**7**
Total	**45**	**47**	**49**	**49**	**51**	**49**	**48**	**49**	**50**	**50**

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

*Less than 500 metric tons nitrous oxide.

P = preliminary data.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

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

Table 30. U.S. Nitrous Oxide Emissions from Industrial Sources, 1990, 1995, and 1998-2005

Source	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Million Metric Tons Carbon Dioxide Equivalent										
Adipic Acid										
Controlled Sources	1.0	1.1	1.5	1.5	1.6	1.4	1.6	1.6	1.6	1.6
Uncontrolled Sources	15.9	18.7	2.0	2.1	2.1	2.1	2.3	1.4	1.4	1.4
Subtotal	**16.8**	**19.8**	**3.5**	**3.6**	**3.7**	**3.5**	**3.9**	**3.0**	**3.1**	**2.9**
Nitric Acid	**11.7**	**13.1**	**13.7**	**13.2**	**12.9**	**10.4**	**11.3**	**11.0**	**10.9**	**10.3**
Total Known Industrial Sources	**28.6**	**32.9**	**17.2**	**16.8**	**16.6**	**14.0**	**15.2**	**14.0**	**14.0**	**13.2**
Thousand Metric Tons Nitrous Oxide										
Adipic Acid										
Controlled Sources	3	4	5	5	5	5	5	5	6	5
Uncontrolled Sources	54	63	7	7	7	7	8	5	5	5
Subtotal	**57**	**67**	**12**	**12**	**13**	**12**	**13**	**10**	**10**	**10**
Nitric Acid	**40**	**44**	**46**	**45**	**43**	**35**	**38**	**37**	**37**	**35**
Total Known Industrial Sources	**96**	**111**	**58**	**57**	**56**	**47**	**51**	**47**	**47**	**45**

P = preliminary data.

Note: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0573(2004) (Washington, DC, December 2005). Totals may not equal sum of components due to independent rounding.

Sources: Data sources and methods documented in Energy Information Administration, *Documentation for Emissions of Greenhouse Gases in the United States 2004*, DOE/EIA-0638(2004) (Washington, DC, November 2006), and *Documentation for Emissions of Greenhouse Gases in the United States 2005*, DOE/EIA-0638(2005) (to be published).

5. Other Gases: Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride

Overview

Total U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	160.2
Change Compared to 2004 (Million Metric Tons Carbon Dioxide Equivalent)	10.7
Change from 2004 *(Percent)*	*7.2%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	73.2
Change from 1990 *(Percent)*	*84.0%*

U.S. emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) in 2005, according to the U.S. Environmental Protection Agency (EPA), totaled 160.2 million metric tons carbon dioxide equivalent ($MMTCO_2e$). Collectively, these "other gases" represented 2.2 percent of total U.S. greenhouse gas emissions. Their 2005 emissions were 7.2 percent (10.7 $MMTCO_2e$) above the 2004 level of 149.5 $MMTCO_2e$, an increase attributed primarily to an 8.9-percent (10.7 $MMTCO_2e$) increase in emissions of HFCs.

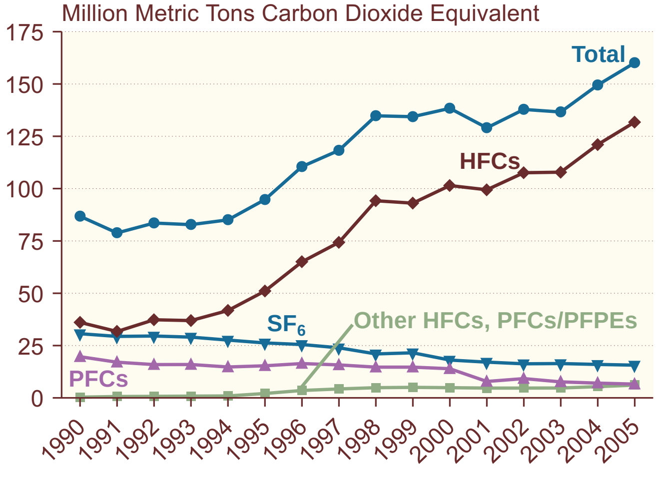
Table 31 at the end of this chapter shows U.S. emissions of HFCs, PFCs, and SF_6 from 1990 to 2005 in carbon dioxide equivalent units, and Table 32 shows their emissions in metric tons of native gas. U.S. emissions of HFCs, PFCs, and SF_6 were 84 percent (73.2 $MMTCO_2e$) higher in 2005 than in 1990 (87.1 $MMTCO_2e$). Revised EPA data for 1990-2004 and new estimates for 2005 show that annual emissions of HFCs have increased significantly since 1990; emissions of PFCs have declined by two-thirds; and SF_6 emissions have declined by almost one-half since 1990 (Figure 4).

The increase in HFC emissions since the early 1990s reflects the use of HFCs as replacements for CFCs (chlorofluorocarbons), HCFCs (hydrochlorofluorocarbons), halons, and other ozone-depleting substances (ODS) that are being phased out under the Montreal Protocol because they damage the Earth's stratospheric ozone layer. ODS are used in a variety of applications, including refrigeration and air conditioning, solvents, foam production, fire extinguishers, aerosols, and sterilization.

PFC emissions have trended downward since 1990, largely as a result of reduced PFC emissions from the aluminum industry, both because of industry efforts to reduce emissions and because aluminum production has declined. SF_6 emissions have also fallen since 1990, mainly due to reduced emissions from electricity transmission and distribution in the electric power industry and increased prices for SF_6.

The emissions estimates in Table 31 are based on data provided by the EPA's Office of Air and Radiation.[75] The EPA data, provided in units of native gas (thousand metric tons), were converted to carbon dioxide equivalent units by the Energy Information Administration (EIA), using values for the global warming potential (GWP) for each gas from the 2001 Third Assessment

Figure 4. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2005



Source: Estimates presented in this chapter.

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[75] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

Report of the Intergovernmental Panel on Climate Change (IPCC). The estimates in Table 32 are taken directly from data supplied by the EPA's Office of Air and Radiation. The 2005 preliminary estimates developed by the EPA and provided to EIA include some revisions to historical emissions estimates, based on recent runs of the EPA's Vintaging Model (see boxes on pages 63 and 64). Those revisions are reflected in the emissions estimates presented in this chapter.

Hydrofluorocarbons (HFCs)

U.S. Emissions of Hydrofluorocarbons, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	131.8
Change Compared to 2004 (Million Metric Tons Carbon Dioxide Equivalent)	10.7
Change from 2004 *(Percent)*	*8.9%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	95.7
Change from 1990 *(Percent)*	*265.4%*

The EPA estimates U.S. emissions of HFCs in 2005 at 131.8 $MMTCO_2e$, equivalent to 1.7 percent of total U.S. greenhouse gas emissions.[76] HFC emissions in 2005 were 8.9 percent (10.7 $MMTCO_2e$) above the 2004 level of 121.1 $MMTCO_2e$ (Table 31). The overall increase included increases in emissions of HFC-23 (0.9 $MMTCO_2e$), HFC-32 (0.1 $MMTCO_2e$), HFC-125 (2.3 $MMTCO_2e$), HFC-134a (4.5 $MMTCO_2e$), and HFC-143a (3.5 $MMTCO_2e$).

U.S. HFC emissions in 2005 were 265 percent (95.7 $MMTCO_2e$) above the 1990 level of 36.1 $MMTCO_2e$. Since 1990, HFC emissions have accounted for a growing share of total emissions of HFCs, PFCs, and SF_6 combined (82 percent in 2005, compared with 41 percent in 1990). By far the largest portion of HFC emissions, 88 percent, can be attributed to their use as replacements for ODS. Emissions of HFCs used as substitutes for ODS (such as HFC-32, HFC-125, HFC-134a, HFC-143a, and HFC-236fa) have grown from trace amounts in 1990 to 112.6 $MMTCO_2e$ in 2005. ODS substitutes—used mainly in refrigeration and air conditioning (85 percent of total use), aerosols (11 percent), and solvents (2 percent)—were the largest and fastest growing sources of all HFC, PFC, and SF_6 emissions through 2004.[77]

HFCs are compounds containing carbon, hydrogen, and fluorine. Although they do not destroy stratospheric ozone, they are powerful greenhouse gases. HFCs are used in many applications, such as solvents, domestic and commercial refrigerants, firefighting agents, propellants for pharmaceutical and industrial aerosols, foam-blowing agents, and in blends for air conditioning refrigerants.

The market for HFCs is expanding. As CFCs and ODS are being phased out under the Montreal Protocol and the Clean Air Act, HFCs have been introduced into the market to fill the void in many key applications. For example, HFCs are used in fire protection applications to replace Halon 1301 and Halon 1211, which are no longer being produced in the United States.[78] HCFCs, now interim replacements for CFCs, will also be phased out. For example, HCFC-141b and HCFC-142b, which are used as blowing agents in insulation foams, will be replaced by HFCs for some uses.[79]

Trifluoromethane (HFC-23)

The EPA estimates 2005 emissions of HFC-23 at 17.3 $MMTCO_2e$.[80] HFC-23 emissions, representing 13 percent of total HFC emissions in 2005, were 5.8 percent (0.9 $MMTCO_2e$) above their 2004 level of 16.3 $MMTCO_2e$ but still 52 percent (18.8 $MMTCO_2e$) below their 1990 level of 36.1 $MMTCO_2e$. Since 1990, annual HFC-23 emissions have fluctuated, peaking in 1998 at 41.6 $MMTCO_2e$ and then falling steadily before edging up in 2004 and 2005.

Nearly all HFC-23 emissions (98 percent) are created as a byproduct in the production of chlorodifluoromethane (HCFC-22) and generally are vented to the atmosphere. In some cases the HFC-23 is captured for use in a limited number of applications. While production of HCFC-22 peaked in 2000, emissions of HFC-23 from this source declined from 1998 until 2003, because the HFC-23 emission rate (i.e., the amount of HFC-23 emitted per kilogram of HCFC-22 manufactured) decreased

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[76] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses GWP values from the IPCC's 1996 Second Assessment Report.

[77] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[78] European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/en/applications/other_app/firefighting.html.

[79] European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/en/applications/insulation_foams.html.

[80] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

Revisions in EPA Emissions Estimation Methodology

The primary source for the emissions estimates presented in this chapter is data obtained from the U.S. Environmental Protection Agency (EPA), Office of Air and Radiation. The Office of Air and Radiation also prepares an annual inventory of greenhouse gas emissions, which is published pursuant to U.S. commitments under the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC encourages parties to revise methods regularly and to recalculate emissions affected by the revisions. The data supporting the EPA inventory, including the emissions estimates for 2005, incorporate a number of revisions to the data and estimation methodologies used for hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) in its most recent emissions inventory.[a] Those changes are reflected in the EPA's historical emissions estimates, as described below:

- *Electricity Transmission and Distribution.* Changes in the calculations of emissions from electricity transmission and distribution resulted in an average annual increase in estimated SF_6 emissions from electric power systems of 0.1 to 0.6 million metric tons carbon dioxide equivalent ($MMTCO_2e$) for the 1990-2003 period.
- *Magnesium Production and Processing.* Emissions estimates from the EPA have been revised to reflect more accurate data on emission factors for sand casting activities and updated historical secondary production data from the U.S. Geological Survey (USGS). The changes resulted in a decrease in estimated SF_6 emissions from magnesium production and processing of 0.1 $MMTCO_2e$ (5 percent) for 2002.
- *Substitution of Ozone-Depleting Substances.* The EPA has updated assumptions for its Vintaging Model pertaining to trends in chemical substitutions, market size and growth rates, and amounts used. The changes resulted in an average annual net decrease in estimated HFC and PFC emissions of 2.0 $MMTCO_2e$ (3 percent) for the 1990-2003 period.
- *Aluminum Production.* The EPA has revised smelter-specific emissions factors and aluminum production levels to reflect recently reported data on smelter operating parameters. The changes resulted in an average annual increase of less than 0.5 $MMTCO_2e$ (0.4 percent) for the 1990-2003 period.

[a] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

significantly, and two of the three plants that manufacture HCFC-22 introduced the use of thermal oxidation.[81] Production of HCFC-22 also fell significantly between 2000 and 2005, to a level equal to 1995 production.[82]

HCFC-22 is used as a component of blowing agents for polyurethane foams and extruded polystyrene foams, and in the refrigerant market for stationary refrigeration and air conditioning (including chillers, room and household [central] air conditioners, and dehumidifiers). The EPA administers a voluntary program (the HFC-23 Emission Reduction Program) with HCFC-22 producers to reduce HFC-23 emissions, which has helped to moderate HFC-23 emissions during periods of rising demand for HCFC-22. In the long term, domestic production of HCFC-22 for non-feedstock uses will be phased out by 2020 under the U.S. Clean Air Act, pursuant to U.S. agreements under the Copenhagen Amendments to the Montreal Protocol. However, HCFC-22 production for use as a feedstock in the production of other chemicals (fluorinated polymers) will be allowed to continue indefinitely.[83]

Difluoromethane (HFC-32)

The EPA estimates 2005 emissions of HFC-32 at 0.4 $MMTCO_2e$.[84] HFC-32 emissions, representing 0.3 percent of total HFC emissions in 2005, were 23 percent (0.1 $MMTCO_2e$) above their 2004 level of 0.3 $MMTCO_2e$, and up by 459 percent (0.4 MMTCO2e) since first appearing in 1996. HFC-32 is increasingly being used to replace HCFC-22 in refrigerant blends.

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[81] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

[82] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[83] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[84] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

The EPA Vintaging Model: Estimation Methods and Uncertainty

The U.S. Environmental Protection Agency (EPA) uses a detailed Vintaging Model for equipment and products containing ozone-depleting substances (ODS) and ODS substitutes to estimate actual versus potential emissions of various ODS substitutes, including hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The model estimates the quantities of equipment and products sold each year that contain ODS and ODS substitutes, and the amounts of chemicals required for their manufacture and/or maintenance over time. Emissions from more than 50 different end uses are estimated by applying annual leak rates and release profiles, which account for the lag in emissions from equipment as it leaks over time.

For most products (refrigerators, air conditioners, fire extinguishers, etc.), emissions calculations are split into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses plus emissions from manufacture; and disposal emissions, which occur when the equipment is discarded. By aggregating the data over different end uses, the model produces estimates of annual use and emissions of each compound.[a]

The EPA periodically attempts to improve the model and reduce the uncertainty of emissions estimates by using more accurate data from emitting industries. The level of detail incorporated in the EPA Vintaging Model is higher than that of the default methodology used by the Intergovernmental Panel on Climate Change, although there still is some uncertainty about some of the model inputs, such as equipment characteristics and sales figures, and end-use emissions profiles.

[a] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003*, EPA-430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html.

Pentafluoroethane (HFC-125)

The EPA estimates U.S. emissions of HFC-125 in 2005 at 22.1 $MMTCO_2e$, equivalent to 17 percent of total HFC emissions.[85] The 2005 emissions level is 12 percent (2.3 $MMTCO_2e$) higher than the 2004 level of 19.8 $MMTCO_2e$. Emissions of HFC-125 have increased steadily from 0.7 $MMTCO_2e$ in 1992 because of its use as a refrigerant blending agent.

HFC-125 is used in the blend R-410A, which is designed to replace HCFC-22 as the refrigerant of choice for stationary commercial refrigeration and air conditioning applications, as well as in the blends R-404A and R-507A. Some manufacturers have already introduced air conditioners that use R-410A, but as yet the product has captured only a small percentage of the market. As the phaseout of HCFC-22 begins to gain momentum, producers expect a rapid increase in demand for R-410A.[86] HFC-125 can also be used as a firefighting agent.

Tetrafluoroethane (HFC-134a)

The EPA estimates 2005 U.S emissions of HFC-134a at 66.1 $MMTCO_2e$.[87] HFC-134a accounts for the largest share of total HFC emissions (50 percent). The 2005 emissions level is 7.3 percent (4.5 $MMTCO_2e$) higher than the 2004 level of 61.6 $MMTCO_2e$. The increase can be attributed primarily to the continued use of HFC-134a as a substitute for CFCs in motor vehicle air conditioning systems.

Annual HFC-134a emissions have grown dramatically from their estimated 1992 level of 0.6 $MMTCO_2e$. Since 1994, HFC-134a has been the transportation industry standard for replacing CFCs in air conditioners for passenger cars, trucks, trains, and buses, because it is nonflammable, has low toxicity, and is not an ODS.

HFC-134a is also used in refrigerant blends (e.g., R-404A) in most new commercial refrigeration equipment built in the United States and in commercial chillers, but leakage from these sources is much less than from automotive air conditioners. Leakage occurs primarily during the servicing of the units rather than during normal operation. Short-term uses of HFC-134a, on the other hand, are becoming an important source of emissions. Such uses include aerosol propellants and open-cell foam blowing, which are denoted as short-term uses because most of the HFC-134a used will be emitted to the atmosphere within a short period of time. In 1994, HFC-134a began to be used as solvents and sterilants. According to the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), worldwide sales of HFC-134a jumped more than fourfold

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[85] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.
[86] J. Ouellette, "Fluorocarbon Market Is Poised To Grow," *Chemical Market Reporter* (June 19, 2000).
[87] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

between 1992 and 1993, doubled again in 1994, and continued growing steadily to 166,899 metric tons of gas in 2003.[88]

Trifluoroethane (HFC-143a)

The EPA estimates U.S. emissions of HFC-143a in 2005 at 23.0 MMTCO$_2$e, equivalent to 17 percent of total HFC emissions.[89] The 2005 emissions level is 18 percent (3.5 MMTCO$_2$e) higher than the 2004 level of 19.5 MMTCO$_2$e. HFC-143a emissions have increased rapidly from 0.1 MMTCO$_2$e in 1993, as demand for HFC-143a as a refrigerant blending agent has increased.

HFC-143a is a halocarbon used in blends for commercial refrigeration and air conditioning, such as R-404A and R-507A. HFC-143a, like other HFCs, is used as a substitute because it contains neither chlorine nor bromine and does not emit ozone-depleting halogen radicals into the stratosphere. Like other halocarbons, HFC-143a does make a positive contribution to atmospheric warming; however, the GWPs of R-404A and R-507A are lower than those of the gases it replaces, such as CFC-12 with a GWP of 10,600.

Hexafluoropropane (HFC-236fa)

The EPA estimates U.S. emissions of HFC-236fa in 2005 at 2.9 MMTCO$_2$e, equivalent to 2.2 percent of total HFC emissions.[90] The 2005 emissions level is 17 percent (0.6 MMTCO$_2$e) lower than the 2004 level of 3.5 MMTCO$_2$e. Emissions of HFC-236fa have increased from 0.1 MMTCO$_2$e in 1997 because of its use as a refrigerant, in particular by the U.S. Navy for shipboard applications.[91] In another application, HFC-236fa is used as a firefighting agent.

Perfluorocarbons (PFCs)

The EPA estimates 2005 emissions of PFCs at 6.7 MMTCO$_2$e, accounting for 4.2 percent of all emissions of HFCs, PFCs, and SF$_6$ combined. The estimate for 2005 is 5.2 percent (0.4 MMTCO$_2$e) lower than the estimate for 2004 (7.0 MMTCO$_2$e) and 67 percent (13.3 MMTCO$_2$e) lower than the 1990 emissions level of 20.0 MMTCO$_2$e.[92] The downward trend in emissions is largely the result of decreases in domestic aluminum production, which creates PFCs as byproducts, as well as process efficiency improvements in the aluminum industry. Moderating the decrease in emissions of the PFCs perfluoromethane (CF$_4$) and perfluoroethane (C$_2$F$_6$) from aluminum manufacture have been increases in their emissions from semiconductor manufacture, which also produces emissions of perfluoropropane (C$_3$F$_8$), perfluorobutene (C$_4$F$_8$), and nitrogen trifluoride (NF$_3$).

Perfluoromethane (CF$_4$)

The EPA estimates U.S. emissions of CF$_4$ in 2005 at 3.2 MMTCO$_2$e, equivalent to 48 percent of total PFC emissions.[93] The 2005 emissions level is 0.5 percent (less than 0.1 MMTCO$_2$e) lower than the 2004 level of 3.2 MMTCO$_2$e. CF$_4$ emissions have dropped by a total of 78 percent (11.4 MMTCO$_2$e) from their 1990 level of 14.6 MMTCO$_2$e.

The two principal sources of CF$_4$, as well as C$_2$F$_6$, are as a byproduct of aluminum smelting created during periods of process inefficiency and disruption, and in the manufacture of semiconductors. The EPA estimates U.S. CF$_4$ emissions in 2005 from aluminum production at 2.2 MMTCO$_2$e and from semiconductor manufacture at 0.9 MMTCO$_2$e.[94] With reductions in primary aluminum production and improvements that reduce anode effects leading to process inefficiency, CF$_4$ emissions from aluminum smelting have been reduced by 84 percent (11.7 MMTCO$_2$e) from their 1990 level of 13.9 MMTCO$_2$e.

U.S. Emissions of Perfluorocarbons, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	6.7
Change Compared to 2004 (Million Metric Tons Carbon Dioxide Equivalent)	-0.4
Change from 2004 *(Percent)*	*-5.2%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	-13.3
Change from 1990 *(Percent)*	*-66.6%*

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[88] Alternative Fluorocarbons Environmental Acceptability Study, Production, Sales and Atmospheric Release, web site www.afeas.org/2003/html/hfc-134a.html.

[89] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

[90] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

[91] E-mail correspondence with the Office of Policy, U.S. Department of Energy, October 18, 2000.

[92] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses GWP values from the IPCC's 1996 Second Assessment Report.

[93] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

[94] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

Aluminum smelting companies that participate in the EPA's Voluntary Aluminum Industry Partnership (VAIP) have achieved efficiency improvements through voluntary actions. Reductions in primary aluminum production have also played a role in reducing PFC emissions. According to data from the U.S. Geological Survey (USGS), domestic primary aluminum production fell between 2003 and 2004 and held steady in 2005. The decline in production resulted from cutbacks in smelter production in response to higher costs of energy and alumina. Most of the production cutbacks took place in the Pacific Northwest.[95]

Another source of CF_4 emissions is semiconductor manufacturing. Emissions from this source peaked in 2000 at just over 1.6 $MMTCO_2e$ and have since declined by 42 percent (0.1 $MMTCO_2e$) to their 2005 level of 0.9 $MMTCO_2e$.[96] This estimate reflects the rapid growth of the semiconductor industry in the 1990s, which has resulted in a 42-percent increase in emissions (0.3 $MMTCO_2e$) from their 1990 level of 0.7 $MMTCO_2e$. CF_4, like C_2F_6, is used as a plasma etchant and cleaning agent in semiconductor manufacturing; some of the gas used in those processes does not react with the materials and, unless abated, is emitted to the atmosphere.

Perfluoroethane (C_2F_6)

The EPA estimates U.S. emissions of C_2F_6 in 2005 at 3.0 $MMTCO_2e$, equivalent to 46 percent of total PFC emissions.[97] The 2005 emissions level is 11.5 percent (0.4 $MMTCO_2e$) below the 2004 level of 3.4 $MMTCO_2e$. Emissions of C_2F_6 have dropped by 43 percent (2.3 $MMTCO_2e$) from their 1990 level of 5.4 $MMTCO_2e$.

C_2F_6 emissions originate from the aluminum and semiconductor industries. Thus, C_2F_6, like CF_4, has had two countervailing trends bearing on its emissions levels. On one side, decreasing aluminum production and increased efficiency in the aluminum industry have tended to lower emissions. C_2F_6 emissions in the aluminum industry fell from 3.5 $MMTCO_2e$ in 1990 to 0.5 $MMTCO_2e$ in 2005, or by 85 percent (2.9 $MMTCO_2e$). On the other side, increased semiconductor production has tended to increase emissions. C_2F_6 emissions in the semiconductor industry, estimated by the EPA at 2.5 $MMTCO_2e$ in 2005, have increased by 32 percent (0.6 $MMTCO_2e$) from their 1990 level of 1.9 $MMTCO_2e$. The net effect has been a 43-percent overall reduction in emissions of C_2F_6 since 1990.

Other HFCs and PFCs/PFPEs

There is a group of other HFCs and PFCs/PFPEs for which the EPA withholds individual emissions data, because the data are considered confidential and could compromise business practices. This group includes HFC-152a, HFC-227ea, HFC-245fa, and HFC-4310mee.[98] The EPA estimates total emissions of this group of "other HFCs" at 6.1 $MMTCO_2e$ in 2005, representing 3.8 percent of all emissions of HFCs, PFCs, and SF_6 reported.[99] Emissions of these HFCs are small but growing rapidly, as they continue to find applications as substitutes for CFCs and HCFCs. Emissions of "other HFCs" increased by 13 percent (0.7 $MMTCO_2e$) in 2005 compared with 2004 (5.4 $MMTCO_2e$).

Other HFCs and HFC blends are also likely to gain market share as a result of the phaseout of CFCs and HCFCs, because no single product is suited for all applications. For example, each potential replacement product has an optimal operating temperature range; hence, the refrigerant best suited for use in ice cream freezers will differ from the best choice for milk coolers.[100]

In addition to replacing HCFC-22 in stationary air conditioning and refrigeration applications, other HFCs are expected to gain new markets as foam-blowing agents. CFCs have already been phased out of this market, having been replaced by HCFCs (primarily HCFC-141b). Among the potential replacements for HCFCs, HFC-245fa (pentafluoropropane) appears to be the strongest contender.[101]

Sulfur Hexafluoride (SF_6)

The EPA estimates 2005 emissions of SF_6 at 15.7 $MMTCO_2e$, accounting for 9.8 percent of all HFC, PFC, and SF_6 emissions combined in 2005.[102] Emissions in 2005 were 2.1 percent (0.3 $MMTCO_2e$) lower than in 2004

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[95] U.S. Department of the Interior, U.S. Geological Survey, *Mineral Commodity Summaries 2006*, web site http://minerals.usgs.gov/minerals/pubs/mcs/2006/mcs2006.pdf.

[96] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

[97] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006.

[98] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 388.

[99] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses GWP values from the IPCC's 1996 Second Assessment Report.

[100] C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).

[101] C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).

[102] Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2006. In compiling its estimates, the EPA receives data from participants in the SF_6 Emission Reduction Partnership for Electric Power Systems and the SF_6 Emission Reduction Partnership for the Magnesium Industry.

U.S. Emissions of Sulfur Hexafluoride, 1990-2005

Estimated 2005 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	15.7
Change Compared to 2004 (Million Metric Tons Carbon Dioxide Equivalent)	-0.3
Change from 2004 *(Percent)*	*-2.1%*
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	-15.0
Change from 1990 *(Percent)*	*-48.9%*

(16.0 MMTCO$_2$e) and 49 percent (15.0 MMTCO$_2$e) lower than the estimate for 1990 (30.7 MMTCO$_2$e). The downward trend in SF$_6$ emissions since 1990 is the result of industry efforts to reduce emissions from electrical power systems, as well as the rising cost of SF$_6$. In contrast, emissions of SF$_6$ from uses in the semiconductor manufacturing industry have increased overall by 84 percent since 1990.

SF$_6$ is used primarily in electrical applications, in which it is an excellent dielectric gas for high-voltage applications, because it is chemically inert, gaseous at low temperatures, nonflammable, nontoxic, and noncorrosive.[103] In electricity transmission and distribution systems, SF$_6$ acts as an insulator and arc interrupter for circuit breakers, switch gear, and other electrical equipment; however, it can escape through seals, especially in older equipment. Emissions also occur during equipment installation, servicing, and disposal.[104]

Other applications that produce SF$_6$ emissions include magnesium metal casting processes that employ SF$_6$ to replace toxic and corrosive materials, such as salt fluxes and sulfur dioxide (SO$_2$). Another use of SF$_6$ is as a cover gas during magnesium production and processing to prevent excessive oxidation of molten magnesium in the presence of air. Although emissions from this source have declined, due in part to process optimizations by industry participants in EPA's SF$_6$ Emission Reduction Partnership for the Magnesium Industry, there was a 3-percent increase in the amount of metal processed in 2004.[105] Pre-treating aluminum melt with SF$_6$ (or an inert gas mixture) prevents porosity and therefore weakening of the metal. It also removes oxides and solid impurities. In addition, mixtures of SF$_6$ and O$_2$ are used as feed gases for plasma etching of semiconductor devices.[106] Because of its extremely low atmospheric concentration, SF$_6$ is also useful as an atmospheric tracer gas for a variety of experimental purposes. Other minor applications include leak detection, loudspeakers, lasers, and as a cover gas or fluxing and degassing agent for specialized casting operations in the aluminum industry.[107]

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[103] European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/en/families/sf6/main_app.html.

[104] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2006.html.

[105] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-32 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2006.html.

[106] European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/en/families/sf6/main_app.html#c.

[107] Historically, emissions of SF$_6$ from the aluminum industry have been omitted from global estimates, because any emissions are expected to be insignificant. The EPA does not estimate emissions from this source due to uncertainties about the quantities used and the amounts destroyed in the applications.

Table 31. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990, 1995, and 1998-2005
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Hydrofluorocarbons										
HFC-23	36.1	28.1	41.6	31.7	30.9	20.6	20.6	12.9	16.3	17.3
HFC-32	0.0	0.0	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4
HFC-125	0.0	4.4	10.7	12.1	13.6	14.9	16.3	17.9	19.8	22.1
HFC-134a	0.0	17.7	35.2	40.2	45.4	49.7	53.5	56.8	61.6	66.1
HFC-143a	0.0	0.9	5.9	7.5	9.3	11.4	13.8	16.5	19.5	23.0
HFC-236fa	0.0	0.0	0.6	1.3	2.0	2.6	3.2	3.5	3.5	2.9
Total HFCs	**36.1**	**51.0**	**94.2**	**93.1**	**101.5**	**99.4**	**107.6**	**107.8**	**121.1**	**131.8**
Perfluorocarbons										
CF_4	14.6	10.0	8.4	8.3	8.4	3.8	5.0	3.8	3.2	3.2
C_2F_6	5.4	5.4	5.8	5.8	4.9	3.3	3.8	3.3	3.4	3.0
NF_3	*	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3
C_3F_8	*	*	*	*	0.1	0.1	0.1	0.1	*	*
C_4F_8	*	*	*	*	*	*	0.1	0.1	0.1	0.1
Total PFCs	**20.0**	**15.5**	**14.2**	**14.2**	**13.6**	**7.3**	**9.2**	**7.6**	**7.0**	**6.7**
Other HFCs, PFCs/PFPEs	**0.4**	**2.1**	**4.9**	**5.0**	**4.9**	**4.7**	**4.7**	**4.7**	**5.4**	**6.1**
Sulfur Hexafluoride	**30.7**	**26.3**	**21.0**	**21.6**	**18.1**	**17.1**	**16.3**	**16.4**	**16.0**	**15.7**
Total Emissions	**87.1**	**94.9**	**134.3**	**133.9**	**138.0**	**128.5**	**137.8**	**136.6**	**149.5**	**160.2**

*Less than 50,000 metric tons carbon dioxide equivalent.

P = preliminary data.

Notes: Other HFCs, PFCs/PFPEs include HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and a variety of PFCs and perfluoropolyethers (PFPEs). They are grouped together to protect confidential data. Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, September and October 2006).

Table 32. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990, 1995, and 1998-2005
(Thousand Metric Tons of Gas)

Gas	1990	1995	1998	1999	2000	2001	2002	2003	2004	P2005
Hydrofluorocarbons										
HFC-23	3.0	2.3	3.5	2.6	2.6	1.7	1.7	1.1	1.4	1.4
HFC-32	0.0	0.0	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.8
HFC-125	0.0	1.3	3.1	3.6	4.0	4.4	4.8	5.3	5.8	6.5
HFC-134a	0.0	13.6	27.1	30.9	34.9	38.2	41.2	43.7	47.4	50.8
HFC-143a	0.0	0.2	1.4	1.7	2.2	2.6	3.2	3.8	4.5	5.4
HFC-236fa	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.4	0.3
Perfluorocarbons										
CF_4	2.6	1.8	1.5	1.5	1.5	0.7	0.9	0.7	0.6	0.6
C_2F_6	0.5	0.5	0.5	0.5	0.4	0.3	0.3	0.3	0.3	0.3
NF_3	*	*	*	*	*	*	*	*	*	*
C_3F_8	*	*	*	*	*	*	*	*	*	*
C_4F_8	*	*	*	*	*	*	*	*	*	*
Other HFCs, PFCs/PFPEs	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Sulfur Hexafluoride	**1.4**	**1.2**	**0.9**	**1.0**	**0.8**	**0.8**	**0.7**	**0.7**	**0.7**	**0.7**

*Less than 50 metric tons of gas.

P = preliminary data. M = mixture of gases.

Notes: Other HFCs, PFCs/PFPEs include HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and a variety of PFCs and perfluoropolyethers (PFPEs). They are grouped together to protect confidential data. Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, September and October 2006).

6. Land-Use Issues

Overview

Land-use and forestry issues are important to national and global inventories of greenhouse gases in three ways:

- Vegetation can "sequester" or remove carbon dioxide from the atmosphere and store it for potentially long periods in above- and below-ground biomass, as well as in soils. Soils, trees, crops, and other vegetation may make significant contributions to reducing net greenhouse gas emissions by serving as carbon "sinks."
- Harvested wood put into wood products, or eventually into landfills, can potentially sequester carbon dioxide from the atmosphere for decades before the carbon stored in the wood products decays and is released to the atmosphere.
- Human-induced land-use changes and forest management practices can alter the quantities of atmospheric and terrestrial carbon stocks, as well as the natural carbon flux among biomass, soils, and the atmosphere.[108]

Land-use issues are of particular interest to U.S. policymakers, because U.S. forests and soils annually sequester large amounts of carbon dioxide. Much of the forest land in the United States was originally cleared for agriculture, lumber, or fuel in the hundred years before 1920. Since then, however, much of the agricultural and pasture land has reverted to forest land, increasing its ability to sequester atmospheric carbon dioxide.

The amount of carbon being sequestered annually is uncertain, in part because of an absence of data and difficulties in measuring carbon sequestration. Moreover, in addition to technical uncertainties, there are also policy and accounting questions about the aspects of the carbon cycle that should be included in national inventories as anthropogenic emissions and removals. Further, recent studies have indicated the possibility that vegetation may also be a source of methane (see box on page 73).

The 1996 revised guidelines for national emissions inventories, published in 1997 by the Intergovernmental Panel on Climate Change (IPCC), include methods for calculating carbon sequestration and net carbon dioxide flux to the atmosphere resulting from land-use changes and land-use activities, such as forestry.[109] The IPCC *Good Practice Guidance for Land Use, Land-Use Change and Forestry*[110] (LULUCF GPG), published in 2003, complements the 1996 IPCC guidelines. The U.S. Environmental Protection Agency (EPA) estimates annual U.S. carbon sequestration in 2004, based on data generated by the U.S. Department of Agriculture (USDA), at 780.1 million metric tons carbon dioxide equivalent (MMTCO$_2$e), a decline of approximately 14 percent from the 910.4 MMTCO$_2$e sequestered in 1990[111] (Table 33). Land use, land-use change, and forestry (LULUCF) practices offset 11 percent of total U.S. greenhouse gas emissions in 2004 and 15 percent in 1990.[112] In terms of anthropogenic carbon dioxide emissions, U.S. LULUCF practices offset 13 percent of U.S. carbon dioxide emissions in 2004, as compared with 18 percent in 1990.

Land-Use Change and Forestry Categories

The EPA, following LULUCF GPG, reported 2004 data on carbon fluxes according to the following categories: forest land remaining forest land, cropland remaining cropland, land converted to cropland, grassland remaining grassland, land converted to grassland, and settlements remaining settlements. Data constraints

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[108] The net numerical difference, or "flux," between carbon sequestration and carbon release due to natural factors can be viewed as a measure of the relative contribution of biomass to the carbon cycle.

[109] Intergovernmental Panel on Climate Change, *Greenhouse Gas Inventory Reference Manual: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 3 (Paris, France, 1997), web site www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

[110] Intergovernmental Panel on Climate Change, *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (Hayama, Japan, 2003), web site www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm. The EPA has been using the LULUCF GPG as well as the 1996 guidelines since its 1990-2003 inventory.

[111] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[112] EIA does not include sequestration from land-use change and forestry as part of its annual estimate of emissions of greenhouse gases in the United States. Note that land use refers to maintaining land within a particular category of use, such as forests remaining forests, whereas land-use change refers to changing from one land-use type to another, as when forest is converted to grassland, or wetlands are drained to create more land for agriculture.

prevented the EPA from reporting on all the LULUCF GPG categories for land use and land-use change.

Forest Land Remaining Forest Land

The values for forest carbon dioxide fluxes reported for this category are based on estimates of changes in forest carbon stocks. The components analyzed are above-ground biomass, below-ground biomass, dead wood, litter, soil organic carbon, harvested wood products in use, and harvested wood products in landfills. The estimated carbon flux (including all carbon-based greenhouse gases) from each of these components—except for soil organic carbon—was calculated using the USDA Forest Inventory and Analysis (FIA) database (FIADB) and methodologies consistent with the LULUCF GPG and the Revised 1996 IPCC Guidelines.[113] The FIADB is based on State surveys carried out at intervals of 5 to 14 years; accordingly, adjustments were made for temporal and spatial gaps, using FIA's recently introduced national plot design and annualized sampling.[114] Estimation of the average density of soil organic carbon (carbon per unit area) was based on USDA's State Soil Geographic (STATSGO) data and FIA survey data (areas of broad forest type).[115]

Nitrous oxide emissions from fertilized forest soils were calculated by using a default methodology consistent with the LULUCF GPG. Pine trees, being the dominant species planted for timber in the southeastern United States, were taken as representative of fertilized forests in the country, and the average reported fertilization rate of 150 pounds of nitrogen per acre was multiplied by the area of pine forest receiving fertilizer.

Cropland Remaining Cropland

Estimates of carbon stock changes from this category include changes in agricultural soil carbon stocks involving both mineral and organic soils on cropland remaining cropland. Also included in this category are carbon stock changes in organic soils on land converted to cropland and emissions of carbon dioxide from the application of crushed limestone and dolomite to all managed lands. The estimation methods used for these estimates are consistent with the Revised 1996 IPCC Guidelines and the LULUCF GPG.

Land Converted to Cropland

Carbon stock changes for this category include only carbon stock changes in mineral soils. Carbon stock changes in organic soils and emissions of carbon dioxide from the application of crushed limestone and dolomite that occur on land converted to cropland, as indicated above, are reported in the category of cropland

Table 33. Net Carbon Dioxide Sequestration from U.S. Land-Use Change and Forestry, 1990 and 1998-2004
(Million Metric Tons Carbon Dioxide Equivalent)

Component	1990	1998	1999	2000	2001	2002	2003	2004
Forest Land Remaining Forest Land: Changes in Forest Carbon Stocks	773.4	618.8	637.9	631.0	634.0	634.6	635.8	637.2
Cropland Remaining Cropland: Changes in Agricultural Soil Carbon Stocks and Liming Emissions	33.1	24.6	24.6	26.1	27.8	27.5	28.7	28.9
Land Converted to Cropland: Changes in Agricultural Soil Carbon Stocks . . .	-1.5	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Grassland Remaining Grassland: Changes in Agricultural Soil Carbon Stocks . . .	4.5	-7.5	-7.5	-7.4	-7.4	-7.4	-7.3	-7.3
Land Converted to Grassland: Changes in Agricultural Soil Carbon Stocks . . .	17.6	21.1	21.1	21.1	21.1	21.1	21.1	21.1
Settlements Remaining Settlements	83.2	84.2	86.8	85.9	89.7	89.9	93.8	97.3
Urban Trees	*58.7*	*73.3*	*77.0*	*77.0*	*80.7*	*80.7*	*84.3*	*88.0*
Landfilled Yard Trimmings and Food Scraps . .	*24.5*	*10.9*	*9.8*	*8.9*	*9.0*	*9.3*	*9.4*	*9.3*
Total Net Flux	**910.4**	**744.0**	**765.7**	**759.5**	**768.0**	**768.6**	**774.8**	**780.1**

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

Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

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[113] The USDA's Forest Inventory and Analysis (FIA) Program provides the information needed to assess forests in the United States. FIADB is the FIA database. Through an annual survey, FIA reports on status and trends in forest area and location. See web site http://fia.fs.fed.us.

[114] For each State survey, FORCARB2 (a combination of conversion methods and models) was used to estimate each forest carbon pool.

[115] The STATSGO database is a 1:250,000 scale generalized soils database, prepared by the National Resources Conservation Service of the U.S. Department of Agriculture. See web site www.ncgc.nrcs.usda.gov/products/datasets/statsgo.

Methane Emissions From Vegetation: New Findings

For several decades, the conventional view of climate scientists has been that terrestrial vegetation produces methane only under anaerobic conditions, through the action of anaerobic bacteria on organic matter in rice paddies and wetlands; however, recent studies by Frank Keppler of the Max Planck Institute for Nuclear Physics, along with researchers at other European institutions, indicate that vegetation can emit methane under aerobic conditions.[a] This discovery has prompted a lively discussion both among scientists and in the press, given the importance of methane as a greenhouse gas of concern (methane is second in importance only to carbon dioxide, with 23 times its global warming potential) and the role of afforestation and reforestation in national and international efforts to mitigate emissions of greenhouse gases.

Keppler and his fellow investigators measured methane emissions from vegetation exposed to methane-free air, using intact plants in plexiglass chambers and freshly collected tree and grass leaves in sealed vials. To rule out a possible role of anaerobic bacteria, gamma radiation was used to kill any such bacteria in the samples. First-estimate extrapolations from laboratory measurements to a global scale, based on net primary productivity, produced an estimate of annual methane emissions from terrestrial vegetation between 62 and 236 MMT. In comparison, previous estimates of global methane emissions from all known sources (wetlands, animals, rice cultivation, biomass burning, and fossil fuel production) have totaled approximately 600 MMT per year. Given the considerable uncertainty associated with methane emissions estimates for those sources, Keppler suggested that up to 50 MMT of methane from vegetation may already be included (erroneously) in some of the previous estimates attributed to sources such as wetlands or rice paddies.

Keppler's estimate of methane emissions from vegetation, extrapolated to the global scale, was then used to estimate annual emissions from various sources, based on type of vegetation, ecosystem, and region. For tropical forests, the researchers estimated mean annual methane emissions of 78.2 MMT per year, and for tropical savannas and grasslands they estimated mean annual emissions of 29.2 MMT per year. The results are in conformity with recent field and satellite measurements, which indicate annual methane emissions in upland zones of the Brazilian Amazon in the range of 4 to 38 MMT[b] and annual emissions in the northern part of the Guyana shield of Venezuela in the range of 30 to 60 MMT for the entire savanna.[c]

Other recent research has compared emissions measured using the SCIAMACHY instrument of the European Space Agency's ENVISAT satellite against modeled data, finding significant discrepancies over tropical forests.[d] The measured values were consistently higher than the modeled values, with a discrepancy of 30 MMT methane per year. Adding the discrepancy to the modeled value of 45 MMT per year yields an estimate of 75 MMT for annual methane emissions from tropical forests, as compared with Keppler's estimate of 78.2 MMT.

The extrapolation of emission rates from laboratory experiments to global emission rates in the study by Keppler was based on the rate of growth of terrestrial vegetation, or "net primary productivity." Other researchers, however, have argued that the use of net primary productivity leads to an overestimate of methane emissions from vegetation, and that estimation methods based on leaf mass and photosynthesis would be more appropriate.[e] Those methods yield global estimates of 10 to 60 MMT methane per year. A similar range, 0 to 46 MMT, has been estimated by researchers using a "top-down" approach based on ice core records.[f]

(continued on page 74)

[a] F. Keppler, J.T.G. Hamilton, M. Braß, and T. Röckmann, "Methane Emissions From Terrestrial Plants Under Aerobic Conditions," *Nature*, Vol. 439 (January 2006), pp. 187-191, web site http://moab.colorado.edu/BRG/Methane.pdf.

[b] J.B. do Carmo, M. Keller, J.D. Dias, P.B. de Camargo, and P. Crill, "A Source of Methane From Upland Forests in the Brazilian Amazon," *Geophysical Research Letters*, Vol. 33, No. 4 (2006), pp. 1-4, web site www.agu.org/pubs/crossref/2006/2005GL025436.shtml.

[c] P. J. Crutzen, E. Sanhueza, and C. A. M. Brenninkmeijer, "Methane Production From Mixed Tropical Savanna and Forest Vegetation in Venezuela," *Atmospheric Chemistry and Physics Discussions*, Vol. 6 (2006), pp. 3093-3097, web site www.copernicus.org/EGU/acp/acpd/6/3093.

[d] C. Frankenberg, J.F. Meirink, M. van Weele, U. Platt, and T. Wagner, "Assessing Methane Emissions From Global Space-Borne Observations," *Science*, Vol. 308, No. 5724 (2005), pp. 1010-1014, web site www.sciencemag.org/cgi/content/abstract/1106644.

[e] M.U.F. Kirschbaum, D. Bruhn, D.M. Etheridge, J.R. Evans, G.D. Farquhar, R.M. Gifford, K.I. Paul, and A.J. Winters, "A Comment on the Quantitative Significance of Aerobic Methane Release by Plants," *Functional Plant Biology*, Vol. 33, No. 6 (2006), pp. 521-530, web site www.publish.csiro.au/nid/102/paper/FP06051.htm.

[f] D.F. Ferretti, J.B. Miller, J.W.C. White, K.R. Lassey, D.C. Lowe, and D.M. Etheridge, "Stable Isotopes Provide Revised Global Limits of Aerobic Methane Emissions from Plants," *Atmospheric Chemistry and Physics Discussions*, Vol. 6 (2006), pp. 5867-5875, web site www.copernicus.org/EGU/acp/acpd/6/5867.

Methane Emissions From Vegetation: New Findings (Continued)

When limits are placed on emissions of greenhouse gases—either through binding international commitments such as the Kyoto Protocol or through voluntary programs, such as those being instituted at the State and Federal levels in the United States—knowing how much methane is emitted from various sources will be of obvious importance. In particular, if tree planting is proposed as a means of mitigating greenhouse gas emissions through carbon sequestration, the possibility that the same trees could be a major source of methane emissions would affect calculations of their potential benefits, depending on the balance between carbon dioxide sequestration and methane emissions.

Writing in the same issue of *Nature* that contains the original article by Keppler et al., David Lowe hinted at some of the policy implications, suggesting that trees in reforestation projects might increase greenhouse warming through methane emissions.[g] On the other hand, researchers in Australia have reported that, based on their own extrapolations of methane emissions from vegetation at the global level, the likely increase in methane emissions as a result of tree planting would offset only a small part (estimated at 0.1 to 1.1 percent) of the benefit resulting from increased carbon sequestration.[h]

[g] D. Lowe, "Global Change: A Green Source of Surprise," *Nature*, Vol. 439 (2006), pp. 148-149, web site www.nature.com/nature/journal/v439/n7073/edsumm/e060112-09.html.

[h] M.U.F. Kirschbaum et al., "A Comment on the Quantitative Significance of Aerobic Methane Release by Plants," *Functional Plant Biology*, Vol. 33, No. 6 (2006), pp. 521-530, web site www.publish.csiro.au/nid/102/paper/FP06051.htm.

remaining cropland. This adjustment is made because of the difficulty in separating the land-use components (cropland remaining cropland) from the land-use change components (land converted to cropland) of the carbon stock changes.

Grassland Remaining Grassland

This category includes carbon stock changes in both organic and mineral soils. It also includes changes in organic soils on land converted to grassland, because it is not possible to separate them from carbon stock changes in organic soils on existing grassland. Emissions of carbon dioxide from the application of crushed limestone and dolomite to grassland remaining grassland are included in the category of cropland remaining cropland because of the difficulty in separating the land-use and land-use change components of the carbon stock changes.

Land Converted to Grassland

This category includes carbon stock changes in mineral soils on land recently converted to grassland. Changes in organic soil carbon stocks and carbon dioxide emissions from the application of crushed limestone and dolomite to land converted to grassland are reported in the category of cropland remaining cropland because of the difficulty in separating the land-use and land-use change components of the carbon stock changes.

Settlements Remaining Settlements

This category includes carbon stock changes from settlements remaining settlements and from land converted to settlements. Carbon stock changes from settled lands include stock changes in urban trees as well as landfilled yard trimmings and food scraps. Stock changes in urban trees were estimated on the basis of field measurements and data on national urban tree cover, using a methodology consistent with the LULUCF GPG to estimate carbon flux. Carbon stocks in landfilled yard trimmings and food scraps were estimated by determining the fraction of carbon stocks from earlier years that had decayed by 2004. Emissions of carbon dioxide emissions from the application of crushed limestone and dolomite to settled lands were reported in the category of cropland remaining cropland. Nitrous oxide emissions from nitrogen applied to turf grass were estimated by assuming that such applications represented 10 percent of all synthetic fertilizer used in the United States.

Land-Use Change and Forestry Carbon Sequestration

The EPA's estimates for carbon sequestration from land-use change and forestry in 2004 include the following categories: (1) changes in forest carbon stocks for forest land remaining forest land (637.2 $MMTCO_2e$ or 82 percent of the total); (2) changes in agricultural soil carbon stocks for cropland remaining cropland (28.9 $MMTCO_2e$ or 3.7 percent of the total); (3) changes in agricultural soil carbon stocks for land converted to cropland (2.8 $MMTCO_2e$ or less than 0.5 percent of the total); (4) changes in agricultural soil carbon stocks for grassland remaining grassland (-7.3 $MMTCO_2e$ or -0.9 percent of the total[116]); (5) changes in agricultural soil carbon stocks for land converted to grassland (21.1

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[116] Negative sequestration numbers indicate an emission source rather than an emission sink.

$MMTCO_2e$ or 2.7 percent of the total); and (6) changes in settlements remaining settlements (97.3 $MMTCO_2e$ or 12 percent of the total, including 88.0 $MMTCO_2e$ from urban trees and 9.3 $MMTCO_2e$ from landfilled yard trimmings and food scraps).[117]

Forest Land Remaining Forest Land: Changes in Forest Carbon Stocks

In the United States, the most significant pressures on the amount of carbon sequestered through forest land are land management activities and the continuing effects of past changes in land use. These activities directly affect carbon flux by shifting the amount of carbon accumulated in forest ecosystems.[118] Land management activities affect both the stocks of carbon that can be stored in land-based carbon sinks, such as forests and soils, and the fluxes of carbon between land-based sinks and the atmosphere (see text box below for the most recent global assessment of the world's forests).

The components or "pools" of forest carbon analyzed by the EPA for its most recent inventory include above-ground biomass, below-ground biomass, dead wood, litter, and soil organic carbon. The EPA also assessed harvested wood products in use, and harvested wood products in landfills. As a result of natural biogeochemical processes occurring in forests, as well as anthropogenic activities, carbon is constantly cycling through these components and between the forest and the atmosphere. The net change in overall forest carbon may not always be equal to the net flux between forests and the atmosphere, because timber harvests may not necessarily result in an instant return of carbon to the atmosphere. Timber harvesting transfers carbon from one of the five "forest carbon pools" to one of the two "wood products carbon pools." Once carbon is transferred to a product pool, it is emitted over time as carbon dioxide or methane as the product decays or is combusted. Emission rates vary significantly, depending on the type of product pool that houses the carbon.[119]

In the United States, enhanced forest management, regeneration of formerly cleared forest areas, and timber harvesting have resulted in net annual sequestration of carbon throughout the past decade. Since the 1920s, deforestation for agricultural purposes has become a

Global Forest Resources Assessment 2005

The Food and Agriculture Organization of the United Nations (FAO) is the main intergovernmental source of data on global forests. FAO's global forest assessments date back to 1948, with the most recent assessment—*Global Forest Resources Assessment 2005*—published in 2005. The FAO's 2000 assessment[a] was the first to include a uniform definition of forests for all regions of the world—that is, areas with at least 10 percent of canopy cover (excluding stands of trees primarily used for agricultural production). The current report estimates the world's forested area in 2005 at approximately 4 billion hectares or 30 percent of the Earth's total land area.

The 2005 report points out that, while the rate of deforestation (mainly through conversion to cropland) continues at the high rate of about 13 million hectares per year, average net annual losses of forest have fallen from 8.9 million hectares per year over the period 1990-2000 to 7.3 million hectares per year over the period 2000-2005. Forest planting, landscape restoration, and the natural expansion of forests have significantly reduced the net loss of forest area.[b]

The largest reported net loss of forest land from 2000 to 2005 was in South America, with 4.3 million hectares lost per year, followed by Africa, which lost 4.0 million hectares annually. North and Central America and Oceania each had a net loss of about 350,000 hectares per year, while Asia reported a net gain of 1 million hectares per year from 2000 to 2005, primarily from large-scale afforestation in China. Forest areas in Europe continued to expand, although at a slower rate than in the 1990s.

[a] Food and Agriculture Organization of the United Nations, *Global Forest Resources Assessment 2000*, "Executive Summary," web site www.fao.org/DOCREP/004/Y1997E/y1997e05.htm#bm05.

[b] Food and Agriculture Organization of the United Nations, *Global Forest Resources Assessment 2005*, "Executive Summary," web site www.fao.org/docrep/008/a0400e/a0400e00.htm.

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[117] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[118] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[119] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), p. 7-4, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

nearly defunct practice. Managed growth practices have become common in eastern forests since the early 1950s, almost doubling their biomass density.[120] In the 1970s and 1980s, federally sponsored tree planting and soil conservation programs were embraced. These programs led to the reforestation of formerly harvested lands, improvement in timber management activities, soil erosion abatement, and the conversion of cropland to forests. Forest harvests have also affected carbon sequestration. The majority of harvested timber in the United States is used in wood products. The bulk of the discarded wood products is landfilled, and thus large quantities of the harvested carbon are relocated to long-term storage pools rather than to the atmosphere. The combined size of the long-term storage pools has increased over the past century.[121]

According to the EPA, carbon sequestration in U.S. forests and harvested wood pools totaled 637.2 MMTCO_2e in 2004 (Table 34). From 1990 to 2004, U.S. forests and harvested wood pools accounted for an average annual net sequestration of 627.0 MMTCO_2e, resulting from domestic forest growth and increases in forested land area; however, there was a decrease of approximately 18 percent in annual sequestration over the same period.[122]

The overall decline of carbon sequestration in forests and harvested wood pools resulted from a 25-percent reduction in the level of sequestration in the forest carbon pool (420.2 MMTCO_2e in 2004 versus 563.3 MMTCO_2e in 1990). The reduction in the sequestration rate for forest carbon pools can be attributed primarily to a reduction in sequestration levels in litter and soil organic carbon. Sequestration in litter declined by 68 percent, from 82.9 MMTCO_2e in 1990 to 26.6 MMTCO_2e in 2004, and sequestration in soil organic carbon declined by 130 percent—that is, soil organic carbon went from being a carbon sink of 33.6 MMTCO_2e in 1990 to an emissions source of 10.1 MMTCO_2e in 2004.

The EPA explains that, because its soil carbon estimates currently assume that soil carbon density depends only on broad forest type, the estimated decrease in annual carbon sequestration depends only on changes in total forest area or changes in forest type.[123] Net forest growth and increasing forest area, particularly before 1997, contributed to rising sequestration; but since 1997, forest land area has remained relatively constant, and the increase in carbon density (per area) has resulted in net forest carbon sequestration. National estimates of forest land are obtained by summing State surveys for the

Table 34. Net Carbon Dioxide Sequestration in U.S. Forests and Harvested Wood Pools, 1990 and 1998-2004
(Million Metric Tons Carbon Dioxide Equivalent)

Carbon Pool	1990	1998	1999	2000	2001	2002	2003	2004
Forests	**563.3**	**412.7**	**423.2**	**420.2**	**420.2**	**420.2**	**420.2**	**420.2**
Above-Ground Biomass	338.5	287.5	306.6	310.3	310.3	310.3	310.3	310.3
Below-Ground Biomass	64.8	55.1	59.5	60.3	60.3	60.3	60.3	60.3
Dead Wood	43.5	41.6	35.5	33.2	33.2	33.2	33.2	33.2
Litter	82.9	12.4	24.9	26.6	26.6	26.6	26.6	26.6
Soil Organic Carbon	33.6	16.0	-3.2	-10.1	-10.1	-10.1	-10.1	-10.1
Harvested Wood	**210.1**	**206.1**	**214.7**	**210.8**	**213.8**	**214.4**	**215.6**	**217.0**
Wood Products	47.6	51.9	61.5	58.7	59.0	59.2	60.4	60.8
Landfilled Wood	162.4	154.2	153.1	152.1	154.8	155.3	155.1	156.2
Total	**773.4**	**618.8**	**637.9**	**631.0**	**634.0**	**634.6**	**635.8**	**637.2**

Notes: The sums of the annual net stock changes in this table (shown in the “Total” row) represent estimates of the actual net flux between the total forest carbon pool and the atmosphere. Forest estimates are based on periodic measurements; harvested wood estimates are based on annual surveys and models. Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

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[120] The term “biomass density” refers to the mass of vegetation per unit area. It is usually measured on a dry-weight basis. Dry biomass is 50 percent carbon by weight.

[121] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), p. 7-5, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[122] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), p. 7-5, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[123] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-06-002 (Washington, DC, April 2006), p. 7-5, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

conterminous United States. Because the State surveys are not completed each year, interpolation between data points is used to provide estimates for years without surveys.

Overall annual sequestration levels in harvested wood carbon stocks increased slightly from 1990 to 2004. The trend in net sequestration amounts has been generally upward, from 210.1 MMTCO$_2$e in 1990 to 217.0 MMTCO$_2$e in 2004 (Table 34). Annual sequestration levels in landfilled wood declined from 162.4 MMTCO$_2$e in 1990 to 156.2 MMTCO$_2$e in 2004, but that decline was offset by an increase in carbon sequestration in harvested wood products, from 47.6 MMTCO$_2$e in 1990 to 60.8 MMTCO$_2$e in 2004.

The EPA has estimated carbon stocks in wood products in use and in landfills from 1910 onward, based on USDA Forest Service historical data and analyses using the North American Pulp and Paper (NAPAP) model,[124] the Timber Assessment Market Model (TAMM),[125] and the Aggregate Timberland Assessment System (ATLAS) model.[126] Carbon decay in harvested wood was analyzed by the EPA for the period 1910 through 2004, using data on annual wood and paper production. The analysis included changes in carbon stocks in wood products, changes in carbon in landfills, and the amount of carbon (carbon dioxide and methane) emitted to the atmosphere both with and without energy recovery. The EPA also followed the "production approach"; that is, carbon stored in imported wood products was not counted, but carbon stored in exports was counted, including logs processed in other countries.[127]

Cropland Remaining Cropland: Changes in Agricultural Soil Carbon Stocks

The amount of organic carbon in soils depends on the balance between the addition of organic material and the loss of carbon through decomposition. The quantity and quality of organic matter within soils, as well as decomposition rates, are determined by the interaction of climate, soil properties, and land use. Agricultural practices—including clearing, drainage, tillage, planting, grazing, crop residue management, fertilization, and flooding—can alter organic matter inputs and decomposition, causing a net flux of carbon to or from soils.

The IPCC methodology, which is used by the EPA to estimate the net flux from agricultural (cropland) soils, is divided into three categories of land use and land management activities (Table 35): (1) agricultural land use and land management activities on mineral soils;[128] (2) agricultural land use and land management activities on organic soils;[129] and (3) liming of soils. Of the three activities, the use and management of mineral soils is estimated to be the most significant contributor to total carbon sequestration from 1990 through 2004. Sequestration in mineral soils in 2004 was estimated to be 63.2 MMTCO$_2$e, and emissions from organic soils and liming were estimated at 30.3 and 4.0 MMTCO$_2$e, respectively. Together, these three activities resulted in a net 28.9 MMTCO$_2$e sequestered through agricultural soils in 2004, or 12 percent below the 1990 carbon sequestration level of 33.0 MMTCO$_2$e.[130]

Land Converted to Cropland

The EPA for the first time provided an estimate of carbon stock changes for land converted to cropland in its 2004 data release. The estimate covers only mineral soils, with estimates for organic soil and liming on land converted to cropland being included in the category of cropland remaining cropland, because it was not possible to subdivide those estimates by land use. Land use and management of land converted to cropland led to carbon losses (emissions) in the early 1990s. In 1990, for example, land converted to cropland led to net emissions of 1.5 MMTCO$_2$e (Table 33). The trend has since

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[124] P.J. Ince, *Recycling and Long-Range Timber Outlook*, USDA Forest Service General Technical Report RM-242 (Fort Collins, CO, February 1994).

[125] U.S. Department of Agriculture, Forest Service, *An Analysis of the Timber Situation in the United States: 1952 to 2050*, General Technical Report PNW-GTR-560 (Portland, OR, February 2003), web site www.fs.fed.us/pnw/pubs/gtr560.

[126] J.R. Mills and J.C. Kincaid, *The Aggregate Timberland Assessment System–ATLAS: A Comprehensive Timber Projection Model*, USDA Forest Service General Technical Report PNW-281 (Portland, OR, June 1992), web site www.fs.fed.us/pnw/pubs/pnw_gtr281.pdf.

[127] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), pp. 7-7–7-8, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG EmissionsUSEmissionsInventory 2006.html.

[128] Mineral soils are soils consisting predominantly of, and having their properties determined predominantly by, mineral matter. They usually contain less than 200 grams of organic carbon per kilogram of soil (less than 120 to 180 grams per kilogram if saturated with water) but may contain an organic surface layer up to 30 centimeters thick.

[129] Organic soils are soils that, when saturated with water, have 174 grams or more of organic carbon per kilogram of soil if the mineral fraction has 500 grams per kilogram or more of clay, or 116 grams per kilogram organic carbon if the mineral fraction has no clay, or has proportional intermediate contents. If the soil is never saturated with water, organic soils have 203 or more grams of organic carbon per kilogram.

[130] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2006.html.

been reversed, and in 2004 land converted to cropland resulted in net carbon sequestration equivalent to 2.8 $MMTCO_2e$, primarily in the intermountain west and central areas of the country.[131]

Grassland Remaining Grassland

Carbon stock changes for this category—also provided for the first time by the EPA in its 2004 data release—include changes in soil carbon storage resulting from agricultural land-use and management activities on mineral and organic soils. Carbon dioxide emissions due to the liming of soils on grassland remaining grassland are not included in this category but instead are placed in the category of cropland remaining cropland, because it is not possible to separate the emissions by land-use categories. In 2004, this category accounted for emissions of 7.3 $MMTCO_2e$, including 4.6 $MMTCO_2e$ from organic soils and 2.7 $MMTCO_2e$ from mineral soils (Table 36). In 1990, this category sequestered 4.5 $MMTCO_2e$, based on net sequestration of 8.8 $MMTCO_2e$ in mineral soils and emissions of 4.3 $MMTCO_2e$ from organic soils. The change in this category to a source of emissions is the result of reduced rates of carbon sequestration in mineral soils in the southern United States and increased emissions from the drainage of organic soils in other regions.[132]

Land Converted to Grassland

Estimates of carbon stock changes for land converted to grassland were also provided for the first time by the EPA in its 2004 data release. The estimates cover only mineral soils. Estimates of changes in organic soil carbon stocks for this category are included in the estimates for the category of grassland remaining grassland, and emissions from liming of soils for this category are included in those reported for the category of cropland remaining cropland, because it was not possible to subdivide the estimates by land use. Net soil carbon storage for this category increased from 17.6 $MMTCO_2e$ in 1990 to 21.1 $MMTCO_2e$ in 2004 (Table 33). The upswing was

Table 35. Net Carbon Dioxide Sequestration in U.S. Cropland Remaining Cropland, 1990 and 1998-2004
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990	1998	1999	2000	2001	2002	2003	2004
Mineral Soils	67.6[a]	59.6[b]	59.3[b]	60.7[b]	62.5[b]	62.8[b]	62.7[b]	63.2[b]
Organic Soils	-29.9[a]	-30.3[b]	-30.3[b]	-30.3[b]	-30.3[b]	-30.3[b]	-30.3[b]	-30.3[b]
Liming of Soils	-4.7[a]	-4.7[a]	-4.5[a]	-4.3[a]	-4.4[a]	-5.0[a]	-3.7[a]	-4.0[b]
Total	**33.0[a]**	**24.6[b]**	**24.6[b]**	**26.1[b]**	**27.8[b]**	**27.5[b]**	**28.7[b]**	**28.9[b]**

[a] Estimates based on historical data.
[b] Estimates based on a combination of historical data and projections.
Note: Negative values indicate net emissions.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

Table 36. Net Carbon Dioxide Sequestration in U.S. Grassland Remaining Grassland, 1990 and 1998-2004
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990	1998	1999	2000	2001	2002	2003	2004
Mineral Soils	8.8[c]	-2.9[d]	-2.9[d]	-2.9[d]	-2.8[d]	-2.8[d]	-2.7[d]	-2.7[d]
Organic Soils[a]	-4.3[c]	-4.6[d]	-4.6[d]	-4.6[d]	-4.6[d]	-4.6[d]	-4.6[d]	-4.6[d]
Liming of Soils[b]	—	—	—	—	—	—	—	—
Total	**4.5[c]**	**-7.5[d]**	**-7.5[d]**	**-7.4[d]**	**-7.4[d]**	**-7.4[d]**	**-7.3[d]**	**-7.3[d]**

[a] Includes emissions resulting from drainage of organic soils in land converted to grassland.
[b] Reported in Table 35 (cropland remaining cropland).
[c] Estimates based on historical data.
[d] Estimates based on a combination of historical data and projections.
Note: Negative values indicate net emissions.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

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[131] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), p. 7-26, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[132] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), p. 7-29, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

the result of increased acreage of cropland converted to pasture, primarily in the Southeast and Northwest.[133]

Settlements Remaining Settlements

Carbon stock changes for this category include carbon stock changes for urban trees and for landfilled yard trimmings and food scraps. Carbon sequestration for this category increased by 17 percent, from 83.2 $MMTCO_2e$ in 1990 to 97.3 $MMTCO_2e$ in 2004 (Table 33), with significant increases in carbon storage by urban trees more than offsetting declines in net carbon storage in landfilled yard trimmings and food scraps.

Changes in Urban Tree Carbon Stocks

Urban forests make up a considerable portion of the total tree canopy cover in the United States. Urban areas, which cover 4.4 percent of the continental United States, account for approximately 3 percent of total tree cover in the United States. The EPA's carbon sequestration estimates for urban trees are derived from estimates by Nowak and Crane,[134] based on data collected from 1989 through 1999 in 10 U.S. cities. Currently, annual changes in sequestration estimates are based solely on changes in total U.S. urban area. Net carbon dioxide sequestration by urban trees increased by 50 percent, to 88.0 $MMTCO_2e$ in 2004 from 58.7 $MMTCO_2e$ in 1990 (Table 33), primarily as a result of increases in urban land area.[135]

Changes in Landfilled Yard Trimming and Food Scrap Carbon Stocks

Carbon stored in landfilled yard trimmings and food scraps can remain sequestered indefinitely. In the United States, yard trimmings (grass clippings, leaves, and branches) and food scraps make up a considerable portion of the municipal waste stream, and significant amounts of the yard trimmings and food scraps collected are discarded in landfills. Both the amount collected annually and the percentage that is landfilled have declined over the past decade. Net carbon dioxide sequestration from landfilled yard trimmings and food scraps has declined accordingly, to 9.3 $MMTCO_2e$ in 2004 from 24.5 $MMTCO_2e$ in 1990—a reduction of 62 percent (Table 37).

Since 1990, municipal policies limiting pickup and disposal have led to an 18-percent decrease in yard trimmings collected. In addition, composting of yard trimmings in municipal facilities has increased significantly, reducing the percentage of collected yard trimmings discarded in landfills from 72 percent in 1990 to 35 percent in 2004. In contrast, the percentage of food scraps disposed of in landfills has decreased only slightly, from 81 percent in 1990 to 78 percent in 2003.[136] The EPA's methodology for estimating carbon storage relies on a life-cycle analysis of greenhouse gas emissions and sinks associated with solid waste management.[137]

Table 37. Net Carbon Dioxide Sequestration from Landfilled Yard Trimmings and Food Scraps, 1990 and 1998-2004
(Million Metric Tons Carbon Dioxide Equivalent)

Description	1990	1998	1999	2000	2001	2002	2003	2004
Yard Trimmings	**21.7**	**8.0**	**6.9**	**5.6**	**5.8**	**6.1**	**6.3**	**6.4**
Grass	2.4	0.8	0.6	0.5	0.6	0.6	0.7	0.7
Leaves	9.8	3.6	3.0	2.5	2.5	2.6	2.7	2.8
Branches	9.6	3.7	3.2	2.7	2.7	2.8	2.9	2.9
Food Scraps	**2.8**	**2.9**	**2.9**	**3.2**	**3.2**	**3.2**	**3.1**	**2.9**
Total	**24.5**	**10.9**	**9.8**	**8.9**	**9.0**	**9.3**	**9.4**	**9.3**

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

Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*, EPA 430-R-06-002 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

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[133] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), p. 7-34, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[134] D.J. Nowak and D.E. Crane, "Carbon Storage and Sequestration by Urban Trees in the United States," *Environmental Pollution*, Vol. 116, No. 3 (2002), pp. 381-389, web site www.uvm.edu/~bwemple/geog242/pdfs/nowak_crane_2002.pdf.

[135] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-04-002 (Washington, DC, April 2006), p. 7-42, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html.

[136] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), p. 7-37, web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2006.html.

[137] U.S. Environmental Protection Agency, *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*, 2nd Edition, EPA530-R-02-006 (Washington, DC, May 2002), web site www.epa.gov/epaoswer/non-hw/muncpl/ghg/ghg.htm.

Land Use and International Climate Change Negotiations

In past international negotiations on climate change, the United States and many other countries have maintained that the inclusion of LULUCF activities in a binding agreement that limits greenhouse gas emissions is of the utmost importance; however, issues of whether and how terrestrial carbon sequestration could be accepted for meeting various commitments and targets have remained subjects of complex and difficult international negotiations.

Many of the countries involved in climate change negotiations have agreed that implementation of LULUCF activities under an international climate change agreement may be complicated by a lack of clear definitions of "reforestation" and "forest." Further, implementation may be hindered by the lack of effective accounting rules. According to research published by the Pew Center on Global Climate Change,[138] implementation of LULUCF provisions in an international climate change agreement raises many issues, such as:

- What is a direct human-induced activity?
- What is a forest and what is reforestation?
- How will the issues of uncertainty and verifiability be addressed?
- How will the issues of (non) permanence and leakage be addressed?
- Which activities beyond afforestation, reforestation, and deforestation (ARD), if any, should be included, and what accounting rules should apply?
- Which carbon pools and which greenhouse gases should be considered?

Uncertainties related to data issues have also slowed international negotiations on climate change.

The Ninth Session of the Conference of the Parties to the UN Framework Convention on Climate Change (COP-9 of the UNFCCC) was held in Milan, Italy, in December 2003. The parties agreed on some of the rules for carbon sequestration projects under the Clean Development Mechanism (CDM), but the issue of how to treat the non-permanence of carbon sinks projects remained unresolved. Delegates at COP-9 decided to limit the duration of credits generated from carbon sequestration projects and addressed the topics of additionality, leakage, uncertainties, and socioeconomic and environmental impacts.[139]

A year later in Buenos Aires, Argentina, delegates at the Tenth Conference of the Parties (COP-10 of the UNFCCC) did address the issue of small-scale afforestation and reforestation project activities under the CDM. The following decisions were made at COP-10:[140]

- Adopt simplified modalities and procedures for small-scale afforestation and reforestation project activities in the first commitment period.
- Limit the designation of small-scale afforestation and reforestation projects to those with net anthropogenic greenhouse gas removals by sinks that are less than 8,000 metric tons carbon dioxide equivalent per year. For projects that result in greenhouse gas removals of more than this quantity, the excess would be ineligible for temporary or long-term certified emissions reductions.
- Exclude funds obtained through small-scale project activities from the share of proceeds to be used to assist developing countries particularly vulnerable to the adverse impacts of climate change. Such countries shall be entitled to a reduced level of the non-reimbursable fee for requesting registration and a reduced rate of the proceeds to cover administrative expenses of the CDM.

In 2005, at the Eleventh Conference of the Parties (COP-11 of the UNFCCC) and the first conference serving as the Meeting of the Parties (MOP) to the Kyoto Protocol, delegates agreed to a set of IPCC Principles, Rules, and Guidelines governing LULUCF activities,[141] such as:

- Carbon stocks must be excluded from greenhouse gas accounting.
- Accounting for LULUCF activities does not imply a transfer of commitments to a future commitment period.
- Reversal of any removal due to LULUCF activities must be accounted for at the appropriate time.

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[138] G. Marland and B. Schlamadinger, *Land Use and Global Climate Change: Forests, Land Management, and the Kyoto Protocol* (Arlington, VA: Pew Center on Global Climate Change, June 2000), p. 5, web site www.pewclimate.org/docUploads/land_use.pdf.

[139] Pew Center on Global Climate Change, "Ninth Session of the Conference of the Parties to the UN Framework Convention on Climate Change" (Milan, Italy, December 1-12, 2003), web site www.pewclimate.org/what_s_being_done/in_the_world/cop9/index.cfm.

[140] International Institute for Sustainable Development, "Summary of the Tenth Conference of the Parties to the UN Framework Convention on Climate Change: 6-18 December 2004," *Earth Negotiations Bulletin*, Vol. 12, No. 260 (December 20, 2004), web site www.iisd.ca/vol12/enb12260e.html.

[141] International Institute for Sustainable Development, "Summary of the Eleventh Conference of the Parties to the UN Framework Convention on Climate Change and First Conference of the Parties Serving as the Meeting of the Parties to the Kyoto Protocol: 28 November – 10 December 2005," *Earth Negotiations Bulletin*, Vol. 12, No. 291 (December 12, 2005), web site www.iisd.ca/vol12/enb12291e.html.

The EPA's most recent inventory report discusses the uncertainty inherent in the methodology used to estimate forest carbon stocks.[142] The estimates of forest carbon in live biomass, dead wood, and litter are based on USDA forest survey data for the conterminous United States, because no survey data are available for Alaska, Hawaii, and the U.S. Territories. The survey data are statistical samples designed to represent vast areas of land. The USDA mandates that the survey data be accurate to within 3 percent, at a confidence level of 67 percent.[143] An analysis of this methodology for the southeastern United States showed that the uncertainty resulted from sampling errors and not from the regression equations used to calculate tree volume (and thus carbon) from survey statistics such as tree height and diameter. The standard errors of 1 to 2 percent for volumes of growing stock in individual States are insignificant; however, those for changes in the volumes of growing stock are much higher, ranging from 12 percent to as much as 139 percent.[144]

Additional uncertainty is associated with the estimates of carbon stocks in other carbon pools, which are based on extrapolations of the relationships among variables in site-specific studies to all forest land. Such extrapolation is needed in the absence of survey data on other carbon pools.[145] The extrapolations bring in uncertainty from modeling errors and conversions between different reporting units. The effect of land-use change and forest management activities (such as harvest) on soil stocks is another large source of uncertainty, with little consensus in the literature.

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[142] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2004*, EPA-430-R-02-006 (Washington, DC, April 2006), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2006.html.

[143] That is, at least 67 percent of the samples are within 3 percent of the actual forested areas.

[144] The larger errors were found to be attributable to small actual changes in volumes of growing stock, which when over- or underestimated contributed disproportionately to the standard errors for total changes in the volume of growing stock.

[145] Thus, site-specific relationships among variables are used to create models or regression equations, which are then applied to large forested areas.

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www.greenhouse.gov.au

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http://cdiac.esd.ornl.gov

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies.
www.caddet-ee.org

Center for Renewable Energy and Sustainable Technology.
http://solstice.crest.org

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Global Environment Facility.
www.gefweb.org

Global Climate Change from the Government of Canada.
www.climatechange.gc.ca

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www.pewclimate.org

Resources for the Future.
www.rff.org

Weathervane, Digital Forum on Global Climate Policy.
www.weathervane.rff.org

Union of Concerned Scientists.
www.ucsusa.org

United Nations Development Programme.
www.undp.org

United Nations Environment Programme.
www.unep.ch

United Nations Environment Programme, Ozone Secretariat (Montreal Protocol).
www.unep.ch/ozone/home.htm

United Nations Food and Agriculture Program.
www.fao.org

United Nations Framework Convention on Climate Change.
www.unfccc.de

U.S. Agency for International Development.
www.usaid.gov

U.S. Department of Agriculture, Global Change Program Office.
www.usda.gov/oce/gcpo/

U.S. Department of Energy, Climate Vision Program.
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U.S. Department of State, Climate Change Homepage.
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World Wildlife Fund, Climate Change Campaign.
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Glossary

Acid stabilization: A circumstance where the pH of the waste mixture in an animal manure management system is maintained near 7.0, optimal conditions for methane production.

Aerobic bacteria: Microorganisms living, active, or occurring only in the presence of oxygen.

Aerobic decomposition: The breakdown of a molecule into simpler molecules or atoms by microorganisms under favorable conditions of oxygenation.

Aerosols: Airborne particles.

Afforestation: Planting of new forests on lands that have not been recently forested.

Agglomeration: The clustering of disparate elements.

Airshed: An area or region defined by settlement patterns or geology that results in discrete atmospheric conditions.

Albedo: The fraction of incident light or electromagnetic radiation that is reflected by a surface or body. See *Planetary albedo*.

Anaerobes: Organisms that live and are active only in the absence of oxygen.

Anaerobic bacteria: Microorganisms living, active, or occurring only in the absence of oxygen.

Anaerobic decomposition: The breakdown of molecules into simpler molecules or atoms by microorganisms that can survive in the partial or complete absence of oxygen.

Anaerobic lagoon: A liquid-based manure management system, characterized by waste residing in water to a depth of at least six feet for a period ranging between 30 and 200 days.

Anode: A positive electrode, as in a battery, radio tube, etc.

Anthracite: The highest rank of coal; used primarily for residential and commercial space heating. It is a hard, brittle, and black lustrous coal, often referred to as hard coal, containing a high percentage of fixed carbon and a low percentage of volatile matter. The moisture content of fresh-mined anthracite generally is less than 15 percent. The heat content of anthracite ranges from 22 to 28 million Btu per ton on a moist, mineral-matter-free basis. The heat content of anthracite coal consumed in the United States averages 25 million Btu per ton, on the as-received basis (i.e., containing both inherent moisture and mineral matter). Note: Since the 1980's, anthracite refuse or mine waste has been used for steam electric power generation. This fuel typically has a heat content of 15 million Btu per ton or less.

Anthropogenic: Made or generated by a human or caused by human activity. The term is used in the context of global climate change to refer to gaseous emissions that are the result of human activities, as well as other potentially climate-altering activities, such as deforestation.

API Gravity: American Petroleum Institute measure of specific gravity of crude oil or condensate in degrees. An arbitrary scale expressing the gravity or density of liquid petroleum products. The measuring scale is calibrated in terms of degrees API; it is calculated as follows: Degrees API = (141.5/sp.gr.60 deg.F/60 deg.F) - 131.5.

Asphalt: A dark brown-to-black cement-like material obtained by petroleum processing and containing bitumens as the predominant component; used primarily for road construction. It includes crude asphalt as well as the following finished products: cements, fluxes, the asphalt content of emulsions (exclusive of water), and petroleum distillates blended with asphalt to make cutback asphalts. Note: The conversion factor for asphalt is 5.5 barrels per short ton.

Associated natural gas: See *Associated-dissolved natural gas* and *Natural gas*.

Associated-dissolved natural gas: Natural gas that occurs in crude oil reservoirs either as free gas (associated) or as gas in solution with crude oil (dissolved gas). See *Natural gas*.

Aviation gasoline (finished): A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in aviation reciprocating engines. Fuel specifications are provided in ASTM Specification D 910 and Military Specification MIL-G-5572. Note: Data on blending components are not counted in data on finished aviation gasoline.

Balancing item: Represents differences between the sum of the components of natural gas supply and the sum of the components of natural gas disposition. These differences may be due to quantities lost or to the effects of data reporting problems. Reporting problems include differences due to the net result of conversions of flow data metered at varying temperature and pressure bases and converted to a standard temperature and pressure base; the effect of variations in company accounting and billing practices; differences between billing cycle and calendar period time frames; and imbalances resulting from the merger of data reporting systems that vary in scope, format, definitions, and type of respondents.

Biofuels: Liquid fuels and blending components produced from biomass (plant) feedstocks, used primarily for transportation.

Biogas: The gas produced from the anaerobic decomposition of organic material in a landfill.

Biogenic: Produced by the actions of living organisms.

Biomass: Organic nonfossil material of biological origin constituting a renewable energy source.

Biosphere: The portion of the Earth and its atmosphere that can support life. The part of the global carbon cycle that includes living organisms and biogenic organic matter.

Bituminous coal: A dense coal, usually black, sometimes dark brown, often with well-defined bands of bright and dull material, used primarily as fuel in steam-electric power generation, with substantial quantities also used for heat and power applications in manufacturing and to make coke. Bituminous coal is the most abundant coal in active U.S. mining regions. Its moisture content usually is less than 20 percent. The heat content of bituminous coal ranges from 21 to 30 million Btu per ton on a moist, mineral-matter-free basis. The heat content of bituminous coal consumed in the United States averages 24 million Btu per ton, on the as-received basis (i.e., containing both inherent moisture and mineral matter).

BOD_5: The biochemical oxygen demand of wastewater during decomposition occurring over a 5-day period. A measure of the organic content of wastewater.

Bromofluorocarbons (halons): Inert, nontoxic chemicals that have at least one bromine atom in their chemical makeup. They evaporate without leaving a residue and are used in fire extinguishing systems, especially for large computer installations.

Bunker fuel: Fuel supplied to ships and aircraft, both domestic and foreign, consisting primarily of residual and distillate fuel oil for ships and kerosene-based jet fuel for aircraft. The term "international bunker fuels" is used to denote the consumption of fuel for international transport activities. *Note*: For the purposes of greenhouse gas emissions inventories, data on emissions from combustion of international bunker fuels are subtracted from national emissions totals. Historically, bunker fuels have meant only ship fuel. See *Vessel bunkering*.

Calcination: A process in which a material is heated to a high temperature without fusing, so that hydrates, carbonates, or other compounds are decomposed and the volatile material is expelled.

Calcium sulfate: A white crystalline salt, insoluble in water. Used in Keene's cement, in pigments, as a paper filler, and as a drying agent.

Calcium sulfite: A white powder, soluble in dilute sulfuric acid. Used in the sulfite process for the manufacture of wood pulp.

Capital stock: Property, plant and equipment used in the production, processing and distribution of energy resources.

Carbon black: An amorphous form of carbon, produced commercially by thermal or oxidative decomposition of hydrocarbons and used principally in rubber goods, pigments, and printer's ink.

Carbon budget: Carbon budget: The balance of the exchanges (incomes and losses) of carbon between carbon sinks (e.g., atmosphere and biosphere) in the carbon cycle. See *Carbon cycle* and *Carbon sink*.

Carbon cycle: All carbon sinks and exchanges of carbon from one sink to another by various chemical, physical, geological, and biological processes. See *Carbon sink* and *Carbon budget*.

Carbon dioxide (CO_2): A colorless, odorless, nonpoisonous gas that is a normal part of Earth's atmosphere. Carbon dioxide is a product of fossil-fuel combustion as well as other processes. It is considered a greenhouse gas as it traps heat (infrared energy) radiated by the Earth into the atmosphere and thereby contributes to the potential for global warming. The global warming potential (GWP) of other greenhouse gases is measured in relation to that of carbon dioxide, which by international scientific convention is assigned a value of one (1). See *Global warming potential (GWP)* and *Greenhouse gases*.

Carbon dioxide equivalent: The amount of carbon dioxide by weight emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another radiatively active gas. Carbon dioxide equivalents are computed by multiplying the weight of the gas being measured (for example, methane) by its estimated global warming potential (which is 21 for methane). "Carbon equivalent units" are defined as carbon dioxide equivalents multiplied by the carbon content of carbon dioxide (i.e., 12/44).

Carbon flux: See *Carbon budget*.

Carbon intensity: The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) of energy. When there is only one fossil fuel under consideration, the carbon intensity and the emissions coefficient are identical. When there are several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels. See *Emissions coefficient* and *Carbon output rate*.

Carbon output rate: The amount of carbon by weight per kilowatthour of electricity produced.

Carbon sequestration: The fixation of atmospheric carbon dioxide in a carbon sink through biological or physical processes.

Carbon sink: A reservoir that absorbs or takes up released carbon from another part of the carbon cycle. The four sinks, which are regions of the Earth within which carbon behaves in a systematic manner, are the atmosphere, terrestrial biosphere (usually including freshwater systems), oceans, and sediments (including fossil fuels).

Catalytic converter: A device containing a catalyst for converting automobile exhaust into mostly harmless products.

Catalytic hydrocracking: A refining process that uses hydrogen and catalysts with relatively low temperatures and high pressures for converting middle boiling or residual material to high octane gasoline, reformer charge stock, jet fuel, and/or high grade fuel oil. The process uses one or more catalysts, depending on product output, and can handle high sulfur feedstocks without prior desulfurization.

Cesspool: An underground reservoir for liquid waste, typically household sewage.

Chlorofluorocarbon (CFC): Any of various compounds consisting of carbon, hydrogen, chlorine, and fluorine used as refrigerants. CFCs are now thought to be harmful to the earth's atmosphere.

Clean Development Mechanism (CDM): A Kyoto Protocol program that enables industrialized countries to finance emissions-avoiding projects in developing countries and receive credit for reductions achieved against their own emissions limitation targets. See *Kyoto Protocol*.

Climate: The average course or condition of the weather over a period of years as exhibited by temperature, humidity, wind velocity, and precipitation.

Climate change: A term used to refer to all forms of climatic inconsistency, but especially to significant change from one prevailing climatic condition to another. In some cases, "climate change" has been used synonymously with the term "global warming"; scientists, however, tend to use the term in a wider sense inclusive of natural changes in climate, including climatic cooling.

Clinker: Powdered cement, produced by heating a properly proportioned mixture of finely ground raw materials (calcium carbonate, silica, alumina, and iron oxide) in a kiln to a temperature of about 2,700^{o}F.

Cloud condensation nuclei: Aerosol particles that provide a platform for the condensation of water vapor, resulting in clouds with higher droplet concentrations and increased albedo.

Coal coke: See *Coke (coal)*.

Coalbed methane: Methane is generated during coal formation and is contained in the coal microstructure. Typical recovery entails pumping water out of the coal to allow the gas to escape. Methane is the principal component of natural gas. Coalbed methane can be added to natural gas pipelines without any special treatment.

Coke (coal): A solid carbonaceous residue derived from low-ash, low-sulfur bituminous coal from which the volatile constituents are driven off by baking in an oven at temperatures as high as 2,000 degrees Fahrenheit so that the fixed carbon and residual ash are fused together. Coke is used as a fuel and as a reducing agent in smelting iron ore in a blast furnace. Coke from coal is grey, hard, and porous and has a heating value of 24.8 million Btu per ton.

Coke (petroleum): A residue high in carbon content and low in hydrogen that is the final product of thermal decomposition in the condensation process in cracking. This product is reported as marketable coke or catalyst coke. The conversion is 5 barrels (of 42 U.S. gallons each) per short ton. Coke from petroleum has a heating value of 6.024 million Btu per barrel.

Combustion: Chemical oxidation accompanied by the generation of light and heat.

Combustion chamber: An enclosed vessel in which chemical oxidation of fuel occurs.

Conference of the Parties (COP): The collection of nations that have ratified the Framework Convention on Climate Change (FCCC). The primary role of the COP is to keep implementation of the FCCC under review and make the decisions necessary for its effective implementation. See *Framework Convention on Climate Change (FCCC)*.

Cracking: The refining process of breaking down the larger, heavier, and more complex hydrocarbon molecules into simpler and lighter molecules.

Criteria pollutant: A pollutant determined to be hazardous to human health and regulated under EPA's National Ambient Air Quality Standards. The 1970 amendments to the Clean Air Act require EPA to describe the health and welfare impacts of a pollutant as the "criteria" for inclusion in the regulatory regime.

Crop residue: Organic residue remaining after the harvesting and processing of a crop.

Cultivar: A horticulturally or agriculturally derived variety of a plant.

Deforestation: The net removal of trees from forested land.

Degasification system: The methods employed for removing methane from a coal seam that could not otherwise be removed by standard ventilation fans and thus would pose a substantial hazard to coal miners. These systems may be used prior to mining or during mining activities.

Degradable organic carbon: The portion of organic carbon present in such solid waste as paper, food waste, and yard waste that is susceptible to biochemical decomposition.

Desulfurization: The removal of sulfur, as from molten metals, petroleum oil, or flue gases.

Diffusive transport: The process by which particles of liquids or gases move from an area of higher concentration to an area of lower concentration.

Distillate fuel: A general classification for one of the petroleum fractions produced in conventional distillation operations. It includes diesel fuels and fuel oils. Products known as No. 1, No. 2, and No. 4 diesel fuel are used in on-highway diesel engines, such as those in trucks and automobiles, as well as off-highway engines, such as those in railroad locomotives and agricultural machinery. Products known as No. 1, No. 2, and No. 4 fuel oils are used primarily for space heating and electric power generation.

Efflux: An outward flow.

Electrical generating capacity: The full-load continuous power rating of electrical generating facilities, generators, prime movers, or other electric equipment (individually or collectively).

EMCON Methane Generation Model: A model for estimating the production of methane from municipal solid waste landfills.

Emissions: Anthropogenic releases of gases to the atmosphere. In the context of global climate change, they consist of radiatively important greenhouse gases (e.g., the release of carbon dioxide during fuel combustion).

Emissions coefficient: A unique value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity (e.g., pounds of carbon dioxide emitted per Btu of fossil fuel consumed).

Enteric fermentation: A digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream of an animal.

Eructation: An act or instance of belching.

ETBE (ethyl tertiary butyl ether): $(CH_3)_3COC_2H$: An oxygenate blend stock formed by the catalytic etherification of isobutylene with ethanol.

Ethylene: An olefinic hydrocarbon recovered from refinery processes or petrochemical processes. Ethylene is used as a petrochemical feedstock for numerous chemical applications and the production of consumer goods.

Ethylene dichloride: A colorless, oily liquid used as a solvent and fumigant for organic synthesis, and for ore flotation.

Facultative bacteria: Bacteria that grow equally well under aerobic and anaerobic conditions.

Flange: A rib or a rim for strength, for guiding, or for attachment to another object (e.g., on a pipe).

Flared: Gas disposed of by burning in flares usually at the production sites or at gas processing plants.

Flatus: Gas generated in the intestines or the stomach of an animal.

Flue gas desulfurization: Equipment used to remove sulfur oxides from the combustion gases of a boiler plant before discharge to the atmosphere. Also referred to as scrubbers. Chemicals such as lime are used as scrubbing media.

Fluidized-bed combustion: A method of burning particulate fuel, such as coal, in which the amount of air required for combustion far exceeds that found in conventional burners. The fuel particles are continually fed into a bed of mineral ash in the proportions of 1 part fuel to 200 parts ash, while a flow of air passes up through the bed, causing it to act like a turbulent fluid.

Flux material: A substance used to promote fusion, e.g., of metals or minerals.

Fodder: Coarse food for domestic livestock.

Forestomach: See *Rumen*.

Fossil fuel: An energy source formed in the earths crust from decayed organic material. The common fossil fuels are petroleum, coal, and natural gas.

Framework Convention on Climate Change (FCCC): An agreement opened for signature at the "Earth Summit" in Rio de Janeiro, Brazil, on June 4, 1992, which has the goal of stabilizing greenhouse gas concentrations in the atmosphere at a level that would prevent significant anthropogenically forced climate change. See *Climate change*.

Fuel cycle: The entire set of sequential processes or stages involved in the utilization of fuel, including extraction, transformation, transportation, and combustion. Emissions generally occur at each stage of the fuel cycle.

Fugitive emissions: Unintended leaks of gas from the processing, transmission, and/or transportation of fossil fuels.

Gasification: A method for converting coal, petroleum, biomass, wastes, or other carbon-containing materials into a gas that can be burned to generate power or processed into chemicals and fuels.

Gate station: Location where the pressure of natural gas being transferred from the transmission system to the distribution system is lowered for transport through small diameter, low pressure pipelines.

Geothermal: Pertaining to heat within the Earth.

Global climate change: See *Climate change*.

Global warming: An increase in the near surface temperature of the Earth. Global warming has occurred in the distant past as the result of natural influences, but the term is today most often used to refer to the warming that some scientists predict will occur as a result of increased anthropogenic emissions of greenhouse gases. See *Climate change*.

Global warming potential (GWP): An index used to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing that would result from the emission of one kilogram of a greenhouse gas to that from the emission of one kilogram of carbon dioxide over a fixed period of time, such as 100 years.

Greenhouse effect: The result of water vapor, carbon dioxide, and other atmospheric gases trapping radiant (infrared) energy, thereby keeping the earth's surface warmer than it would otherwise be. Greenhouse gases within the lower levels of the atmosphere trap this radiation, which would otherwise escape into space, and subsequent re-radiation of some of this energy back to the Earth maintains higher surface temperatures than would occur if the gases were absent. See *Greenhouse gases*.

Greenhouse gases: Those gases, such as water vapor, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride, that are transparent to solar (short-wave) radiation but opaque to long-wave (infrared) radiation, thus preventing long-wave radiant energy from leaving the Earth's atmosphere. The net effect is a trapping of absorbed radiation and a tendency to warm the planet's surface.

Gross gas withdrawal: The full-volume of compounds extracted at the wellhead, including nonhydrocarbon gases and natural gas plant liquids.

Gypsum: Calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), a sludge constituent from the conventional lime scrubber process, obtained as a byproduct of the dewatering operation and sold for commercial use.

Halogenated substances: A volatile compound containing halogens, such as chlorine, fluorine or bromine.

Halons: See *Bromofluorocarbons*.

Heating degree-days (HDD): A measure of how cold a location is over a period of time relative to a base temperature, most commonly specified as 65 degrees Fahrenheit. The measure is computed for each day by subtracting the average of the day's high and low temperatures from the base temperature (65 degrees), with negative values set equal to zero. Each day's heating degree-days are summed to create a heating degree-day measure for a specified reference period. Heating degree-days are used in energy analysis as an indicator of space heating energy requirements or use.

Herbivore: A plant-eating animal.

Hydrocarbon: An organic chemical compound of hydrogen and carbon in either gaseous, liquid, or solid phase. The molecular structure of hydrocarbon compounds varies from the simple (e.g., methane, a constituent of natural gas) to the very heavy and very complex.

Hydrochlorofluorocarbons (HCFCs): Chemicals composed of one or more carbon atoms and varying numbers of hydrogen, chlorine, and fluorine atoms.

Hydrofluorocarbons (HFCs): A group of man-made chemicals composed of one or two carbon atoms and varying numbers of hydrogen and fluorine atoms. Most

HFCs have 100-year Global Warming Potentials in the thousands.

Hydroxyl radical (OH): An important chemical scavenger of many trace gases in the atmosphere that are greenhouse gases. Atmospheric concentrations of OH affect the atmospheric lifetimes of greenhouse gases, their abundance, and, ultimately, the effect they have on climate.

Intergovernmental Panel on Climate Change (IPCC): A panel established jointly in 1988 by the World Meteorological Organization and the United Nations Environment Program to assess the scientific information relating to climate change and to formulate realistic response strategies.

International bunker fuels: See *Bunker fuels*.

Jet fuel: A refined petroleum product used in jet aircraft engines. It includes kerosene-type jet fuel and naphtha-type jet fuel.

Joint Implementation (JI): Agreements made between two or more nations under the auspices of the Framework Convention on Climate Change (FCCC) whereby a developed country can receive "emissions reduction units" when it helps to finance projects that reduce net emissions in another developed country (including countries with economies in transition).

Kerosene: A light petroleum distillate that is used in space heaters, cook stoves, and water heaters and is suitable for use as a light source when burned in wick-fed lamps. Kerosene has a maximum distillation temperature of 400 degrees Fahrenheit at the 10-percent recovery point, a final boiling point of 572 degrees Fahrenheit, and a minimum flash point of 100 degrees Fahrenheit. Included are No. 1-K and No. 2-K, the two grades recognized by ASTM Specification D 3699 as well as all other grades of kerosene called range or stove oil, which have properties similar to those of No. 1 fuel oil. See *Kerosene-type jet fuel*.

Kerosene-type jet fuel: A kerosene-based product having a maximum distillation temperature of 400 degrees Fahrenheit at the 10-percent recovery point and a final maximum boiling point of 572 degrees Fahrenheit and meeting ASTM Specification D 1655 and Military Specifications MIL-T-5624P and MIL-T-83133D (Grades JP-5 and JP-8). It is used for commercial and military turbojet and turboprop aircraft engines.

Kyoto Protocol: The result of negotiations at the third Conference of the Parties (COP-3) in Kyoto, Japan, in December of 1997. The Kyoto Protocol sets binding greenhouse gas emissions targets for countries that sign and ratify the agreement. The gases covered under the Protocol include carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride.

Ketone-alcohol (cyclohexanol): An oily, colorless, hygroscopic liquid with a camphor-like odor. Used in soapmaking, dry cleaning, plasticizers, insecticides, and germicides.

Leachate: The liquid that has percolated through the soil or other medium.

Lignite: The lowest rank of coal, often referred to as brown coal, used almost exclusively as fuel for steam-electric power generation. It is brownish-black and has a high inherent moisture content, sometimes as high as 45 percent The heat content of lignite ranges from 9 to 17 million Btu per ton on a moist, mineral-matter-free basis. The heat content of lignite consumed in the United States averages 13 million Btu per ton, on the as-received basis (i.e., containing both inherent moisture and mineral matter).

Liquefied petroleum gases: A group of hydrocarbon-based gases derived from crude oil refining or natural gas fractionation. They include ethane, ethylene, propane, propylene, normal butane, butylene, isobutane, and isobutylene. For convenience of transportation, these gases are liquefied through pressurization.

Lubricants: Substances used to reduce friction between bearing surfaces, or incorporated into other materials used as processing aids in the manufacture of other products, or used as carriers of other materials. Petroleum lubricants may be produced either from distillates or residues. Lubricants include all grades of lubricating oils, from spindle oil to cylinder oil to those used in greases.

Methane: A colorless, flammable, odorless hydrocarbon gas (CH4) which is the major component of natural gas. It is also an important source of hydrogen in various industrial processes. Methane is a greenhouse gas. See also *Greenhouse gases*.

Methanogens: Bacteria that synthesize methane, requiring completely anaerobic conditions for growth.

Methanol: A light alcohol that can be used for gasoline blending. See oxygenate.

Methanotrophs: Bacteria that use methane as food and oxidize it into carbon dioxide.

Methyl chloroform (trichloroethane): An industrial chemical (CH_3CCl_3) used as a solvent, aerosol propellant, and pesticide and for metal degreasing.

Methyl tertiary butyl ether (MTBE): A colorless, flammable, liquid oxygenated hydrocarbon containing 18.15 percent oxygen.

Methylene chloride: A colorless liquid, nonexplosive and practically nonflammable. Used as a refrigerant in centrifugal compressors, a solvent for organic materials, and a component in nonflammable paint removers.

Mole: The quantity of a compound or element that has a weight in grams numerically equal to its molecular weight. Also referred to as gram molecule or gram molecular weight.

Montreal Protocol: The Montreal Protocol on Substances that Deplete the Ozone Layer (1987). An international agreement, signed by most of the industrialized nations, to substantially reduce the use of chlorofluorocarbons (CFCs). Signed in January 1989, the original document called for a 50-percent reduction in CFC use by 1992 relative to 1986 levels. The subsequent London Agreement called for a complete elimination of CFC use by 2000. The Copenhagen Agreement, which called for a complete phaseout by January 1, 1996, was implemented by the U.S. Environmental Protection Agency.

Motor gasoline (finished): A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in spark-ignition engines. Motor gasoline, as defined in ASTM Specification D 4814 or Federal Specification VV-G-1690C, is characterized as having a boiling range of 122 to 158 degrees Fahrenheit at the 10 percent recovery point to 365 to 374 degrees Fahrenheit at the 90 percent recovery point. “Motor Gasoline” includes conventional gasoline; all types of oxygenated gasoline, including gasohol; and reformulated gasoline, but excludes aviation gasoline. Note: Volumetric data on blending components, such as oxygenates, are not counted in data on finished motor gasoline until the blending components are blended into the gasoline.

Multiple cropping: A system of growing several crops on the same field in one year.

Municipal solid waste: Residential solid waste and some nonhazardous commercial, institutional, and industrial wastes.

Naphtha less than 401 degrees Fahrenheit: A naphtha with a boiling range of less than 401 degrees Fahrenheit that is intended for use as a petrochemical feedstock. Also see *Petrochemical feedstocks*.

Naphtha-type jet fuel: A fuel in the heavy naphtha boiling range having an average gravity of 52.8 degrees API, 20 to 90 percent distillation temperatures of 290 degrees to 470 degrees Fahrenheit, and meeting Military Specification MIL-T-5624L (Grade JP-4). It is used primarily for military turbojet and turboprop aircraft engines because it has a lower freeze point than other aviation fuels and meets engine requirements at high altitudes and speeds.

Natural gas: A mixture of hydrocarbons and small quantities of various nonhydrocarbons in the gaseous phase or in solution with crude oil in natural underground reservoirs.

Natural gas liquids (NGLs): Those hydrocarbons in natural gas that are separated as liquids from the gas. Includes natural gas plant liquids and lease condensate.

Natural gas, pipeline quality: A mixture of hydrocarbon compounds existing in the gaseous phase with sufficient energy content, generally above 900 Btu, and a small enough share of impurities for transport through commercial gas pipelines and sale to end-users.

Nitrogen oxides (NO_x): Compounds of nitrogen and oxygen produced by the burning of fossil fuels.

Nitrous oxide (N_2O): A colorless gas, naturally occurring in the atmosphere. Nitrous oxide has a 100-year Global Warming Potential of 310.

Nonmethane volatile organic compounds (NMVOCs): Organic compounds, other than methane, that participate in atmospheric photochemical reactions.

Octane: A flammable liquid hydrocarbon found in petroleum. Used as a standard to measure the antiknock properties of motor fuel.

Oil reservoir: An underground pool of liquid consisting of hydrocarbons, sulfur, oxygen, and nitrogen trapped within a geological formation and protected from evaporation by the overlying mineral strata.

Organic content: The share of a substance that is of animal or plant origin.

Organic waste: Waste material of animal or plant origin.

Oxidize: To chemically transform a substance by combining it with oxygen.

Oxygenates: Substances which, when added to gasoline, increase the amount of oxygen in that gasoline blend. Ethanol, Methyl Tertiary Butyl Ether (MTBE), Ethyl Tertiary Butyl Ether (ETBE), and methanol are common oxygenates.

Ozone: A molecule made up of three atoms of oxygen. Occurs naturally in the stratosphere and provides a protective layer shielding the Earth from harmful ultraviolet radiation. In the troposphere, it is a chemical oxidant, a greenhouse gas, and a major component of photochemical smog.

Ozone precursors: Chemical compounds, such as carbon monoxide, methane, nonmethane hydrocarbons, and nitrogen oxides, which in the presence of solar radiation react with other chemical compounds to form ozone.

Paraffinic hydrocarbons: Straight-chain hydrocarbon compounds with the general formula C_nH_{2n+2}.

Perfluorocarbons (PFCs): A group of man-made chemicals composed of one or two carbon atoms and four to six fluorine atoms, containing no chlorine. PFCs have no commercial uses and are emitted as a byproduct of aluminum smelting and semiconductor manufacturing. PFCs have very high 100-year Global Warming Potentials and are very long-lived in the atmosphere.

Perfluoromethane: A compound (CF_4) emitted as a byproduct of aluminum smelting.

Petrochemical feedstocks: Chemical feedstocks derived from petroleum principally for the manufacture of chemicals, synthetic rubber, and a variety of plastics.

Petroleum: A broadly defined class of liquid hydrocarbon mixtures. Included are crude oil, lease condensate, unfinished oils, refined products obtained from the processing of crude oil, and natural gas plant liquids. Note: Volumes of finished petroleum products include nonhydrocarbon compounds, such as additives and detergents, after they have been blended into the products.

Petroleum coke: See *Coke (petroleum)*.

Photosynthesis: The manufacture by plants of carbohydrates and oxygen from carbon dioxide and water in the presence of chlorophyll, with sunlight as the energy source. Carbon is sequestered and oxygen and water vapor are released in the process.

Pig iron: Crude, high-carbon iron produced by reduction of iron ore in a blast furnace.

Pipeline, distribution: A pipeline that conveys gas from a transmission pipeline to its ultimate consumer.

Pipeline, gathering: A pipeline that conveys gas from a production well/field to a gas processing plant or transmission pipeline for eventual delivery to end-use consumers.

Pipeline, transmission: A pipeline that conveys gas from a region where it is produced to a region where it is to be distributed.

Planetary albedo: The fraction of incident solar radiation that is reflected by the Earth-atmosphere system and returned to space, mostly by backscatter from clouds in the atmosphere.

Pneumatic device: A device moved or worked by air pressure.

Polystyrene: A polymer of styrene that is a rigid, transparent thermoplastic with good physical and electrical insulating properties, used in molded products, foams, and sheet materials.

Polyvinyl chloride (PVC): A polymer of vinyl chloride. Tasteless. odorless, insoluble in most organic solvents. A member of the family vinyl resin, used in soft flexible films for food packaging and in molded rigid products, such as pipes, fibers, upholstery, and bristles.

Post-mining emissions: Emissions of methane from coal occurring after the coal has been mined, during transport or pulverization.

Radiative forcing: A change in average net radiation at the top of the troposphere (known as the tropopause) because of a change in either incoming solar or exiting infrared radiation. A positive radiative forcing tends on average to warm the earth's surface; a negative radiative forcing on average tends to cool the earth's surface. Greenhouse gases, when emitted into the atmosphere, trap infrared energy radiated from the earth's surface and therefore tend to produce positive radiative forcing. See *Greenhouse gases*.

Radiatively active gases: Gases that absorb incoming solar radiation or outgoing infrared radiation, affecting the vertical temperature profile of the atmosphere. See *Radiative forcing*.

Ratoon crop: A crop cultivated from the shoots of a perennial plant.

Redox potential: A measurement of the state of oxidation of a system.

Reflectivity: The ratio of the energy carried by a wave after reflection from a surface to its energy before reflection.

Reforestation: Replanting of forests on lands that have recently been harvested or otherwise cleared of trees.

Reformulated gasoline: Finished motor gasoline formulated for use in motor vehicles, the composition and properties of which meet the requirements of the reformulated gasoline regulations promulgated by the U.S. Environmental Protection Agency under Section 211(k) of the Clean Air Act. Note: This category includes oxygenated fuels program reformulated gasoline (OPRG) but excludes reformulated gasoline blendstock for oxygenate blending (RBOB).

Renewable energy resources: Energy resources that are naturally replenishing but flow-limited. They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable energy resources include: biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action.

Residual fuel oil: A general classification for the heavier oils, known as No. 5 and No. 6 fuel oils, that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations. It conforms to ASTM Specifications D 396 and D 975 and Federal Specification VV-F-815C. No. 5, a residual fuel oil of medium viscosity, is also known as Navy Special and is defined in Military Specification MIL-F-859E, including Amendment 2 (NATO Symbol F-770). It is used in steam-powered vessels in government service and inshore powerplants. No. 6 fuel oil includes Bunker C fuel oil and is used for the production of electric power, space heating, vessel bunkering, and various industrial purposes.

Rumen: The large first compartment of the stomach of certain animals in which cellulose is broken down by the action of bacteria.

Sample: A set of measurements or outcomes selected from a given population.

Sequestration: See *Carbon sequestration*.

Septic tank: A tank in which the solid matter of continuously flowing sewage is disintegrated by bacteria.

Sinter: A chemical sedimentary rock deposited by precipitation from mineral waters, especially siliceous sinter and calcareous sinter.

Sodium silicate: A grey-white powder soluble in alkali and water, insoluble in alcohol and acid. Used to fireproof textiles, in petroleum refining and corrugated paperboard manufacture, and as an egg preservative. Also referred to as liquid gas, silicate of soda, sodium metasilicate, soluble glass, and water glass.

Sodium tripolyphosphate: A white powder used for water softening and as a food additive and texturizer.

Stabilization lagoon: A shallow artificial pond used for the treatment of wastewater. Treatment includes removal of solid material through sedimentation, the decomposition of organic material by bacteria, and the removal of nutrients by algae.

Still gas (refinery gas): Any form or mixture of gases produced in refineries by distillation, cracking, reforming, and other processes. The principal constituents are methane, ethane, ethylene, normal butane, butylene, propane, propylene, etc. Still gas is used as a refinery fuel and a petrochemical feedstock. The conversion factor is 6 million Btu per fuel oil equivalent barrel.

Stratosphere: The region of the upper atmosphere extending from the tropopause (8 to 15 kilometers altitude) to about 50 kilometers. Its thermal structure, which is determined by its radiation balance, is generally very stable with low humidity.

Stripper well: An oil or gas well that produces at relatively low rates. For oil, stripper production is usually defined as production rates of between 5 and 15 barrels of oil per day. Stripper gas production would generally be anything less than 60 thousand cubic feet per day.

Styrene: A colorless, toxic liquid with a strong aromatic aroma. Insoluble in water, soluble in alcohol and ether; polymerizes rapidly; can become explosive. Used to make polymers and copolymers, polystyrene plastics, and rubber.

Subbituminous coal: A coal whose properties range from those of lignite to those of bituminous coal and used primarily as fuel for steam-electric power generation. It may be dull, dark brown to black, soft and crumbly, at the lower end of the range, to bright, jet black, hard, and relatively strong, at the upper end. Subbituminous coal contains 20 to 30 percent inherent moisture by weight. The heat content of subbituminous coal ranges from 17 to 24 million Btu per ton on a moist, mineral-matter-free basis. The heat content of subbituminous coal consumed in the United States averages 17 to 18 million Btu per ton, on the as-received basis (i.e., containing both inherent moisture and mineral matter).

Sulfur dioxide (SO_2): A toxic, irritating, colorless gas soluble in water, alcohol, and ether. Used as a chemical intermediate, in paper pulping and ore refining, and as a solvent.

Sulfur hexafluoride (SF_6): A colorless gas soluble in alcohol and ether, and slightly less soluble in water. It is used as a dielectric in electronics. It possesses the highest 100-year Global Warming Potential of any gas (23,900).

Sulfur oxides (SO_x): Compounds containing sulfur and oxygen, such as sulfur dioxide (SO_2) and sulfur trioxide (SO_3).

Tertiary amyl methyl ether ($(CH_3)_2(C_2H_5)COCH_3$): An oxygenate blend stock formed by the catalytic etherification of isoamylene with methanol.

Troposphere: The inner layer of the atmosphere below about 15 kilometers, within which there is normally a steady decrease of temperature with increasing altitude. Nearly all clouds form and weather conditions manifest themselves within this region. Its thermal structure is caused primarily by the heating of the earth's surface by solar radiation, followed by heat transfer through turbulent mixing and convection.

Uncertainty: A measure used to quantify the plausible maximum and minimum values for emissions from any source, given the biases inherent in the methods used to calculate a point estimate and known sources of error.

Vapor displacement: The release of vapors that had previously occupied space above liquid fuels stored in tanks. These releases occur when tanks are emptied and filled.

Ventilation system: A method for reducing methane concentrations in coal mines to non-explosive levels by blowing air across the mine face and using large exhaust fans to remove methane while mining operations proceed.

Vessel bunkering: Includes sales for the fueling of commercial or private boats, such as pleasure craft, fishing boats, tugboats, and ocean-going vessels, including vessels operated by oil companies. Excluded are volumes sold to the U.S. Armed Forces.

Volatile organic compounds (VOCs): Organic compounds that participate in atmospheric photochemical reactions.

Volatile solids: A solid material that is readily decomposable at relatively low temperatures.

Waste flow: Quantity of a waste stream generated by an activity.

Wastewater: Water that has been used and contains dissolved or suspended waste materials.

Wastewater, domestic and commercial: Wastewater (sewage) produced by domestic and commercial establishments.

Wastewater, industrial: Wastewater produced by industrial processes.

Water vapor: Water in a vaporous form, especially when below boiling temperature and diffused (e.g., in the atmosphere).

Wax: A solid or semi-solid material derived from petroleum distillates or residues by such treatments as chilling, precipitating with a solvent, or de-oiling. It is a light-colored, more-or-less translucent crystalline mass, slightly greasy to the touch, consisting of a mixture of solid hydrocarbons in which the paraffin series predominates. Includes all marketable wax, whether crude scale or fully refined. The three grades included are microcrystalline, crystalline-fully refined, and crystalline-other. The conversion factor is 280 pounds per 42 U.S. gallons per barrel.

Weanling system: A cattle management system that places calves on feed starting at 165 days of age and continues until the animals have reached slaughter weight.

Wellhead: The point at which the crude (and/or natural gas) exits the ground. Following historical precedent, the volume and price for crude oil production are labeled as “wellhead,” even though the cost and volume are now generally measured at the lease boundary. In the context of domestic crude price data, the term “wellhead” is the generic term used to reference the production site or lease property.

Wetlands: Areas regularly saturated by surface or groundwater and subsequently characterized by a prevalence of vegetation adapted for life in saturated-soil conditions.

Wood energy: Wood and wood products used as fuel, including roundwood (cordwood), limbwood, wood chips, bark, sawdust, forest residues, charcoal, pulp waste, and spent pulping liquor..

Yearling system: A cattle management system that includes a stocker period from 165 days of age to 425 days of age followed by a 140-day feedlot period.