

Emissions of Greenhouse Gases in the United States 2008

December 2009

U.S. Energy Information Administration
Office of Integrated Analysis and Forecasting
U.S. Department of Energy
Washington, DC 20585

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Contacts

This report, *Emissions of Greenhouse Gases in the United States 2008*, was prepared under the general direction of John Conti, Director of the Office of Integrated Analysis and Forecasting, and Glen E. Sweetnam, Director, International, Economic, and Greenhouse Gases Division, Energy Information Administration. General questions concerning the content of this report may be directed to the National Energy Information Center at 202/586-8800.

Technical information concerning the content of the report may be obtained from Perry Lindstrom at

202/586-0934 (e-mail, perry.lindstrom@eia.doe.gov). Without the assistance of Science Applications International Corporation (SAIC), this report would not have been possible. In particular we would like to thank Erin Beddingfield, Keith Forbes, Kristin Igusky, Makely Lyon, Michael Mondshine, and Richard Richards. We also wish to acknowledge the work done by our summer intern, Christine Donnelly (EIA).

Specific questions about the report should be referred to the following analysts:

Overview	Paul McArdle	(paul.mcardle@eia.doe.gov ,	202/586-4445)
Carbon Dioxide	Perry Lindstrom	(perry.lindstrom@eia.doe.gov ,	202/586-0934)
Methane	Perry Lindstrom	(perry.lindstrom@eia.doe.gov ,	202/586-0934)
Nitrous Oxide	Perry Lindstrom	(perry.lindstrom@eia.doe.gov ,	202/586-0934)
High-GWP Gases (Greenhouse Gases with High Global Warming Potentials)	Paul McArdle	(paul.mcardle@eia.doe.gov ,	202/586-4445)
Land Use, Land-Use Change, and Forests	Paul McArdle	(paul.mcardle@eia.doe.gov ,	202/586-4445)

For this report, activity data on coal and natural gas consumption and electricity sales and losses by sector were obtained from the November 2009 *Monthly Energy Review (MER)*.

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 by 12/44.

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.

This report—the seventeenth annual report—presents the Energy Information Administration’s latest estimates of emissions for carbon dioxide, methane, nitrous oxide, and other greenhouse gases. Documentation for these estimates is available online at www.eia.doe.gov/oiaf/1605/ggrpt.

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Greenhouse Gas Emissions Overview

Total Emissions

Summary

- Total U.S. greenhouse gas emissions in 2008 were 2.2 percent below the 2007 total.
- The decline in total emissions—from 7,209.8 million metric tons carbon dioxide equivalent (MMT_{CO₂e}) in 2007 to 7,052.6 MMT_{CO₂e} in 2008—was largely the result of a 177.8-MMT_{CO₂e} drop in carbon dioxide (CO₂) emissions. There were small percentage increases in emissions of other greenhouse gases, but their absolute contributions to the change in total emissions were relatively small: 14.8 MMT_{CO₂e} growth for methane (CH₄), 0.4 MMT_{CO₂e} growth for nitrous oxide (N₂O), and 5.3 MMT_{CO₂e} growth for the man-made gases with high global warming potentials (high-GWP gases). As a result, the increases in emissions of these gases were more than offset by the drop in CO₂ emissions (Table 1).
- The decrease in U.S. CO₂ emissions in 2008 resulted primarily from three factors: higher energy prices—especially during the summer driving season—that led to a drop in petroleum consumption; economic

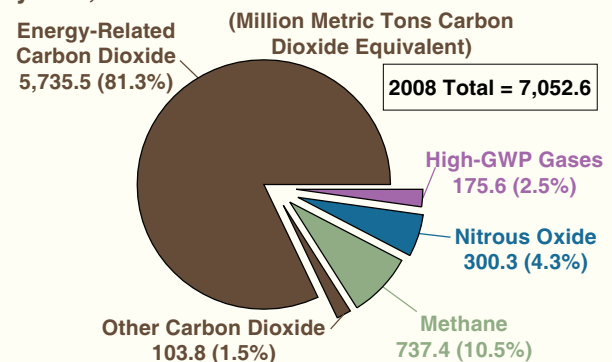
contraction in three out of four quarters of the year that resulted in lower energy demand for the year as a whole in all sectors except the commercial sector; and lower demand for electricity along with lower carbon intensity of electricity supply.

- Methane emissions totaled 737.4 MMT_{CO₂e} in 2008 (Figure 1), up by 14.8 MMT_{CO₂e} (2 percent) from 2007. Most of the increase came from coal mining and from natural gas production and processing. Emissions from petroleum systems decreased. Emissions from stationary combustion—primarily from wood combustion for residential heating—increased.
- Emissions of nitrous oxide (N₂O) increased by 0.4 MMT_{CO₂e} (0.1 percent).
- Based on a partial estimate, U.S. emissions of high-GWP gases totaled 175.6 MMT_{CO₂e} in 2008—5.4 MMT_{CO₂e} above the 2007 level. The increase resulted mainly from higher emissions levels for hydrofluorocarbons (HFCs, up by 5.0 MMT_{CO₂e}).

U.S. Anthropogenic Greenhouse Gas Emissions, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	6,187.4	7,209.8	7,052.6
Change from 1990 (Million Metric Tons CO ₂ e)		1,022.4	865.1
(Percent)		16.5%	14.0%
Average Annual Change from 1990 (Percent)		0.9%	0.7%
Change from 2007 (Million Metric Tons CO ₂ e)			-157.3
(Percent)			-2.2%

Figure 1. U.S. Greenhouse Gas Emissions by Gas, 2008



Source: EIA estimates.

Table 1. U.S. Emissions of Greenhouse Gases, Based on Global Warming Potential, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Carbon Dioxide	5,022.3	5,341.5	5,886.4	5,849.1	5,908.8	6,009.9	6,029.0	5,928.7	6,017.0	5,839.3
Methane	783.5	756.2	683.0	673.3	681.6	686.6	691.8	706.3	722.7	737.4
Nitrous Oxide	279.3	305.6	289.8	283.7	283.0	302.2	304.0	305.2	299.8	300.3
High-GWP Gases ^a	102.3	119.0	150.5	148.1	141.8	153.5	157.8	160.5	170.3	175.6
Total	6,187.4	6,522.3	7,009.8	6,954.2	7,015.2	7,152.1	7,182.6	7,100.8	7,209.8	7,052.6
Difference from 2000	—	—	—	-55.6	5.5	142.3	172.8	91.0	200.0	42.8
Percent Difference from 2000	—	—	—	-0.8	0.1	2.0	2.5	1.3	2.9	0.6

^aHydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆).

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.

Sources: **Emissions:** EIA estimates. **Global Warming Potentials:** Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis: Errata* (Cambridge, UK: Cambridge University Press, 2008), web site http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Errata_2008-12-01.pdf.

Greenhouse Gas Emissions Overview

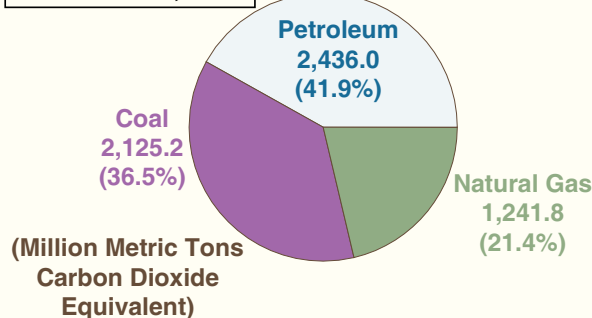
Energy-Related Carbon Dioxide Emissions by Fuel and End-Use Sector

Summary

- Energy-related CO₂ emissions dominate total U.S. greenhouse gas emissions (see Figure 1). The figures below show the shares of energy-related CO₂ emissions accounted for by major energy fuels and by energy end-use sectors.
- Petroleum is the largest fossil fuel source for energy-related CO₂ emissions, contributing 42 percent of the total (Figure 2).
- Coal is the second-largest fossil fuel contributor, at 37 percent. Although coal produces more CO₂ per unit of energy, petroleum consumption—in terms of British thermal units (Btu)—made up 44.6 percent of total fossil fuel energy consumption in 2008, as compared with coal's 26.8 percent.
- Natural gas, with a carbon intensity that is 55 percent of the carbon intensity for coal and 75 percent of the carbon intensity for petroleum, accounted for 28.5 percent of U.S. fossil energy use in 2008 but only 21 percent of total energy-related CO₂ emissions.
- In Figure 3 below, emissions are divided into three categories: emissions from the direct use of fossil fuels in homes (for example, natural gas for heating), commercial buildings, and industry; emissions from fuel use for transportation (principally, petroleum); and emissions from the conversion of primary energy to electricity in the electric power sector.
- The electric power sector is the largest source, accounting for 40.6 percent of all energy-related CO₂ emissions. The electric power sector consists of those entities whose primary business is the production of electricity (NAICS-22).
- The transportation sector is the second-largest source, at 33.1 percent of the total. Those emissions are principally from the combustion of motor gasoline, diesel fuel, and jet fuel.
- Direct fuel use in the residential and commercial sectors (mainly, for heating) and the use of fuels to produce process heat in the industrial sector account for 26.3 percent of total emissions.

Figure 2. U.S. Energy-Related Carbon Dioxide Emissions by Major Fuel, 2008

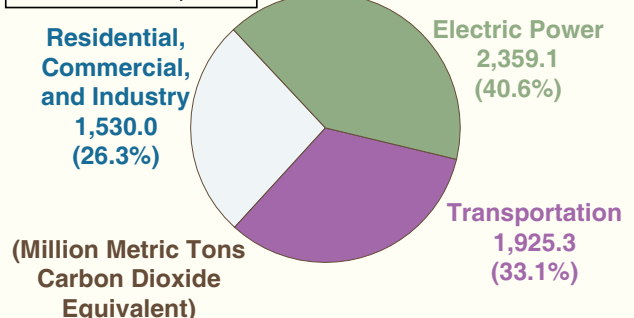
2008 Total = 5,814.4*



*Includes small amounts of CO₂ from non-biogenic municipal solid waste and geothermal energy (0.2 percent of total).
Source: EIA estimates.

Figure 3. U.S. Energy-Related Carbon Dioxide Emissions by End-Use Sector, 2008

2008 Total = 5,814.4



Source: EIA estimates.

Greenhouse Gas Emissions Overview

Decomposition of U.S. Greenhouse Gas Changes

Summary

- From 2007 to 2008, the greenhouse gas intensity of the U.S. economy—measured as metric tons carbon dioxide equivalent (MTCO₂e) emitted per million dollars of real gross domestic product (GDP)—fell by 2.6 percent.
- Economic growth of 0.4 percent in 2008, coupled with a 2.2-percent decrease in total greenhouse gas emissions, accounted for the decrease (improvement) in U.S. greenhouse gas intensity from 2007 to 2008 (Table 2).
- Because energy-related CO₂ is such a large component of greenhouse gas emissions, it is helpful to analyze energy-related CO₂ emissions by using an equation known as the *Kaya identity*. The Kaya identity relates percent changes in energy-related

CO₂ emissions to changes in the economy through the following approximation:

$$\% \Delta \text{CO}_2 \approx \% \Delta \text{GDP} + \% \Delta (\text{Energy}/\text{GDP}) + \% \Delta (\text{CO}_2/\text{Energy})$$

where %Δ represents percentage change.

As indicated in Figure 4, energy intensity (Energy/GDP) has gone down in every year since 2000. The carbon intensity of the energy supply (CO₂/Energy) has gone down in some years and up in others. While GDP growth was positive in all years from 2000 through 2008, it has varied. In 2008, economic growth was low (0.4 percent), while there were decreases in both energy intensity (-2.5 percent) and carbon intensity (-0.8 percent), leading to a 2.9-percent decline in energy-related CO₂ emissions.

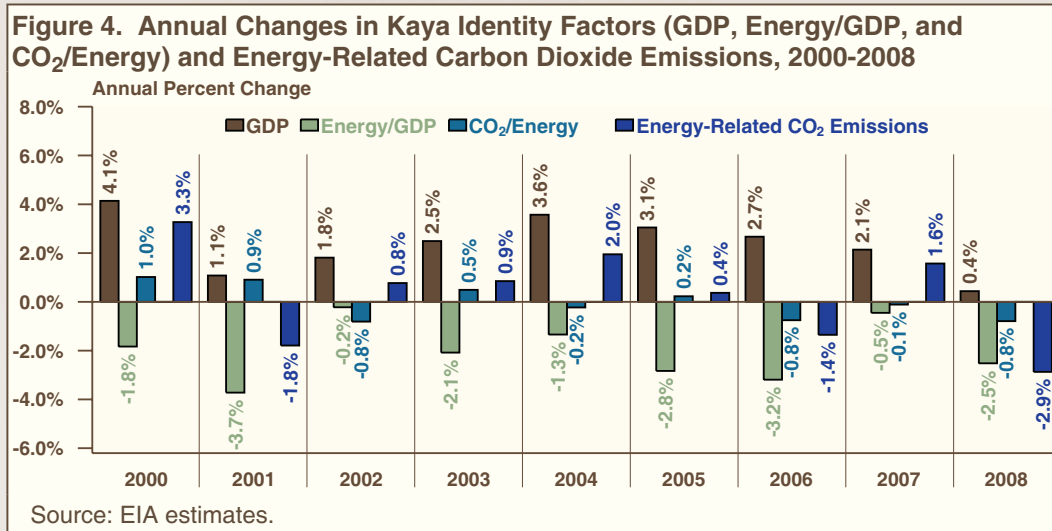


Table 2. U.S. Greenhouse Gas Intensity and Related Factors, 1990-2008

	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Gross Domestic Product (Billion 2005 Dollars)	8,033.9	9,093.7	11,226.0	11,553.0	11,840.7	12,263.8	12,638.4	12,976.2	13,254.1	13,312.2
Greenhouse Gas Emissions (MMTCO ₂ e)	6,187.4	6,522.3	7,009.8	6,954.2	7,015.2	7,152.1	7,182.6	7,100.8	7,209.8	7,052.6
Greenhouse Gas Intensity (MTCO ₂ e per Million 2005 Dollars)	770.2	717.2	624.4	601.9	592.5	583.2	568.3	547.2	544.0	529.8
Change from Previous Year (Percent)										
Energy-Related CO ₂ Emissions	—	1.0	3.3	0.8	0.8	2.0	0.4	-1.3	1.6	-2.9
Gross Domestic Product (GDP)	—	2.5	4.1	1.8	2.5	3.6	3.1	2.7	2.1	0.4
Energy/GDP	—	-0.3	-1.8	-0.2	-2.1	-1.3	-2.8	-3.2	-0.5	-2.5
CO ₂ /Energy	—	-1.2	1.0	-0.8	0.5	-0.2	0.2	-0.7	-0.1	-0.8

Note: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008).

Sources: **Emissions:** EIA estimates. **GDP:** U.S. Department of Commerce, Bureau of Economic Analysis, web site www.bea.gov (November 12, 2009).

Greenhouse Gas Emissions Overview

Greenhouse Gas Emissions in the U.S. Economy

The diagram on page 5 illustrates the flow of U.S. greenhouse gas emissions in 2008, from their sources to their end uses. The left side shows CO₂ quantities, by fuel sources, and quantities for other gases; the right side shows their distribution by sector. The center of the diagram indicates the split between CO₂ 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 United Nations Framework Convention on Climate Change (UNFCCC).

CO₂. CO₂ emission sources include energy-related emissions (primarily from fossil fuel combustion) and emissions from industrial processes. The energy subtotal (5,814 MMTCO₂e) includes petroleum, coal, and natural gas consumption and smaller amounts from non-biogenic municipal solid waste and some forms of geothermal power generation. The energy subtotal also includes emissions from nonfuel uses of fossil fuels, mainly as inputs to other products. Industrial process emissions (104 MMTCO₂e) 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 CO₂ emissions (5,918 MMTCO₂e). The energy component of unadjusted emissions can be divided into direct fuel use (3,381 MMTCO₂e) and fuel converted to electricity (2,433 MMTCO₂e).

Non-CO₂ Gases. Methane (737 MMTCO₂e) and nitrous oxide (300 MMTCO₂e) sources include emissions related to energy, agriculture, waste management, and industrial processes. Other, high-GWP gases (176 MMTCO₂e) include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆). 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, CO₂ emissions from U.S. Territories (48 MMTCO₂e) are added to the U.S. total, and CO₂ emissions from fuels used for international transport (both oceangoing vessels and airplanes) (127 MMTCO₂e) are subtracted to derive total U.S. greenhouse gas emissions (7,053 MMTCO₂e).

Emissions by End-Use Sector. CO₂ 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. CO₂ emissions from purchased electricity are allocated to the end-use sectors based on their shares of total electricity sales. Non-CO₂ 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 (1,244 MMTCO₂e) include energy-related CO₂ emissions (1,230 MMTCO₂e) and non-CO₂ emissions (14 MMTCO₂e). The non-CO₂ sources include methane and nitrous oxide emissions from direct fuel use. Non-CO₂ indirect emissions attributable to purchased electricity, including methane and nitrous oxide emissions from electric power generation and SF₆ emissions related to electricity transmission and distribution, are also included.

Emissions in the **commercial** sector (1,353 MMTCO₂e) include both energy-related CO₂ emissions (1,084 MMTCO₂e) and non-CO₂ emissions (269 MMTCO₂e). The non-CO₂ emissions include direct emissions from landfills, wastewater treatment plants, commercial refrigerants, and stationary combustion emissions of methane and nitrous oxide. Non-CO₂ indirect emissions attributable to purchased electricity, including methane and nitrous oxide emissions from electric power generation and SF₆ emissions related to electricity transmission and distribution, are also included.

Industrial emissions (2,510 MMTCO₂e) include CO₂ emissions (1,706 MMTCO₂e)—which can be broken down between combustion (1,602 MMTCO₂e) and process emissions (104 MMTCO₂e)—and non-CO₂ emissions (804 MMTCO₂e). The non-CO₂ 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 SF₆), and direct stationary combustion emissions of methane and nitrous oxide. Non-CO₂ indirect emissions attributable to purchased electricity, including methane and nitrous oxide emissions from electric power generation and SF₆ emissions related to electricity transmission and distribution, are also included.

Transportation emissions (1,946 MMTCO₂e) include energy-related CO₂ emissions from mobile source combustion (1,819 MMTCO₂e); and non-CO₂ emissions (127 MMTCO₂e). The non-CO₂ 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 5)

Greenhouse Gas Emissions Overview

Greenhouse Gas Emissions in the U.S. Economy

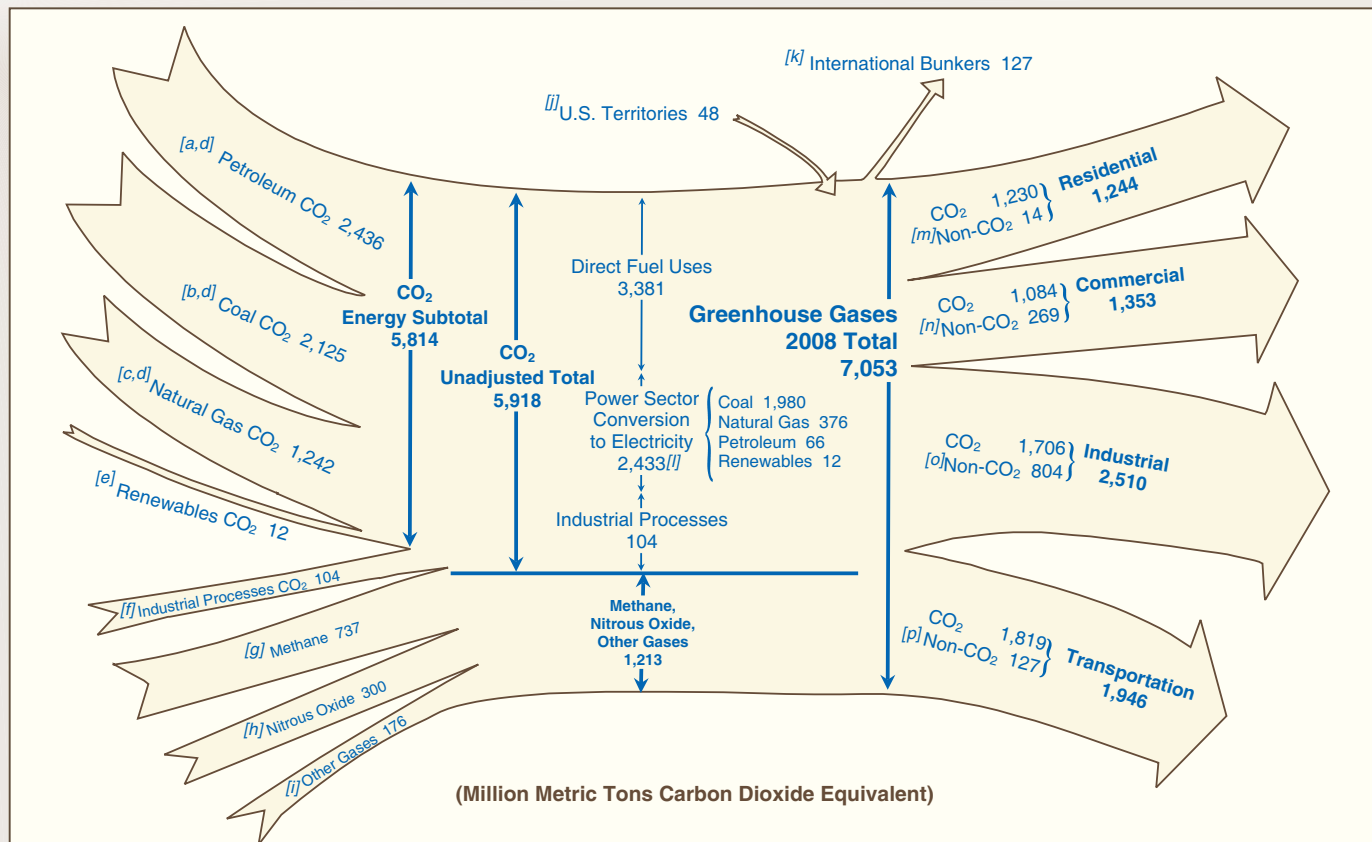


Diagram Notes

[a] CO₂ emissions related to petroleum consumption (includes 84.0 MMTCO₂ of non-fuel-related emissions).

[b] CO₂ emissions related to coal consumption (includes 0.5 MMTCO₂ of non-fuel-related emissions).

[c] CO₂ emissions related to natural gas consumption (includes 18.1 MMTCO₂ of non-fuel-related emissions).

[d] Excludes carbon sequestered in nonfuel fossil products.

[e] CO₂ emissions from the plastics portion of municipal solid waste (11.2 MMTCO₂) combusted for electricity generation and very small amounts (0.4 MMTCO₂) 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 CO₂ emissions from fossil fuels. Emissions are allocated to end-use sectors in proportion to U.S. ratios. Therefore, the sector CO₂ values shown here do not match the values in the carbon dioxide chapter.

[k] Includes vessel bunkers and jet fuel consumed for international travel. Under the UNFCCC, these emissions are not included in country emission inventories. Emissions are subtracted from the transportation sector total.

[l] CO₂ emissions from electricity generation in the commercial and industrial sectors are included in those sectors.

[m] Non-CO₂: Direct stationary combustion emissions of methane and nitrous oxide plus indirect power sector emissions of methane, nitrous oxide, and other greenhouse gases.

[n] Non-CO₂: 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.

[o] Non-CO₂: 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.

[p] Non-CO₂: Direct mobile combustion emissions of methane and nitrous oxide. Also, emissions related to transportation refrigerants are included.

Source: Estimates presented in this report. CO₂ emissions by end-use sector are based on EIA's estimates of energy consumption by sector and on industrial process emissions. CO₂ emissions from the electric power sector are allocated to the end-use sectors based on electricity sales to the sector. Non-CO₂ 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 6)

Greenhouse Gas Emissions Overview

Greenhouse Gas Emissions in the U.S. Economy

Distribution of Total U.S. Greenhouse Gas Emissions by End-Use Sector, 2008					
Greenhouse Gas and Source	Sector				
	Residential	Commercial	Industrial	Transportation	Total
Carbon Dioxide					
Million Metric Tons Carbon Dioxide Equivalent					
Energy-Related (adjusted)	1,230.3	1,084.1	1,602.3	1,818.8	5,735.5
Industrial Processes	—	—	103.8	—	103.8
Total CO₂	1,230.3	1,084.1	1,706.1	1,818.8	5,839.2
Methane					
Energy					
Coal Mining	—	—	82.0	—	82.0
Natural Gas Systems	—	—	178.9	—	178.9
Petroleum Systems	—	—	22.1	—	22.1
Stationary Combustion	4.5	1.0	1.8	—	7.3
Stationary Combustion: Electricity	0.3	0.3	0.2	—	0.8
Mobile Sources	—	—	—	4.6	4.6
Waste Management					
Landfills	—	184.3	—	—	184.3
Domestic Wastewater Treatment	—	17.6	—	—	17.6
Industrial Wastewater Treatment	—	—	10.2	—	10.2
Industrial Processes	—	—	4.7	—	4.7
Agricultural Sources					
Enteric Fermentation	—	—	148.6	—	148.6
Animal Waste	—	—	64.5	—	64.5
Rice Cultivation	—	—	10.6	—	10.6
Crop Residue Burning	—	—	1.3	—	1.3
Total Methane	4.8	203.2	524.8	4.6	737.4
Nitrous Oxide					
Agriculture					
Nitrogen Fertilization of Soils	—	—	165.0	—	165.0
Solid Waste of Animals	—	—	52.3	—	52.3
Crop Residue Burning	—	—	0.6	—	0.6
Energy Use					
Mobile Combustion	—	—	—	48.8	48.8
Stationary Combustion	0.9	0.3	4.1	—	5.4
Stationary Combustion: Electricity	3.6	3.4	2.7	—	9.7
Industrial Sources	—	—	15.1	—	15.1
Waste Management					
Human Sewage in Wastewater	—	3.0	—	—	3.0
Waste Combustion	—	—	—	—	0.0
Waste Combustion: Electricity	0.1	0.1	0.1	—	0.4
Total Nitrous Oxide	4.6	6.9	239.9	48.8	300.2
Hydrofluorocarbons (HFCs)					
HFC-23	—	—	21.9	—	21.9
HFC-32	—	1.2	—	—	1.2
HFC-125	—	22.1	—	—	22.1
HFC-134a	—	—	—	73.6	73.6
HFC-143a	—	22.5	—	—	22.5
HFC-236fa	—	1.4	—	—	1.4
Total HFCs	0.0	47.2	21.9	73.6	142.7
Perfluorocarbons (PFCs)					
CF ₄	—	—	5.2	—	5.2
C ₂ F ₆	—	—	4.2	—	4.2
NF ₃ , C ₃ F ₈ , and C ₄ F ₈	—	—	0.7	—	0.7
Total PFCs	0.0	0.0	10.1	0.0	10.1
Other HFCs, PFCs/PFPEs	—	7.1	—	—	7.1
Sulfur Hexafluoride (SF₆)					
SF ₆ : Utility	4.5	4.3	3.3	—	12.1
SF ₆ : Other	—	—	3.7	—	3.7
Total SF₆	4.5	4.3	7.0	0.0	15.8
Total Non-CO₂	13.9	268.7	803.7	127.0	1,213.3
Total Emissions	1,244.1	1,352.8	2,509.8	1,945.8	7,052.6

Greenhouse Gas Emissions Overview

U.S. Emissions in a Global Perspective

Summary

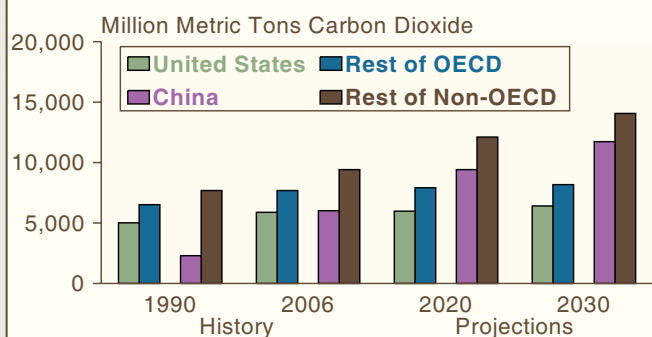
- Based on the 2008 emissions inventory report, total U.S. energy-related CO₂ emissions in 2006 (including nonfuel uses of fossil fuels) were estimated at 5,894 MMT—about 20 percent of the 2006 world total for energy-related CO₂ emissions, estimated at 29,017 MMT (see Table 3 on page 8).
- CO₂ emissions related to energy use in 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—were estimated at 13,582 MMT in 2006, or 47 percent of the world total. With the remaining 53 percent of worldwide energy-related CO₂ emissions (15,435 MMT) estimated to have come from non-OECD countries, 2006 was the second year in which emissions from the non-OECD economies surpassed those from the OECD economies (Figure 5).
- In EIA's *International Energy Outlook 2009* (IEO2009) reference case, projections of energy use and emissions are sensitive to economic growth rates and energy prices. Projections for a range of alternative growth and price scenarios are presented in *IEO2009*.
- U.S. energy-related CO₂ emissions are projected to increase by an average of 0.2 percent per year from 2006 to 2030 in the *IEO2009* reference case, while emissions from the non-OECD economies grow by 2.2 percent per year. Both rates are lower than previous projections as a result of the 2008-2009 global recession and newly enacted energy policies. Consequently, the U.S. share of world CO₂ emissions is projected to fall to 15.4 percent in 2030 (6,207 MMT out of a global total of 40,178 MMT) (Figure 6).
- China's share of global energy-related CO₂ emissions is projected to grow from 21 percent in 2006 to 29 percent in 2030, and China accounts for 51 percent of the projected increase in world emissions over the period. India accounts for the second-largest share of the projected increase, 7 percent.

World Energy-Related Carbon Dioxide Emissions, 1990, 2006, and 2030

	1990	2006	2030*
Estimated Emissions (Million Metric Tons)	21,518	29,017	40,178
Change from 1990 (Million Metric Tons)		7,499	18,660
(Percent)		34.8%	86.7%
Average Annual Change from 1990 (Percent)		2.0%	1.6%
Change from 2006 (Million Metric Tons)			11,161
(Percent)			38.5%

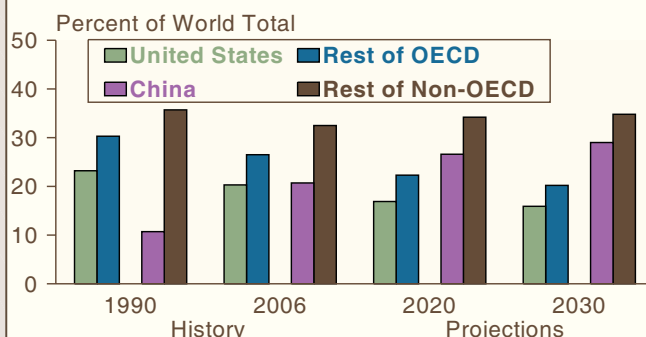
*EIA, *International Energy Outlook 2009*.

Figure 5. World Carbon Dioxide Emissions by Region, 1990, 2006, 2020, and 2030



Sources: This report and EIA, *Updated Annual Energy Outlook 2009 Reference Case* (April 2009), web site www.eia.doe.gov/oiaf/servicerpt/stimulus.

Figure 6. Regional Shares of World Carbon Dioxide Emissions, 1990, 2006, 2020, and 2030



Sources: This report and EIA, *Updated Annual Energy Outlook 2009 Reference Case* (April 2009), web site www.eia.doe.gov/oiaf/servicerpt/stimulus.

Greenhouse Gas Emissions Overview

U.S. Emissions in a Global Perspective

Table 3. World Energy-Related Carbon Dioxide Emissions by Region, 1990-2030
(Million Metric Tons Carbon Dioxide, Percent Share of World Emissions)

Region/Country	History ^a			Projections ^a					Average Annual Percent Change, 2006-2030 ^b
	1990	2005	2006	2010	2015	2020	2025	2030	
OECD									
OECD North America	5,793	7,006	6,936	6,739	6,889	7,046	7,262	7,495	0.3
	(26.9%)	(24.8%)	(23.9%)	(21.8%)	(20.9%)	(19.9%)	(19.2%)	(18.7%)	(5.0%)
United States ^c	5,020	5,974	5,894	5,746	5,830	5,905	6,047	6,207	0.2
	(23.3%)	(21.1%)	(20.3%)	(18.6%)	(17.6%)	(16.7%)	(16.0%)	(15.4%)	(2.8%)
Canada	471	629	611	622	645	675	705	731	0.7
	(2.2%)	(2.2%)	(2.1%)	(2.0%)	(2.0%)	(1.9%)	(1.9%)	(1.8%)	(1.1%)
Mexico	302	403	431	371	414	466	510	557	1.1
	(1.4%)	(1.4%)	(1.5%)	(1.2%)	(1.3%)	(1.3%)	(1.3%)	(1.4%)	(1.1%)
OECD Europe	4,149	4,424	4,429	4,335	4,368	4,450	4,489	4,519	0.1
	(19.3%)	(15.6%)	(15.3%)	(14.0%)	(13.2%)	(12.6%)	(11.9%)	(11.2%)	(0.8%)
OECD Asia	1,595	2,201	2,217	2,221	2,287	2,327	2,346	2,367	0.3
	(7.4%)	(7.8%)	(7.6%)	(7.2%)	(6.9%)	(6.6%)	(6.2%)	(5.9%)	(1.3%)
Japan	1,054	1,250	1,247	1,169	1,204	1,219	1,188	1,157	-0.3
	(4.9%)	(4.4%)	(4.3%)	(3.8%)	(3.6%)	(3.4%)	(3.1%)	(2.9%)	(-0.8%)
South Korea	243	497	515	598	614	617	651	680	1.2
	(1.1%)	(1.8%)	(1.8%)	(1.9%)	(1.9%)	(1.7%)	(1.7%)	(1.7%)	(1.5%)
Australia/New Zealand	298	454	455	454	469	491	507	530	0.6
	(1.4%)	(1.6%)	(1.6%)	(1.5%)	(1.4%)	(1.4%)	(1.3%)	(1.3%)	(0.7%)
Total OECD	11,537	13,631	13,582	13,295	13,544	13,823	14,097	14,381	0.2
	(53.6%)	(48.2%)	(46.8%)	(43.0%)	(41.0%)	(39.1%)	(37.3%)	(35.8%)	(7.2%)
Non-OECD									
Non-OECD Europe and Eurasia	4,246	2,889	2,886	3,069	3,234	3,323	3,362	3,422	0.7
	(19.7%)	(10.2%)	(9.9%)	(9.9%)	(9.8%)	(9.4%)	(8.9%)	(8.5%)	(4.8%)
Russia	2,393	1,699	1,704	1,803	1,894	1,945	1,950	1,978	0.6
	(11.1%)	(6.0%)	(5.9%)	(5.8%)	(5.7%)	(5.5%)	(5.2%)	(4.9%)	(2.5%)
Other	1,853	1,190	1,182	1,266	1,339	1,378	1,412	1,443	0.8
	(8.6%)	(4.2%)	(4.1%)	(4.1%)	(4.1%)	(3.9%)	(3.7%)	(3.6%)	(2.3%)
Non-OECD Asia	3,677	8,305	8,988	10,465	11,900	13,590	15,382	17,033	2.7
	(17.1%)	(29.4%)	(31.0%)	(33.9%)	(36.0%)	(38.4%)	(40.7%)	(42.4%)	(72.1%)
China	2,293	5,429	6,018	7,222	8,204	9,417	10,707	11,730	2.8
	(10.7%)	(19.2%)	(20.7%)	(23.4%)	(24.8%)	(26.6%)	(28.3%)	(29.2%)	(51.2%)
India	573	1,192	1,292	1,366	1,572	1,783	1,931	2,115	2.1
	(2.7%)	(4.2%)	(4.5%)	(4.4%)	(4.8%)	(5.0%)	(5.1%)	(5.3%)	(7.4%)
Other Non-OECD Asia	811	1,684	1,678	1,877	2,124	2,390	2,744	3,188	2.7
	(3.8%)	(6.0%)	(5.8%)	(6.1%)	(6.4%)	(6.8%)	(7.3%)	(7.9%)	(13.5%)
Middle East	704	1,393	1,456	1,686	1,830	1,939	2,088	2,279	1.9
	(3.3%)	(4.9%)	(5.0%)	(5.5%)	(5.5%)	(5.5%)	(5.5%)	(5.7%)	(7.4%)
Africa	659	985	982	1,086	1,161	1,239	1,325	1,409	1.5
	(3.1%)	(3.5%)	(3.4%)	(3.5%)	(3.5%)	(3.5%)	(3.5%)	(3.5%)	(3.8%)
Central and South America	695	1,093	1,123	1,311	1,368	1,437	1,547	1,654	1.6
	(3.2%)	(3.9%)	(3.9%)	(4.2%)	(4.1%)	(4.1%)	(4.1%)	(4.1%)	(4.8%)
Brazil	235	366	374	437	488	543	612	682	2.5
	(1.1%)	(1.3%)	(1.3%)	(1.4%)	(1.5%)	(1.5%)	(1.6%)	(1.7%)	(2.8%)
Other Central/South America	460	727	749	874	881	894	935	972	1.1
	(2.1%)	(2.6%)	(2.6%)	(2.8%)	(2.7%)	(2.5%)	(2.5%)	(2.4%)	(2.0%)
Total Non-OECD	9,981	14,665	15,435	17,616	19,494	21,528	23,703	25,797	2.2
	(46.4%)	(51.8%)	(53.2%)	(57.0%)	(59.0%)	(60.9%)	(62.7%)	(64.2%)	(92.8%)
Total World	21,518	28,296	29,017	30,911	33,038	35,351	37,800	40,178	1.4

^aValues adjusted for nonfuel sequestration.

^bValues in parentheses indicate percentage share of total world absolute change from 2006 to 2030.

^cIncludes the 50 States and the District of Columbia.

Note: The U.S. numbers include carbon dioxide emissions attributable to geothermal energy and nonbiogenic materials in municipal solid waste.

Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea/; and data presented in this report. **Projections:** EIA, *Annual Energy Outlook 2009*, DOE/EIA-0383(2009) (Washington, DC, March 2009), Table 1, web site www.eia.doe.gov/oiiaf/aeo/; *Updated Annual Energy Outlook 2009 Reference Case* (Washington, DC, April 2009), web site www.eia.doe.gov/oiiaf/servicept/stimulus/; and *International Energy Outlook 2009*, DOE/EIA-0484(2009) (Washington, DC, May 2009), Table A10.

Greenhouse Gas Emissions Overview

Recent U.S. and International Developments in Global Climate Change

United States

Federal Actions

- The Consolidated Appropriations Act of 2008, which became Public Law 110-161 on December 26, 2007, directed the U.S. Environmental Protection Agency (EPA) to develop a mandatory reporting rule for greenhouse gases (GHGs). The Final Rule was signed by the Administrator of the EPA on September 22, 2009. The Rule requires that emitters of GHGs from 31 different source categories report their emissions to the EPA. Approximately 80 to 85 percent of total U.S. GHG emissions from 10,000 facilities are expected to be covered by the Rule. Reporters must begin to monitor their emissions on January 1, 2010; the first annual emissions reports will be due in 2011.
- On April 2, 2007, the U.S. Supreme Court ruled that Section 202(a)(1) of the Clean Air Act (CAA) gives the EPA authority to regulate tailpipe emissions of GHGs. On April 17, 2009, the EPA Administrator signed a Proposed Endangerment and Cause or Contribute Findings for Greenhouse Gases. The proposal finds that the six key GHGs pose a threat to public health and welfare for current and future generations, and that GHG emissions from new motor vehicles and motor vehicle engines contribute to climate change. Finalization of the "Endangerment Finding" must occur before the EPA can implement its proposed standards for GHG emissions from stationary sources and from vehicles (see below). The Final Finding was sent to the White House Office of Management and Budget (OMB) on November 6, 2009.
- As one result of the Supreme Court's decision in 2007, the EPA drafted the Prevention of Significant Deterioration/Title V Greenhouse Gas Tailoring Rule. The draft rule, published in the *Federal Register* on October 27, 2009, limits the applicability of CO₂ emissions standards under the CAA to new and modified stationary sources that emit more than 25,000 MTCO₂e annually, rather than applying the threshold of 250 tons per source for triggering the regulation of criteria pollutants specified in Title V of the CAA. At the 25,000 MTCO₂e level, the EPA expects that 14,000 large industrial sources, which are responsible for nearly 70 percent of U.S. GHG emissions, will be required to obtain Title V operating permits. The threshold would cover power plants, refineries, and other large industrial operations but exempt small farms, restaurants, schools, and other small facilities.
- On September 15, 2009, the EPA and the U.S. Department of Transportation (DOT) jointly proposed new nationwide standards for corporate average fuel economy (CAFE) and GHG emissions standards for new light- and medium-duty vehicles. The proposal formalizes an agreement announced in May 2009 between the Administration and automobile industry stakeholders to accelerate the existing CAFE mandate and impose nationwide the tailpipe GHG standards sought by California. The proposed rule outlines fuel economy and GHG emissions standards for five model years 2012 through 2016 for cars sold in the United States. The Final Rule must be published by April 2010 if it is to take effect on schedule for model year 2012.¹
- The American Recovery and Reinvestment Act of 2009 ("The Stimulus Bill") was signed into law by President Obama on February 17, 2009. Under the Act, the U.S. Department of Energy (DOE) received \$36.7 billion to fund renewable energy, carbon capture and storage, energy efficiency, and smart grid projects, among others. The projects are expected to provide reductions in both energy use and GHG emissions.
- On May 26, 2009, the EPA published a Notice of Proposed Rulemaking for the national Renewable Fuel Standard (RFS2), as revised by the Energy Independence and Security Act of 2007 (EISA). The revised statutory requirements establish new specific volume standards for cellulosic biofuel, biomass-based diesel, advanced biofuels, and total renewable fuel that must be used in transportation fuel each year. The revisions also include new definitions and criteria for both renewable fuels and the feedstocks used to produce them, including new GHG emission thresholds for renewable fuels. The EPA's proposed rulemaking includes guidelines on how life-cycle emissions from each type of renewable fuel would be calculated and compared against those of traditional fossil-based motor fuels. EPA's proposed method of life-cycle accounting includes GHG emissions from production and transport of the feedstock; land use change; production, distribution, and blending of the renewable fuel; and end use of the renewable fuel. The Final Rule establishing the standards for 2010 is expected to be published in December 2009.

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¹U.S. Environmental Protection Agency, "Transportation and Climate: Regulations and Standards: Vehicles/Engines," web site <http://epa.gov/otaq/climate/regulations.htm>. Standards expire after 5 years.

Greenhouse Gas Emissions Overview

Recent U.S. and International Developments in Global Climate Change

United States (continued)

Congressional Initiatives

- On June 26, 2009, the U. S. House of Representatives passed The American Clean Energy and Security Act of 2009 (ACESA). The legislation includes a Federal GHG emissions “cap-and-trade” program that would take effect in 2012. The declining emissions cap requires that total GHG emissions be 17 percent below 2005 levels by 2020 (5,056 MMTCO₂e) and 83 percent below 2005 levels by 2050 (1,035 MMTCO₂e). In addition to the cap-and-trade title, the legislation includes provisions for the use of domestic and international offsets to meet the requirements of the emissions cap in lieu of allowances; funding for carbon capture and sequestration projects; standards and programs designed to boost energy efficiency; and a combined renewable electricity and energy efficiency standard of 20 percent by 2020.
- In the Senate, two major pieces of a comprehensive energy and climate bill have passed out of their respective committees. In June, the Energy and Natural Resources Committee voted out an energy package that includes a renewable electricity and efficiency standard of 15 percent by 2021, along with provisions addressing energy project financing, expanded oil and natural gas leasing, and energy efficiency. In November, the Environment and Public Works Committee passed a GHG cap-and-trade bill that borrows much of its structure and content from the House-passed ACESA. Notably, the emissions cap was tightened to 20 percent below 2005 levels by 2020. Several other committees are expected to weigh in before a final bill is crafted and brought to the Senate floor.

Regional and State Efforts

Although ACESA includes a provision that, when enacted, would prohibit State and regional cap-and-trade programs from operating between 2012 and 2017, activity continues across the various regional GHG emissions reduction initiatives in the United States.

- On September 9, 2009, the Regional Greenhouse Gas Initiative (RGGI) held its fifth auction of CO₂ emissions allowances. Over the three auctions held so far in 2009, approximately 90 million allowances have been sold, generating more than \$432.8 million to be used by the participating States for energy efficiency and renewable energy programs. Auction 6 is scheduled for December 2009. Additionally, the RGGI participants signed a letter of intent on December 31, 2008, to develop a low-carbon fuel standard for

transportation fuels. A draft program Memorandum of Understanding is due by December 31, 2009. Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont are signatory States to the RGGI agreement.

- The Western Climate Initiative (WCI) continues to develop its proposed comprehensive regional market-based cap-and-trade program. The program seeks to reduce emissions across participating States to 15 percent below 2005 levels by 2020. On July 16, 2009, the partnership released its “Essential Requirements for Mandatory Reporting,” which will require facilities in participating States and provinces that emit more than 10,000 MTCO₂e annually to report their GHG emissions. During 2009, the WCI Committees also released draft white papers and scoping documents related to offset limits, offset definition and eligibility, competitiveness, and early reduction allowances. The objective of the partnership remains the launch of its emissions trading system on January 1, 2012. Participating U.S. States include Arizona, California, Montana, New Mexico, Oregon, Utah, and Washington. Canadian provinces participating include British Columbia, Manitoba, Ontario, and Quebec.
- On June 8, 2009, members of the Midwestern Greenhouse Gas Reduction Accord (MGGRA) released their Advisory Group’s draft final recommendations for a regional cap-and-trade program. The Advisory Group recommends emission reduction targets of 18 to 20 percent below 2005 levels by 2020 and 80 percent below 2005 levels by 2050. Sectors for which emission caps are proposed include electricity generation and imports, industrial combustion and process sources, transportation fuels, and residential, commercial, and industrial fuels not otherwise covered. Only entities emitting more than 25,000 MTCO₂e annually would be capped. The Advisory Group’s recommendations also include a proposal that one-third of allowances should be auctioned initially, with the remainder sold for a small fee. The program would transition to full auction over time. Member States include Iowa, Illinois, Kansas, Michigan, Minnesota, and Wisconsin, as well as the Canadian province of Manitoba. Observer States include Indiana, Ohio, and South Dakota, as well as the Canadian province of Ontario.
- On September 25, 2009, the State of California became the second government body in the United States (after Boulder, Colorado) to impose a fee on carbon emissions. The California Air Resources Board voted to

(continued on page 11)

Greenhouse Gas Emissions Overview

Recent U.S. and International Developments in Global Climate Change

United States (continued)

Regional and State Efforts (continued)

apply the GHG emissions fee in order to fund implementation of the State's GHG cap-and-trade program, which was established in 2006 under Assembly Bill 32. The fee—which is expected to raise

\$63 million per year from approximately 350 large emitting entities in the State—will go into effect in fiscal year 2010-2011 and will be apportioned among entities on the basis of their annual GHG emissions, at a cost of approximately 15.5 cents per MTCO₂e.

International: United Nations Framework Convention on Climate Change and the Kyoto Protocol

United Nations Framework Convention on Climate Change and the Kyoto Protocol

COP-14 and CMP-4

In December 2008, the Fourteenth Conference of the Parties to the United Nations Framework Convention on Climate Change (COP-14) and the Fourth Meeting of the Parties to the Kyoto Protocol (CMP-4) were held in Poznań, Poland. Key areas of discussion included the following:

- Governments resolved in Poznań to shift into “full negotiating mode” in hopes of delivering a comprehensive new climate change agreement in December 2009 in Copenhagen.
- Work programs for 2009 were established for the Parties for parallel negotiations under the Kyoto Protocol and the UNFCCC in 2009.
- The European Union called on developed countries as a group to reduce their emissions to 30 percent below 1990 levels by 2020 and on developing countries to reduce their emissions by 15 to 30 percent below business-as-usual levels.
- Ministers encouraged the Parties to view the global economic crisis as an opportunity to address climate change and, simultaneously, contribute to economic recovery, rather than as a hindrance to progress on climate change.

Major Economies Forum

On March 28, 2009, President Obama launched the Major Economies Forum on Energy and Climate. The Forum is intended to facilitate dialog among the major

economies, leading up to an agreement at the Fifteenth Conference of the Parties to the United Nations Framework Convention on Climate Change (COP-15) in Copenhagen, Denmark. Further, the Forum seeks to advance joint ventures to develop clean energy resources. Discussions have centered on adaptation, mitigation, measuring, reporting and verification, and technological cooperation. There are 17 major economies participating in the Forum: Australia, Brazil, Canada, China, the European Union, France, Germany, India, Indonesia, Italy, Japan, South Korea, Mexico, Russia, South Africa, the United Kingdom, and the United States.

Hydrofluorocarbon Emissions

On September 15, 2009, the United States, Canada, and Mexico expressed their support for a proposal to include HFCs—a class of gases with high GWPs that are used primarily in refrigeration and air conditioning applications—under the Montreal Protocol. The proposal calls for reductions in the consumption and production of HFCs around the world, with developed nations taking the lead. The Montreal Protocol, which was signed in 1987, mandates the phaseout of production and use of ozone-depleting hydrochlorofluorocarbons (HCFCs), which have largely been replaced by the use of HFCs, resulting in increased GHG emissions worldwide. At the 21st Meeting of the Parties in Egypt in November, nations considered whether to alter the Montreal Protocol, but no agreement was reached. Further discussion of the issue is expected at COP-15.

Greenhouse Gas Emissions Overview

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 U.S. measurement units, because 1 metric ton is about 10 percent heavier than a short ton.

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 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 25 for methane). In 2008, the IPCC Working Group I released Errata to its Fourth Assessment Report, *Climate Change 2007: The Physical Science Basis*.² The Errata revise the reported GWPs for a small number of high-GWP gases. The GWPs published in the Errata to the Fourth Assessment Report (AR4) were used in the calculation of carbon dioxide equivalent emissions for this report. Table 4 on page 13 summarizes the GWP values from the Second, Third, and Fourth Assessment Reports.

²Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis: Errata* (Cambridge, UK: Cambridge University Press, 2008), web site http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Errata_2008-12-01.pdf.

Greenhouse Gas Emissions Overview

Units for Measuring Greenhouse Gases

Table 4. Greenhouse Gases and 100-Year Net Global Warming Potentials

Greenhouse Gas	Chemical Formula	Global Warming Potential		
		SAR ^a	TAR ^b	AR4 ^c
Carbon Dioxide	CO ₂	1	1	1
Methane	CH ₄	21	23	25
Nitrous Oxide	N ₂ O	310	296	298
Hydrofluorocarbons				
HFC-23 (Trifluoromethane)	CHF ₃	11,700	12,000	14,800
HFC-32 (Difluoromethane)	CH ₂ F ₂	650	550	675
HFC-41 (Monofluoromethane)	CH ₃ F	150	97	92
HFC-125 (Pentafluoroethane)	CHF ₂ CF ₃	2,800	3,400	3,500
HFC-134 (1,1,2,2-Tetrafluoroethane)	CHF ₂ CHF ₂	1,000	1,100	1,100
HFC-134a (1,1,1,2-Tetrafluoroethane)	CH ₂ FCF ₃	1,300	1,300	1,430
HFC-143 (1,1,2-Trifluoroethane)	CHF ₂ CH ₂ F	300	330	353
HFC-143a (1,1,1-Trifluoroethane)	CF ₃ CH ₃	3,800	4,300	4,470
HFC-152 (1,2-Difluoroethane)	CH ₂ FCH ₂ F	—	43	53
HFC-152a (1,1-Difluoroethane)	CH ₃ CHF ₂	140	120	124
HFC-161 (Ethyl Fluoride)	CH ₃ CH ₂ F	—	12	12
HFC-227ea (Heptafluoropropane)	CF ₃ CHFCF ₃	2,900	3,500	3,220
HFC-236cb (1,1,1,2,2,3-Hexafluoropropane)	CH ₂ FCF ₂ CF ₃	—	1,300	1,340
HFC-236ea (1,1,1,2,3,3-Hexafluoropropane)	CHF ₂ CHFCF ₃	—	1,200	1,370
HFC-236fa (1,1,1,3,3,3-Hexafluoropropane)	CF ₃ CH ₂ CF ₃	6,300	9,400	9,810
HFC-245ca (1,1,2,2,3-Pentafluoropropane)	CH ₂ FCF ₂ CHF ₂	560	640	693
HFC-245fa (1,1,1,3,3-Pentafluoropropane)	CHF ₂ CH ₂ CF ₃	—	950	1,030
HFC-365mfc (Pentafluorobutane)	CF ₃ CH ₂ CF ₂ CH ₃	—	890	794
HFC-43-10mee (Decafluoropentane)	CF ₃ CHFCF ₂ CF ₃	1,300	1,500	1,640
Perfluorocarbons				
Perfluoromethane	CF ₄	6,500	5,700	7,390
Perfluoroethane	C ₂ F ₆	9,200	11,900	12,200
Perfluoropropane	C ₃ F ₈	7,000	8,600	8,830
Perfluorobutane (FC 3-1-10)	C ₄ F ₁₀	7,000	8,600	8,860
Perfluorocyclobutane	c-C ₄ F ₈	8,700	10,000	10,300
Perfluoropentane	C ₅ F ₁₂	7,500	8,900	9,160
Perfluorohexane (FC 5-1-14)	C ₆ F ₁₄	7,400	9,000	9,300
Sulfur Hexafluoride	SF ₆	23,900	22,200	22,800
Nitrogen Trifluoride	NF ₃	—	10,800	17,200

Sources: ^aIntergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change* (Cambridge, UK: Cambridge University Press, 1996). This document was part of the Second Assessment Report (SAR) by the Intergovernmental Panel on Climate Change. ^bIntergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), web site www.ipcc.ch/ipccreports/tar/wg1/index.htm. This document was part of the Third Assessment Report (TAR) by the Intergovernmental Panel on Climate Change. ^cIntergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis: Errata* (Cambridge, UK: Cambridge University Press, 2008), web site http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Errata_2008-12-01.pdf. This document describes errata in parts of the Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change.

Greenhouse Gas Emissions Overview

Methodology Updates for This Report

Carbon Dioxide

For the first time, the nonfuel calculations in this report for carbon sequestered in petrochemical products include updates from EIA's 2006 Manufacturing Energy Consumption Survey.

Methane

For the first time, emissions from the treatment of wastewater produced by ethanol production and by petroleum refining are included in this inventory for all years.

Methane emissions factors for stationary combustion have been revised to the values published in the 2006 IPCC guidelines, resulting in a significant decline in calculated emissions from this source category.

Emissions factors for methane from ethylene, ethylene dichloride, and methanol associated with chemical production and from sinter and coke in iron and steel production have been updated to match revised values in the 2006 IPCC guidelines.

Additional emissions factors, conversion factors, and constants applied to the calculation of agriculture- and livestock-related emissions have been updated on the basis of the most recent values published by the EPA or IPCC, as applicable.

Nitrous Oxide

Emissions factors for direct and indirect emissions of N₂O from nitrogen fertilization of agricultural soils and from runoff of fertilizer and manure applied to soils have been revised to the values provided in the 2006 IPCC guidelines. The indirect emission factor for N₂O from domestic wastewater also has been updated, from the 1996 to the 2006 IPCC value.

According to the 2006 IPCC guidelines, the fraction of nitrogen from manure and synthetic fertilizers that is volatilized no longer is subtracted from the nitrogen total before the direct emission factor is applied.

Because final data on fertilizer consumption in 2008 are not yet available, emissions of nitrous oxide from the use of synthetic nitrogen fertilizers in 2008 are based on a preliminary estimate of the change in fertilizer consumption from 2007.

High-GWP Gases

For the first time, the emissions class "Other HFCs" has been calculated using AR4 GWP values. TAR GWP values were used in previous editions of this report.

Land Use

Because of the complexity of the methodologies used to calculate emissions and sequestration from land use, land-use change, and forests, changes in this year's report are discussed in the chapter itself.

Carbon Dioxide Emissions

Total Emissions

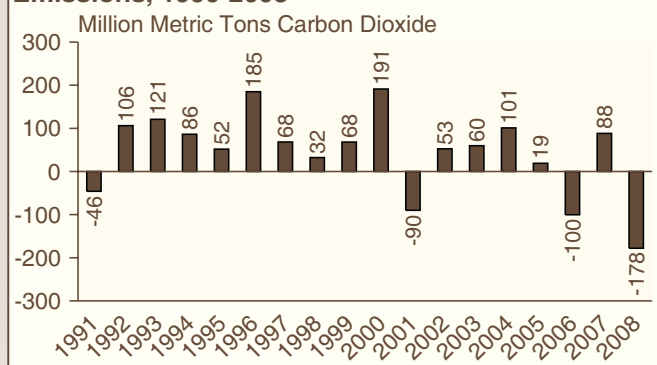
Summary

- Total U.S. carbon dioxide emissions in 2008, compared with 2007 emissions (Figure 7), fell by 177.8 million metric tons (MMT), or 3.0 percent, to 5,839.3 MMT. The decrease—the largest over the 18-year period beginning with the 1990 baseline—puts 2008 emissions 47.1 MMT below the 2000 level.
- The important factors that contributed to the decrease in carbon dioxide emissions in 2008 included higher energy prices, especially during the summer driving season, slowing economic growth, and a decrease in the carbon intensity of energy supply.
- Energy-related carbon dioxide emissions account for 98 percent of U.S. carbon dioxide emissions (Table 5). The vast majority of carbon dioxide emissions come from fossil fuel combustion, with smaller amounts from the nonfuel use of energy inputs, and the total adjusted for emissions from U.S. Territories and international bunker fuels. Other sources include emissions from industrial processes, such as cement and limestone production.

U.S. Anthropogenic Carbon Dioxide Emissions, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons)	5,022.3	6,017.0	5,839.3
Change from 1990 (Million Metric Tons)		994.7	817.0
(Percent)		19.8%	16.3%
Average Annual Change from 1990 (Percent)		1.1%	0.8%
Change from 2007 (Million Metric Tons)			-177.8
(Percent)			-3.0%

Figure 7. Annual Change in U.S. Carbon Dioxide Emissions, 1990-2008



Source: EIA estimates.

Table 5. U.S. Carbon Dioxide Emissions from Energy and Industry, 1990-2008

(Million Metric Tons Carbon Dioxide)

Fuel Type or Process	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Energy Consumption										
Petroleum	2,185.9	2,208.4	2,461.3	2,469.9	2,516.7	2,605.4	2,625.7	2,594.9	2,588.6	2,436.0
Coal	1,803.4	1,899.9	2,138.1	2,077.2	2,115.6	2,140.3	2,161.0	2,129.9	2,154.5	2,125.2
Natural Gas	1,024.7	1,183.7	1,240.6	1,229.5	1,194.6	1,195.4	1,176.1	1,157.1	1,231.7	1,241.8
Renewables ^a	6.1	10.2	10.4	13.0	11.7	11.4	11.5	11.8	11.6	11.6
Energy Subtotal	5,020.1	5,302.3	5,850.4	5,789.6	5,838.6	5,952.5	5,974.3	5,893.7	5,986.4	5,814.4
Nonfuel Use Emissions ^b	97.1	104.9	109.8	103.7	101.7	110.8	104.7	108.9	106.7	100.2
Nonfuel Use Sequestration ^c	252.7	286.6	308.2	296.0	292.1	315.4	305.1	301.9	293.7	264.2
Adjustments to Energy	-82.9	-63.1	-61.7	-38.2	-28.7	-44.6	-48.8	-70.9	-74.9	-79.0
Adjusted Energy Subtotal	4,937.2	5,239.1	5,788.7	5,751.4	5,809.9	5,907.9	5,925.5	5,822.8	5,911.5	5,735.5
Other Sources	85.1	102.3	97.8	97.7	98.9	102.0	103.5	106.0	105.6	103.8
Total	5,022.3	5,341.5	5,886.4	5,849.1	5,908.8	6,009.9	6,029.0	5,928.7	6,017.0	5,839.3

^aIncludes emissions from electricity generation using nonbiogenic municipal solid waste and geothermal energy.

^bEmissions from nonfuel uses are included in the energy subtotal above.

^cThe Btu value of carbon sequestered by nonfuel uses is subtracted from energy consumption before emissions are calculated.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding. Adjusted energy subtotal includes U.S. Territories but excludes international bunker fuels.

Source: EIA estimates.

Carbon Dioxide Emissions

Energy-Related Emissions

Summary

- Energy-related carbon dioxide emissions account for more than 80 percent of U.S. greenhouse gas emissions. EIA breaks energy use into four end-use sectors (Table 6), and emissions from the electric power sector are attributed to the end-use sectors. Growth in energy-related carbon dioxide emissions since 1990 has resulted largely from increases associated with electric power generation and transportation fuel use. All other energy-related carbon dioxide emissions (from direct fuel use in the residential, commercial, and industrial sectors) have been either flat or declining in recent years (Figure 8). In 2008, however, emissions from both electric power and transportation fuel use were down—by 2.1 percent and 4.7 percent, respectively.
- Reasons for the long-term growth in electric power and transportation sector emissions include: increased demand for electricity for computers and

electronics in homes and offices; strong growth in demand for commercial lighting and cooling; substitution of new electricity-intensive technologies, such as electric arc furnaces for steelmaking, in the industrial sector; and increased demand for transportation services as a result of relatively low fuel prices and robust economic growth in the 1990s and early 2000s. Likewise, the recent declines in emissions from both the transportation and electric power sectors are tied to the economy, with people driving less and consuming less electricity in 2008 than in 2007.

- Other U.S. energy-related carbon dioxide emissions have remained flat or declined, for reasons that include increased efficiencies in heating technologies, declining activity in older “smokestack” industries, and the growth of less energy-intensive industries, such as computers and electronics.

U.S. Energy-Related Carbon Dioxide Emissions, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons)	5,020.1	5,986.4	5,814.4
Change from 1990 (Million Metric Tons)		966.3	794.4
(Percent)		19.2%	15.8%
Average Annual Change from 1990 (Percent)		1.0%	0.8%
Change from 2007 (Million Metric Tons)			-171.9
(Percent)			-2.9%

Figure 8. U.S. Energy-Related Carbon Dioxide Emissions by Sector, 1990-2008

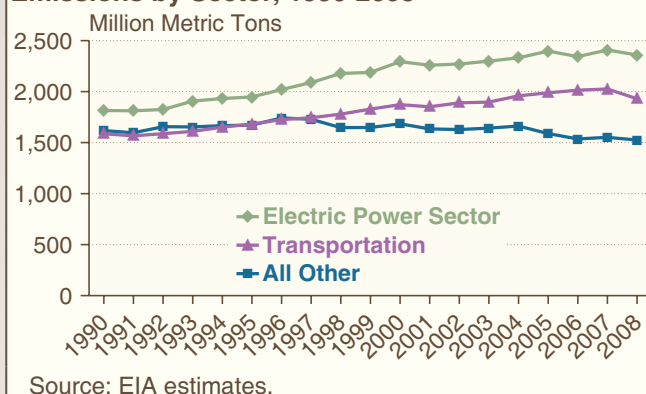


Table 6. U.S. Energy-Related Carbon Dioxide Emissions by End-Use Sector, 1990-2008
(Million Metric Tons Carbon Dioxide)

Sector	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Residential	958.6	1,035.5	1,179.8	1,197.6	1,224.9	1,221.9	1,254.5	1,186.7	1,235.1	1,220.1
Commercial	785.1	845.1	1,013.1	1,018.0	1,026.1	1,043.3	1,059.6	1,034.9	1,070.3	1,075.1
Industrial	1,689.5	1,739.5	1,784.7	1,683.3	1,690.3	1,728.5	1,671.4	1,657.8	1,655.2	1,589.1
Transportation	1,586.9	1,682.2	1,872.7	1,890.7	1,897.4	1,958.9	1,988.7	2,014.3	2,025.7	1,930.1
Total	5,020.1	5,302.3	5,850.4	5,789.6	5,838.6	5,952.5	5,974.3	5,893.7	5,986.4	5,814.4
Electricity Generation ^a	1,814.6	1,947.9	2,293.5	2,270.5	2,298.8	2,331.3	2,396.8	2,343.5	2,409.1	2,359.1

^aElectric power sector emissions are distributed across the end-use sectors. Emissions allocated to sectors are unadjusted. Adjustments are made to total emissions only.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.

Source: EIA estimates.

Carbon Dioxide Emissions

Carbon Capture and Storage: A Potential Option for Reducing Future Emissions

The possibility of future constraints on greenhouse gas emissions has heightened interest in carbon capture and storage (CCS) technologies as an option to control CO₂ emissions. The U.S. Department of Energy (DOE) has received increased funding for the continued development of new CCS technologies,⁶ and as the scale and scope of CCS projects grow, it will be important for EIA to track volumes of carbon stored, so that they can be subtracted appropriately in greenhouse gas inventory estimates.

The United States emits about 1.9 billion metric tons of CO₂ annually from coal-fired power plants—33 percent of total energy-related CO₂ emissions and 81 percent of CO₂ emissions from the U.S. electric power sector. Coal-fired power plants are the most likely source of CO₂ for storage; however, other sources are possible.

CCS involves three steps: capture of CO₂ from a fossil-fueled power plant or other industrial process; transport of the compressed gas via pipeline to a storage site; and injection and storage in a geologic formation.

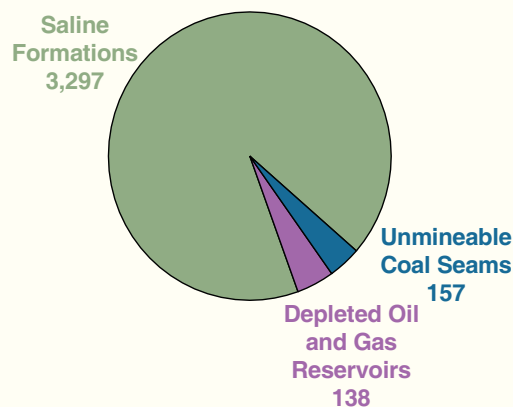
CO₂ Capture: There are three types of CO₂ capture: post-combustion, pre-combustion, and oxy-combustion. Post-combustion capture is a well-known technology, which currently is used to a limited degree. It involves capture of CO₂ from flue gases after a fossil fuel has been burned. Pre-combustion capture involves gasifying the fossil fuel, instead of using direct combustion. The CO₂ can be captured readily from the gasification exhaust stream. For oxy-combustion capture, coal is burned in pure oxygen instead of air, so that the resulting exhaust contains only CO₂ and water vapor. Systems that use these technologies currently are being developed to capture at least 90 percent of emitted CO₂.⁷

Pipeline Transportation: Captured CO₂ emissions are transported most commonly as highly pressurized gas

through pipeline networks to storage sites. Currently, more than 1,550 miles of pipeline transport some 48 MMT per year in the United States from natural and anthropogenic sources, mostly to oil fields in Texas and New Mexico for enhanced oil recovery (EOR).⁸ As is done for natural gas pipelines, fugitive emissions from the transport of gaseous CO₂ will need to be accounted for in EIA's greenhouse gas inventories.⁹

Geological Storage: Three main types of geological formation—each with varying capacities—currently are viewed as possible reservoirs for the storage of captured CO₂: oil and gas reservoirs, saline formations, and unmineable coal seams (see figure below).

U.S. Carbon Dioxide Storage Potential
(Billion Metric Tons)



Source: National Energy Technology Laboratory, 2008 *Carbon Sequestration Atlas of the United States and Canada*.

Oil and Gas Reservoirs: Currently in the United States, about 48 MMT of CO₂ per year is injected into oil and gas fields for EOR.¹⁰ CO₂ also may be pumped into oil and gas reservoirs strictly for storage: as a result of EOR operations, about 9 MMT of CO₂ is stored per year.¹¹ Storage capacity for CO₂ in depleted oil and gas fields in the United States and Canada currently is
(continued on page 18)

⁶U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, "Secretary Chu Announces First Awards from \$1.4 Billion for Industrial Carbon Capture and Storage Projects" (News Release, October 2, 2009), web site www.netl.doe.gov/publications/press/2009/09072-DOE_Announces_Industrial_CCS.html.

⁷U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, "Technologies: Carbon Sequestration," web site www.netl.doe.gov/technologies/carbon_seq/index.html.

⁸U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, "Carbon Sequestration: FAQ Information Portal," www.netl.doe.gov/technologies/carbon_seq/FAQs/carbon-capture.html.

⁹H.S. Eggleston, "Estimation of Emissions from CO₂ Capture and Storage: The 2006 IPCC Guidelines for National Greenhouse Gas Inventories," web site http://unfccc.int/files/meetings/workshops/other_meetings/2006/application/pdf/ccs_20060723.pdf.

¹⁰U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, "Program Facts: Carbon Sequestration Through Enhanced Oil Recovery" (April 2008), web site www.netl.doe.gov/publications/factsheets/program/Prog053.pdf.

¹¹*Ibid.*

Carbon Dioxide Emissions

Carbon Capture and Storage: A Potential Option for Reducing Future Emissions (continued)

estimated at 138 billion metric tons.¹² Worldwide, CO₂ storage capacity in EOR projects and other depleted oil and gas fields is estimated at 675 to 1,200 billion metric tons.¹³

Saline Formations: A second type of geologic formation that could be used to store CO₂ is saline formations, which have an estimated worldwide storage capacity of up to 20,000 billion metric tons.¹⁴ These formations have the potential to trap CO₂ in pore spaces, and many large point sources of CO₂ emissions are relatively close to saline formations. The United States and Canada have an estimated combined storage capacity of 3,300 to 12,600 billion metric tons in saline formations.¹⁵

Unmineable Coal Seams: When CO₂ is injected into an unmineable coal seam, it displaces methane and remains sequestered in the bed. Although the method

is relatively untested, and the resulting methane recovery would add cost to the CCS process, sales of the methane could provide some cost offsets.¹⁶ Coal seam sequestration has an estimated storage capacity of 10 to 200 billion metric tons worldwide,¹⁷ including an estimated 157 to 178 billion metric tons of capacity in the United States and Canada.¹⁸

The table on page 19 lists CCS projects that currently are either operating or actively being prepared for deployment. At present, there are few commercial-scale projects in operation that integrate carbon capture from a coal-fired power plant with transportation to a permanent storage site; however, a number of projects and locations have been proposed. Given the possibility of delays and project cancellations, it is unlikely that all the projects listed will become operational on the dates planned. On the other hand, other projects that are not included in the table may come to fruition.

¹²U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, *2008 Carbon Sequestration Atlas of the United States and Canada*, Second Edition (November 2008), web site www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/atlasII.pdf.

¹³International Energy Agency, *CO₂ Capture and Storage: A Key Abatement Option* (Paris, France, 2008), web site www.iea.org/publications/free_new_Desc.asp?PUBS_ID=2145.

¹⁴*Ibid.*

¹⁵U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, *2008 Carbon Sequestration Atlas of the United States and Canada*, Second Edition (November 2008), web site www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/atlasII.pdf.

¹⁶Massachusetts Institute of Technology, *The Future of Coal: Options for a Carbon-Constrained World* (Cambridge, MA, 2007), Appendix 4.A, "Unconventional CO₂ Storage Targets," pp. 159-160, web site http://web.mit.edu/coal/The_Future_of_Coal.pdf.

¹⁷Intergovernmental Panel on Climate Change, IPCC Special Report, *Carbon Dioxide Capture and Storage: Summary for Policymakers and Technical Summary* (Cambridge, UK: Cambridge University Press, 2005), "Technical Summary," web site www.ipcc.ch/publications_and_data/publications_and_data_reports_carbon_dioxide.htm.

¹⁸U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory, *2008 Carbon Sequestration Atlas of the United States and Canada*, Second Edition (November 2008), web site www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/atlasII.pdf.

Carbon Dioxide Emissions

Carbon Capture and Storage: A Potential Option for Reducing Future Emissions (continued)

U.S. Potential for Short-Term and Long-Term Carbon Storage Projects

Storage Site ^a	Geologic Formation	Source of Carbon Capture	Expected Start of Operation	Expected Duration (Years)
Short-Term Projects				
SaskPower Plant: Poplar Dome Storage (1)	Sandstone Formation	Pulverized Combustion Retrofit (Canada)	2011	2
Nugget Sandstone/Riley Ridge (1)	Sandstone Formation	Natural Gas Processing Plant	2015	2.5
Williston Basin CO ₂ Sequestration and EOR (2)	Depleted Oil Field	Post-Combustion Capture Facility	2012	4
Decatur Sequestration (3)	Mt. Simon Saline Formation	Ethanol Plant	2010	3
Michigan Basin (4)	Deep Saline Reservoir	Natural Gas Processing Plant	2010	1
TAME Ethanol Plant (4)	Sandstone	Ethanol Plant	2012	4
Cranfield Early Test (5)	Depleted Oil Field	Natural Source	2010	1.5
Permian Basin, Texas (6)	—	—	—	—
Paradox Basin, Utah (6)	Deep Saline Formation	Natural Sources	2010	3.5
San Juan Basin/Allison Unit, New Mexico (6)	Enhanced Coalbed Methane	Natural Sources	2010	1
Farnham Dome, Utah (6)	Deep Saline Reservoir	Natural Sources	2010	2.5
Entrada Sandstone (6)	Deep Saline Reservoir	Natural Gas Processing Plant	2010	4
Kimberlina, San Joaquin Basin (7)	Sandstone Formation	Oxyfuel Combustion	2012	4
AEP Alstom Mountaineer (8)	Deep Saline Reservoir	Coal-Fired Plant, Post-Combustion	2009	2
AEP Pleasant Prairie (8)	Deep Saline Reservoir	Coal-Fired Plant, Post-Combustion	2010	1.5
Long-Term Projects				
Wallula Energy Resource Center (1)	Basalt Formation	IGCC/Pre-Combustion	2020	—
Plant Barry (5)	Depleted Oil Field	Coal-Fired Plant, Post-Combustion	2011	—
Great Plains Synfuels Plant (8)	Canada Oil Reservoir EOR	Synthetic Fuel Plant	2000	—
ExxonMobil LaBarge, Wyoming (8)	EOR	Natural Gas Processing Plant	2010	—
Basin Electric Power Cooperative, Antelope Valley Station (8)	EOR	Coal-Fired Plant, Post-Combustion	2012	—
AEP Alstom Northeastern (8)	EOR	Coal-Fired Plant, Post-Combustion	2012	—
WA Parish Plant (8)	EOR	Coal-Fired Plant, Post-Combustion	2012	—
Duke Energy Corporation (8)	Deep Saline Aquifer	Coal Gasification Power Plant	2015	—
Hydrogen Energy California Project (8)	EOR	IGCC for Petroleum Coke	2015	—
FutureGen (8)	Deep Saline Formation	IGCC Plant	2020	—

^aStorage site affiliations: (1) Big Sky Carbon Sequestration Partnership; (2) Plains CO₂ Reduction Partnership (PCOR); (3) Midwest Geological Sequestration Consortium (MGSC); (4) Midwest Regional Carbon Sequestration Partnership (MRCSP); (5) Southeast Regional Carbon Sequestration Partnership (SECARB); (6) Southwest Regional Partnership on Carbon Sequestration (SWP); (7) West Coast Regional Carbon Sequestration Partnership (WESTCARB); (8) Existing, integrated, or independent project.

Carbon Dioxide Emissions

Residential Sector

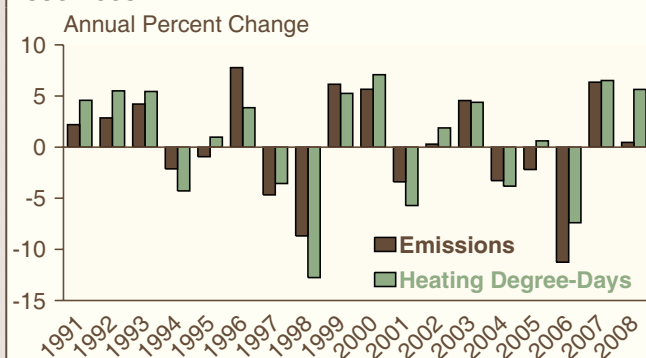
Summary

- Residential sector carbon dioxide emissions originate primarily from:
 - Direct fuel consumption (principally, natural gas) for heating and cooking
 - Electricity for cooling (and heating), appliances, lighting, and increasingly for televisions, computers, and other household electronic devices (Table 7).
- Energy consumed for heating in homes and businesses has a large influence on the annual fluctuations in energy-related carbon dioxide emissions.
 - The 5.6-percent increase in heating degree-days in 2008 was one of the few upward pressures on emissions in 2008 (Figure 9).
 - Although annual changes in cooling degree-days have a smaller impact on energy demand, the 8.7-percent decrease in 2008 offset some of the upward pressure from the increase in heating degree-days.
- In the longer run, residential emissions are affected by population growth, income, and other factors. From 1990 to 2008:
 - Residential sector carbon dioxide emissions grew by an average of 1.3 percent per year.
 - U.S. population grew by an average of 1.1 percent per year.
 - Per-capita income (measured in constant dollars) grew by an average of 1.7 percent per year.
 - Energy efficiency improvements for homes and appliances have offset much of the growth in the number and size of housing units. As a result, direct fuel emissions from petroleum, coal, and natural gas consumed in the residential sector in 2008 were only 1.5 percent higher than in 1990.

Residential Sector Carbon Dioxide Emissions, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons)	958.6	1,235.1	1,220.1
Change from 1990 (Million Metric Tons)		276.5	261.5
(Percent)		28.8%	27.3%
Average Annual Change from 1990 (Percent)		1.5%	1.3%
Change from 2007 (Million Metric Tons)			-15.0
(Percent)			-1.2%

Figure 9. Annual Changes in U.S. Heating Degree-Days and Residential Sector CO₂ Emissions from Direct Fuel Combustion, 1990-2008



Source: EIA estimates.

Table 7. U.S. Carbon Dioxide Emissions from Residential Sector Energy Consumption, 1990-2008
(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Petroleum										
Liquefied Petroleum Gas . . .	23.0	25.5	35.6	34.2	35.6	33.5	32.6	28.7	30.4	28.6
Distillate Fuel	71.6	66.2	66.2	62.9	66.2	67.6	62.5	52.1	53.1	50.1
Kerosene	4.6	5.4	6.8	4.3	5.1	6.1	6.1	4.8	3.2	1.4
Petroleum Subtotal	99.2	97.1	108.6	101.5	106.8	107.2	101.1	85.5	86.7	80.1
Coal	3.0	1.7	1.1	1.2	1.2	1.1	0.8	0.6	0.7	0.7
Natural Gas	238.3	262.9	270.8	266.1	277.5	264.5	262.7	237.5	256.8	265.0
Electricity ^a	618.2	673.9	799.3	828.9	839.5	849.1	889.9	863.0	890.9	874.4
Total	958.6	1,035.5	1,179.8	1,197.6	1,224.9	1,221.9	1,254.5	1,186.7	1,235.1	1,220.1

^aShare of total electric power sector carbon dioxide emissions weighted by sales to the residential sector.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.

Source: EIA estimates.

Carbon Dioxide Emissions

Commercial Sector

Summary

- Commercial sector emissions (Table 8) are largely the result of energy use for lighting, heating, and cooling in commercial structures, such as office buildings, shopping malls, schools, hospitals, and restaurants.
- The commercial sector was the only sector that showed positive growth in emissions in 2008.
- Lighting accounts for a larger component of energy demand in the commercial sector (approximately 18 percent of total demand in 2007) than in the residential sector (approximately 11 percent of the total).
- Commercial sector emissions are affected less by weather than are residential sector emissions:

heating and cooling accounted for approximately 38 percent of energy demand in the residential sector in 2007 but only about 21 percent in the commercial sector.¹⁹

- In the longer run, trends in emissions from the commercial sector parallel economic trends. Commercial sector emissions grew at an average annual rate of 1.8 percent from 1990 to 2008—slightly more than the growth in real income per capita (Figure 10).
- Emissions from direct fuel consumption in the commercial sector declined from 1990 to 2008, while the sector's electricity-related emissions increased by an average of 2.4 percent per year.

Commercial Sector Carbon Dioxide Emissions, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons)	785.1	1,070.3	1,075.1
Change from 1990 (Million Metric Tons)		285.3	290.0
(Percent)		36.3%	36.9%
Average Annual Change from 1990 (Percent)		1.8%	1.8%
Change from 2007 (Million Metric Tons)			4.8
(Percent)			0.4%

Figure 10. U.S. Commercial Sector CO₂ Emissions and Per Capita Income, 1990-2008

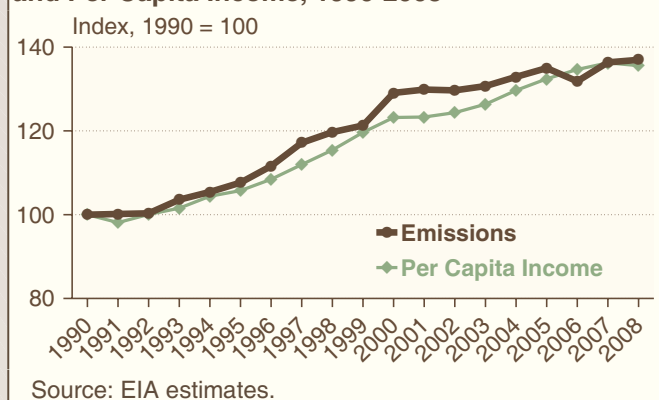


Table 8. U.S. Carbon Dioxide Emissions from Commercial Sector Energy Consumption, 1990-2008
(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Petroleum										
Motor Gasoline	7.9	1.3	3.1	3.2	4.2	3.4	3.2	3.4	4.2	4.0
Liquefied Petroleum Gas. . .	4.1	4.5	6.3	6.0	6.3	5.9	5.8	5.1	5.4	5.0
Distillate Fuel.	39.2	35.0	35.9	32.5	35.2	34.4	32.7	29.4	28.1	26.5
Residual Fuel	18.1	11.1	7.2	6.3	8.8	9.7	9.1	5.9	5.9	5.6
Kerosene.	0.9	1.6	2.1	1.2	1.3	1.5	1.6	1.1	0.7	0.3
Petroleum Subtotal^a	70.1	53.6	54.7	49.2	55.8	54.9	52.4	44.8	44.3	41.4
Coal.	11.8	11.1	8.8	8.6	7.8	9.8	9.2	6.2	6.7	6.4
Natural Gas.	142.3	164.3	172.5	171.1	173.7	170.0	163.2	154.0	164.2	169.9
Electricity ^b	560.8	616.1	777.2	789.2	788.7	808.6	834.8	830.0	855.2	857.3
Total	785.1	845.1	1,013.1	1,018.0	1,026.1	1,043.3	1,059.6	1,034.9	1,070.3	1,075.1

^aIncludes small amounts of petroleum coke.

^bShare of total electric power sector carbon dioxide emissions weighted by sales to the commercial sector.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.

Source: EIA estimates.

¹⁹Energy Information Administration, *Annual Energy Outlook 2009*, DOE/EIA-0383(2009) (Washington, DC, March 2009), Tables A4 and A5, web site www.eia.doe.gov/oiaf/aec/pdf/appa.pdf.

Carbon Dioxide Emissions

Industrial Sector

Summary

- Unlike commercial sector emissions, trends in U.S. industrial sector emissions (Table 9) have not followed aggregate economic growth trends but have been tied to trends in energy-intensive industries. In 2008, industrial carbon dioxide emissions fell by 4.0 percent from their 2007 level and were 5.9 percent (100.4 MMT) below their 1990 level. Decreases in industrial sector carbon dioxide emissions have resulted largely from a structural shift away from energy-intensive manufacturing in the U.S. economy.
- Coke plants consumed 22.1 million short tons of coal in 2008, down from 38.9 million short tons in 1990. Other industrial coal consumption declined from

76.3 million short tons in 1990 to 54.5 million short tons in 2008, as reflected by the drop in emissions from coal shown in Figure 11.

- 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 the more energy-intensive industries has fallen.
- By fuel, only total petroleum and net imports of coke in 2008 were above 1990 levels for the industrial sector. As mentioned above, coal use has fallen since 1990, and natural gas use, which rose in the 1990s, has fallen since 2000.

Industrial Sector Carbon Dioxide Emissions, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons)	1,689.5	1,655.2	1,589.1
Change from 1990 (Million Metric Tons)		-37.4	-100.4
(Percent)		-2.0%	-5.9%
Average Annual Change from 1990 (Percent)		-0.1%	-0.3%
Change from 2007 (Million Metric Tons)			-66.1
(Percent)			-4.0%

Figure 11. U.S. Industrial Sector CO₂ Emissions and Major Industrial Fuel Use, 1990-2008

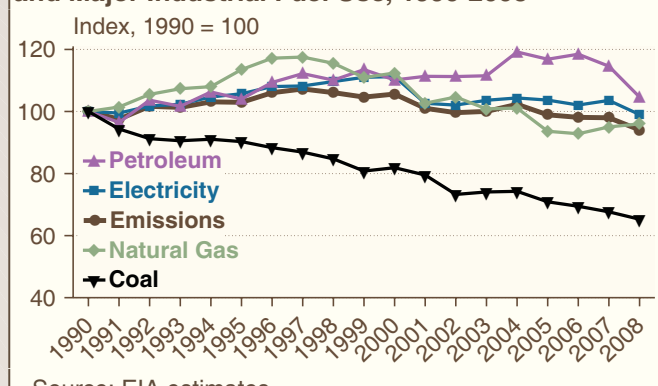


Table 9. U.S. Carbon Dioxide Emissions from Industrial Sector Energy Consumption, 1990-2008
(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Petroleum										
Motor Gasoline	13.2	14.1	10.6	21.7	22.6	25.9	24.7	26.0	21.0	20.1
Liquefied Petroleum Gas	40.6	47.3	59.1	56.9	52.4	57.7	53.7	58.0	57.0	54.2
Distillate Fuel	83.9	82.4	87.4	87.7	82.6	88.3	91.8	91.7	91.9	87.3
Residual Fuel	30.6	24.5	17.0	13.2	15.5	17.5	19.9	16.4	12.7	11.9
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	6.9	6.6	7.0	6.4	5.9	6.0	5.9	5.8	6.0	5.6
Kerosene	0.9	1.1	1.1	1.0	1.7	2.0	2.8	2.1	1.0	0.4
Petroleum Coke	63.8	66.9	74.1	76.2	76.0	82.1	79.7	82.2	80.0	76.2
Other Petroleum	127.3	113.6	116.8	127.3	139.7	141.6	140.6	150.2	147.6	129.7
Petroleum Subtotal	367.2	356.5	373.1	390.4	396.5	421.1	419.2	432.5	417.2	385.3
Coal	256.8	231.5	210.0	188.1	190.2	190.7	182.0	178.3	173.7	167.5
Coal Coke Net Imports	0.5	7.0	7.5	6.9	5.8	15.7	5.0	6.9	2.9	4.7
Natural Gas	432.5	490.0	480.7	449.1	431.7	432.0	397.9	394.3	403.6	409.0
Electricity ^a	632.5	654.6	713.4	648.8	666.1	668.9	667.2	645.8	657.7	622.6
Total^b	1,689.5	1,739.5	1,784.7	1,683.3	1,690.3	1,728.5	1,671.4	1,657.8	1,655.2	1,589.1

^aShare of total electric power sector carbon dioxide emissions weighted by sales to the industrial sector.

^bIncludes 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 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.

Source: EIA estimates.

Carbon Dioxide Emissions Transportation Sector

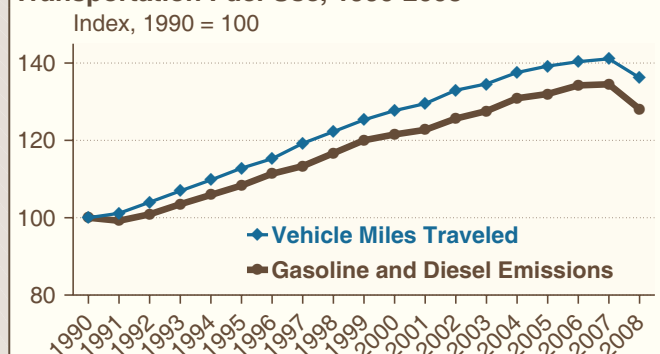
Summary

- Transportation sector carbon dioxide emissions in 2008 were 95.6 MMT lower than in 2007 but still 343.2 MMT higher than in 1990 (Table 10).
- The transportation sector has led all U.S. end-use sectors in emissions of carbon dioxide since 1999; however, with higher fuel prices and slower economic growth in 2008, emissions from the transportation sector fell by 4.7 percent from their 2007 level.
- Petroleum combustion is the largest source of carbon dioxide emissions in the transportation sector.
- Increases in ethanol fuel consumption in recent years have mitigated the growth in transportation sector emissions. Reported emissions from energy inputs to ethanol production plants are counted in the industrial sector).
- Transportation sector emissions from gasoline and diesel fuel combustion since 1990 generally have paralleled total vehicle miles traveled (Figure 12).

Transportation Sector Carbon Dioxide Emissions, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons)	1,586.9	2,025.7	1,930.1
Change from 1990 (Million Metric Tons)		438.8	343.2
(Percent)		27.7%	21.6%
Average Annual Change from 1990 (Percent)		1.4%	1.1%
Change from 2007 (Million Metric Tons)			-95.6
(Percent)			-4.7%

Figure 12. U.S. Vehicle Miles Traveled and CO₂ Emissions from Gasoline and Diesel Transportation Fuel Use, 1990-2008



Source: EIA estimates.

Table 10. U.S. Carbon Dioxide Emissions from Transportation Sector Energy Consumption, 1990-2008
(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Petroleum										
Motor Gasoline	966.2	1,029.8	1,122.0	1,156.1	1,159.9	1,181.3	1,184.2	1,186.9	1,187.4	1,134.9
Liquefied Petroleum Gas	1.4	1.1	0.7	0.8	1.0	1.1	1.7	1.6	1.3	1.2
Jet Fuel	222.6	222.1	253.8	236.8	231.5	239.8	246.3	239.5	238.0	226.3
Distillate Fuel	267.8	306.9	377.8	394.5	414.5	433.9	444.4	469.2	472.3	445.7
Residual Fuel	80.1	71.7	69.9	53.3	45.0	58.3	66.0	71.4	78.3	74.1
Lubricants ^a	6.5	6.2	6.7	6.0	5.6	5.6	5.6	5.5	5.6	5.2
Aviation Gasoline	3.1	2.7	2.5	2.3	2.1	2.2	2.4	2.3	2.2	2.0
Petroleum Subtotal	1,547.7	1,640.5	1,833.4	1,849.8	1,859.5	1,922.2	1,950.7	1,976.4	1,985.1	1,889.4
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Natural Gas	36.1	38.4	35.7	37.2	33.4	32.0	33.1	33.2	35.4	35.9
Electricity ^b	3.2	3.2	3.6	3.6	4.5	4.7	4.9	4.7	5.2	4.9
Total	1,586.9	1,682.2	1,872.7	1,890.7	1,897.4	1,958.9	1,988.7	2,014.3	2,025.7	1,930.1

^aIncludes emissions from nonfuel uses of fossil fuels. See Table 12 for details by fuel category.

^bShare of total electric power sector carbon dioxide emissions weighted by sales to the transportation sector.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.

Source: EIA estimates.

Carbon Dioxide Emissions

Electric Power Sector

Summary

- The electric power sector transforms primary energy fuels into electricity. The sector consists of companies whose primary business is the generation of electricity.
- Carbon dioxide emissions from electric power generation declined by 2.1 percent in 2008 (Figure 13 and Table 11). The drop resulted from a decrease of 38.7 billion kilowatthours (1.0 percent) in the sector's total electricity generation and a 1.1-percent reduction in the carbon intensity of the electricity supply.
- The lower overall carbon intensity of power generation in 2008 was the result of a 50-percent increase (17.6 billion kilowatthours) in generation from wind resources.
- Other non-carbon sources combined accounted for an additional 1 billion kilowatthours of increased generation, despite a slight decline in generation from nuclear power.
- Electricity generation from all fossil fuels fell by 57.4 billion kilowatthours from 2007 to 2008.

Electric Power Sector Carbon Dioxide Emissions, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons)	1,814.6	2,409.1	2,359.1
Change from 1990 (Million Metric Tons)		594.4	544.5
(Percent)		32.8%	30.0%
Average Annual Change from 1990 (Percent)		1.7%	1.5%
Change from 2007 (Million Metric Tons)			-50.0
(Percent)			-2.1%

Figure 13. U.S. Electric Power Sector Energy Sales and Losses and CO₂ Emissions from Primary Fuel Combustion, 1990-2008

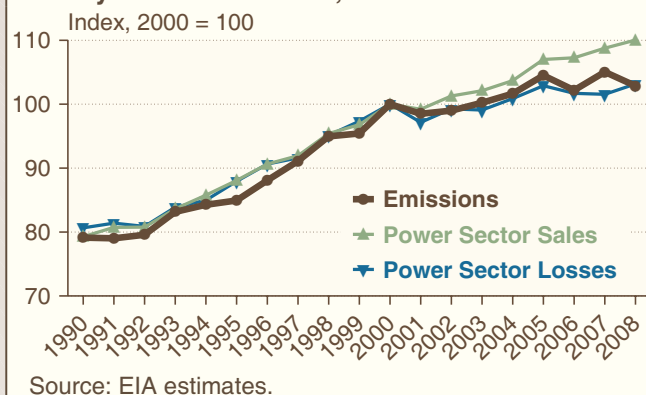


Table 11. U.S. Carbon Dioxide Emissions from Electric Power Sector Energy Consumption, 1990-2008
(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Petroleum										
Residual Fuel Oil	91.6	44.6	68.6	51.9	68.5	69.3	69.1	28.4	31.3	18.8
Distillate Fuel Oil	7.1	7.9	12.8	9.3	11.8	8.1	8.4	5.4	6.5	5.2
Petroleum Coke	3.1	8.2	10.1	17.9	17.8	22.7	24.9	21.8	17.5	15.8
Petroleum Subtotal	101.8	60.7	91.5	79.1	98.1	100.1	102.3	55.6	55.3	39.7
Coal	1,531.2	1,648.7	1,910.8	1,872.4	1,910.7	1,922.9	1,963.9	1,937.8	1,970.6	1,945.9
Natural Gas	175.5	228.2	280.9	306.0	278.3	296.8	319.1	338.2	371.7	362.0
Municipal Solid Waste	5.7	9.9	10.0	12.6	11.3	11.1	11.1	11.4	11.2	11.2
Geothermal	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Total	1,814.6	1,947.9	2,293.5	2,270.5	2,298.8	2,331.3	2,396.8	2,343.5	2,409.1	2,359.1

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). 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.

Source: EIA estimates.

Carbon Dioxide Emissions

Nonfuel Uses of Energy Inputs

Summary

- Nonfuel uses of fossil fuels (for purposes other than their energy value) create carbon dioxide emissions and also sequester carbon in nonfuel products.
- In 2008, carbon dioxide emissions from nonfuel uses of energy inputs totaled 100.2 MMT—6.1 percent below the 2007 total (Table 12).
- Carbon sequestration from nonfuel uses of energy inputs in 2008 included 264.2 MMTCO₂e that was embedded in plastics and other nonfuel products rather than emitted to the atmosphere (see Table 13 on page 26).
- The 2008 sequestration total was 10.1 percent below the 2007 total.

Carbon Dioxide Emissions from Nonfuel Uses of Energy Inputs, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons)	97.1	106.7	100.2
Change from 1990 (Million Metric Tons)		9.5	3.0
(Percent)		9.8%	3.1%
Average Annual Change from 1990 (Percent)		0.6%	0.2%
Change from 2007 (Million Metric Tons)			-6.5
(Percent)			-6.1%

Carbon Sequestration from Nonfuel Uses of Energy Inputs, 1990, 2007, and 2008

	1990	2007	2008
Estimated Sequestration (Million Metric Tons CO ₂ e)	252.7	293.7	264.2
Change from 1990 (Million Metric Tons CO ₂ e)		41.0	11.5
(Percent)		16.2%	4.5%
Average Annual Change from 1990 (Percent)		0.9%	0.2%
Change from 2007 (Million Metric Tons CO ₂ e)			-29.5
(Percent)			-10.1%

Table 12. U.S. Carbon Dioxide Emissions from Nonfuel Use of Energy Fuels, 1990-2008
(Million Metric Tons Carbon Dioxide)

End Use and Type	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Industrial										
Petroleum										
Liquefied Petroleum Gases	14.8	19.5	20.4	19.9	19.0	19.4	18.3	18.7	18.9	17.7
Distillate Fuel Oil	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.6
Residual Fuel Oil	1.9	2.1	2.0	1.7	1.9	2.1	2.3	2.5	2.5	2.5
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	6.9	6.6	7.0	6.4	5.9	6.0	5.9	5.8	6.0	5.6
Other (Subtotal)	51.6	52.0	54.2	53.1	52.9	61.0	56.1	59.8	57.1	52.4
Pentanes Plus	1.1	4.1	3.2	2.3	2.3	2.3	2.0	1.4	1.8	1.6
Petrochemical Feed	33.6	36.0	36.8	33.5	36.5	41.8	38.4	40.1	37.1	32.2
Petroleum Coke	9.1	6.8	7.2	9.8	8.2	13.2	11.1	13.1	12.5	12.4
Special Naphtha	7.8	5.2	7.1	7.5	5.9	3.7	4.6	5.1	5.7	6.2
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	75.5	80.5	84.1	81.5	80.2	89.0	83.2	87.3	85.2	78.8
Coal	0.5	0.7	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Natural Gas	14.7	17.5	18.4	15.7	15.5	15.6	15.4	15.7	15.4	15.7
Industrial Subtotal	90.6	98.6	103.1	97.7	96.1	105.2	99.1	103.5	101.0	94.9
Transportation										
Lubricants	6.5	6.2	6.7	6.0	5.6	5.6	5.6	5.5	5.6	5.2
Total	97.1	104.9	109.8	103.7	101.7	110.8	104.7	108.9	106.7	100.2

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 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates.

Carbon Dioxide Emissions Nonfuel Uses of Energy Inputs

Table 13. U.S. Carbon Sequestered by Nonfuel Use of Energy Fuels, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

End Use and Type	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Industrial										
Petroleum										
Liquefied Petroleum Gases . . .	59.2	78.2	81.7	79.6	76.0	77.6	73.2	74.6	75.8	70.9
Distillate Fuel	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.6
Residual Fuel	1.9	2.1	2.0	1.7	1.9	2.1	2.3	2.5	2.5	2.5
Asphalt and Road Oil	88.5	89.1	96.4	93.7	92.2	98.6	100.0	95.4	90.5	76.5
Lubricants	6.9	6.6	7.0	6.4	5.9	6.0	5.9	5.8	6.0	5.6
Other (<i>Subtotal</i>)	63.0	76.3	81.6	76.6	79.9	88.9	83.0	81.0	76.4	68.2
Pentanes Plus	4.4	16.2	12.7	9.2	9.0	9.1	8.0	5.7	7.4	6.3
Petrochemical Feed	46.0	50.0	57.7	55.1	59.2	69.1	64.2	63.2	57.5	49.9
Petroleum Coke	9.1	6.8	7.2	9.8	8.2	13.2	11.1	13.1	12.5	12.4
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 . .	12.6	10.2	11.2	12.3	11.6	10.7	10.7	12.0	11.5	12.0
<i>Petroleum Subtotal</i>	228.9	259.3	276.4	268.3	264.6	287.0	276.2	273.0	264.3	236.7
Coal	1.4	2.1	1.8	1.5	1.5	1.5	1.5	1.4	1.4	1.4
Natural Gas	15.9	19.0	23.3	20.2	20.4	21.3	21.8	22.0	22.4	20.9
Industrial Subtotal	246.2	280.4	301.6	290.0	286.5	309.8	299.4	296.5	288.1	259.0
Transportation										
Lubricants	6.5	6.2	6.7	6.0	5.6	5.6	5.6	5.5	5.6	5.2
Total	252.7	286.6	308.2	296.0	292.1	315.4	305.1	301.9	293.7	264.2

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 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.

Sources: EIA estimates.

Carbon Dioxide Emissions

Adjustments to Energy Consumption

Summary

• EIA's greenhouse gas emissions inventory includes two "adjustments to energy consumption" (Table 14). First, the energy consumption and carbon dioxide emissions data in this report correspond to EIA's coverage of energy consumption, which includes the 50 States and the District of Columbia, but under the UNFCCC the United States is also responsible for emissions emanating from its Territories; therefore, their emissions are added to the U.S. total. Second, because the UNFCCC definition of energy consumption excludes international bunker fuels,

emissions from international bunker fuels are subtracted from the U.S. total. Similarly, because the UNFCCC excludes emissions from military bunker fuels from national totals, they are subtracted from the U.S. total.

• The net adjustment in emissions has been negative in every year from 1990 to 2008, because emissions from international and military bunker fuels have always exceeded emissions from U.S. Territories. The net negative adjustment for 2008 was 79.0 MMT.

Carbon Dioxide Emissions from U.S. Territories,* 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons)	31.6	54.8	48.4
Change from 1990 (Million Metric Tons)		23.1	16.8
(Percent)		73.2%	53.0%
Average Annual Change from 1990 (Percent)		3.3%	2.4%
Change from 2007 (Million Metric Tons)			-6.4
(Percent)			-11.6%

*Added to total U.S. emissions.

Carbon Dioxide Emissions from International Bunker Fuels,* 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons)	114.5	129.7	127.4
Change from 1990 (Million Metric Tons)		15.2	12.9
(Percent)		13.2%	11.3%
Average Annual Change from 1990 (Percent)		0.7%	0.6%
Change from 2007 (Million Metric Tons)			-2.3
(Percent)			-1.8%

*Subtracted from total U.S. emissions.

Table 14. U.S. Carbon Dioxide Emissions: Adjustments for U.S. Territories and International Bunker Fuels, 1990-2008
(Million Metric Tons Carbon Dioxide)

Fuel	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Emissions from U.S. Territories										
Puerto Rico	20.2	24.3	27.7	35.2	37.5	38.2	39.9	41.4	38.5	36.1
U.S. Virgin Islands	7.5	8.6	9.8	13.7	15.3	18.4	13.8	12.8	12.4	8.8
American Samoa	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Guam	1.8	3.6	2.9	2.1	2.4	2.0	2.2	1.9	1.6	1.1
U.S. Pacific Islands	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Wake Island	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4
Subtotal^a	31.6	38.6	42.6	53.3	57.4	60.7	58.1	58.4	54.8	48.4
Emissions from Bunker Fuels										
Marine Bunkers (Subtotal)	62.7	47.0	37.9	24.4	20.0	29.6	29.8	50.3	51.5	56.1
Distillate Fuel	6.3	5.8	2.9	1.6	1.5	1.7	2.4	3.1	3.6	4.5
Residual Fuel	56.4	41.2	35.0	22.8	18.5	27.9	27.4	47.2	47.9	51.6
Aviation Bunkers (Subtotal)	38.4	45.8	58.5	59.0	56.9	65.7	67.9	71.0	69.7	62.9
U.S. Carriers	18.7	21.3	26.2	23.9	23.4	26.7	28.6	28.8	29.7	29.6
Foreign Carriers	19.7	24.5	32.3	35.1	33.5	39.0	39.3	42.2	40.1	33.3
Military Bunkers (Subtotal)	13.4	8.9	7.9	8.1	9.2	10.1	9.2	8.0	8.4	8.4
Subtotal^b	114.5	101.7	104.3	91.5	86.1	105.4	106.9	129.3	129.7	127.4
Net Adjustment	-82.9	-63.1	-61.7	-38.2	-28.7	-44.6	-48.8	-70.9	-74.9	-79.0

^aAdded to total U.S. emissions.

^bSubtracted from total U.S. emissions.

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

Source: EIA estimates.

Carbon Dioxide Emissions

Other Sources

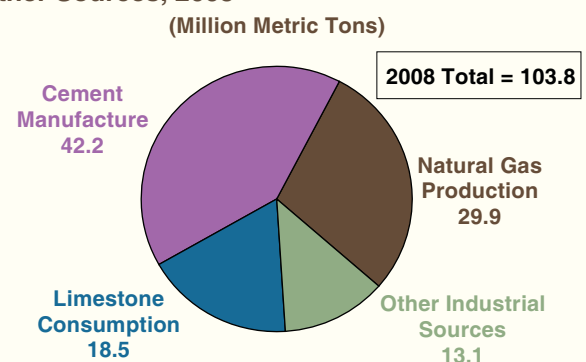
Summary

- “Other emissions sources” in total accounted for 1.8 percent (103.8 MMT) of all U.S. carbon dioxide emissions in 2008 (Figure 14).
- The largest source of U.S. carbon dioxide emissions other than fossil fuel consumption is cement manufacture (Table 15), where most emissions result from the production of clinker (consisting of calcium carbonate sintered with silica in a cement kiln to produce calcium silicate).
- Limestone consumption, especially for lime manufacture, is the source of 15 to 20 MMT of carbon dioxide emissions per year.
- In addition, “other sources” include: soda ash manufacture and consumption; carbon dioxide manufacture; aluminum manufacture; flaring of natural gas at the wellhead; carbon dioxide scrubbed from natural gas; and waste combustion in the commercial and industrial sectors.

Carbon Dioxide Emissions from Other Sources, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons)	85.1	105.6	103.8
Change from 1990 (Million Metric Tons)		20.5	18.7
(Percent)		24.1%	22.0%
Average Annual Change from 1990 (Percent)		1.3%	1.1%
Change from 2007 (Million Metric Tons)			-1.8
(Percent)			-1.7%

Figure 14. U.S. Carbon Dioxide Emissions from Other Sources, 2008



Source: EIA estimates.

Table 15. U.S. Carbon Dioxide Emissions from Other Sources, 1990-2008
(Million Metric Tons Carbon Dioxide)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Cement Manufacture	33.3	36.9	41.3	43.0	43.2	45.7	46.1	46.7	45.4	42.2
Clinker Production	32.6	36.1	40.4	42.0	42.2	44.7	45.1	45.7	44.4	41.3
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	0.9	0.9	0.9	0.9	0.8
Limestone Consumption	15.9	17.8	18.6	17.0	18.0	18.9	18.8	19.6	18.9	18.5
Lime Manufacture	12.4	14.5	15.4	14.1	15.1	15.7	15.7	16.5	15.9	15.5
Iron Smelting	1.7	1.2	1.1	0.9	0.9	1.0	0.8	0.9	0.8	0.8
Steelmaking	0.3	0.5	0.5	0.5	0.4	0.4	0.3	0.4	0.3	0.3
Copper Refining	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Glass Manufacture	0.1	0.3	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Flue Gas Desulfurization	0.7	0.9	1.2	1.3	1.3	1.4	1.5	1.5	1.5	1.5
Dolomite Manufacture	0.5	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1
Natural Gas Production	23.1	33.9	23.8	24.4	24.5	24.3	25.3	26.6	28.5	29.9
Carbon Dioxide in Natural Gas	14.0	16.7	18.3	18.4	18.6	18.4	18.1	18.7	19.3	20.8
Natural Gas Flaring	9.1	17.2	5.5	6.0	5.9	5.8	7.2	7.8	9.1	9.1
Other	12.7	13.8	14.1	13.3	13.2	13.1	13.2	13.0	12.9	13.1
Soda Ash Manufacture	3.4	3.8	3.6	3.5	3.6	3.8	3.9	3.9	4.0	4.1
Soda Ash Consumption	0.5	0.8	0.6	0.4	0.6	0.6	0.6	0.6	0.6	0.5
Carbon Dioxide Manufacture	0.9	1.0	1.3	1.4	1.5	1.5	1.6	1.6	1.7	1.8
Aluminum Manufacture	5.9	4.9	5.4	4.0	4.0	3.7	3.6	3.3	3.7	3.9
Shale Oil Production	0.2	*	*	*	*	*	*	*	*	*
Waste Combustion	1.9	3.2	3.2	4.0	3.6	3.5	3.6	3.6	2.8	2.8
Total	85.1	102.3	97.8	97.7	98.9	102.0	103.5	106.0	105.6	103.8

*Less than 0.05 million metric tons.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.

Source: EIA estimates.

Methane Emissions

Total Emissions

Summary

- The major sources of U.S. methane emissions are energy production, distribution, and use; agriculture; and waste management (Figure 15).
- U.S. methane emissions in 2008 totaled 737.4 MMTCO₂e, 2.0 percent higher than the 2007 total of 722.7 MMTCO₂e (Table 16).
- Methane emissions declined steadily from 1990 to 2001, as emissions from coal mining and landfills fell.
- From 2002 to 2008, methane emissions rose as a result of moderate increases in emissions related to energy, agriculture, and waste management that

more than offset a decline in industrial emissions of methane over the same period.

- The energy sector—including coal mining, natural gas systems, petroleum systems, and stationary and mobile combustion—is the largest source of U.S. methane emissions, accounting for 295.7 MMTCO₂e in 2008.
- Agricultural emissions (primarily from livestock management) and emissions from waste management (primarily landfills) also are large sources of U.S. methane emissions, contributing 225.0 and 212.1 MMTCO₂e, respectively, in 2008.

Total U.S. Anthropogenic Methane Emissions, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	783.5	722.7	737.4
Change from 1990 (Million Metric Tons CO ₂ e)		-60.9	-46.1
(Percent)		-7.8%	-5.9%
Average Annual Change from 1990 (Percent)		-0.5%	-0.3%
Change from 2007 (Million Metric Tons CO ₂ e)			14.8
(Percent)			2.0%

Figure 15. U.S. Methane Emissions by Source, 1990-2008

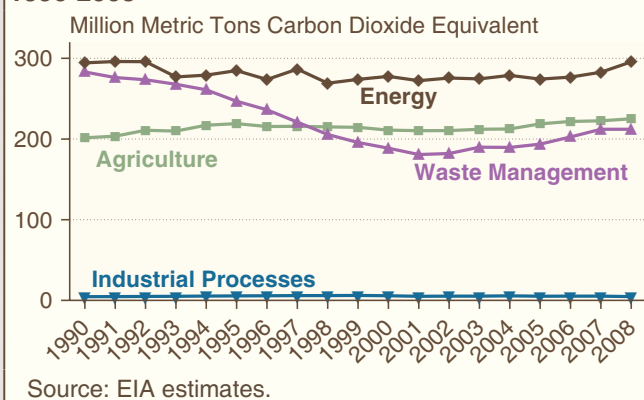


Table 16. U.S. Methane Emissions from Anthropogenic Sources, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Energy Sources	294.4	284.8	277.6	275.6	274.5	278.9	274.2	276.7	282.8	295.7
Agricultural Sources	201.5	219.1	211.1	210.4	212.0	212.5	218.8	221.8	222.6	225.0
Waste Management	283.0	246.8	188.6	182.0	189.8	189.6	193.7	202.6	212.1	212.1
Industrial Processes	4.6	5.6	5.7	5.3	5.2	5.6	5.1	5.2	5.2	4.7
Total	783.5	756.2	683.0	673.3	681.6	686.6	691.8	706.3	722.7	737.4

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). 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 2007*. Emissions calculations based on Intergovernmental Panel on Climate Change, *IPCC Guidelines for National Greenhouse Gas Inventories* (2006 and revised 1996 guidelines), web site www.ipcc-nggip.iges.or.jp/public/gl/invs6.html; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007*, EPA 430-R-09-004 (Washington, DC, April 2009), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Methane Emissions Energy Sources

Summary

- Natural gas systems and coal mines are the major sources of methane emissions in the energy sector (Figure 16 and Table 17).
- U.S. methane emissions from natural gas systems grew from 1990 to 2008, largely because of increases in natural gas consumption.
- Emissions from coal mines declined from 1990 to 2002 and remained nearly steady through 2007. In 2008, emissions from ventilation of underground mines jumped by 24.6 percent, leading to a 15.3-percent increase in total mining emissions over their 2007 level. Much of the 2008 increase can be attributed to the larger number of gassy mines in operation throughout the year and to the fact that, as

mining proceeds into deeper seams, more methane emissions tend to be produced per ton of coal mined.

- With domestic oil production dropping by 30 percent from 1990 to 2008, methane emissions from petroleum systems also declined.
- Residential wood consumption accounted for nearly 45 percent of U.S. methane emissions from stationary combustion in 2008.
- Methane emissions from passenger cars fell by 51.3 percent from 1990 to 2008, as the use of catalytic converters increased. A 9.2-percent drop in annual miles traveled by passenger cars from 2002 to 2008 also contributed to the decrease in emissions.

Methane Emissions from Energy Sources, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	294.4	282.8	295.7
Change from 1990 (Million Metric Tons CO ₂ e)		-11.6	1.2
(Percent)		-4.0%	0.4%
Average Annual Change from 1990 (Percent)		-0.2%	0.0%
Change from 2007 (Million Metric Tons CO ₂ e)			12.9
(Percent)			4.6%

Figure 16. U.S. Methane Emissions from Energy Sources, 1990-2008

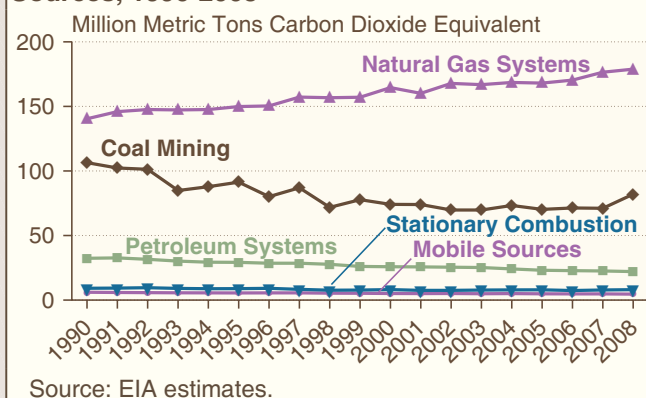


Table 17. U.S. Methane Emissions from Energy Sources, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Natural Gas Systems	140.4	149.9	164.5	167.8	166.8	168.6	168.1	170.4	176.5	178.9
Production	36.8	39.3	43.5	46.2	46.7	47.4	48.2	49.2	50.9	52.2
Processing	16.2	18.0	17.9	16.9	15.7	16.2	15.9	15.7	16.6	17.5
Transmission and Storage	52.6	53.7	60.4	60.6	59.6	58.5	58.3	56.2	60.1	60.3
Distribution	34.9	38.9	42.8	44.1	44.8	46.4	45.7	49.3	48.9	48.9
Coal Mining	106.4	91.4	74.1	69.7	69.8	73.3	70.3	71.4	71.1	82.0
Surface	11.6	12.2	13.5	14.2	13.8	14.3	14.7	15.5	15.3	15.7
Underground	94.8	79.1	60.6	55.6	56.0	59.0	55.6	55.9	55.8	66.4
Petroleum Systems	32.4	29.2	25.8	25.5	25.2	24.1	23.1	22.8	22.6	22.1
Refineries	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6
Exploration and Production	31.6	28.4	25.0	24.7	24.4	23.3	22.3	21.9	21.8	21.3
Crude Oil Transportation	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Stationary Combustion	9.1	8.8	8.1	7.5	7.7	7.9	7.9	7.4	7.8	8.1
Mobile Sources	6.1	5.5	5.1	5.1	4.9	5.0	4.9	4.8	4.8	4.6
Total	294.4	284.8	277.6	275.6	274.5	278.9	274.2	276.7	282.8	295.7

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

Methane Emissions Agriculture

Summary

- Livestock management—including emissions from enteric fermentation (66 percent) and management of animal wastes (29 percent)—accounts for most of the U.S. methane emissions from agricultural activities (Table 18).
- Since 1990, there has been a shift in livestock management to larger facilities that manage waste in liquid systems, increasing the amount of methane generated from livestock waste. Increases in the U.S. swine population since 1990 have also contributed to the rise in methane emissions. Emissions of methane from animal waste rose by 2.0 percent from 2007 to 2008. Swine accounted for 45.9 percent (29.7 MMTCO₂e) and dairy cattle 36.2 percent (23.3 MMTCO₂e) of the 2008 total.
- Enteric fermentation (food digestion) in ruminant animals also produces methane emissions, and digestion by cattle accounts for 95 percent of U.S.

methane emissions from this source. With little change in the cattle population since 1990, the level of emissions from enteric fermentation has been relatively stable. Small declines in cattle and goat populations in 2008 were offset by increases in horse, goat and swine populations, which caused methane emissions from enteric fermentation to increase slightly (by 0.5 MMTCO₂e, or 0.3 percent) from their 2007 level.

- Despite lower crop yields, U.S. rice production rose by 7 percent in 2008 as a result of increases in area harvested in Missouri, Texas, Arkansas, Louisiana, and Mississippi. Consequently, emissions from this source increased by 7.1 percent from 2007 to 2008.
- Although emissions from crop residue burning grew by 2.0 percent in 2008, residue burning remains the smallest contributor to methane emissions from agriculture, representing less than 1 percent of total U.S. methane emissions from agriculture (Figure 17).

Methane Emissions from Agricultural Sources, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	201.5	222.6	225.0
Change from 1990 (Million Metric Tons CO ₂ e)		21.1	23.5
(Percent)		10.5%	11.7%
Average Annual Change from 1990 (Percent)		0.6%	0.6%
Change from 2007 (Million Metric Tons CO ₂ e)			2.5
(Percent)			1.1%

Figure 17. U.S. Methane Emissions from Agriculture by Source, 2008

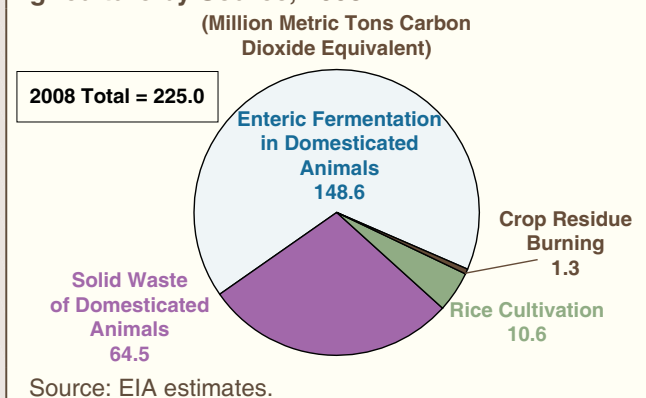


Table 18. U.S. Methane Emissions from Agricultural Sources, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Enteric Fermentation in Domesticated Animals	145.4	155.1	143.9	142.6	144.0	142.9	145.4	147.4	148.1	148.6
Solid Waste of Domesticated Animals	45.0	51.9	54.9	55.6	56.2	56.4	60.6	63.3	63.3	64.5
Rice Cultivation	10.1	11.1	11.1	11.1	10.7	11.8	11.5	9.9	9.9	10.6
Crop Residue Burning	1.0	1.0	1.2	1.1	1.2	1.3	1.3	1.2	1.3	1.3
Total	201.5	219.1	211.1	210.4	212.0	212.5	218.8	221.8	222.6	225.0

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

Methane Emissions Waste Management

Summary

- Methane emissions from waste management are dominated by the decomposition of solid waste in municipal and industrial landfills (Table 19).
- Emissions from landfills declined substantially from 1990 to 2001 as a result of increases in recycling and in the recovery of landfill methane for energy; since 2001, increases in the total amount of waste deposited in landfills have resulted in increasing methane emissions (Figure 18).
- Rapid growth in methane recovery during the 1990s can be traced in part to the Federal Section 29 tax credit for alternative energy sources, which provided a subsidy of approximately 1 cent per kilowatt-hour for electricity generated from landfill gas before June 1998.
- The U.S. EPA's New Source Performance Standards and Emission Guidelines, which require large landfills to collect and burn landfill gas, have also played an important role in the growth of methane recovery.
- The American Recovery and Reinvestment Act of 2009, signed into law on February 17, 2009, included a 2-year extension (through December 31, 2012) of the production tax credit (PTC) for renewable energy, including waste-to-energy and landfill gas combustion.
- Wastewater treatment, including both domestic wastewater (two-thirds) and industrial wastewater (one-third), is responsible for 13.1 percent (27.8 MMTCO₂e) of methane emissions from waste management.
- Emissions from the treatment of wastewater from ethanol production and from petroleum refineries are included for the first time in the 2008 inventory, increasing the estimates of methane emissions from industrial wastewater in previous years by 8.0 to 11.4 percent. In 2008, emissions from wastewater at petroleum refineries accounted for 7.3 percent (0.74 MMTCO₂e) of total emissions from industrial wastewater, and emissions from ethanol production accounted for 2.9 percent (0.30 MMTCO₂e).

Methane Emissions from Waste Management, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	283.0	212.1	212.1
Change from 1990 (Million Metric Tons CO ₂ e)		-70.9	-71.0
(Percent)		-25.1%	-25.1%
Average Annual Change from 1990 (Percent)		-1.7%	-1.6%
Change from 2007 (Million Metric Tons CO ₂ e)			0.0
(Percent)			0.0%

Figure 18. U.S. Methane Emissions from Waste Management by Source, 1990-2008

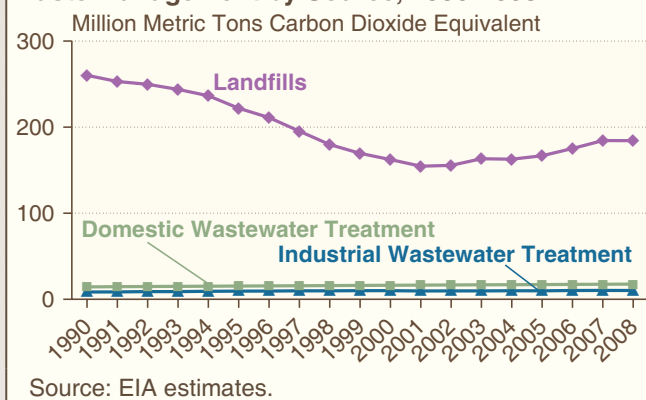


Table 19. U.S. Methane Emissions from Waste Management, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Landfills	260.2	221.9	162.3	155.6	163.3	162.7	166.8	175.2	184.4	184.3
Domestic Wastewater Treatment	14.4	15.4	16.3	16.6	16.8	17.0	17.1	17.3	17.4	17.6
Industrial Waste Water Treatment	8.4	9.5	10.0	9.8	9.7	9.9	9.8	10.1	10.2	10.2
Total	283.0	246.8	188.6	182.0	189.8	189.6	193.7	202.6	212.1	212.1

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

Methane Emissions Industrial Processes

Summary

- Methane emissions are generated by industrial processes in the production of iron and steel and in chemical production (Figure 19 and Table 20).
- Methane emissions from industrial processes declined by a net 0.6 MMTCO₂e (10.7 percent) from 2007 to 2008, as a result of declines in both chemical production and iron and steel production.
- Since 1990, methane emissions from industrial processes have increased by 0.1 MMTCO₂e (2.4 percent). A 32.4-percent decline (0.4 MMTCO₂e) in emissions

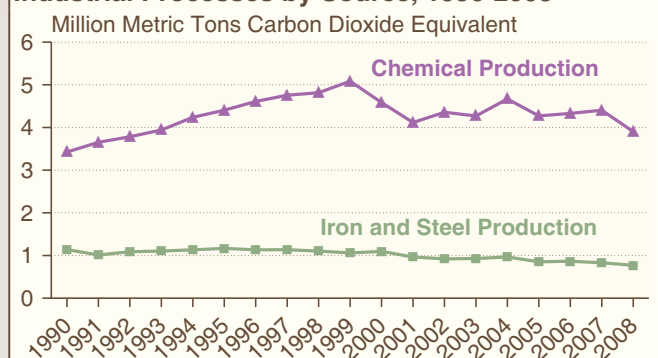
from iron and steel production since 1990 has been offset by an increase of 0.5 MMTCO₂e (13.9 percent) in emissions from chemical production.

- Estimates of industrial emissions of methane in the 2008 inventory are approximately 50 to 65 percent higher for all years, as a result of applying the IPCC's revised emissions factors for methane from ethylene, ethylene dichloride, and methanol production in the chemical industry and for methane from sinter and coke in iron and steel production.

Methane Emissions from Industrial Processes, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e) . . .	4.6	5.2	4.7
Change from 1990 (Million Metric Tons CO ₂ e)		0.7	0.1
(Percent)		14.7%	2.4%
Average Annual Change from 1990 (Percent)		0.8%	0.1%
Change from 2007 (Million Metric Tons CO ₂ e)			-0.6
(Percent)			-10.7%

Figure 19. U.S. Methane Emissions from Industrial Processes by Source, 1990-2008



Source: EIA estimates.

Table 20. U.S. Methane Emissions from Industrial Processes, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Chemical Production										
Ethylene	2.5	3.2	3.4	3.2	3.1	3.5	3.3	3.4	3.5	3.1
Ethylene Dichloride	*	*	*	*	*	*	*	*	*	*
Styrene	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.5	0.4
Methanol	0.2	0.3	0.3	0.3	0.2	0.3	0.1	0.1	0.1	0.1
Carbon Black	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Subtotal	3.4	4.4	4.6	4.4	4.3	4.7	4.3	4.3	4.4	3.9
Iron and Steel Production										
Coke ^a	*	*	*	*	*	*	*	*	*	*
Sinter	*	*	*	*	*	*	*	*	*	*
Pig Iron	1.1	1.1	1.1	0.9	0.9	1.0	0.8	0.9	0.8	0.8
Subtotal	1.1	1.2	1.1	0.9	0.9	1.0	0.9	0.9	0.8	0.8
Total	4.6	5.6	5.7	5.3	5.2	5.6	5.1	5.2	5.2	4.7

^aBased on total U.S. production of metallurgical coke, including for uses other than iron and steel manufacture.

*Less than 0.05 million metric tons.

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.

Source: EIA estimates.

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Nitrous Oxide Emissions

Total Emissions

Summary

- U.S. nitrous oxide emissions in 2008 were 0.1 percent (0.4 MMTCO₂e) above their 2007 total (Table 21).
- Sources of U.S. nitrous oxide emissions include agriculture, energy use, industrial processes, and waste management. The largest source is agriculture, and the majority of agricultural emissions result from nitrogen fertilization of agricultural soils (75.7 percent) and the management of animal waste (24.0 percent).
- Annual U.S. nitrous oxide emissions rose from 1990 to 1994, then fell from 1994 to 2003 (Figure 20). They rose sharply from 2003 to 2008, largely as a result of

increased use of synthetic fertilizers, which grew by more than 30 percent from 2005 to 2008.

- Since 2005, when the Renewable Fuels Standard was signed into law, U.S. ethanol production has more than doubled (a 130-percent increase from 2005 to 2008). Nearly all U.S. ethanol production is from corn, and with corn production rising by 8.9 percent since 2005, the percentage used for ethanol production also has risen, from 16.1 percent to 21.1 percent of total U.S. corn production. As the demand for corn has increased, use of synthetic fertilizer (a nitrous oxide emitter that is used most heavily in corn production) has risen by 8.2 percent.

Total Anthropogenic Nitrous Oxide Emissions, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	279.3	299.8	300.3
Change from 1990 (Million Metric Tons CO ₂ e)		20.5	20.9
(Percent)		7.3%	7.5%
Average Annual Change from 1990 (Percent)		0.4%	0.4%
Change from 2007 (Million Metric Tons CO ₂ e)			0.4
(Percent)			0.1%

Figure 20. U.S. Nitrous Oxide Emissions by Source, 1990-2008

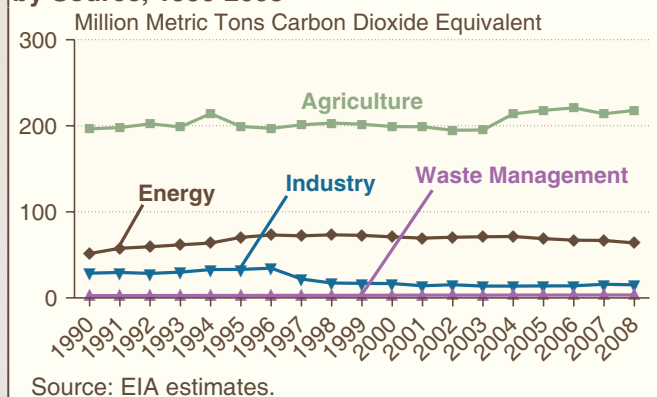


Table 21. U.S. Nitrous Oxide Emissions from Anthropogenic Sources, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Agriculture										
Nitrogen Fertilization of Soils	142.8	143.4	146.2	142.6	143.3	162.3	165.6	168.1	161.0	165.0
Solid Waste of Domesticated Animals	53.2	55.4	52.4	51.7	51.3	51.0	51.7	52.2	52.3	52.3
Crop Residue Burning	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.6
Subtotal	196.4	199.2	199.1	194.8	195.1	213.9	217.9	220.8	213.9	217.9
Energy Use										
Mobile Combustion	37.7	55.9	55.2	55.4	55.7	55.7	53.1	51.6	51.2	48.8
Stationary Combustion	13.9	14.5	15.7	15.1	15.3	15.6	15.7	15.4	15.6	15.1
Subtotal	51.6	70.4	71.0	70.4	71.0	71.4	68.8	67.1	66.8	63.9
Industrial Sources	28.8	33.1	16.7	15.3	13.7	13.7	14.0	14.0	15.9	15.1
Waste Management										
Human Sewage in Wastewater	2.3	2.5	2.8	2.9	2.8	2.9	2.9	3.0	3.0	3.0
Waste Combustion	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.4
Subtotal	2.6	2.8	3.1	3.2	3.2	3.2	3.3	3.3	3.4	3.4
Total	279.3	305.6	289.8	283.7	283.0	302.2	304.0	305.2	299.8	300.3

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). 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, *IPCC Guidelines for National Greenhouse Gas Inventories* (2006 and revised 1996 guidelines), web site www.ipcc-nggip.iges.or.jp/public/gl/invs6.html; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007*, EPA 430-R-09-004 (Washington, DC, April 2009), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Nitrous Oxide Emissions Agriculture

Summary

- Agricultural sources, at 217.9 MMTCO₂e, account for 73 percent of U.S. nitrous oxide emissions. Nitrous oxide emissions from agricultural sources increased by 1.9 percent (4.0 MMTCO₂e) from 2007 to 2008 (Table 22).
- Three-quarters (165.0 MMTCO₂e) of U.S. agricultural emissions of nitrous oxide in 2008 is attributable to nitrogen fertilization of soils (Figure 21), including 145.2 MMTCO₂e from direct emissions and 19.8 MMTCO₂e from indirect emissions.
- Microbial denitrification of solid waste from domestic animals in the United States, primarily cattle, emitted 52.3 MMTCO₂e of nitrous oxide in 2008. The amount released is a function of animal size and manure production, the amount of nitrogen in the waste, and the method of managing the waste.
- Agricultural emissions of nitrous oxide are 23 to 28 percent lower in all years in the 2008 inventory than in the 2007 inventory, following the IPCC's downward revisions of direct and indirect emissions factors for nitrogen from the fertilization of agricultural soils.

Nitrous Oxide Emissions from Agriculture, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	196.4	213.9	217.9
Change from 1990 (Million Metric Tons CO ₂ e)		17.5	21.5
(Percent)		8.9%	10.9%
Average Annual Change from 1990 (Percent)		0.5%	0.6%
Change from 2007 (Million Metric Tons CO ₂ e).			4.0
(Percent)			1.9%

Figure 21. U.S. Nitrous Oxide Emissions from Agriculture by Source, 2008

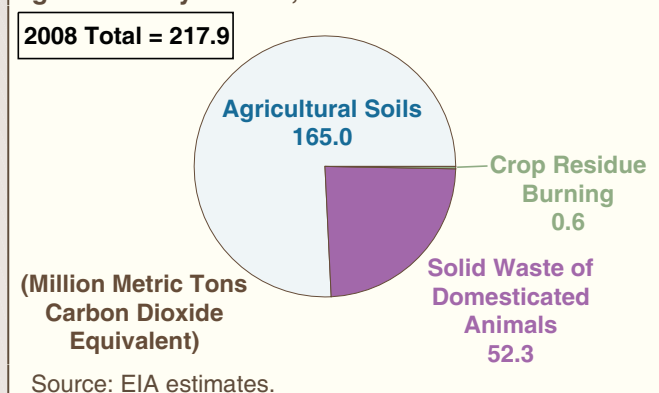


Table 22. U.S. Nitrous Oxide Emissions from Agricultural Sources, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Agricultural Soils										
Direct Emissions										
Biological Fixation in Crops	50.6	53.4	57.9	55.6	53.4	60.3	60.1	60.4	52.7	56.5
Synthetic Nitrogen Fertilizers	47.5	45.9	40.8	40.8	43.0	48.6	51.8	53.6	54.8	53.5
Crop Residues	22.0	21.9	27.0	25.7	25.6	30.2	29.3	28.9	28.1	29.9
Other	5.0	5.1	5.2	5.2	5.2	5.2	5.2	5.3	5.2	5.3
Total Direct Emissions	125.1	126.3	130.9	127.3	127.2	144.2	146.4	148.2	140.8	145.2
Indirect Emissions										
Soil Leaching	11.1	10.7	9.6	9.6	10.0	11.3	12.0	12.4	12.7	12.4
Atmospheric Deposition	6.6	6.4	5.7	5.7	6.0	6.8	7.2	7.4	7.6	7.7
Total Indirect Emissions	17.7	17.1	15.3	15.3	16.1	18.1	19.2	19.9	20.3	19.8
Solid Waste of Domesticated Animals										
Cattle	49.0	51.1	48.2	47.7	47.4	47.0	47.5	47.9	47.9	47.8
Swine	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.5	1.6
Poultry	0.9	1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4
Horses	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.6	0.6	0.6
Sheep	1.1	0.8	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Goats	0.3	0.3	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4
Total Solid Waste	53.2	55.4	52.4	51.7	51.3	51.0	51.7	52.2	52.3	52.3
Crop Residue Burning	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6
Total Agricultural Sources	196.4	199.2	199.1	194.8	195.1	213.9	217.9	220.8	213.9	217.9

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

Nitrous Oxide Emissions

Energy Use

Summary

- Emissions from energy sources made up about 21 percent of total U.S. nitrous oxide emissions in 2008. Nitrous oxide is a byproduct of fuel combustion in mobile and stationary sources (Figure 22).
- More than three-quarters of U.S. nitrous oxide emissions from energy use can be traced to mobile sources—motor vehicles, primarily passenger cars and light trucks (Table 23). Emissions from mobile sources dropped by 4.8 percent (2.4 MMTCO₂e)

- from 2007 to 2008, primarily because of a 5.2-percent decrease in emissions from passenger cars and light trucks. Vehicle miles traveled by passenger vehicles were 3.3 percent lower in 2008 than in 2007, as a result of higher gasoline prices and economic uncertainty.
- Nitrous oxide emissions from stationary combustion sources result predominantly from the burning of coal at electric power plants (9.2 MMTCO₂e, or 61.2 percent of all nitrous oxide from stationary combustion).

U.S. Nitrous Oxide Emissions from Energy Use, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	51.6	66.8	63.9
Change from 1990 (Million Metric Tons CO ₂ e)		15.2	12.3
(Percent)		29.4%	23.8%
Average Annual Change from 1990 (Percent)		1.5%	1.2%
Change from 2007 (Million Metric Tons CO ₂ e).			-2.9
(Percent)			-4.3%

Figure 22. U.S. Nitrous Oxide Emissions from Energy Use by Source, 1990-2008

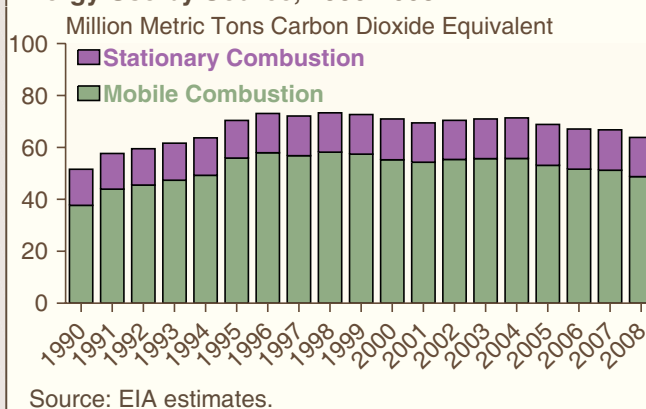


Table 23. U.S. Nitrous Oxide Emissions from Energy Use, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Item	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Mobile Combustion										
Motor Vehicles	34.1	52.3	51.3	51.8	52.3	52.0	49.2	47.7	47.2	44.9
Passenger Cars	21.7	31.4	29.3	28.7	28.3	27.2	25.5	24.1	23.5	21.9
Light-Duty Trucks	10.5	18.6	19.4	20.4	21.3	21.9	20.9	20.7	20.9	20.1
Other Motor Vehicles	1.8	2.2	2.6	2.7	2.7	2.8	2.8	2.8	2.8	2.8
Other Mobile Sources	3.6	3.6	3.9	3.6	3.4	3.8	3.9	4.0	4.0	3.9
Total	37.7	55.9	55.2	55.4	55.7	55.7	53.1	51.6	51.2	48.8
Stationary Combustion										
Residential and Commercial . . .	1.5	1.4	1.3	1.2	1.3	1.3	1.3	1.1	1.2	1.2
Industrial	4.6	4.9	4.8	4.5	4.4	4.7	4.5	4.6	4.5	4.1
Electric Power	7.8	8.3	9.6	9.4	9.6	9.7	9.9	9.7	9.9	9.7
Total	13.9	14.5	15.7	15.1	15.3	15.6	15.7	15.4	15.6	15.1
Total from Energy Use	51.6	70.4	71.0	70.4	71.0	71.4	68.8	67.1	66.8	63.9

Notes: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.

Source: EIA estimates

Nitrous Oxide Emissions

Industrial Sources

Summary

- U.S. industrial sources emitted 15.1 MMTCO₂e of nitrous oxide in 2008, a decrease of 4.6 percent from 2007 (Table 24).
- The two industrial sources of nitrous oxide emissions are production of adipic acid and production of nitric acid.
- Nitric acid, a primary ingredient in fertilizers, usually is manufactured by oxidizing ammonia with a platinum catalyst. The oxidation process releases nitrous oxide emissions.
- Adipic acid is a fine white powder used primarily in the manufacture of nylon fibers and plastics. The three companies operating the U.S. plants manufacture adipic acid by oxidizing a ketone-alcohol mixture with nitric acid. The chemical reaction results in nitrous oxide emissions.
- A large decline in nitrous oxide emissions from industrial processes since 1996 (Figure 23) is a result of emissions control technology at three of the four adipic acid plants operating in the United States.

U.S. Nitrous Oxide Emissions from Industrial Sources, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	28.8	15.9	15.1
Change from 1990 (Million Metric Tons CO ₂ e)		-12.9	-13.6
(Percent)		-44.8%	-47.3%
Average Annual Change from 1990 (Percent)		-3.4%	-3.5%
Change from 2007 (Million Metric Tons CO ₂ e)			-0.7
(Percent)			-4.6%

Figure 23. U.S. Nitrous Oxide Emissions from Industry by Source, 1990-2008

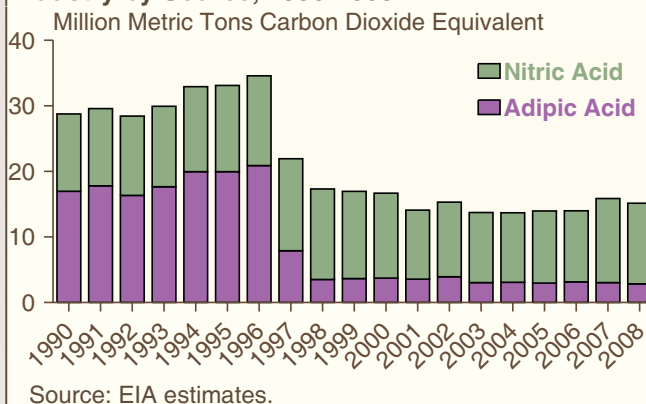


Table 24. U.S. Nitrous Oxide Emissions from Industrial Sources, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Adipic Acid										
Controlled Sources	1.0	1.1	1.6	1.6	1.6	1.7	1.6	1.7	1.6	1.5
Uncontrolled Sources	16.0	18.9	2.1	2.3	1.4	1.4	1.4	1.5	1.4	1.3
Subtotal	17.0	20.0	3.7	3.9	3.0	3.1	3.0	3.2	3.0	2.8
Nitric Acid	11.8	13.1	12.9	11.4	10.7	10.6	11.0	10.8	12.8	12.3
Total Known Industrial Sources	28.8	33.1	16.7	15.3	13.7	13.7	14.0	14.0	15.9	15.1

Note: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

Nitrous Oxide Emissions

Waste Management

Summary

- In 2008, treatment of residential and commercial wastewater produced 89.5 percent (3.0 MMTCO₂e) of all nitrous oxide emissions from waste management. An additional 0.4 MMTCO₂e was emitted from the combustion of municipal solid waste (Figure 24 and Table 25).
- Estimates of nitrous oxide emissions from wastewater are directly related to population size and per-capita intake of protein.
- Nitrous oxide is emitted from wastewater that contains nitrogen-based organic materials, such as those

found in human or animal waste. Factors that influence the amount of nitrous oxide generated from wastewater include temperature, acidity, biochemical oxygen demand, and nitrogen concentration.

- The emissions factor for nitrous oxide from sewage, which has been updated for the 2008 inventory in accordance with the IPCC's 2006 inventory guidelines, is 50 percent lower than in previous reports, resulting in a corresponding decline in reported nitrous oxide emissions from wastewater.

U.S. Anthropogenic Nitrous Oxide Emissions from Waste Management, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	2.6	3.4	3.4
Change from 1990 (Million Metric Tons CO ₂ e)		0.7	0.8
(Percent)		28.1%	29.5%
Average Annual Change from 1990 (Percent)		1.5%	1.4%
Change from 2007 (Million Metric Tons CO ₂ e).			*
(Percent)			1.1%

*Less than 0.05 million metric tons.

Figure 24. U.S. Nitrous Oxide Emissions from Waste Management by Source, 1990-2008

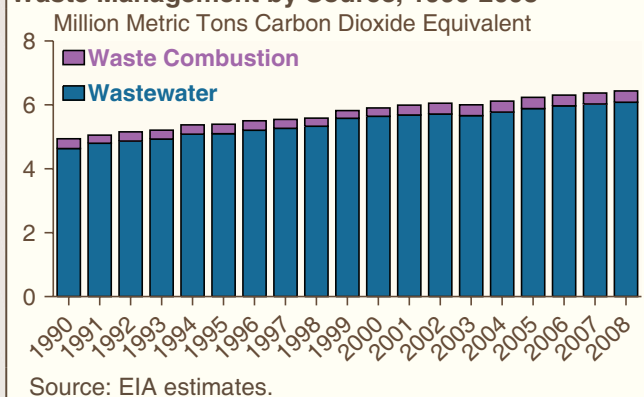


Table 25. U.S. Nitrous Oxide Emissions from Waste Management, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Domestic and Commercial Wastewater	2.3	2.5	2.8	2.9	2.8	2.9	2.9	3.0	3.0	3.0
Waste Combustion	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.4
Total	2.6	2.8	3.1	3.2	3.2	3.2	3.3	3.3	3.4	3.4

Note: Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2007*, DOE/EIA-0573(2007) (Washington, DC, December 2008). Totals may not equal sum of components due to independent rounding.
Source: EIA estimates.

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High-GWP Gases

Total Emissions

Summary

- Greenhouse gases with high global warming potential (high-GWP gases) are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆), which together represented 2.5 percent of U.S. greenhouse gas emissions in 2008.
- Emissions estimates for the high-GWP gases are provided to EIA by the EPA's Office of Air and Radiation. The estimates are derived from the EPA Vintaging Model.
- For this year's EIA inventory, 2007 values for PFCs and SF₆ are used as placeholders. The updated values will be available when the U.S. inventory is submitted to the UNFCCC in April 2010.
- Emissions of high-GWP gases have increased steadily since 1990 (Figure 25 and Table 26), largely because HFCs are being used to replace chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and other ozone-depleting substances that are being phased out under the terms of the Montreal Protocol, which entered into force on January 1, 1989.
- PFC emissions have declined since 1990 as a result of production declines in the U.S. aluminum industry as well as industry efforts to lower emissions per unit of output.
- Emissions of "other" HFCs, which are aggregated to protect confidential data, have been updated for 2008, showing a 4.4-percent increase from 2007.

U.S. Anthropogenic Emissions of High-GWP Gases, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	102.3	170.3	175.6
Change from 1990 (Million Metric Tons CO ₂ e)		68.0	73.3
(Percent)		66.4%	71.7%
Average Annual Change from 1990 (Percent)		3.0%	3.0%
Change from 2007 (Million Metric Tons CO ₂ e)			5.4
(Percent)			3.1%

Figure 25. U.S. Anthropogenic Emissions of High-GWP Gases, 1990-2008

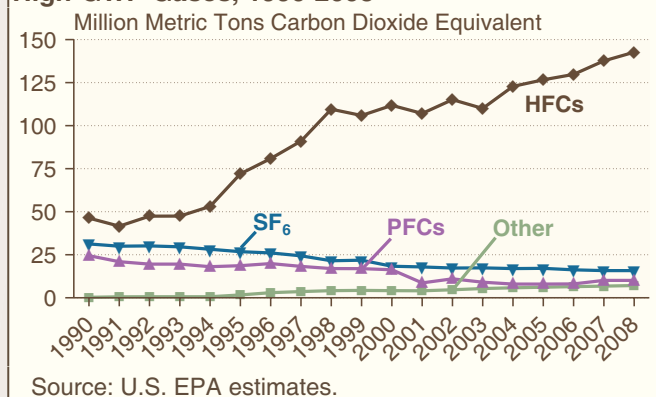


Table 26. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Hydrofluorocarbons	46.3	72.0	111.8	115.1	110.0	122.8	126.6	129.8	137.7	142.7
Perfluorocarbons	24.4	18.6	16.3	11.0	9.1	8.0	8.0	8.1	10.1	10.1
Other HFCs, PFCs/PFPEs	0.3	1.6	4.1	4.7	5.4	5.8	6.1	6.4	6.8	7.1
Sulfur Hexafluoride	31.3	26.8	18.3	17.3	17.4	16.9	17.1	16.2	15.8	15.8
Total Emissions	102.3	119.0	150.5	148.1	141.8	153.5	157.8	160.5	170.3	175.6

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, November 2009 for hydrofluorocarbons and other HFCs, PFCs/PFPEs; November 2008 for perfluorocarbons and sulfur hexafluoride).

High-GWP Gases Hydrofluorocarbons

Summary

- HFCs are compounds that contain carbon, hydrogen, and fluorine. Although they do not destroy stratospheric ozone, they are powerful greenhouse gases.
- HFCs are used as solvents, residential and commercial refrigerants, firefighting agents, and propellants for aerosols.
- Emissions of substitutes for ozone-depleting substances, including HFC-32, HFC-125, HFC-134a, and HFC-236fa, have grown from trace amounts in 1990 to nearly 143 MMTCO₂e in 2008 (Table 27).
- Nearly 90 percent of the growth in HFC emissions since 1990 can be attributed to the use of HFCs as replacements for ozone-depleting substances. The market is expanding, with HFCs used in fire

protection applications to replace Halon 1301 and Halon 1211.

- Since 2000, HFC-134a—used as a replacement for CFCs in air conditioners for passenger vehicles, trains, and buses—has accounted for the largest share of HFC emissions (Figure 26).
- Under the Clean Air Act, manufacture and import of HCFC-22, except for use as a feedstock and in equipment manufacture before 2010, are scheduled to be phased out by January 1, 2010. Manufacturers of HCFC-22 are using cost-effective methods to make voluntary reductions in the amount of HFC-23 that is created as a byproduct of HCFC-22 manufacture; however, HCFC-22 production remains a large and steady source of U.S. emissions of HFC-23.

U.S. Anthropogenic Emissions of HFCs, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	46.3	137.7	142.7
Change from 1990 (Million Metric Tons CO ₂ e)		91.4	96.4
(Percent)		197.4%	208.3%
Average Annual Change from 1990 (Percent)		6.6%	6.5%
Change from 2007 (Million Metric Tons CO ₂ e)			5.0
(Percent)			3.7%

Figure 26. U.S. Anthropogenic Emissions of HFCs, 1990-2008

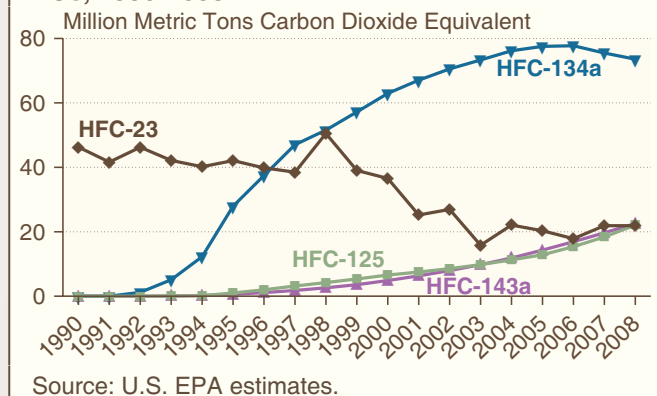


Table 27. U.S. Emissions of Hydrofluorocarbons, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
HFC-23	46.3	42.1	36.5	26.9	15.8	22.1	20.3	17.9	21.9	21.9
HFC-32	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.6	0.9	1.2
HFC-125	0.0	1.0	6.6	8.5	9.8	11.3	12.9	15.4	18.4	22.1
HFC-134a	0.0	27.9	62.9	70.5	73.3	76.2	77.5	77.7	75.5	73.6
HFC-143a	0.0	0.6	4.9	8.0	9.8	11.9	14.3	16.9	19.7	22.5
HFC-236fa	0.0	0.4	0.8	1.0	1.1	1.2	1.2	1.3	1.3	1.4
Total HFCs	46.3	72.0	111.8	115.1	110.0	122.8	126.6	129.8	137.7	142.7

Note: 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, November 2009).

High-GWP Gases

Perfluorocarbons

Summary

- The two principal sources of PFC emissions are domestic aluminum production and semiconductor manufacture, which yield perfluoromethane (CF₄) and perfluoroethane (C₂F₆) (Figure 27 and Table 28).
- While PFC emissions from aluminum production have declined markedly since 1990, the decline has been offset in part by increased emissions from semiconductor manufacturing.
- Emissions from process inefficiencies during aluminum production (known as “anode effects”) have been greatly reduced; in addition, high costs for alumina and energy have led to production cutbacks.
- Perfluoroethane is used as an etchant and cleaning agent in semiconductor manufacturing. The portion of the gas that does not react with the materials is emitted to the atmosphere.

U.S. Anthropogenic Emissions of PFCs, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	24.4	10.1	NA
Change from 1990 (Million Metric Tons CO ₂ e)		-14.4	NA
(Percent)		-58.8%	NA
Average Annual Change from 1990 (Percent)		-5.1%	NA
Change from 2007 (Million Metric Tons CO ₂ e)			NA
(Percent)			NA

NA = 2008 data not yet available.

Figure 27. U.S. Anthropogenic Emissions of PFCs, 1990-2008

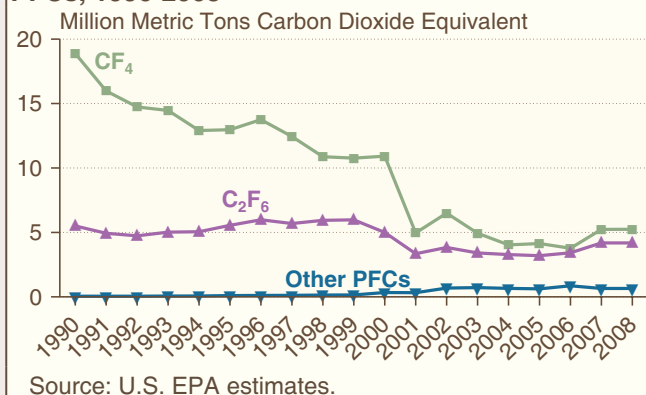


Table 28. U.S. Emissions of Perfluorocarbons, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
CF ₄	18.9	13.0	10.9	6.5	4.9	4.0	4.1	3.8	5.2	5.2
C ₂ F ₆	5.5	5.6	5.0	3.8	3.4	3.3	3.2	3.4	4.2	4.2
NF ₃	*	0.1	0.2	0.5	0.5	0.5	0.4	0.7	0.5	0.5
C ₃ F ₈	*	*	0.2	0.1	0.1	0.1	*	*	0.1	0.1
C ₄ F ₈	*	*	*	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total PFCs	24.4	18.6	16.3	11.0	9.1	8.0	8.0	8.1	10.1	10.1

*Less than 0.05 million metric tons carbon dioxide equivalent.

Note: 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/ (estimates, November 2008); 2007 values are used as proxies for 2008.

High-GWP Gases

Sulfur Hexafluoride

Summary

- SF₆, an excellent dielectric gas for high-voltage applications, is used primarily in electrical applications—as an insulator and arc interrupter for circuit breakers, switch gear, and other equipment in electricity transmission and distribution systems.
- Industry efforts to reduce emissions of SF₆ from electrical power systems have led to a decline in emissions since 1990 (Figure 28 and Table 29).
- SF₆ is also used in magnesium metal casting, as a cover gas during magnesium production, and as an atmospheric tracer for experimental purposes.
- Other, minor applications of SF₆ include leak detection and the manufacture of loudspeakers and lasers.

U.S. Anthropogenic Emissions of SF₆, 1990, 2007, and 2008

	1990	2007	2008
Estimated Emissions (Million Metric Tons CO ₂ e)	31.3	15.8	NA
Change from 1990 (Million Metric Tons CO ₂ e)		-15.5	NA
(Percent)		-49.5%	NA
Average Annual Change from 1990 (Percent)		-3.9%	NA
Change from 2007 (Million Metric Tons CO ₂ e)			NA
(Percent)			NA
NA = 2008 data not yet available.			

Figure 28. U.S. Anthropogenic Emissions of SF₆ by Source, 1990-2008

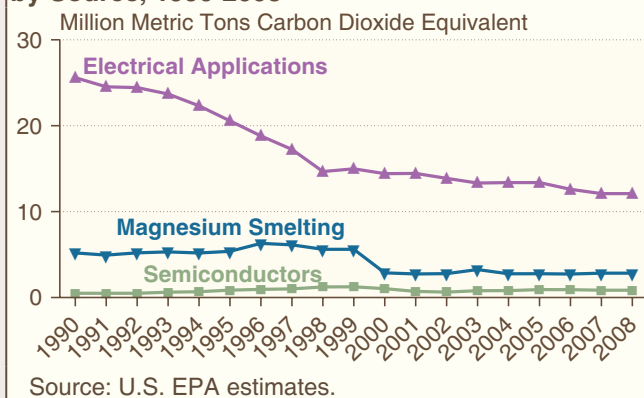


Table 29. U.S. Emissions of Sulfur Hexafluoride by Source, 1990-2008
(Million Metric Tons Carbon Dioxide Equivalent)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008
Electrical Applications	25.6	20.6	14.4	13.9	13.3	13.4	13.4	12.6	12.1	12.1
Magnesium Smelting	5.2	5.4	2.9	2.8	3.3	2.8	2.8	2.7	2.8	2.8
Semiconductors	0.5	0.9	1.0	0.6	0.8	0.8	0.9	0.9	0.9	0.9
Total SF₆	31.3	26.8	18.3	17.3	17.4	16.9	17.1	16.2	15.8	15.8

Note: 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/ (estimates, November 2009); 2007 values are used as proxies for 2008.

Land Use Overview

Summary

- In 2007, land use, land-use change, and forests accounted for net carbon sequestration of 1,062.6 MMTCO₂e (Table 30), representing 17.7 percent of total U.S. CO₂ emissions.
- Net carbon sequestration from land use, land-use change, and forestry activities in 2007 was about 26 percent greater than in 1990 (Figure 29). The increase resulted primarily from a higher average annual rate of net carbon accumulation in forest carbon stocks.
- Sequestration from land use, land-use change, and forestry peaked in 2004 at 1,294.6 MMTCO₂e. By 2006 it had fallen to 1,050.5 MMTCO₂e, and in 2007 it rose slightly to 1,062.6 MMTCO₂e.
- Because forest land is the predominant category, its fluctuations drive the total. It is the category with the

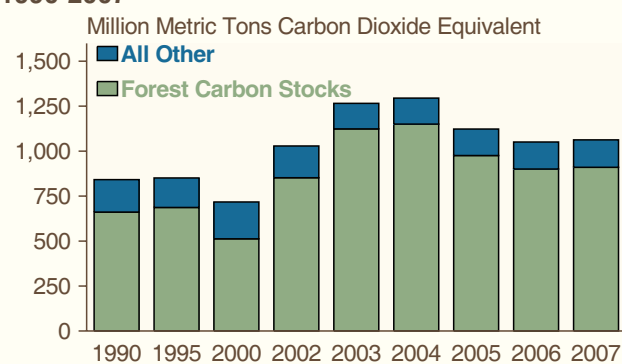
largest change since 1990 in absolute terms (249 MMTCO₂e).

- The largest percentage changes from 1990 to 2007 were seen for urban trees, which increased by 61 percent, and for grasslands remaining grasslands, which decreased by 91 percent.
- Among the categories of estimated greenhouse gas emissions, land-use change has a relatively high degree of uncertainty. As discussed on the following pages, the estimated values are highly dependent on the estimation methods used. Thus, countries that submit their emissions estimates to the UNFCCC generally provide two estimates: without land-use change (gross emissions) and with land-use change (net emissions).

U.S. Carbon Sequestration from Land Use, Land-Use Change and Forestry, 1990, 2006, and 2007

	1990	2006	2007
Estimated Sequestration (Million Metric Tons CO ₂ e)	841.4	1,050.5	1,062.6
Change from 1990 (Million Metric Tons CO ₂ e)		209.1	221.1
(Percent)		24.9%	26.3%
Average Annual Change from 1990 (Percent)		1.4%	1.4%
Change from 2006 (Million Metric Tons CO ₂ e)			12.0
(Percent)			1.1%

Figure 29. U.S. Carbon Sequestration from Land Use, Land-Use Change, and Forestry, 1990-2007



Source: U.S. EPA estimates.

Table 30. Net U.S. Carbon Dioxide Sequestration from Land Use, Land-Use Change, and Forestry, 1990-2007

(Million Metric Tons Carbon Dioxide Equivalent)

Component	1990	1995	2000	2002	2003	2004	2005	2006	2007
Forest Land Remaining Forest Land ^a	661.1	686.6	512.6	852.1	1,123.4	1,150.2	975.7	900.3	910.1
Cropland Remaining Cropland ^b	29.4	22.9	30.2	11.5	17.7	18.1	18.3	19.1	19.7
Land Converted to Cropland	-2.2	-2.9	-2.4	-4.8	-5.9	-5.9	-5.9	-5.9	-5.9
Grassland Remaining Grassland	46.7	36.4	51.4	43.1	4.5	4.5	4.6	4.6	4.7
Land Converted to Grassland	22.3	22.5	32.0	28.3	26.7	26.7	26.7	26.7	26.7
Settlements Remaining Settlements:									
Urban Trees ^c	60.6	71.5	82.4	86.8	88.9	91.1	93.3	95.5	97.6
Other:									
Landfilled Yard Trimmings and Food Scraps	23.5	13.9	11.3	11.8	10.1	9.9	10.2	10.4	9.8
Total Net Flux	841.4	851.0	717.5	1,028.7	1,265.4	1,294.6	1,122.7	1,050.5	1,062.6

^aEstimates include carbon stock changes in both Forest Land Remaining Forest Land and Land Converted to Forest Land.

^bEstimates include carbon stock changes in mineral soils and organic soils on Cropland Remaining Cropland and liming emissions from all Cropland, Grassland, and Settlement categories.

^cEstimates include carbon stock changes in both Settlements Remaining Settlements and Land Converted to Settlements.

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: 1990-2007*, EPA 430-R-09-004 (Washington, DC, April 2009), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Land Use

Forest Lands and Harvested Wood Pools

Summary

- Carbon sequestration attributed to forest land remaining forest land in 2007 totaled 910.1 MMTCO₂e (Figure 30 and Table 31). According to the EPA, that total has a 95-percent probability of being between 736 and 1,083 MMTCO₂e.
- Changes in underlying data from the USDA Forest Service Forestry Inventory Analysis Database (FIADB) have led to changes in estimates across the time series. Most States have added new data or modified existing data in the inventory.
- Version 3.0 of the FIADB includes more use of moving averages, which affect extrapolations of stocks and stock changes. The major changes in estimates for 1990-2007 relative to 1990-2006 is a spike in the 2002-2006 estimates for forest carbon.
- According to the USDA, average carbon densities have been updated from 331 million grams per hectare (Mg/ha) to 179 Mg/ha for Alaska and from 89 Mg/ha to 91 Mg/ha for the lower 48 States.
- The largest changes for the 1990-2007 period are in the estimates for soil organic carbon and dead wood, which increased by 153 percent and 139 percent, respectively.

Carbon Sequestration in U.S. Forest Lands and Harvested Wood Pools, 1990, 2006, and 2007

	1990	2006	2007
Estimated Sequestration (Million Metric Tons CO ₂ e)	661.1	900.3	910.1
Change from 1990 (Million Metric Tons CO ₂ e)		239.2	249.0
(Percent)		36.2%	37.7%
Average Annual Change from 1990 (Percent)		2.0%	1.9%
Change from 2006 (Million Metric Tons CO ₂ e)			9.8
(Percent)			1.1%

Figure 30. Carbon Sequestration in U.S. Forest Lands and Harvested Wood Pools, 2007

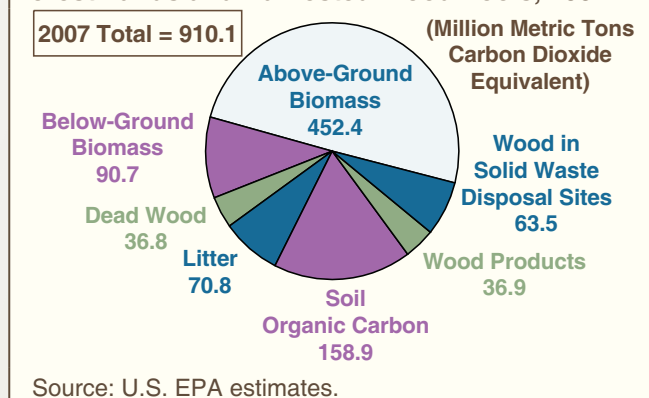


Table 31. Net Carbon Dioxide Sequestration in U.S. Forests and Harvested Wood Pools, 1990-2007
(Million Metric Tons Carbon Dioxide Equivalent)

Carbon Pool	1990	1995	2000	2002	2003	2004	2005	2006	2007
Forests	529.3	568.2	399.7	754.1	1,028.6	1,044.8	871.7	791.7	809.6
Above-Ground Biomass	321.5	390.9	352.1	438.9	529.2	531.6	469.4	442.7	452.4
Below-Ground Biomass	61.8	78.2	71.5	88.4	105.7	105.6	93.3	88.9	90.7
Dead Wood	15.4	27.3	18.2	31.2	42.6	44.5	39.4	35.6	36.8
Litter	67.8	37.2	14.8	68.5	92.2	93.0	79.6	68.7	70.8
Soil Organic Carbon	62.8	34.6	-56.9	127.1	258.8	270.1	190.1	155.9	158.9
Harvested Wood	131.8	118.4	112.9	98.0	94.8	105.4	103.9	108.6	100.4
Wood Products	64.8	55.2	47.0	34.9	35.5	45.6	44.1	45.2	36.9
Wood in Solid Waste Disposal Sites	67.0	63.2	65.9	63.1	59.3	59.8	59.8	63.3	63.5
Total	661.1	686.6	512.6	852.1	1,123.4	1,150.2	975.7	900.3	910.1

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: 1990-2007*, EPA 430-R-09-004 (Washington, DC, April 2009), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Land Use

Croplands and Grasslands

Summary

- For 2007, aggregate carbon flux for the four agricultural categories shown in Table 32 was 45.1 MMTCO₂e.
- Land converted to grassland, cropland remaining cropland, and grassland remaining grassland sequestered 26.7, 19.7, and 4.7 MMTCO₂e, respectively, in 2007. Land converted to cropland emitted 5.9 MMTCO₂e (Figure 31 and Table 32).
- In the USDA National Resources Inventory (NRI), land is classified as cropland remaining cropland in a given year if it has been used as cropland for 20 years.
- In previous inventory reports, land use data for 1997 were used for all subsequent years; however, the availability of new NRI data has extended the

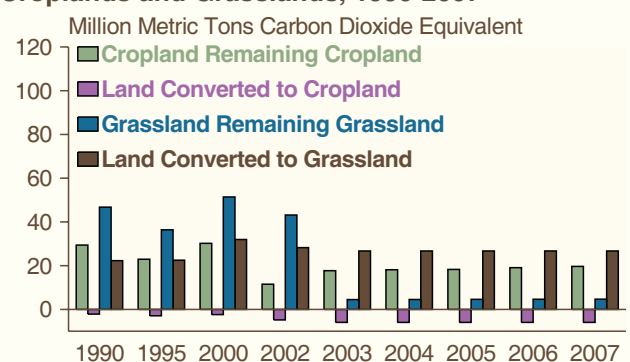
information on land use from 1997 to 2003. In Table 32, the data for 2004-2007 are extrapolations, except for the data on liming of soils, which extend through 2006.

- Annual area data (rather than 5-year increments) were used to estimate soil carbon stock changes for the current inventory, leading to more accurate estimates; and each NRI point was simulated separately, instead of simulating clusters of common cropping rotation histories and soil characteristics in a county.
- NRI area data were reconciled with the forest area estimates in the FIADB data and incorporated into the estimation of soil carbon stock changes, leading to adjustments in grassland areas in the NRI data, including land converted to grassland.

Carbon Sequestration in U.S. Croplands and Grasslands, 1990, 2006, and 2007

	1990	2006	2007
Estimated Sequestration (Million Metric Tons CO ₂ e)	96.3	44.5	45.1
Change from 1990 (Million Metric Tons CO ₂ e)		-51.8	-51.2
(Percent)		-53.8%	-53.2%
Average Annual Change from 1990 (Percent)		-4.7%	-4.4%
Change from 2006 (Million Metric Tons CO ₂ e)			0.6
(Percent)			1.4%

Figure 31. Carbon Sequestration in U.S. Croplands and Grasslands, 1990-2007



Source: U.S. EPA estimates.

Table 32. Net Carbon Dioxide Sequestration in U.S. Croplands and Grasslands, 1990-2007
(Million Metric Tons Carbon Dioxide Equivalent)

Carbon Pool	1990	1995	2000	2002	2003	2004	2005	2006	2007
Cropland Remaining Cropland	29.4	22.9	30.2	11.5	17.7	18.1	18.3	19.1	19.7
Mineral Soils	56.8	50.6	57.9	39.2	45.3	45.8	45.9	46.8	47.3
Organic Soils	-27.4	-27.7	-27.7	-27.7	-27.7	-27.7	-27.7	-27.7	-27.7
Land Converted to Cropland	-2.2	-2.9	-2.4	-4.8	-5.9	-5.9	-5.9	-5.9	-5.9
Mineral Soils	0.3	-0.3	0.3	-2.2	-3.3	-3.3	-3.3	-3.3	-3.3
Organic Soils	-2.4	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6
Grassland Remaining Grassland	46.7	36.4	51.4	43.1	4.5	4.5	4.6	4.6	4.7
Mineral Soils	50.6	40.1	55.1	46.8	8.2	8.2	8.3	8.3	8.4
Organic Soils	-3.9	-3.7	-3.7	-3.7	-3.7	-3.7	-3.7	-3.7	-3.7
Land Converted to Grassland	22.3	22.5	32.0	28.3	26.7	26.7	26.7	26.7	26.7
Mineral Soils	22.7	23.4	32.8	29.1	27.6	27.6	27.6	27.6	27.6
Organic Soils	-0.5	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9
Total Sequestration	96.3	78.9	111.2	78.1	42.9	43.4	43.6	44.5	45.1
Liming of Soils	-4.7	-4.4	-4.3	-5.0	-4.6	-3.9	-4.3	-4.2	-4.1

Note: Negative values indicate emissions.

Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007*, EPA 430-R-09-004 (Washington, DC, April 2009), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

Land Use

Urban Trees, Yard Trimmings, and Food Scraps

Summary

- Urban trees, yard trimmings, and food scraps sequestered 107.4 MMTCO₂e in 2007 (Figure 32 and Table 33).
- Updated data from *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: 2007 Facts and Figures*,¹² used in this report—including revisions to the amounts of food scraps generated in 2000

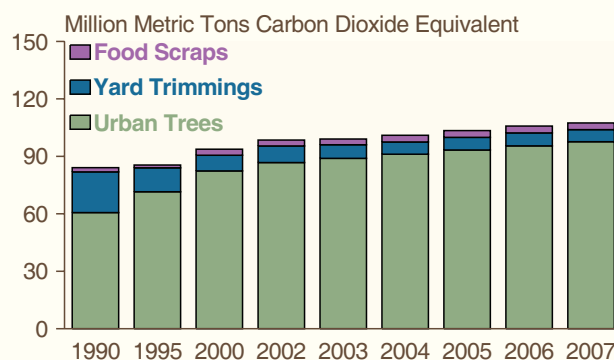
and 2004-2007—resulted in an average 1.0-percent decrease in carbon storage across the time series for yard trimmings and food scraps.

- Carbon sequestration in yard trimmings showed the largest change from 1990 to 2007, with a decrease of 70 percent attributable to an increase in municipal collection and composting of yard trimmings.

Carbon Sequestration in U.S. Urban Trees, Yard Trimmings, and Food Scraps, 1990, 2006, and 2007

	1990	2006	2007
Estimated Sequestration (Million Metric Tons CO ₂ e)	84.1	105.8	107.4
Change from 1990 (Million Metric Tons CO ₂ e)		21.7	23.3
(Percent)		25.8%	27.7%
Average Annual Change from 1990 (Percent)		1.4%	1.4%
Change from 2006 (Million Metric Tons CO ₂ e).			1.6
(Percent)			1.5%

Figure 32. Carbon Sequestration in U.S. Urban Trees, Yard Trimmings, and Food Scraps, 1990-2007



Source: U.S. EPA estimates.

Table 33. Net Carbon Dioxide Sequestration in U.S. Urban Trees, Yard Trimmings, and Food Scraps, 1990-2007

(Million Metric Tons Carbon Dioxide Equivalent)

Carbon Pool	1990	1995	2000	2002	2003	2004	2005	2006	2007
Urban Trees	60.6	71.5	82.4	86.8	88.9	91.1	93.3	95.5	97.6
Yard Trimmings	21.2	12.5	8.2	8.7	7.1	6.4	6.6	6.8	6.3
Grass	1.9	0.8	0.4	0.6	0.4	0.3	0.4	0.5	0.4
Leaves	9.7	6.0	4.0	4.2	3.5	3.2	3.3	3.3	3.1
Branches	9.7	5.8	3.7	3.9	3.2	2.9	3.0	3.0	2.8
Food Scraps	2.2	1.4	3.1	3.1	3.0	3.5	3.5	3.6	3.5
Total Net Flux	84.1	85.5	93.7	98.5	99.0	101.0	103.5	105.8	107.4

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: 1990-2007*, EPA 430-R-09-004 (Washington, DC, April 2009), web site www.epa.gov/climatechange/emissions/usinventoryreport.html.

¹²U.S. Environmental Protection Agency, *Municipal Solid Waste in the United States: 2007 Facts and Figures*, EPA 530-R-08-010 (Washington, DC, November 2008).

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 = $(141.5/\text{sp.gr.}60 \text{ deg.F}/60 \text{ deg.F}) - 131.5$.

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 cut-back 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).

BOD₅: 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 (CO₂): 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 kilowatt-hour 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 that refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

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°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): $(\text{CH}_3)_3\text{COC}_2\text{H}$: 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 earth's 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: A gradual increase, observed or projected, in global surface temperature, as one of the consequences of radiative forcing caused by anthropogenic emissions. 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 ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), 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 (CH₃CCl₃) 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 (N₂O): A colorless gas, naturally occurring in the atmosphere.

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 anti-knock 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 (CF₄) 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 fire-proof textiles, in petroleum refining and corrugated paperboard manufacture, and as an egg preservative. Also referred to as liquid glass, 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 (SO₂): 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 (SF₆): A colorless gas soluble in alcohol and ether, and slightly less soluble in water. It is used as a dielectric in electronics.

Sulfur oxides (SO_x): Compounds containing sulfur and oxygen, such as sulfur dioxide (SO₂) and sulfur trioxide (SO₃).

Tertiary amyl methyl ether ((CH₃)₂(C₂H₅)COCH₃): 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.

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