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# Emissions of Greenhouse Gases in the United States 2009

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### **Disclaimer**

This report was prepared by the U.S. Energy Information Administration (EIA), the statistical and analytical agency within the U.S. Department of Energy. By law, EIA's data, analyses, and forecasts are independent of approval by any other officer or employee of the United States Government. The views in this report therefore should not be construed as representing those of the Department of Energy or other Federal agencies.

## Preface

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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 eighteenth annual report—presents the U.S. 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.gov/oiaf/1605/ggrpt](http://www.eia.gov/oiaf/1605/ggrpt).

This report uses activity data on coal and natural gas consumption and electricity sales and losses by sector from the January 2011 *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.

Data on ozone-depleting gases with high global warming potentials (high-GWP gases) are directly from the U.S. Environmental Protection Agency (EPA). For this report, updated EPA values were available for hydrofluorocarbons (HFCs). However, no updates were available for perfluorocarbons (PFCs) or sulfur hexafluoride (SF<sub>6</sub>), and last year’s values are used instead.

Historical data in the chapter tables are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

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# 1. Greenhouse gas emissions overview

## 1.1. Total emissions

Total U.S. anthropogenic (human-caused) greenhouse gas emissions in 2009 were 5.8 percent below the 2008 total (Table 1). The decline in total emissions—from 6,983 million metric tons carbon dioxide equivalent (MMT<sub>CO<sub>2</sub>e</sub>) in 2008 to 6,576 MMT<sub>CO<sub>2</sub>e</sub> in 2009—was the largest since emissions have been tracked over the 1990-2009 time frame. It was largely the result of a 419-MMT<sub>CO<sub>2</sub>e</sub> drop in carbon dioxide (CO<sub>2</sub>) emissions (7.1 percent). There was a small increase of 7 MMT<sub>CO<sub>2</sub>e</sub> (0.9 percent) in methane (CH<sub>4</sub>) emissions, and an increase of 8 MMT<sub>CO<sub>2</sub>e</sub> (4.9 percent), based on partial data, in emissions of man-made gases with high global warming potentials (high-GWP gases). (Draft estimates for emissions of HFC and PFC substitutes for ozone-depleting substances in 2009 are included; 2008 data are used for emissions of other high-GWP gases.) Emissions of nitrous oxide (N<sub>2</sub>O), on the other hand, fell by 4 MMT<sub>CO<sub>2</sub>e</sub> (1.7 percent).

The decrease in U.S. CO<sub>2</sub> emissions in 2009 resulted primarily from three factors: an economy in recession, a particularly hard-hit energy-intensive industries sector, and a large drop in the price of natural gas that caused fuel switching away from coal to natural gas in the electric power sector.

Methane emissions totaled 731 MMT<sub>CO<sub>2</sub>e</sub> in 2009 (Figure 1), up by 7 MMT<sub>CO<sub>2</sub>e</sub> (0.9 percent) from 2008. Increases in energy-related methane emissions—largely from underground coal mining—were offset by decreases in emissions from agricultural sources. Methane emissions from waste management systems rose by 7 MMT<sub>CO<sub>2</sub>e</sub>, while industrial emissions declined by 0.4 MMT<sub>CO<sub>2</sub>e</sub>.

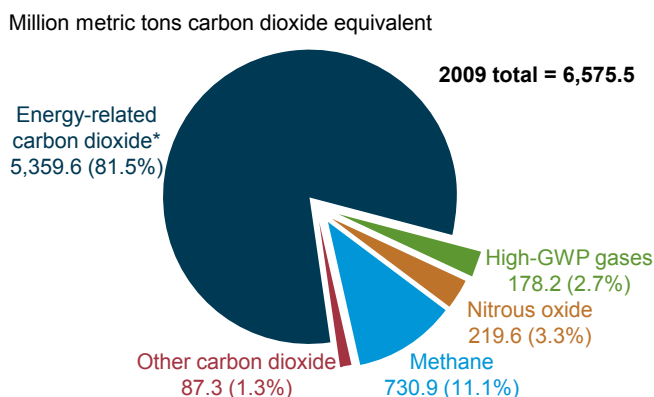
Emissions of nitrous oxide dropped by 4 MMT<sub>CO<sub>2</sub>e</sub> (1.7 percent) to 220 MMT<sub>CO<sub>2</sub>e</sub>. The decrease came mainly from a reduction in energy-related emissions, as well as declines in industrial-related and agricultural nitrous oxide emissions.

Based on a partial estimate, U.S. emissions of high-GWP gases totaled 178 MMT<sub>CO<sub>2</sub>e</sub> in 2009—8 MMT<sub>CO<sub>2</sub>e</sub> (4.9 percent) above the 2008 level. Emissions of hydrofluorocarbons (HFCs) rose by 7 MMT<sub>CO<sub>2</sub>e</sub> (5.4 percent) from 2008 to 2009.

### U.S. greenhouse gas emissions, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	6,133.2	7,109.4	6,983.1	6,575.5
Change from 1990 (million metric tons CO <sub>2</sub> e)		976.1	849.8	442.3
(percent)		15.9%	13.9%	7.2%
Average annual change from 1990 (percent)		1.0%	0.7%	0.4%
Change from 2005 (million metric tons CO <sub>2</sub> e)			-126.3	-533.8
(percent)			-1.8%	-7.5%
Change from 2008 (million metric tons CO <sub>2</sub> e)				-407.5
(percent)				-5.8%

Figure 1. U.S. greenhouse gas emissions by gas, 2009



\*Adjusted by removing emissions from bunker fuels and adding emissions from U.S. Territories.

Table 1. U.S. emissions of greenhouse gases, based on global warming potential,<sup>a</sup> 1990-2009 (million metric tons carbon dioxide equivalent)

Gas	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Carbon dioxide	5,040.9	5,353.4	5,900.3	5,923.3	6,031.3	6,055.2	5,961.6	6,059.5	5,865.5	5,446.8
Methane	768.8	732.7	663.1	660.6	661.6	669.2	678.5	690.9	724.2	730.9
Nitrous oxide	221.4	236.2	217.8	211.8	222.0	223.6	223.7	228.6	223.5	219.6
High-GWP gases <sup>b</sup>	102.1	119.4	154.0	145.4	157.0	161.3	163.6	171.4	169.9	178.2
<b>Total</b>	<b>6,133.2</b>	<b>6,441.7</b>	<b>6,935.3</b>	<b>6,941.1</b>	<b>7,071.9</b>	<b>7,109.4</b>	<b>7,027.4</b>	<b>7,150.4</b>	<b>6,983.1</b>	<b>6,575.5</b>
Difference from 2005	—	—	—	—	—	—	-82.0	41.0	-126.3	-533.8
Percent difference from 2005	—	—	—	—	—	—	-1.2%	0.6%	-1.8%	-7.5%

<sup>a</sup>Net, 100-year global warming potentials as presented in Intergovernmental Panel on Climate Change, *Fourth Assessment Report: Climate Change 2007: The Physical Science Basis* (Cambridge University Press, September 2007).

<sup>b</sup>Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF<sub>6</sub>).

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

## 1.2. Energy-related carbon dioxide emissions by fuel and end use

Energy-related CO<sub>2</sub> emissions dominate total U.S. greenhouse gas emissions (Figure 1). The figures below show the shares of energy-related CO<sub>2</sub> emissions accounted for by major energy fuels and by energy sectors.

Petroleum is the largest fossil fuel source for energy-related CO<sub>2</sub> emissions, contributing 43 percent of the total (Figure 2).

Coal is the second-largest fossil fuel contributor, at 35 percent. Although coal produces more CO<sub>2</sub> per unit of energy produced than petroleum does (i.e., coal has a higher carbon intensity than petroleum), petroleum consumption—in terms of British thermal units (Btu)—made up 45.0 percent of total fossil fuel energy consumption in 2009, as compared with coal’s 25 percent.

Natural gas, with a carbon intensity that is about 55 percent of the carbon intensity of coal and 75 percent of the carbon intensity of petroleum, accounted for 30 percent of U.S. fossil energy use in 2009 but only 22 percent of total energy-related CO<sub>2</sub> emissions.

In Figure 3, 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.

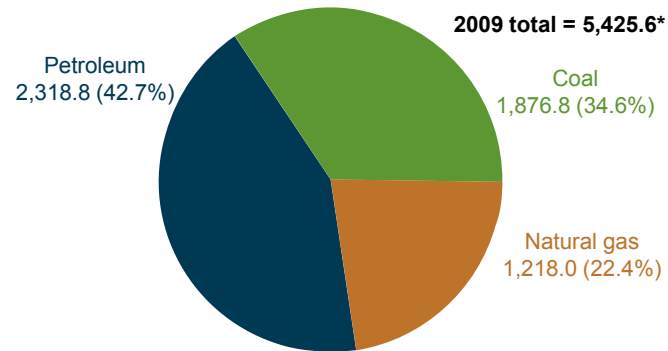
The electric power sector is the largest source, accounting for 40 percent of all energy-related CO<sub>2</sub> emissions. The electric power sector consists of those entities whose primary business is the production of electricity.

The transportation sector is the second-largest source, at 34 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 together accounted for 26 percent of total CO<sub>2</sub> emissions in 2009.

**Figure 2. U.S. energy-related carbon dioxide emissions by major fuel, 2009**

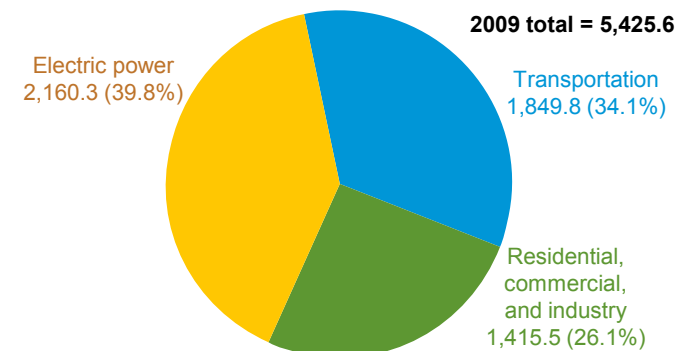
Million metric tons carbon dioxide



\*Includes small amounts of CO<sub>2</sub> from non-biogenic municipal solid waste and geothermal energy (0.2 percent of total).

**Figure 3. U.S. energy-related carbon dioxide emissions by sector, 2009**

Million metric tons carbon dioxide



Note: Elsewhere in this report, electric power sector emissions are allocated to the end-use sectors by sales. These values are unadjusted for bunker fuels and U.S. Territories.

### 1.3. Decomposition of U.S. greenhouse gas changes

While the U.S. economy declined by 2.6 percent in 2009, a 5.8-percent decrease in total greenhouse gas emissions meant that U.S. greenhouse gas intensity decreased by 3.3 percent from 2008 to 2009.

Because energy-related CO<sub>2</sub> is such a large component of greenhouse gas emissions, it is helpful to analyze energy-related CO<sub>2</sub> emissions by using an equation known as the Kaya identity. The Kaya identity relates percent changes in energy-related CO<sub>2</sub> emissions to changes in the economy through the following approximation:

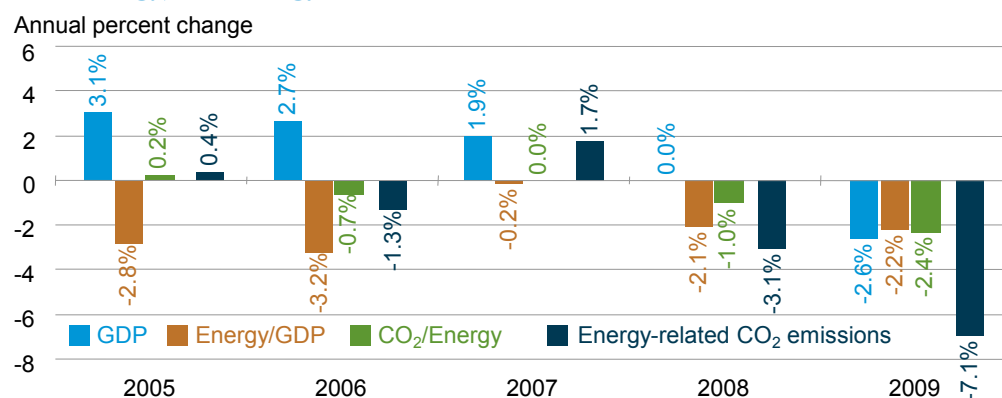
$$\% \Delta \text{CO}_2 \approx \% \Delta \text{GDP} + \% \Delta (\text{Energy}/\text{GDP}) + \% \Delta (\text{CO}_2/\text{Energy})$$

where % $\Delta$  represents percentage change.

As indicated in Figure 4, energy-related CO<sub>2</sub> emissions have declined in every year since 2005, with the exception of 2007. Although this is not a long period of time, it is instructive to examine the reasons for the change in trend as compared with the period from 1990 to 2005. A lower rate of economic growth from 2005 to 2009 (averaging 0.5 percent per year, as compared with the average of 3.1 percent per year from 1990 to 2005) is a key driver of the changing trend in emissions.

Over both periods, the energy intensity of the economy declined by an average of 1.9 percent per year, as the trend toward a service-oriented, post-industrial U.S. economy continued. In contrast, a drop in the carbon intensity of the U.S. energy supply may represent a new trend: from 1990 to 2005, carbon intensity increased on average by 1.0 percent per year, but from 2005 to 2009 it fell by an average of 1.9 percent per year, as natural gas was increasingly substituted for coal, and renewable electricity generation continued to grow. In combination, these factors resulted in a 7.1-percent decline in energy-related CO<sub>2</sub> emissions from 2008 to 2009 (Table 2).

**Figure 4. Annual changes in Kaya identity terms (GDP, Energy/GDP, CO<sub>2</sub>/Energy) and energy-related carbon dioxide emissions, 2005-2009**



**Table 2. U.S. greenhouse gas intensity and related factors, 1990-2009**

	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Gross domestic product (billion 2005 dollars)	8,033.9	9,093.7	11,226.0	11,840.7	12,263.8	12,638.4	12,976.2	13,228.9	13,228.8	12,880.6
Greenhouse gas emissions (MMTCO <sub>2</sub> e)	6,133.2	6,441.7	6,935.3	6,941.1	7,071.9	7,109.4	7,027.4	7,150.4	6,983.1	6,575.5
Greenhouse gas intensity (MTCO <sub>2</sub> e per million 2005 dollars)	763.4	708.4	617.8	586.2	576.6	562.5	541.6	540.5	527.9	510.5
Change from previous year (percent)										
Energy-related CO <sub>2</sub> emissions		1.1	3.3	0.8	2.0	0.4	-1.3	1.7	-3.1	-7.1
Gross domestic product (GDP)		2.5	4.1	2.5	3.6	3.1	2.7	1.9	0.0	-2.6
Energy/GDP		-0.4	-1.8	-2.1	-1.3	-2.8	-3.2	-0.2	-2.1	-2.2
CO <sub>2</sub> /Energy		-1.1	1.0	0.5	-0.2	0.2	-0.7	0.0	-1.0	-2.4
Greenhouse gas intensity		-1.6	-1.3	-1.6	-1.6	-2.4	-3.7	-0.2	-2.3	-3.3

## 1.4. Greenhouse gas emissions in the U.S. economy

Figure 5 illustrates the flow of U.S. greenhouse gas emissions in 2009, from their sources to their end uses. The left side shows CO<sub>2</sub> 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 CO<sub>2</sub> emissions from direct fuel combustion and those from 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).

**CO<sub>2</sub>.** CO<sub>2</sub> emission sources include energy-related emissions (primarily from fossil fuel consumption) and emissions from industrial processes. The energy subtotal (5,426 MMTCO<sub>2</sub>e) includes petroleum, coal, and natural gas consumption and smaller amounts from nonbiogenic 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 (87 MMTCO<sub>2</sub>e) include CO<sub>2</sub> stripped from natural gas and flared natural gas, cement manufacture, limestone and dolomite calcination, soda ash manufacture and consumption, CO<sub>2</sub> manufacture, and aluminum production. The sum of the energy subtotal and industrial processes equals unadjusted CO<sub>2</sub> emissions (5,513 MMTCO<sub>2</sub>e). The energy component of unadjusted emissions can be divided into direct fuel use (3,265 MMTCO<sub>2</sub>e) and fuel converted to electricity (2,160 MMTCO<sub>2</sub>e).

**Non-CO<sub>2</sub> gases.** Methane (731 MMTCO<sub>2</sub>e) and nitrous oxide (220 MMTCO<sub>2</sub>e) sources include emissions related to energy, agriculture, waste management, and industrial processes. High-GWP gases (178 MMTCO<sub>2</sub>e) include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF<sub>6</sub>). These gases have a variety of uses in the U.S. economy, including as refrigerants, insulators, solvents, and aerosols; as etching, cleaning, and firefighting agents; and as cover gases in various manufacturing processes.

**Adjustments.** In keeping with the UNFCCC, CO<sub>2</sub> emissions from U.S. Territories (47 MMTCO<sub>2</sub>e) are added to the U.S. total, and CO<sub>2</sub> emissions from fuels used for international transport (both oceangoing vessels and airplanes) (113 MMTCO<sub>2</sub>e) are subtracted to derive total U.S. greenhouse gas emissions (6,576 MMTCO<sub>2</sub>e).

**Emissions by end-use sector.** CO<sub>2</sub> emissions by end-use sector are based on EIA's estimates of energy consumption (direct fuel use and purchased electricity) by sector and on the attribution of industrial process emissions by sector. CO<sub>2</sub> emissions from purchased electricity are allocated to the end-use sectors, based on their shares of total electricity sales. Non-CO<sub>2</sub> 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 on the basis of electricity sales.

**Residential** emissions (1,186 MMTCO<sub>2</sub>e) include energy-related CO<sub>2</sub> emissions (1,172 MMT) and non-CO<sub>2</sub> emissions (14 MMTCO<sub>2</sub>e). The non-CO<sub>2</sub> sources include methane and nitrous oxide emissions from direct fuel use. Non-CO<sub>2</sub> indirect emissions attributable to purchased electricity, including methane and nitrous oxide emissions from electric power generation and SF<sub>6</sub> emissions related to electricity transmission and distribution, are also included.

**Commercial** emissions (1,288 MMTCO<sub>2</sub>e) include both energy-related CO<sub>2</sub> emissions (1,012 MMT) and non-CO<sub>2</sub> emissions (276 MMTCO<sub>2</sub>e). The non-CO<sub>2</sub> emissions include direct emissions from landfills, wastewater treatment plants, and commercial refrigerants, and emissions of methane and nitrous oxide from stationary combustion. Non-CO<sub>2</sub> indirect emissions attributable to purchased electricity, including methane and nitrous oxide emissions from electric power generation and SF<sub>6</sub> emissions related to electricity transmission and distribution, are also included.

**Industrial** emissions (2,240 MMTCO<sub>2</sub>e) include CO<sub>2</sub> emissions (1,505 MMT)—which can be broken down between combustion (1,418 MMT) and process emissions (87 MMT)—and non-CO<sub>2</sub> emissions (735 MMTCO<sub>2</sub>e). The non-CO<sub>2</sub> direct emissions include emissions from agriculture (methane and nitrous oxide), coal mines (methane), petroleum and natural gas pipelines (methane), industrial process emissions (methane, nitrous oxide, HFCs, PFCs, and SF<sub>6</sub>), and direct stationary combustion emissions of methane and nitrous oxide. Non-CO<sub>2</sub> indirect emissions attributable to purchased electricity, including methane and nitrous oxide emissions from electric power generation and SF<sub>6</sub> emissions related to electricity transmission and distribution, are also included.

**Transportation** emissions (1,861 MMTCO<sub>2</sub>e) include energy-related CO<sub>2</sub> emissions from mobile source combustion (1,757 MMT) and non-CO<sub>2</sub> emissions (104 MMTCO<sub>2</sub>e). The non-CO<sub>2</sub> 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.

Figure 5. Greenhouse gas emissions in the U.S. economy

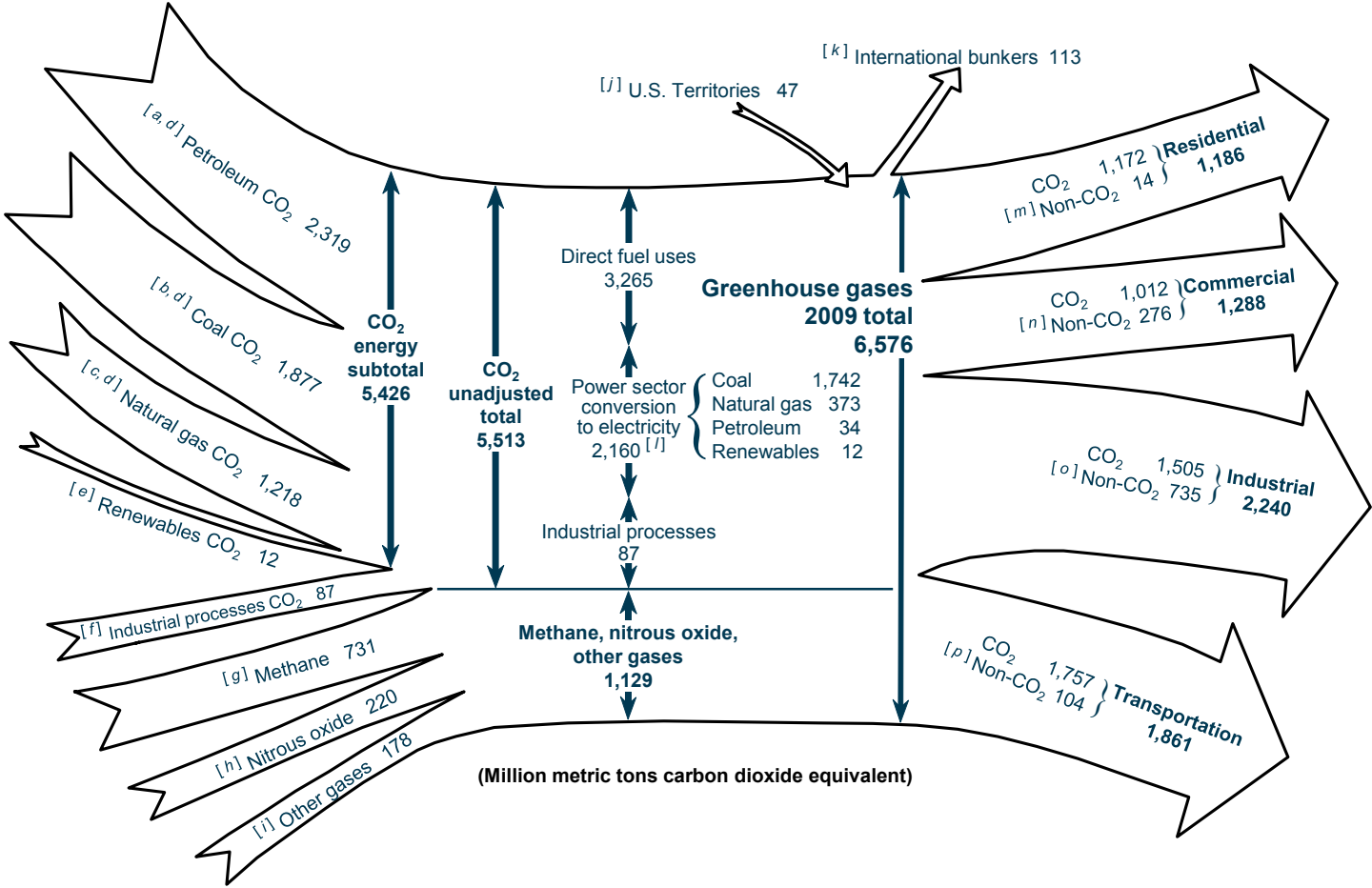


Diagram notes

- [a] CO<sub>2</sub> emissions related to petroleum consumption (includes 64 MMTCO<sub>2</sub> of nonfuel-related emissions).
- [b] CO<sub>2</sub> emissions related to coal consumption (includes 0.3 MMTCO<sub>2</sub> of nonfuel-related emissions).
- [c] CO<sub>2</sub> emissions related to natural gas consumption (includes 13 MMTCO<sub>2</sub> of nonfuel-related emissions).
- [d] Excludes carbon sequestered in nonfuel fossil products.
- [e] CO<sub>2</sub> emissions from the plastics portion of municipal solid waste (11 MMTCO<sub>2</sub>) combusted for electricity generation and very small amounts (0.4 MMTCO<sub>2</sub>) of geothermal-related emissions.
- [f] Includes mainly direct process emissions. Some combustion emissions are included from waste combustion outside the electric power sector and flaring of non-marketed natural gas.
- [g] Includes methane emissions related to energy, agriculture, waste management, and industrial processes.
- [h] Includes nitrous oxide emissions related to agriculture, energy, industrial processes, and waste management.
- [i] Includes hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.
- [j] Includes only energy-related CO<sub>2</sub> emissions from fossil fuels. Emissions are allocated to end-use sectors in proportion to U.S. ratios. Therefore, the sector CO<sub>2</sub> 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] CO<sub>2</sub> emissions from electricity generation in the commercial and industrial sectors are included in those sectors.
  - [m] Non-CO<sub>2</sub>: Direct stationary combustion emissions of methane and nitrous oxide plus indirect power sector emissions of methane, nitrous oxide, and other greenhouse gases.
  - [n] Non-CO<sub>2</sub>: 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-CO<sub>2</sub>: 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-CO<sub>2</sub>: Direct mobile combustion emissions of methane and nitrous oxide. Also, emissions related to transportation refrigerants are included.
- Source:** Estimates presented in this report. CO<sub>2</sub> emissions by end-use sector are based on EIA's estimates of energy consumption by sector and on industrial process emissions. CO<sub>2</sub> emissions from the electric power sector are allocated to the end-use sectors based on electricity sales to the sector. Non-CO<sub>2</sub> 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.

**Table 3. Distribution of total U.S. greenhouse gas emissions by end-use sector, 2009  
(million metric tons carbon dioxide equivalent)**

Greenhouse gas and source	Sector				Total
	Residential	Commercial	Industrial	Transportation	
Carbon dioxide					
Energy-related (adjusted)	1,172.3	1,012.3	1,417.7	1,757.3	5,359.6
Industrial processes	—	—	87.3	—	87.3
<i>Carbon dioxide subtotal</i>	<i>1,172.3</i>	<i>1,012.3</i>	<i>1,505.0</i>	<i>1,757.3</i>	<i>5,446.8</i>
Methane					
Energy					
Coal mining	—	—	86.0	—	86.0
Natural gas systems	—	—	183.0	—	183.0
Petroleum systems	—	—	23.5	—	23.5
Stationary combustion	4.4	1.0	1.6	—	7.1
Stationary combustion: electricity	0.3	0.3	0.2	—	0.8
Mobile sources	—	—	—	2.7	2.7
Waste management					
Landfills	—	179.7	—	—	179.7
Domestic wastewater treatment	—	17.8	—	—	17.8
Industrial wastewater treatment	—	—	10.4	—	10.4
Industrial processes	—	—	4.2	—	4.2
Agriculture					
Enteric fermentation	—	—	144.9	—	144.9
Animal waste	—	—	58.3	—	58.3
Rice cultivation	—	—	11.2	—	11.2
Crop residue burning	—	—	1.4	—	1.4
<i>Methane subtotal</i>	<i>4.7</i>	<i>198.8</i>	<i>524.7</i>	<i>2.7</i>	<i>730.9</i>
Nitrous oxide					
Agriculture					
Nitrogen fertilization of soils	—	—	139.6	—	139.6
Solid waste of animals	—	—	20.8	—	20.8
Crop residue burning	—	—	0.6	—	0.6
Energy					
Mobile combustion	—	—	—	28.8	28.8
Stationary combustion	0.9	0.3	3.7	—	5.0
Stationary combustion: electricity	3.3	3.2	2.2	—	8.7
Industrial processes	—	—	10.8	—	10.8
Waste management					
Human sewage in wastewater	—	4.8	—	—	4.8
Waste combustion	—	—	—	—	0.0
Waste combustion: electricity	0.2	0.2	0.1	—	0.4
<i>Nitrous oxide subtotal</i>	<i>4.4</i>	<i>8.4</i>	<i>177.9</i>	<i>28.9</i>	<i>219.6</i>

(continued on page 7)

**Table 3. Distribution of total U.S. greenhouse gas emissions by end-use sector, 2009 (continued)**  
**(million metric tons carbon dioxide equivalent)**

Greenhouse gas and source	Sector				Total
	Residential	Commercial	Industrial	Transportation	
Hydrofluorocarbons (HFCs)					
HFC-23	—	—	17.6	—	17.6
HFC-32	—	1.7	—	—	1.7
HFC-125	—	27.2	—	—	27.2
HFC-134a	—	—	—	72.4	72.4
HFC-143a	—	25.9	—	—	25.9
HFC-236fa	—	1.4	—	—	1.4
<i>HFCs subtotal</i>	<i>0.0</i>	<i>56.3</i>	<i>17.6</i>	<i>72.4</i>	<i>146.3</i>
Perfluorocarbons (PFCs)					
CF <sub>4</sub>	—	—	4.0	—	4.0
C <sub>2</sub> F <sub>6</sub>	—	—	4.1	—	4.1
NF <sub>3</sub> , C <sub>3</sub> F <sub>8</sub> , and C <sub>4</sub> F <sub>8</sub>	—	—	0.5	—	0.5
<i>PFCs subtotal</i>	<i>0.0</i>	<i>0.0</i>	<i>8.6</i>	<i>0.0</i>	<i>8.6</i>
Other HFCs, PFCs/PFPEs	—	7.9	—	—	7.9
Sulfur hexafluoride (SF <sub>6</sub> )					
Electric applications	4.8	4.5	3.2	—	12.4
Other sources	—	—	2.9	—	2.9
<i>SF<sub>6</sub> subtotal</i>	<i>4.8</i>	<i>4.9</i>	<i>6.1</i>	<i>0.0</i>	<i>15.4</i>
<b>Total greenhouse gas emissions</b>	<b>1,186.2</b>	<b>1,288.3</b>	<b>2,239.9</b>	<b>1,861.2</b>	<b>6,575.5</b>

### 1.5. U.S. emissions in a global perspective

Total U.S. energy-related CO<sub>2</sub> emissions in 2007 (including nonfuel uses of fossil fuels) are estimated at 6,022 MMT—about 20 percent of the 2007 world total for energy-related CO<sub>2</sub> emissions, estimated at 29,728 MMT (Table 4).

CO<sub>2</sub> 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, South Korea, and Australia/New Zealand—were estimated at 13,711 MMT in 2007, or 46 percent of the world total, with the remaining 54 percent of worldwide energy-related CO<sub>2</sub> emissions (16,017 MMT) estimated to have come from non-OECD countries (Figure 6).

In EIA's *International Energy Outlook 2010 (IEO2010)* 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 *IEO2010*.

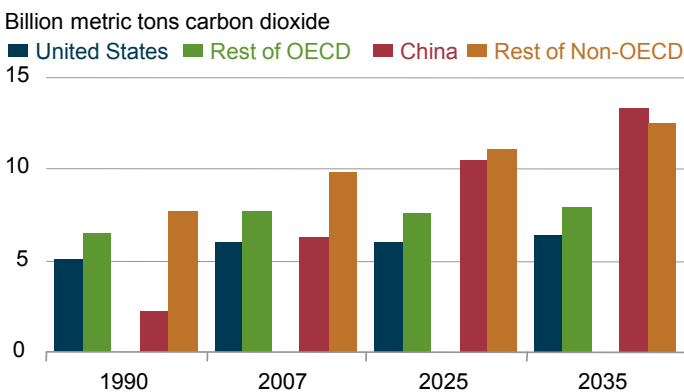
U.S. energy-related CO<sub>2</sub> emissions are projected to increase by an average of 0.2 percent per year from 2007 to 2035 in the *Annual Energy Outlook 2011 (AEO2011)* Reference case, while emissions from the non-OECD economies (*IEO2010* Reference case) grow by 1.7 percent per year. Both rates 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 CO<sub>2</sub> emissions is projected to fall to 15.8 percent (6,320 MMT out of a global total of 39,975 MMT) in 2035 (Figure 7).

China's share of global energy-related CO<sub>2</sub> emissions is projected to grow from 21 percent in 2007 to 31 percent in 2035, and China accounts for 56 percent of the projected increase in world emissions over the period. India accounts for the second-largest share of the projected increase, 7 percent.

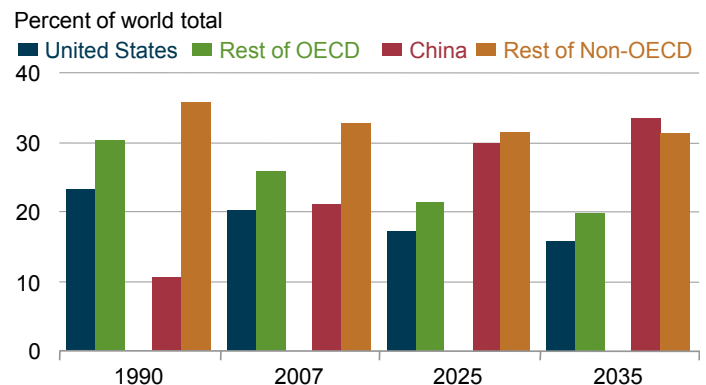
**World energy-related carbon dioxide emissions, 1990, 2005, 2007, and 2035**

	1990	2005	2007	2035
Estimated emissions (million metric tons)	21,537	28,329	29,728	42,386
Change from 1990 (million metric tons)		6,793	8,191	20,849
(percent)		31.5%	38.0%	96.8%
Average annual change from 1990 (percent)		1.8%	1.9%	1.7%
Change from 2005 to 2035 (million metric tons)				14,057
(percent)				49.6%
Annual average change from 2005 to 2035 (percent)				1.4%

**Figure 6. World carbon dioxide emissions by region, 1990, 2007, 2025, and 2035**



**Figure 7. Regional shares of world carbon dioxide emissions, 1990, 2007, 2025, and 2035**





**Table 4. World energy-related carbon dioxide emissions by region, 1990-2035**  
(million metric tons carbon dioxide, percent share of world emissions)

Region/Country	History				Projections					Average annual percent change, 2007-2035 <sup>a</sup>
	1990	2005	2006	2007	2015	2020	2025	2030	2035	
OECD										
OECD North America	5,812	7,034	6,940	7,052	6,683	6,827	7,078	7,360	7,699	0.3
	(27.0%)	(24.8%)	(24.1%)	(23.7%)	(21.2%)	(20.2%)	(19.5%)	(18.8%)	(18.2%)	(5.1%)
United States <sup>b</sup>	5,039	5,996	5,918	6,022	5,679	5,774	5,931	6,110	6,315	0.2
	(23.4%)	(21.2%)	(20.5%)	(20.3%)	(18.1%)	(17.1%)	(16.3%)	(15.6%)	(14.9%)	(2.3%)
Canada	471	628	596	586	553	554	579	609	643	0.3
	(2.2%)	(2.2%)	(2.1%)	(2.0%)	(1.8%)	(1.6%)	(1.6%)	(1.6%)	(1.5%)	(0.5%)
Mexico	302	410	426	444	451	499	568	641	741	1.8
	(1.4%)	(1.4%)	(1.5%)	(1.5%)	(1.4%)	(1.5%)	(1.6%)	(1.6%)	(1.7%)	(2.3%)
OECD Europe	4,149	4,398	4,426	4,386	4,110	4,042	4,037	4,052	4,107	-0.2
	(19.3%)	(15.5%)	(15.3%)	(14.8%)	(13.1%)	(12.0%)	(11.1%)	(10.3%)	(9.7%)	-(2.2%)
OECD Asia	1,595	2,203	2,196	2,273	2,149	2,201	2,263	2,318	2,388	0.2
	(7.4%)	(7.8%)	(7.6%)	(7.6%)	(6.8%)	(6.5%)	(6.2%)	(5.9%)	(5.6%)	(0.9%)
Japan	1,054	1,254	1,253	1,262	1,102	1,114	1,106	1,085	1,064	-0.6
	(4.9%)	(4.4%)	(4.3%)	(4.2%)	(3.5%)	(3.3%)	(3.0%)	(2.8%)	(2.5%)	-(1.6%)
South Korea	243	496	486	516	535	570	627	687	757	1.4
	(1.1%)	(1.8%)	(1.7%)	(1.7%)	(1.7%)	(1.7%)	(1.7%)	(1.8%)	(1.8%)	(1.9%)
Australia/ New Zealand	298	453	457	495	512	517	530	546	567	0.5
	(1.4%)	(1.6%)	(1.6%)	(1.7%)	(1.6%)	(1.5%)	(1.5%)	(1.4%)	(1.3%)	(0.6%)
<b>Total OECD</b>	<b>11,556</b>	<b>13,635</b>	<b>13,562</b>	<b>13,711</b>	<b>12,942</b>	<b>13,070</b>	<b>13,378</b>	<b>13,730</b>	<b>14,194</b>	<b>0.1</b>
	<b>(53.7%)</b>	<b>(48.1%)</b>	<b>(47.0%)</b>	<b>(46.1%)</b>	<b>(41.1%)</b>	<b>(38.7%)</b>	<b>(36.8%)</b>	<b>(35.0%)</b>	<b>(33.5%)</b>	<b>(3.8%)</b>

(continued on page 10)

<sup>a</sup>Values in parentheses indicate percentage share of total world absolute change from 2007 to 2035.

<sup>b</sup>Includes 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.

**Table 4. World energy-related carbon dioxide emissions by region, 1990-2035 (continued)**  
**(million metric tons carbon dioxide, percent share of world emissions)**

Region/Country	History				Projections					Average annual percent change, 2007-2035 <sup>a</sup>
	1990	2005	2006	2007	2015	2020	2025	2030	2035	
Non-OECD										
Non-OECD Europe and Eurasia	4,246	2,843	2,876	2,896	2,882	2,914	2,965	3,042	3,172	0.3
	(19.7%)	(10.0%)	(10.0%)	(9.7%)	(9.2%)	(8.6%)	(8.2%)	(7.8%)	(7.5%)	(2.2%)
Russia	2,393	1,650	1,672	1,663	1,642	1,648	1,666	1,715	1,811	0.3
	(11.1%)	(5.8%)	(5.8%)	(5.6%)	(5.2%)	(4.9%)	(4.6%)	(4.4%)	(4.3%)	(1.2%)
Other	1,853	1,193	1,204	1,233	1,240	1,266	1,299	1,327	1,361	0.4
	(8.6%)	(4.2%)	(4.2%)	(4.1%)	(3.9%)	(3.8%)	(3.6%)	(3.4%)	(3.2%)	(1.0%)
Non-OECD Asia	3,677	8,382	8,830	9,426	11,228	12,971	14,897	16,906	18,984	2.5
	(17.1%)	(29.6%)	(30.6%)	(31.7%)	(35.7%)	(38.5%)	(41.0%)	(43.1%)	(44.8%)	(75.5%)
China	2,293	5,558	5,862	6,284	7,716	9,057	10,514	11,945	13,326	2.7
	(10.6%)	(19.6%)	(20.3%)	(21.1%)	(24.5%)	(26.8%)	(28.9%)	(30.5%)	(31.4%)	(55.6%)
India	573	1,187	1,287	1,399	1,566	1,751	1,905	2,079	2,296	1.8
	(2.7%)	(4.2%)	(4.5%)	(4.7%)	(5.0%)	(5.2%)	(5.2%)	(5.3%)	(5.4%)	(7.1%)
Other Non-OECD Asia	811	1,637	1,681	1,743	1,946	2,163	2,478	2,882	3,362	2.4
	(3.8%)	(5.8%)	(5.8%)	(5.9%)	(6.2%)	(6.4%)	(6.8%)	(7.4%)	(7.9%)	(12.8%)
Middle East	704	1,395	1,446	1,515	1,939	2,134	2,287	2,450	2,692	2.1
	(3.3%)	(4.9%)	(5.0%)	(5.1%)	(6.2%)	(6.3%)	(6.3%)	(6.2%)	(6.4%)	(9.3%)
Africa	659	982	988	1,011	1,157	1,237	1,347	1,461	1,610	1.7
	(3.1%)	(3.5%)	(3.4%)	(3.4%)	(3.7%)	(3.7%)	(3.7%)	(3.7%)	(3.8%)	(4.7%)
Central and South America	695	1,092	1,133	1,169	1,311	1,407	1,502	1,613	1,734	1.4
	(3.2%)	(3.9%)	(3.9%)	(3.9%)	(4.2%)	(4.2%)	(4.1%)	(4.1%)	(4.1%)	(4.5%)
Brazil	235	366	380	394	478	534	601	682	761	2.4
	(1.1%)	(1.3%)	(1.3%)	(1.3%)	(1.5%)	(1.6%)	(1.7%)	(1.7%)	(1.8%)	(2.9%)
Other Central/South America	460	726	753	775	833	873	901	931	973	0.8
	(2.1%)	(2.6%)	(2.6%)	(2.6%)	(2.6%)	(2.6%)	(2.5%)	(2.4%)	(2.3%)	(1.6%)
<b>Total Non-OECD</b>	<b>9,981</b>	<b>14,694</b>	<b>15,273</b>	<b>16,017</b>	<b>18,517</b>	<b>20,663</b>	<b>22,998</b>	<b>25,472</b>	<b>28,192</b>	<b>2.0</b>
	<b>(46.3%)</b>	<b>(51.9%)</b>	<b>(53.0%)</b>	<b>(53.9%)</b>	<b>(58.9%)</b>	<b>(61.3%)</b>	<b>(63.2%)</b>	<b>(65.0%)</b>	<b>(66.5%)</b>	<b>(96.2%)</b>
<b>Total World</b>	<b>21,537</b>	<b>28,329</b>	<b>28,835</b>	<b>29,728</b>	<b>31,459</b>	<b>33,733</b>	<b>36,376</b>	<b>39,202</b>	<b>42,386</b>	<b>1.3</b>

<sup>a</sup>Values in parentheses indicate percentage share of total world absolute change from 2007 to 2035.

## 1.6. Recent U.S. and international developments in global climate change

### United States: Federal actions

#### U.S. Environmental Protection Agency

Rules for Mandatory Reporting of Greenhouse Gases by 31 industries and emissions sources were finalized by the U.S. Environmental Protection Agency (EPA) in October 2009.<sup>1</sup> Final rules and methods were proposed in April 2010 for a second group of industries: oil and natural gas systems; five industries that emit fluorinated greenhouse gases (GHGs); and facilities that inject and store CO<sub>2</sub> underground for the purposes of geologic sequestration or enhanced oil and gas recovery. The rules were finalized in November and December 2010, with data collection for this second group beginning in January 2011. Reporting rules for the remaining sources from the original proposed rule that were not finalized in October 2009 were finalized in June 2010. This batch of final rules included magnesium production, underground coal mines, industrial wastewater treatment, and industrial landfills. However, the EPA has not acted to finalize the proposed rules for ethanol production, food processing, and coal suppliers.

In December 2009, the EPA issued its final endangerment and cause or contribute findings for greenhouse gas emissions from light-duty vehicles, classifying them as a danger to public health and welfare. As a result, the EPA and the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA), in April 2010, jointly published Corporate Average Fuel Economy (CAFE) and GHG emissions standards to regulate emissions from light-duty vehicles of model years 2012-2016.

In May 2010, a Presidential memo declared that the rulemaking to set standards for light-duty vehicles of model years 2017-2025 would begin, and also directed the EPA and NHTSA for the first time to draft efficiency rules for medium- and heavy-duty engines and vehicles.<sup>2</sup> A Notice of Intent to conduct a joint rulemaking on light-duty vehicles for model years 2017-2025, which includes the Agencies' initial assessment of a potential future standard, was released in September 2010.<sup>3</sup> Proposed rules covering model years 2014-2018 were announced in October 2010. Also in May 2010, the EPA published its Tailoring Rule, which details the Agency's plans to begin regulating GHG emissions from large industrial GHG sources, including power generation facilities, industrial boilers, and oil refineries.<sup>4</sup> The EPA began requiring Clean Air Act (CAA) permits for stationary GHG sources under the Prevention of Significant Deterioration (PSD) requirements of the CAA in January 2011.<sup>5</sup> In August 2010, the EPA announced plans to amend or take over State permitting operations in cases where the State Implementation Plan (SIP) for PSD permitting did not adequately address GHG emissions, as would be required by the CAA.<sup>6</sup>

#### Other Federal agencies and offices

**Implementation of Executive Order 13514 (EO 13514).** The White House Council on Environmental Quality (CEQ) and DOE's Federal Energy Management Program (FEMP) developed guidance and calculation methodologies for Federal agencies to conduct and report their GHG inventories under the requirements of EO 13514, *Federal Leadership in Environmental, Energy, and Economic Performance* (October 5, 2009). The final guidelines for FY 2008 and FY 2010 inventory submissions were published in October 2010. CEQ and FEMP will continue to update the guidelines and methodologies to cover additional emissions sources and provide improved calculation methods for future inventory years.

Individual agencies submitted their Strategic Sustainability Performance Plans in June 2010, detailing their strategies to help reach the overall Federal Government-wide goal to reduce Scope 1 and 2 emissions by 28 percent and Scope 3 emissions by 13 percent.<sup>7</sup>

**New home appliance efficiency standards agreement.** In August, a coalition of energy and water efficiency and consumer advocacy groups, along with major home appliance manufacturers and their industry association, announced an agreement to increase the efficiency of Energy Star home appliances and to seek tax credits for the production of super-efficient appliances.

**American Recovery and Reinvestment Act.** As of September 30, 2010, the close of the government's fiscal year 2010, DOE had used \$35.2 billion in Recovery Act appropriations and \$7.5 billion in Treasury tax incentive programs to support more than \$100 billion

<sup>1</sup>U.S. Environmental Protection Agency, "Climate Change—Regulatory Initiatives: Greenhouse Gas Reporting Program," website [www.epa.gov/climatechange/emissions/ghgrulemaking.html](http://www.epa.gov/climatechange/emissions/ghgrulemaking.html).

<sup>2</sup>National Highway Traffic Safety Administration, "NHTSA and EPA To Propose Greenhouse Gas and Fuel Efficiency Standards for Medium- and Heavy-Duty Trucks; Begin Process for Further Light-Duty Standards: Fact Sheet" (May 2010), website [www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/LD\\_HD\\_FE\\_FactSheet.pdf](http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/LD_HD_FE_FactSheet.pdf).

<sup>3</sup>U.S. Environmental Protection Agency and U.S. Department of Transportation, "Notice of Upcoming Joint Rulemaking To Establish 2017 and Later Model Year Light Duty Vehicle GHG Emissions and CAFE Standards" (September 30, 2010), website [www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/2017+CAFE\\_and\\_GHG\\_Notice\\_of\\_Intent.pdf](http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/2017+CAFE_and_GHG_Notice_of_Intent.pdf).

<sup>4</sup>U.S. Environmental Protection Agency, "Regulations & Standards," website [www.epa.gov/NSR/actions.html](http://www.epa.gov/NSR/actions.html); and Pew Center on Global Climate Change, "EPA's 'Tailoring' Rule," website [www.pewclimate.org/federal/executive/epa-tailoring-rule](http://www.pewclimate.org/federal/executive/epa-tailoring-rule).

<sup>5</sup>U.S. Environmental Protection Agency, "Proposed Rules on Clean Air Act Permits for Sources of Greenhouse Gas Emissions Under the Prevention of Significant Deterioration Program," website [www.epa.gov/NSR/documents/20100810SIPFIPFactSheet.pdf](http://www.epa.gov/NSR/documents/20100810SIPFIPFactSheet.pdf).

<sup>6</sup>"Action To Ensure Authority To Issue Permits Under the Prevention of Significant Deterioration Program to Sources of Greenhouse Gas Emissions: Federal Implementation Plan," *Federal Register* (September 2, 2010), website [www.federalregister.gov/articles/2010/09/02/2010-21706/action-to-ensure-authority-to-issue-permits-under-the-prevention-of-significant-deterioration](http://www.federalregister.gov/articles/2010/09/02/2010-21706/action-to-ensure-authority-to-issue-permits-under-the-prevention-of-significant-deterioration); and "Proposed Rules," *Federal Register* (September 2, 2010), website [www.gpo.gov/fdsys/pkg/FR-2010-09-02/pdf/2010-21706.pdf](http://www.gpo.gov/fdsys/pkg/FR-2010-09-02/pdf/2010-21706.pdf).

<sup>7</sup>Scope 1 emissions include direct GHG emissions from sources that are owned or controlled by a Federal agency. Scope 2 emissions include direct GHG emissions that result from the generation of electricity, heat, or steam purchased by a Federal agency. Scope 3 emissions include GHG emissions from sources not owned or directly controlled by a Federal agency, such as vendor supply chains, delivery services, and employee travel and commuting.

in clean energy projects. This funding went to support more than 8,000 projects across the country, selected from among more than 30,000 applications.<sup>8</sup>

## United States: Regional and State initiatives

### Regional GHG initiatives

The Western Climate Initiative (WCI) consists of seven western U.S. member States, four Canadian member provinces, and an additional 14 observing States and provinces in the United States, Canada, and Mexico. The U.S. member States hold 19 percent of the total U.S. population and produce 20 percent of U.S. GDP.<sup>9</sup> In July 2010, WCI released its comprehensive design strategy, which outlines its plan to reduce regional GHG emissions to 15 percent below 2005 levels by 2020.

### State energy and GHG legislation

A number of new energy efficiency, renewable energy, and climate change laws were enacted in States across the country in 2010,<sup>10</sup> including: RPS amendments (Maryland increased its solar carve-out, and Colorado increased its solar energy target to 30 percent of total energy production by 2020); an ocean energy development goal (Maine); electric vehicle incentives (Maryland); a carbon tax (Montgomery County, Maryland); a low carbon fuel standard for vehicle fuels (California); energy efficiency standards for utilities (Massachusetts) and for new commercial buildings (California); smart grid policy development (Maine); and planning for reductions in GHG emissions from the transportation sector (Oregon).

In July 2010, the Governors of Rhode Island and Massachusetts signed a Memorandum of Understanding (MOU) on the development of offshore wind energy facilities in the Federal waters off of their coasts. The MOU requires that the States coordinate and collaborate on wind energy efforts in an "area of mutual interest" in their overlapping shared waters.<sup>11</sup>

## International actions

### UNFCCC and the Kyoto Protocol

The 15th Conference of the Parties (COP-15) and 5th Meeting of the Parties to the Kyoto Protocol (CMP-5) were held in Copenhagen, Denmark, in December 2009. The main product of the meetings was the Copenhagen Accord, which had been agreed to by 140 of the 192 UNFCCC nations as of November 2010.<sup>12</sup> The Accord is a non-binding statement pledging action on:

- A goal to limit global warming to 2 degrees Celsius
- Submission of mitigation goals by individual nations
- Funding \$30 billion in "new and additional" financing for mitigation, adaptation, technology development, and capacity building in developing nations over the 2010-2012 period, increasing to \$100 billion per year by 2020
- Reporting and verification of national inventories and mitigation actions
- Establishment of a mechanism to use developed country financing in support of efforts to reduce emissions from deforestation and forest degradation and to enhance carbon sinks.

COP-16 and CMP-6 convened from November 29 through December 10, 2010, in Cancun, Mexico. The Parties adopted a package of agreements that reaffirms and builds upon the Copenhagen Accord of 2009. The Cancun Agreements<sup>13</sup> include the following actions:

- Reaffirm the Accord's goal to limit global average temperature rise to 2 degrees Celsius above pre-industrial levels
- Formally recognize the reduction pledges made in the Copenhagen Accord for the first time by "taking note" of the pledges made by both developed and developing nations
- Indicate that the Clean Development Mechanism (CDM) and Joint Implementation, by which Annex I nations may use non-Annex I mitigation projects to offset their emissions, will continue beyond 2012
- Create a new "standardized baseline" process for some types of CDM projects

<sup>8</sup>U.S. Department of Energy, Secretary Stephen Chu, "Progress" (email to DOE employees) (October 6, 2010).

<sup>9</sup>Western Climate Initiative, *Design for the WCI Regional Program*, "Design Summary and Documentation" (July 27, 2010), p. 3, website <http://westernclimateinitiative.org/component/remository/func-startdown/281>; and Pew Center on Global Climate Change, "Western Climate Initiative (WCI) Partners Release Comprehensive Strategy to Address Climate Change," website [www.pewclimate.org/news/WCI\\_design/WCI\\_07\\_10](http://www.pewclimate.org/news/WCI_design/WCI_07_10).

<sup>10</sup>Pew Center on Global Climate Change, "States News," website [www.pewclimate.org/states-regions/news](http://www.pewclimate.org/states-regions/news); and Environment Northeast, "2010.01.29- New York Times-Massachusetts Sets Ambitious Energy Standards" (January 1, 2010), website [www.env-ne.org/resources/open/p/id/1048](http://www.env-ne.org/resources/open/p/id/1048).

<sup>11</sup>Rhode Island Government, "Rhode Island and Massachusetts Sign Agreement To Collaborate on the Development of Offshore Wind in Federal Waters" (July 26, 2010), website [www.ri.gov/press/view/11879](http://www.ri.gov/press/view/11879).

<sup>12</sup>United Nations Framework Convention on Climate Change, "Copenhagen Accord," website <http://unfccc.int/home/items/5262.php>.

<sup>13</sup>Pew Center on Global Climate Change, "Sixteenth Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change and Sixth Session of the Meeting of the Parties to the Kyoto Protocol" (December, 2010), website [www.pewclimate.org/docUploads/cancun-climate-conference-cop16-summary.pdf](http://www.pewclimate.org/docUploads/cancun-climate-conference-cop16-summary.pdf); and United Nations Framework Convention on Climate Change, "UN Climate Change Conference in Cancun Delivers Balanced Package of Decisions, Restores Faith in Multilateral Process" (December 11, 2010), website [http://unfccc.int/files/press/news\\_room/press\\_releases\\_and\\_advisories/application/pdf/pr\\_20101211\\_cop16\\_closing.pdf](http://unfccc.int/files/press/news_room/press_releases_and_advisories/application/pdf/pr_20101211_cop16_closing.pdf).

- Set out a reporting framework that continues annual submission of inventories by developed nations and creates a new registry for developing nations to report on mitigation actions that receive international financing and includes general guidelines for reporting autonomous actions
- Provide a framework to develop financing and other policies to Reduce Emissions from Deforestation and Degradation (REDD+) and call upon developing nations to develop national strategies and reference levels for future efforts to reduce deforestation
- Establish the World Bank as interim trustee of The Green Climate Fund, which seeks to raise \$100 billion per year from public and private sources by 2020 to support greenhouse gas mitigation efforts in developing countries
- Set up the Cancun Adaptation Framework to formalize and outline efforts to enhance adaptation activities by all UNFCCC members
- Establish the Technology Mechanism to assist developing countries with identification, transfer, and application of appropriate low-carbon technologies.

### Montreal Protocol

The United States, Canada, and Mexico continued to move forward with their proposal, first announced in 2009, to amend the Montreal Protocol to include a binding schedule for phasing down production and consumption of 20 hydrofluorocarbons (HFCs). The proposal calls for developed countries to reduce their production and consumption of the 20 HFCs to 15 percent of a 2004-2006 average baseline by 2033, and for developing nations to meet the same level by 2043. The proposal was considered at the 22nd Meeting of the Parties to the Montreal Protocol in Bangkok in November. The United States, Canada, and Mexico also offered a proposal to increase project-based efforts to control emissions from HFC-23 and HCFC-22 production.<sup>14</sup> (For more information on domestic efforts to reduce emissions of high-GWP gases, see Chapter 5.)

### Major Economies Forum

The 6th, 7th, and 8th Meetings of the Leaders' Representatives to the Major Economies Forum on Energy and Climate Change convened during 2010.<sup>15</sup> Representatives of the 17 major economies, the United Nations, and guest smaller nations discussed the path forward after COP-15 in Copenhagen and toward COP-16 in Cancun. Discussions centered around further development of the Copenhagen Accord and goals for progress in Cancun, including an emphasis on monitoring, reporting, verification, and transparency; quick implementation of the Accord's Fast Start Financing provisions; the future of the Kyoto Protocol; and different notions of equity. Separately, a Clean Energy Ministerial meeting track was launched to advance initiatives related to energy supply, energy efficiency, and energy access. The Ministerial met in July to develop steps toward accelerated deployment of clean energy technologies and will meet again in April 2011 in Abu Dhabi.<sup>16</sup>

### Bilateral and multilateral agreements

The U.S. State Department signed two memoranda of understanding (MOU) in 2010 related to cooperation on greenhouse gas emissions. In March, the United States signed an MOU with Brazil establishing a "Climate Change Policy Dialogue," which aims to increase cooperation between the two nations on energy efficiency, capacity building, and combating deforestation.<sup>17</sup> In July, the United States and China signed an MOU to cooperate in the development of clean energy and energy efficiency technologies and engage in a policy dialog.<sup>18</sup>

<sup>14</sup>United Nations Environment Programme, "Issues for Discussion by and Information for the Attention of the Twenty-Second Meeting of the Parties" (July 9th, 2010), website [http://ozone.unep.org/Meeting\\_Documents/mop/22mop/MOP-22-2E.pdf](http://ozone.unep.org/Meeting_Documents/mop/22mop/MOP-22-2E.pdf).

<sup>15</sup>Major Economies Forum on Energy and Climate, "Past Meetings," website [www.majoreconomiesforum.org/past-meetings/](http://www.majoreconomiesforum.org/past-meetings/).

<sup>16</sup>Clean Energy Ministerial, "2010 Clean Energy Ministerial," website <http://cleanenergyministerial.org/>.

<sup>17</sup>U.S. Department of State, "Secretary Clinton and Brazilian Foreign Minister Amorim Announce Increased Cooperation on Climate Change" (March 3, 2010), website [www.state.gov/r/pa/prs/ps/2010/03/137723.htm](http://www.state.gov/r/pa/prs/ps/2010/03/137723.htm).

<sup>18</sup>U.S. Department of State, "U.S.-China Memorandum of Understanding to Enhance Cooperation on Climate Change, Energy and the Environment" (July 28, 2010), website [www.state.gov/r/pa/prs/ps/2009/july/126592.htm](http://www.state.gov/r/pa/prs/ps/2009/july/126592.htm).

## 1.7. Special topic: Energy and carbon initiatives at the U.S. Department of Energy

Under EO 13514, all Federal Government agencies are required to develop integrated sustainability plans that include greenhouse gas emission reductions; efficient water use; waste reduction and pollution prevention; and increased efficiency in buildings, products, and vehicle fleets.<sup>19</sup> At the U.S. Department of Energy (DOE), the mission of the Federal Energy Management Program (FEMP) is to facilitate the Federal Government's implementation of sound, cost-effective energy management and investment practices in order to enhance the Nation's energy security and environmental stewardship. Serving its mission, FEMP assists DOE and other agencies in planning and implementing strategies to achieve conservation, efficiency, and renewable energy goals under EO 13514 and other mandates.

DOE has more than 15,000 Federal employees in offices and laboratories around the country. Under the EO 13514 requirement to quantify Agency GHG emissions, DOE calculated a fiscal year (FY) 2008 baseline of 5 MMTCO<sub>2</sub>e and established a goal of a 28-percent absolute reduction in its emissions by 2020.<sup>20</sup>

In October 2010, FEMP released its *Annual GHG and Sustainability Data Report, Version 1.0* to coincide with the release of the *Federal Greenhouse Gas Accounting and Reporting Guidance* and *Technical Support Document* by the White House Council on Environmental Quality. The documents and reporting tool aid Federal agencies in gauging their progress toward goals set under EO 13514 by providing guidance and the means for the necessary data collection.<sup>21</sup> The *Data Report* includes reporting requirements for facility and operational energy and water use, as well as calculation of Federal fleet fuel use, fulfilling previous FEMP requirements. FEMP will continue to release updated versions of the *Data Report* to aid agencies in realizing their EO 13514 goals. Notable initiatives contributing to DOE's efforts to achieve EO 13514 goals are described below.

### DOE Headquarters facilities

DOE Headquarters (HQ) is located in the James Forrestal building in downtown Washington, DC, and in Germantown, MD. The HQ facilities house more than 5,800 of the Agency's Federal and contract employees. Initiatives to increase energy savings and efficiency at DOE HQ buildings include the following.

#### Solar array

Installed on the roof of the Forrestal building in September 2008, the solar array generates about 235,000 kilowatthours of electricity per year. The array is also important for technology demonstration and testing purposes. In addition to the main configuration, the array contains several examples of solar panel technologies, along with monitoring stations to measure power generation in relation to weather conditions.

#### Energy savings

In December 2009, DOE entered into an Energy Savings Performance Contract (ESPC) involving a large-scale HQ retrofit project. An ESPC allows DOE to finance the project with minimal initial cost, because the installation costs will be offset by monetary savings associated with reduced resource consumption.<sup>22</sup> The project focuses on reducing energy consumption in the Forrestal building and water consumption at the Germantown facilities. Construction is scheduled to be completed by December 2011. The efforts are expected to result in reductions of energy consumption by 22 percent at the Forrestal building and water consumption by 11 percent in Germantown.

In spring 2010, the Forrestal corridor lighting system was rewired to allow for all lights, with the exception of emergency lighting, to be turned off during night and weekend hours. This upgrade should reduce energy consumption by about 280,000 kilowatthours per year.

#### Forrestal west and south buildings cool roofs

DOE has completed a "cool roof" on the cafeteria and plans to complete one for the south building at the Forrestal complex over the summer of 2011. The project includes roof engineering designs that will reflect sunlight and emit heat more efficiently than existing roofs, reducing energy consumption and costs associated with summertime cooling. It also includes solar hot water heating for the cafeteria, energy savings and life-cycle cost evaluation, and other technical and economic analyses.

(continued on page 15)

<sup>19</sup>U.S. Department of Energy, Energy Efficiency & Renewable Energy, "Energy Management at DOE" (May 2010), website [www1.eere.energy.gov/femp/about/energymanage.html](http://www1.eere.energy.gov/femp/about/energymanage.html).

<sup>20</sup>A. Lawrence, "Implementing Executive Order 13514, Federal Leadership in Environmental, Energy, and Economic Performance at the Department of Energy" (March 2010), website [www.hss.energy.gov/nuclearsafety/env/training/eo13514\\_overview\\_presentation.pdf](http://www.hss.energy.gov/nuclearsafety/env/training/eo13514_overview_presentation.pdf), slide 30, "DOE Scope 1 and 2 GHGs."

<sup>21</sup>Federal Facilities Environmental Stewardship & Compliance Assistance Center, "FEMP Releases Greenhouse Gas Inventory Reporting Tool for Federal Agencies" (October 2010), website [www.fedcenter.gov/Announcements/index.cfm?id=16388&page\\_id=1854](http://www.fedcenter.gov/Announcements/index.cfm?id=16388&page_id=1854).

<sup>22</sup>U.S. Department of Energy, Energy Efficiency & Renewable Energy, "Energy Savings Performance Contracts" (September 2010), website [www1.eere.energy.gov/femp/financing/espcs.html](http://www1.eere.energy.gov/femp/financing/espcs.html).

## 1.7. Special topic: Energy and carbon initiatives at the U.S. Department of Energy (continued)

### Other notable DOE projects

During December 2009, DOE awarded 16 new Energy Savings Performance Contracts (ESPCs), including the following.

#### Savannah River Biomass Steam Plant, Aiken, South Carolina

DOE's Savannah River Biomass Steam Plant is one of the largest of its kind. Originally powered by coal-burning boilers, the project, financed by an ESPC, has replaced the original boilers with two steam boilers powered by the combustion of woody biomass. These upgrades are estimated to save \$34 million a year in fuel, operations, and maintenance costs.

#### Existing Building Assessment Tool

In 2009, DOE continued to use the Existing Building Assessment Tool (EBAT), part of the High Performance Sustainable Building Assessment Tool. EBAT aids in identifying and prioritizing sustainability projects for retrofitting DOE's building stock with energy-efficient technologies.<sup>23</sup> DOE's building portfolio currently includes 20 Leadership in Energy and Environmental Design (LEED) certified buildings. LEED is an internationally recognized green building certification system, which verifies that a building was designed and constructed to improve energy savings, CO<sub>2</sub> emission reductions, and other environmental factors.<sup>24</sup> The assessment tool is being used to identify candidate projects that would enable additional buildings to gain certification.

#### National Renewable Energy Laboratory, Golden, Colorado

DOE's National Renewable Energy Laboratory (NREL) facility in Golden, Colorado, has begun efforts to achieve net-zero energy consumption. Part of the initiative includes "greening" its data center by consolidating servers from 250 to 50, arranging servers to enable more efficient air flow, and using more energy-efficient methods to cool the air around servers. The efforts will reduce power consumption at the data center by 65 percent.<sup>25</sup>

### Future DOE projects

#### Data center acceleration campaign

DOE is planning a \$2.5 million strategic energy efficiency plan for its information technology infrastructure. The plan emphasizes 41 data centers. FEMP projects a 30-percent energy savings through the implementation of existing technologies under the initiative.<sup>26</sup>

#### Biomass generation plant at Oak Ridge, Tennessee

DOE's research facilities in Oak Ridge, Tennessee, will house a biomass steam generation plant, scheduled to be operational in 2011. The project replaces four natural-gas-fired boilers and will eliminate more than 55,000 metric tons of carbon dioxide emissions each year, in addition to reductions in nitrogen oxide and sulfur dioxide emissions.<sup>27</sup>

<sup>23</sup>U.S. Department of Energy, Energy Efficiency & Renewable Energy, FEMP Year in Review 2009 (December 2009), website [www1.eere.energy.gov/femp/pdfs/yrinreview\\_2009.pdf](http://www1.eere.energy.gov/femp/pdfs/yrinreview_2009.pdf), p. 8.

<sup>24</sup>U.S. Green Building Council, "Intro—What LEED Is" (2010), website [www.usgbc.org/DisplayPage.aspx?CMSPageID=1988](http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1988).

<sup>25</sup>White House Council on Environmental Quality, "Leading by Example—Making the Federal Government More Sustainable, E.O. 13514: Agencies Leading by Example" (February 2010), website [www.whitehouse.gov/sites/default/files/microsites/20100128-ceq-agency-stories.pdf](http://www.whitehouse.gov/sites/default/files/microsites/20100128-ceq-agency-stories.pdf); and National Renewable Energy Laboratory, "NREL Targets Data Centers for Energy Savings" (June 2008), website [www.nrel.gov/features/20080601\\_green\\_it.html](http://www.nrel.gov/features/20080601_green_it.html).

<sup>26</sup>Future DOE projects described in this section are detailed in U.S. Department of Energy, Energy Efficiency & Renewable Energy, FEMP Year in Review 2009 (December 2009), p. 15, website [www1.eere.energy.gov/femp/pdfs/yrinreview\\_2009.pdf](http://www1.eere.energy.gov/femp/pdfs/yrinreview_2009.pdf).

<sup>27</sup>White House Council on Environmental Quality, "Leading by Example—Making the Federal Government More Sustainable, E.O. 13514: Agencies Leading by Example" (February 2010), website [www.whitehouse.gov/sites/default/files/microsites/20100128-ceq-agency-stories.pdf](http://www.whitehouse.gov/sites/default/files/microsites/20100128-ceq-agency-stories.pdf).

## 1.8. Units for measuring greenhouse gases

Emissions data are reported here in metric units. Metric tons are relatively intuitive for users of U.S. measurement units, because 1 metric ton is only 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 global warming potentials (GWPs). Carbon dioxide equivalents are the amount of carbon dioxide by weight emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another radiatively active gas.

Carbon dioxide equivalents are computed by multiplying the weight of the gas being measured (for example, methane) by its estimated GWP (which is 25 for methane). As indicated in Table 5, the GWP for methane was estimated at 21 in the second scientific assessment and 23 in the third. These changes reflect enhanced knowledge, through climate research, of methane's radiative efficiency. Also, as the level of carbon dioxide in the atmosphere increases, it becomes marginally less potent as a greenhouse gas. Consequently, other gases with lower atmospheric concentrations are relatively more potent. In 2008, the IPCC Working Group I released Errata to its Fourth Assessment Report, *Climate Change 2007: The Physical Science Basis*.<sup>28</sup> 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 5 summarizes the GWP values from the Second, Third, and Fourth Assessment Reports.

<sup>28</sup>Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis: Errata* (Cambridge, UK: Cambridge University Press, 2008), website [www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-errata.pdf](http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-errata.pdf).



**Table 5. Greenhouse gases and 100-year net global warming potentials**

Greenhouse gas	Chemical formula	Global warming potential		
		SAR <sup>a</sup>	TAR <sup>b</sup>	AR4 <sup>c</sup>
Carbon dioxide	CO <sub>2</sub>	1	1	1
Methane	CH <sub>4</sub>	21	23	25
Nitrous oxide	N <sub>2</sub> O	310	296	298
<b>Hydrofluorocarbons</b>				
HFC-23 (trifluoromethane)	CHF <sub>3</sub>	11,700	12,000	14,800
HFC-32 (difluoromethane)	CH <sub>2</sub> F <sub>2</sub>	650	550	675
HFC-41 (monofluoromethane)	CH <sub>3</sub> F	150	97	92
HFC-125 (pentafluoroethane)	CHF <sub>2</sub> CF <sub>3</sub>	2,800	3,400	3,500
HFC-134 (1,1,2,2-tetrafluoroethane)	CHF <sub>2</sub> CHF <sub>2</sub>	1,000	1,100	1,100
HFC-134a (1,1,1,2-tetrafluoroethane)	CH <sub>2</sub> FCF <sub>3</sub>	1,300	1,300	1,430
HFC-143 (1,1,2-trifluoroethane)	CHF <sub>2</sub> CH <sub>2</sub> F	300	330	353
HFC-143a (1,1,1-trifluoroethane)	CF <sub>3</sub> CH <sub>3</sub>	3,800	4,300	4,470
HFC-152 (1,2-difluoroethane)	CH <sub>2</sub> FCH <sub>2</sub> F	—	43	53
HFC-152a (1,1-difluoroethane)	CH <sub>3</sub> CHF <sub>2</sub>	140	120	124
HFC-161 (ethyl fluoride)	CH <sub>3</sub> CH <sub>2</sub> F	—	12	12
HFC-227ea (heptafluoropropane)	CF <sub>3</sub> CHF <sub>2</sub> CF <sub>3</sub>	2,900	3,500	3,220
HFC-236cb (1,1,1,2,2,3-hexafluoropropane)	CH <sub>2</sub> FCF <sub>2</sub> CF <sub>3</sub>	—	1,300	1,340
HFC-236ea (1,1,1,2,3,3-hexafluoropropane)	CHF <sub>2</sub> CHF <sub>2</sub> CF <sub>3</sub>	—	1,200	1,370
HFC-236fa (1,1,1,3,3,3-hexafluoropropane)	CF <sub>3</sub> CH <sub>2</sub> CF <sub>3</sub>	6,300	9,400	9,810
HFC-245ca (1,1,2,2,3-pentafluoropropane)	CH <sub>2</sub> FCF <sub>2</sub> CHF <sub>2</sub>	560	640	693
HFC-245fa (1,1,1,3,3-pentafluoropropane)	CHF <sub>2</sub> CH <sub>2</sub> CF <sub>3</sub>	—	950	1,030
HFC-365mfc (pentafluorobutane)	CF <sub>3</sub> CH <sub>2</sub> CF <sub>2</sub> CH <sub>3</sub>	—	890	794
HFC-43-10mee (decafluoropentane)	CF <sub>3</sub> CHFCH <sub>2</sub> CF <sub>2</sub> CF <sub>3</sub>	1,300	1,500	1,640
<b>Perfluorocarbons</b>				
Perfluoromethane	CF <sub>4</sub>	6,500	5,700	7,390
Perfluoroethane	C <sub>2</sub> F <sub>6</sub>	9,200	11,900	12,200
Perfluoropropane	C <sub>3</sub> F <sub>8</sub>	7,000	8,600	8,830
Perfluorobutane (FC 3-1-10)	C <sub>4</sub> F <sub>10</sub>	7,000	8,600	8,860
Perfluorocyclobutane	c-C <sub>4</sub> F <sub>8</sub>	8,700	10,000	10,300
Perfluoropentane	C <sub>5</sub> F <sub>12</sub>	7,500	8,900	9,160
Perfluorohexane (FC 5-1-14)	C <sub>6</sub> F <sub>14</sub>	7,400	9,000	9,300
Sulfur hexafluoride	SF <sub>6</sub>	23,900	22,200	22,800
Nitrogen trifluoride	NF <sub>3</sub>	—	10,800	17,200

<sup>a</sup>IPCC's second scientific assessment report.

<sup>b</sup>IPCC's third scientific assessment report.

<sup>c</sup>IPCC's fourth scientific assessment report.

## 1.9. Methodology updates for this report

### Carbon dioxide

Revised coal and motor gasoline carbon factors have been adopted, based on work done by the U.S. EPA.<sup>29</sup>

For the first time, EIA is providing estimates of biogenic CO<sub>2</sub> emissions from biofuels and bioenergy, based on energy consumption data from EIA's *Monthly Energy Review (MER)*. The estimates are provided in [Chapter 6](#) for informational purposes and are not included in the total emissions estimate, because they are considered to be part of the natural carbon cycle and so are excluded under UNFCCC guidelines.

### Methane

Styrene has been dropped as a source of CH<sub>4</sub> emissions from the chemicals industry, based on guidance from the 2006 IPCC guidelines. Those emissions have been removed from all years of this inventory.

CH<sub>4</sub> emission factors for passenger cars and light-duty vehicles have been revised to the values published in the 2006 IPCC guidelines, resulting in a significant decline in calculated emissions from this source category from 1990 to 2008.

Updates have been made to the specificity of the calculations used to estimate emissions from the production and management of manure, including conducting a State-level analysis of swine manure emissions for the first time. In addition, sheep populations have been separated into those on feedlots and those not on feedlots; and populations of pullets, other chickens, and turkeys have been included in the poultry account for the first time. These updates also affect the estimation of N<sub>2</sub>O emissions from manure management.

Changes in livestock population data that are used to derive the emissions factors for calculating CH<sub>4</sub> emissions from enteric fermentation resulted in an average increase in emissions of 3 percent over the series.

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

For the first time in this report, CH<sub>4</sub> emissions from composting and from the combustion of waste are included in the inventory.

### Nitrous oxide

Emissions calculations methodologies for direct and indirect emissions of N<sub>2</sub>O from nitrogen fertilization of agricultural soils and from runoff of fertilizer and manure applied to soils have been revised to align more completely with methods in the 2006 IPCC guidelines. Most notably, the revised IPCC methodology, which accounts for nitrogen in below-ground crop residues but omits biological fixation of nitrogen, has been implemented for the 2009 inventory.

Emissions resulting from manure that is directly deposited on lands by grazing or pasture-raised animals have been transferred from the manure management category to the agricultural soils category, and new sources of indirect emissions from soil leaching and volatilization have been included in nitrogen fertilization of soils.

The specificity of direct and indirect emissions from manure management has been improved by implementing State-level calculation of swine emissions and updating the waste management system distributions for dairy cattle and swine to annually variable State-level values.

N<sub>2</sub>O emission factors for passenger cars and light-duty vehicles have been revised to the values published in the 2006 IPCC guidelines, resulting in a significant decline in calculated emissions from this source category from 1990 to 2008.

Emissions estimates for 2007 and 2008 have been corrected to account for the 2006 closing of the smallest adipic acid plant in the United States, which was the only remaining plant that did not use abatement technology. Also, the N<sub>2</sub>O emission factor for adipic acid production has been revised to the value published in the 2006 IPCC guidelines.

For the first time in this report, N<sub>2</sub>O emissions from composting are included in the inventory.

### High-GWP gases

Data for 2009 covering the use or production of HFCs, PFCs, and SF<sub>6</sub> in industrial applications are not yet available for inclusion in the 2009 GHG inventory. To obtain a total, the 2008 values for those emissions were used. Draft estimates for emissions of HFC and PFC substitutes for ozone-depleting substances are included in Chapter 5. Complete final estimates of those emissions will be available in the EPA's 2009 inventory of greenhouse gas emissions and sinks, to be published in April 2011.<sup>30</sup>

<sup>29</sup>U.S. Environmental Protection Agency, 40 CFR: Protection of the Environment, Part 98—Mandatory Greenhouse Gas Reporting, "Table C-1 to Subpart C of Part 98—Default CO<sub>2</sub> Emission Factors and High Heat Values for Various Types of Fuel," *Federal Register*, Vol. 74, No. 209 (October 30, 2009), p. 56410, website [www.epa.gov/climatechange/emissions/downloads09/GHG-MRR-FinalRule.pdf](http://www.epa.gov/climatechange/emissions/downloads09/GHG-MRR-FinalRule.pdf).

<sup>30</sup>For details on the changes described above, see U.S. Energy Information Administration, *Documentation For Emissions of Greenhouse Gases in the United States 2009* (to be published).

## 1.10. Special topic: Black carbon

### What is black carbon?

Black carbon is an aerosol component of particulate matter formed through the incomplete combustion of fossil fuels, biofuels, and biomass. It is found in both anthropogenic (human-caused) and naturally occurring soot. The science and understanding of black carbon have evolved rapidly over the past decade. This has drawn attention to black carbon's contribution to climate change. Globally, the primary sources of black carbon include emissions from diesel engines, cook stoves, wood fires, and forest fires. In contrast with CO<sub>2</sub>, which has an atmospheric lifetime of more than 100 years, black carbon remains in the atmosphere for only a few weeks. Therefore, reducing black carbon emissions may be an effective way to slow climate change in the short term. The 20-year GWP of black carbon is estimated at 2,200, with a 100-year GWP of 680.<sup>31</sup> Because of its relatively short atmospheric lifetime, the 20-year GWP is considered a more accurate estimate of the climate impact of black carbon emissions.

Black carbon contributes to changes in the atmosphere in two ways. First, when it is suspended in the air it absorbs sunlight and generates heat and can affect regional cloud formation and precipitation patterns, which may have a cooling effect. Second, when deposited on snow and ice, it absorbs sunlight, generating heat and counteracting the usual reflective (cooling) effects of pure snow, thus warming both the air above and the snow and ice below, accelerating melting, and further reducing the reflective power of snow and ice cover. Its warming effects in the polar regions are of particular concern.

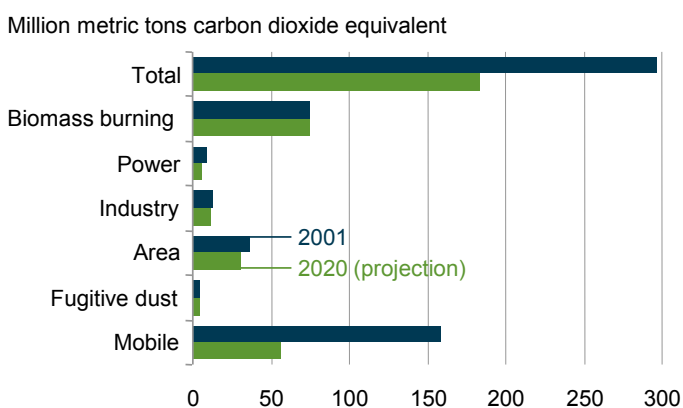
In 2010, in the Department of the Interior, Environment and Related Agencies Appropriations Act, the U.S. Congress allocated money for the EPA to conduct a study of black carbon emissions and their possible effects on climate change. The study is due to be published in April 2011.<sup>32</sup>

### Regional sources of black carbon emissions

Since 1950, the United States, Europe, and the former Soviet Union have significantly reduced black carbon emissions from fossil fuel sources.<sup>33</sup> U.S. emissions of black carbon—measured as elemental carbon—are estimated to have fallen by 30 percent from 1990 to 2005, when they made up about 6 percent of total world black carbon emissions.<sup>34</sup> The primary source of black carbon emissions in the United States is mobile combustion (vehicle fuels), and 90 percent of emissions in this category are from diesel fuel use. Figure 8 shows a breakdown of U.S. black carbon emissions sources in 2001 and projections for 2020. After mobile emissions, biomass combustion is the second-largest source of black carbon emissions in the United States, and its share of the total is expected to grow as diesel emissions continue to be reduced.

Technology has played a major role in reducing black carbon emissions. Important technologies include filters placed in diesel vehicle engines to capture the emissions, fuel switching (e.g., from diesel to natural gas in buses), and cleaner-burning, more

**Figure 8. U.S. emissions of black carbon by source, 2001 and 2020**



Note: For additional details see Notes and Sources, p. 66.

(continued on page 20)

<sup>31</sup>T. Bond and H. Sun, "Can Reducing Black Carbon Emissions Counteract Global Warming?" *Environmental Science & Technology*, Vol. 39, No. 16 (2005), p. 5922, website <http://pubs.acs.org/doi/pdfplus/10.1021/es0480421>.

<sup>32</sup>Office of Management and Budget, Appendix, Budget of the United States Government, Fiscal Year 2011 (Washington, DC, 2010), "U.S. Environmental Protection Agency," p. 1142, website [www.whitehouse.gov/sites/default/files/omb/budget/fy2011/assets/appendix.pdf](http://www.whitehouse.gov/sites/default/files/omb/budget/fy2011/assets/appendix.pdf).

<sup>33</sup>T. Novakov, V. Ramanathan, J.E. Hansen, T.W. Kirchstetter, M. Sato, J. E. Sinton, and J.A. Sathaye, *Large Historical Changes of Fossil-Fuel Black Carbon Aerosols*, LBNL-50881 (Berkeley, CA: Lawrence Berkeley National Laboratory, September 2002), website <http://ies.lbl.gov/drupal/files/ies.lbl.gov.sandbox/50881.pdf>.

<sup>34</sup>V. Rao and J.H. Somers, "Black Carbon as a Short-Lived Climate Forcer: A Profile of Emission Sources and Co-Emitted Pollutants," presented at the 19th Annual International Emission Inventory Conference: Emissions Inventories—Informing Emerging Issues (San Antonio, TX: September 27-30, 2010), website [www.epa.gov/ttn/chieff/conference/ei19/session5/rao.pdf](http://www.epa.gov/ttn/chieff/conference/ei19/session5/rao.pdf).

### 1.10. Special topic: Black carbon (continued)

efficient cook stoves in developing nations. Today, the majority of black carbon emissions come from developing countries.<sup>35</sup> The leading emitters are Asia, Latin America, and Africa.<sup>36</sup> China and India, in particular, are responsible for more than one-fourth of global black carbon pollution.<sup>37</sup> Significant sources of biomass-related emissions in the developing world include deforestation by burning, wildfires, and savannah burning.<sup>38</sup>

#### Reducing emissions of black carbon

The United States does not have any regulations in force that are directly aimed at reducing black carbon emissions. However, some States have included black carbon emissions and corresponding reduction strategies in their Climate Action Plans.<sup>39</sup> Also, Federal rules developed to address particulate matter, a class of criteria pollutant under the Clean Air Act, and smog-forming nitrogen oxide from engines and stationary sources have the added effect of reducing black carbon emissions. Key regulations in effect include National Ambient Air Quality Standards (NAAQS) for airborne particulates, the Clean Air Highway Diesel Rule (2001), the Diesel Emissions Reduction Act (2005), and the Clean Air Visibility Rule (2005).<sup>40</sup> These regulations typically require the use of emission control technologies, such as particulate filters, to reduce emissions. The EPA estimates that the rules already finalized will lead to reductions in U.S. emissions of black carbon by 38 percent in 2020 from their 2001 baseline (Figure 8), primarily by achieving additional reductions in the mobile emissions sector.<sup>41</sup> The 2020 projection assumes continued implementation of the Clean Air Nonroad Diesel Rule, the Clean Air Highway Diesel Rule, and the Clean Air Interstate Rule, among others. If all areas meet their NAAQS requirements for small-diameter particulate matter (PM<sub>2.5</sub>), the reduction is projected to reach 42 percent, with total U.S. emissions of black carbon falling to 255,000 metric tons in 2020. The State of Maine estimates that the cost of reducing black carbon emissions through use of ultra-low-sulfur diesel (ULSD) and clean diesel technologies would be \$14 per ton CO<sub>2</sub>e.<sup>42</sup>

In December 2009, the United States pledged \$5 million in funding for the development and implementation of black carbon mitigation strategies for the Arctic.<sup>43</sup> The pledge came in the wake of the April 2009 Tromsø Declaration, in which the Arctic Council recognized the impacts of black carbon, methane, and other short-lived climate-forcing emissions on climate change in the Arctic.<sup>44</sup>

International strategies to reduce emissions from deforestation, such as the Reducing Emissions from Deforestation and Forest Degradation (REDD) policies being discussed under the UNFCCC process, could also contribute to black carbon emissions reductions, particularly in the developing world.

<sup>35</sup>T.C. Bond, E. Bhardwaj, R. Dong, R. Jogani, S. Jung, C. Roden, D. G. Streets, and N. M. Trautmann, "Historical Emissions of Black and Organic Carbon Aerosol from Energy-Related Combustion, 1850–2000," *Global Biogeochemical Cycles*, Vol. 21, GB2018 (May 30, 2007), Figure 6, website [www.cee.mtu.edu/~nurban/classes/ce5508/2008/Readings/Bond07.pdf](http://www.cee.mtu.edu/~nurban/classes/ce5508/2008/Readings/Bond07.pdf).

<sup>36</sup>T.C. Bond, E. Bhardwaj, R. Dong, R. Jogani, S. Jung, C. Roden, D. G. Streets, and N. M. Trautmann, "Historical Emissions of Black and Organic Carbon Aerosol from Energy-Related Combustion, 1850–2000," *Global Biogeochemical Cycles*, Vol. 21, GB2018 (May 30, 2007), Figure 6, website [www.cee.mtu.edu/~nurban/classes/ce5508/2008/Readings/Bond07.pdf](http://www.cee.mtu.edu/~nurban/classes/ce5508/2008/Readings/Bond07.pdf).

<sup>37</sup>T.C. Bond, E. Bhardwaj, R. Dong, R. Jogani, S. Jung, C. Roden, D. G. Streets, and N. M. Trautmann, "Historical Emissions of Black and Organic Carbon Aerosol from Energy-Related Combustion, 1850–2000," *Global Biogeochemical Cycles*, Vol. 21, GB2018 (May 30, 2007), Figure 6, website [www.cee.mtu.edu/~nurban/classes/ce5508/2008/Readings/Bond07.pdf](http://www.cee.mtu.edu/~nurban/classes/ce5508/2008/Readings/Bond07.pdf).

<sup>38</sup>T.C. Bond, "Confidence and Key Uncertainties in Black Carbon Emissions & Radiative Impacts," presentation at U.S. Environmental Protection Agency, SLCF Workshop (March 3, 2010), website [www.epa.gov/air/oaqps/eog/video/pdfs/bond\\_epa\\_slcf\\_march\\_3\\_2010.pdf](http://www.epa.gov/air/oaqps/eog/video/pdfs/bond_epa_slcf_march_3_2010.pdf).

<sup>39</sup>See, for example, Maine Department of Environmental Protection, A Climate Action Plan for Maine 2004 (December 2004), website <http://mainegh.raabassociates.org/Articles/MaineClimateActionPlan2004Volume%201.pdf>.

<sup>40</sup>M.A. Bahner, K.A. Weitz, A. Zapata, and B. DeAngelo, "Use of Black Carbon and Organic Carbon Inventories for Projections and Mitigation Analysis," presentation at 16th Annual International Emission Inventory Conference (Raleigh, NC, May 14-17, 2007), website [www.epa.gov/ttn/chief/conference/ei16/session3/k.weitz.pdf](http://www.epa.gov/ttn/chief/conference/ei16/session3/k.weitz.pdf); and U.S. Environmental Protection Agency, "Reducing Particle Pollution," website [www.epa.gov/oar/particlepollution/reducing.html](http://www.epa.gov/oar/particlepollution/reducing.html).

<sup>41</sup>M.A. Bahner, K.A. Weitz, A. Zapata, and B. DeAngelo, website [www.epa.gov/ttn/chief/conference/ei16/session3/k.weitz.pdf](http://www.epa.gov/ttn/chief/conference/ei16/session3/k.weitz.pdf).

<sup>42</sup>Maine Department of Environmental Protection, website <http://mainegh.raabassociates.org/Articles/MaineClimateActionPlan2004Volume%201.pdf>.

<sup>43</sup>U.S. Department of State, "Strategy to Reduce Black Carbon Emissions Affecting the Arctic" (December 17, 2009), website <http://cop15.state.gov/pressroom/133771.htm>.

<sup>44</sup>The Arctic Council, "Tromsø Declaration" (April 29, 2009), website <http://arctic-council.org/filearchive/Tromsoe%20Declaration-1..pdf>.

## 2. Carbon dioxide emissions

### 2.1. Total carbon dioxide emissions

Annual U.S. carbon dioxide emissions fell by 419 million metric tons in 2009 (7.1 percent), to 5,447 million metric tons (Figure 9 and Table 6). The annual decrease—the largest over the 19-year period beginning with the 1990 baseline—puts 2009 emissions 608 million metric tons below the 2005 level, which is the Obama Administration’s benchmark year for its goal of reducing U.S. emissions by 17 percent by 2020.

The key factors contributing to the decrease in carbon dioxide emissions in 2009 included an economy in recession with a decrease in gross domestic product of 2.6 percent, a decrease in the energy intensity of the economy of 2.2 percent, and a decrease in the carbon intensity of energy supply of 2.4 percent.

Energy-related carbon dioxide emissions accounted for 98 percent of U.S. carbon dioxide emissions in 2009 (Table 6) when adjusted for bunker fuels and U.S. Territories. The predominant share of carbon dioxide emissions comes from fossil fuel combustion, with smaller amounts from the nonfuel use of energy and emissions from U.S. Territories and international bunker fuels. Other relatively small sources include emissions from industrial processes, such as cement and limestone production.

#### U.S. carbon dioxide emissions, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	5,040.9	6,055.2	5,865.5	5,446.8
Change from 1990 (million metric tons)		1,014.3	824.6	405.9
(percent)		20.1%	16.4%	8.1%
Average annual change from 1990 (percent)		1.2%	0.8%	0.4%
Change from 2005 (million metric tons)			-189.7	-608.4
(percent)			-3.1%	-10.0%
Change from 2008 (million metric tons)				-418.7
(percent)				-7.1%

Figure 9. Annual change in U.S. carbon dioxide emissions, 1991-2009

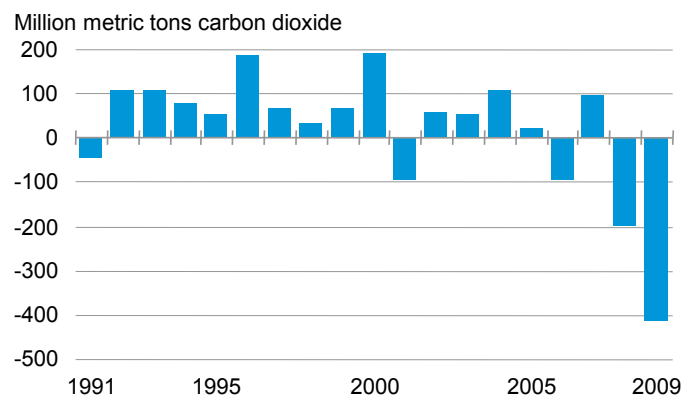


Table 6. U.S. carbon dioxide emissions from energy and industry, 1990-2009 (million metric tons carbon dioxide)

Fuel type or process	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
<b>Energy consumption</b>										
Petroleum	2,186.6	2,207.1	2,460.6	2,518.4	2,608.6	2,627.6	2,602.5	2,603.2	2,443.5	2,318.8
Coal	1,821.4	1,913.1	2,155.5	2,135.7	2,160.2	2,181.9	2,146.9	2,172.2	2,139.4	1,876.8
Natural gas	1,024.6	1,183.7	1,240.6	1,191.1	1,194.4	1,175.2	1,157.0	1,234.7	1,243.0	1,218.0
Renewables <sup>a</sup>	6.2	10.3	10.5	11.8	11.5	11.6	11.9	11.7	12.0	12.0
<i>Energy subtotal</i>	<i>5,038.7</i>	<i>5,314.3</i>	<i>5,867.2</i>	<i>5,856.9</i>	<i>5,974.7</i>	<i>5,996.4</i>	<i>5,918.3</i>	<i>6,021.8</i>	<i>5,838.0</i>	<i>5,425.6</i>
Nonfuel use emissions <sup>b</sup>	94.1	101.9	105.5	97.3	105.0	100.7	103.5	101.7	97.7	82.8
Nonfuel use sequestration <sup>c</sup>	250.0	283.6	306.0	290.0	313.4	303.5	299.8	292.1	264.4	245.7
Adjustments to energy <sup>d</sup>	-82.9	-63.2	-64.7	-32.6	-45.3	-44.6	-62.7	-67.5	-76.1	-66.0
<i>Adjusted energy subtotal</i>	<i>4,955.9</i>	<i>5,251.1</i>	<i>5,802.6</i>	<i>5,824.3</i>	<i>5,929.3</i>	<i>5,951.8</i>	<i>5,855.7</i>	<i>5,954.2</i>	<i>5,761.9</i>	<i>5,359.6</i>
Other sources	85.1	102.3	97.8	98.9	102.0	103.5	105.9	105.3	103.6	87.3
<b>Total</b>	<b>5,040.9</b>	<b>5,353.4</b>	<b>5,900.3</b>	<b>5,923.3</b>	<b>6,031.3</b>	<b>6,055.2</b>	<b>5,961.6</b>	<b>6,059.5</b>	<b>5,865.5</b>	<b>5,446.8</b>

<sup>a</sup>Includes emissions from electricity generation using nonbiogenic municipal solid waste and geothermal energy.

<sup>b</sup>Emissions from nonfuel uses are included in the energy subtotal above.

<sup>c</sup>The energy content of nonfuel uses in which carbon is sequestered is subtracted from energy consumption before emissions are calculated.

<sup>d</sup>Adjustments include adding emissions from U.S. Territories and subtracting emissions from international bunker fuels, in keeping with international practices.

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

## 2.2. Energy-related carbon dioxide emissions

Energy-related carbon dioxide emissions account for more than 80 percent of U.S. greenhouse gas emissions. These emissions were down by 7.1 percent from 5,838 million metric tons in 2008 to 5,426 million metric tons in 2009. EIA breaks energy use into four end-use sectors (Table 7), and emissions from the electric power sector are attributed to the end-use sectors based on electricity sales to each sector. 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 10). In 2009, however, emissions from both electric power and transportation fuel use were down—by 9.0 percent and 4.3 percent, respectively—continuing a trend from 2008.

Reasons for the long-term growth in electric power and transportation sector emissions include: population growth; 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 travel 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 over the years 2008 and 2009.

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

### U.S. energy-related carbon dioxide emissions, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	5,038.7	5,996.4	5,838.0	5,425.6
Change from 1990 (million metric tons)		957.7	799.2	386.9
(percent)		19.0%	15.9%	7.7%
Average annual change from 1990 (percent)		1.2%	0.8%	0.4%
Change from 2005 (million metric tons)			-158.4	-570.8
(percent)			-2.6%	-9.5%
Change from 2008 (million metric tons)				-412.4
(percent)				-7.1%

Figure 10. Energy-related carbon dioxide emissions for selected sectors, 1990-2009

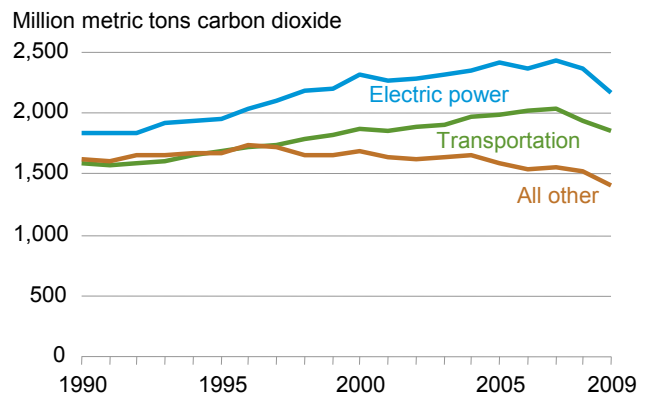


Table 7. U.S. energy-related carbon dioxide emissions by end-use sector, 1990-2009 (million metric tons carbon dioxide)

Sector	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Residential	963.4	1,039.1	1,185.1	1,230.1	1,227.8	1,261.5	1,192.0	1,242.0	1,229.0	1,162.2
Commercial	792.6	851.4	1,022.0	1,036.0	1,053.5	1,069.0	1,043.4	1,078.6	1,073.5	1,003.6
Industrial	1,695.1	1,742.8	1,788.1	1,691.9	1,731.1	1,675.2	1,661.1	1,661.6	1,597.6	1,405.4
Transportation	1,587.7	1,681.0	1,872.0	1,898.9	1,962.3	1,990.7	2,021.9	2,039.6	1,937.9	1,854.5
<b>Total</b>	<b>5,038.7</b>	<b>5,314.3</b>	<b>5,867.2</b>	<b>5,856.9</b>	<b>5,974.7</b>	<b>5,996.4</b>	<b>5,918.3</b>	<b>6,021.8</b>	<b>5,838.0</b>	<b>5,425.6</b>
Electricity generation <sup>a</sup>	1,831.0	1,960.1	2,310.2	2,319.2	2,351.5	2,416.9	2,359.5	2,425.9	2,373.7	2,160.3

<sup>a</sup>Electric power sector emissions are distributed across the end-use sectors. Emissions allocated to sectors are unadjusted for U.S. Territories and international bunker fuels. Adjustments are made to total emissions only.

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

### 2.3. Residential sector carbon dioxide emissions

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 8).

Energy consumed for heating and cooling in homes and businesses has a large influence on annual fluctuations in energy-related carbon dioxide emissions because of variability in the weather as measured by heating and cooling degree-days. In 2009, heating degree-days were down slightly from 2008 (Figure 11). Although annual changes in cooling degree-days have a smaller impact on energy demand, the 4-percent decrease in 2009 helped to reduce emissions further.

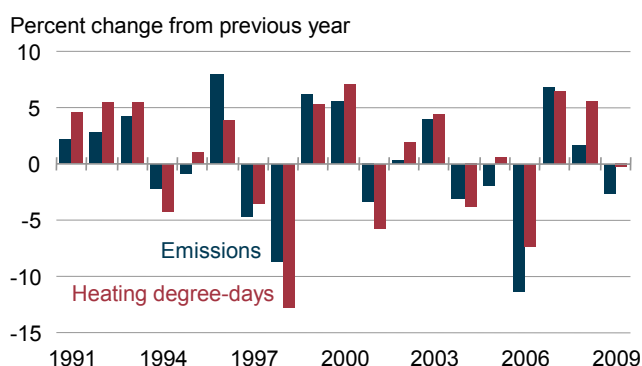
In the longer run, residential emissions are affected by population growth, income, and other factors. From 1990 to 2009:

- Residential sector carbon dioxide emissions grew by an average of 1.0 percent per year.
- U.S. population is estimated to have grown by an average of about 1.1 percent per year.
- Income per capita (measured in constant dollars) grew by an average of 1.4 percent per year.
- Energy efficiency improvements for homes and appliances offset much of the growth in the number and size of housing units. As a result, direct emissions of carbon dioxide from the consumption of petroleum, coal, and natural gas in the residential sector in 2009 were up by only 0.9 percent from the 1990 level.

#### Residential sector carbon dioxide emissions, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	963.4	1,261.5	1,229.0	1,162.2
Change from 1990 (million metric tons)		298.1	265.6	198.8
(percent)		30.9%	27.6%	20.6%
Average annual change from 1990 (percent)		1.8%	1.4%	1.0%
Change from 2005 (million metric tons)			-32.5	-99.3
(percent)			-2.6%	-7.9%
Change from 2008 (million metric tons)				-66.8
(percent)				-5.4%

**Figure 11. Annual changes in U.S. heating degree-days and residential sector carbon dioxide emissions from direct fuel combustion, 1990-2009**



**Table 8. U.S. carbon dioxide emissions from residential sector energy consumption, 1990-2009 (million metric tons carbon dioxide)**

Fuel	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
<b>Petroleum</b>										
Liquefied petroleum gas	22.2	24.9	35.0	34.3	32.3	32.3	28.1	30.5	34.9	36.5
Distillate fuel	71.6	66.2	66.2	66.2	67.6	62.5	52.1	53.1	48.5	44.5
Kerosene	4.6	5.4	6.8	5.1	6.1	6.1	4.8	3.2	1.5	1.9
<i>Petroleum subtotal</i>	<i>98.4</i>	<i>96.5</i>	<i>108.0</i>	<i>105.6</i>	<i>106.0</i>	<i>100.9</i>	<i>85.0</i>	<i>86.8</i>	<i>84.9</i>	<i>82.9</i>
Coal	3.0	1.7	1.1	1.2	1.1	0.8	0.6	0.7	0.7	0.6
Natural gas	238.3	262.9	270.8	276.4	264.3	262.4	237.5	257.3	265.8	259.1
Electricity <sup>a</sup>	623.7	678.1	805.2	846.9	856.4	897.3	868.9	897.2	877.5	819.5
<b>Total</b>	<b>963.4</b>	<b>1,039.1</b>	<b>1,185.1</b>	<b>1,230.1</b>	<b>1,227.8</b>	<b>1,261.5</b>	<b>1,192.0</b>	<b>1,242.0</b>	<b>1,229.0</b>	<b>1,162.2</b>

<sup>a</sup>Share of total electric power sector carbon dioxide emissions weighted by sales to the residential sector.

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

## 2.4. Commercial sector carbon dioxide emissions

In the commercial sector, carbon dioxide emissions result largely from energy use for lighting, heating, and cooling in commercial structures, such as office buildings, shopping malls, schools, hospitals, and restaurants.

Commercial sector emissions declined by 6.5 percent in 2009.

Lighting accounts for a larger component of energy demand in the commercial sector (approximately 18 percent of total demand in 2008) than in the residential sector (approximately 11 percent of total demand).

Commercial sector emissions are affected less by weather than are residential sector emissions: heating and cooling accounted for approximately 37 percent of energy demand in the residential sector in 2008 but only about 21 percent in the commercial sector.

In the longer run, trends in commercial sector emissions parallel trends in population growth and the economy. Commercial sector emissions grew at an average annual rate of 1.2 percent from 1990 to 2009—slightly less than the average growth of 1.4 percent per year in real income per capita (Figure 12).

Emissions from direct fuel consumption in the commercial sector declined from 1990 to 2009 (Table 9), while the sector's electricity-related emissions increased by an average of 1.7 percent per year.

### Commercial sector carbon dioxide emissions, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	792.6	1,069.0	1,073.5	1,003.6
Change from 1990 (million metric tons)		276.4	280.8	210.9
(percent)		34.9%	35.4%	26.6%
Average annual change from 1990 (percent)		2.0%	1.7%	1.2%
Change from 2005 (million metric tons)			4.4	-65.5
(percent)			0.4%	-6.1%
Change from 2008 (million metric tons)				-69.9
(percent)				-6.5%

Figure 12. U.S. commercial sector carbon dioxide emissions and per capita income, 1990-2009

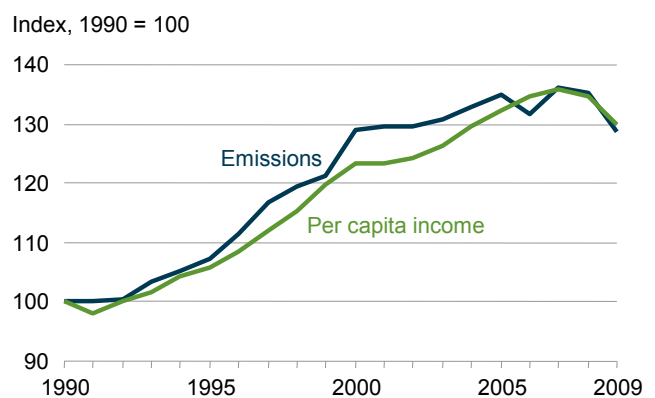


Table 9. U.S. carbon dioxide emissions from commercial sector energy consumption, 1990-2009 (million metric tons carbon dioxide)

Fuel	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
<b>Petroleum</b>										
Motor gasoline	7.9	1.3	3.1	4.2	3.1	3.2	3.4	4.2	3.1	3.1
Liquefied petroleum gas	6.5	6.9	9.5	9.9	9.6	8.3	7.8	7.7	10.0	10.4
Distillate fuel	39.2	35.0	35.9	35.2	34.4	32.7	29.4	28.1	27.0	24.7
Residual fuel	18.1	11.1	7.2	8.8	9.7	9.1	5.9	5.9	5.8	4.9
Kerosene	0.9	1.6	2.1	1.3	1.5	1.6	1.1	0.7	0.3	0.4
<i>Petroleum subtotal<sup>a</sup></i>	<b>72.5</b>	<b>55.9</b>	<b>57.9</b>	<b>59.4</b>	<b>58.3</b>	<b>54.9</b>	<b>47.6</b>	<b>46.6</b>	<b>46.1</b>	<b>43.6</b>
Coal	12.0	11.2	8.8	7.8	9.8	9.3	6.2	6.7	6.5	5.8
Natural gas	142.3	164.3	172.5	173.0	169.8	163.1	154.0	164.2	171.3	169.1
Electricity <sup>b</sup>	565.9	620.0	782.8	795.8	815.6	841.8	835.6	861.1	849.5	785.1
<b>Total</b>	<b>792.6</b>	<b>851.4</b>	<b>1,022.0</b>	<b>1,036.0</b>	<b>1,053.5</b>	<b>1,069.0</b>	<b>1,043.4</b>	<b>1,078.6</b>	<b>1,073.5</b>	<b>1,003.6</b>

<sup>a</sup>Includes small amounts of petroleum coke.

<sup>b</sup>Share of total electric power sector carbon dioxide emissions weighted by sales to the commercial sector.

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



## 2.5. Energy-related industrial sector carbon dioxide emissions

Trends in U.S. industrial sector emissions are closely tied to economic output in energy-intensive manufacturing. In 2009, industrial carbon dioxide emissions fell by 12.0 percent from their 2008 level and were 17.1 percent (290 million metric tons) below their 1990 level (Table 10). Decreases in industrial sector carbon dioxide emissions have resulted largely from a structural shift away from energy-intensive manufacturing in the U.S. economy. 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.

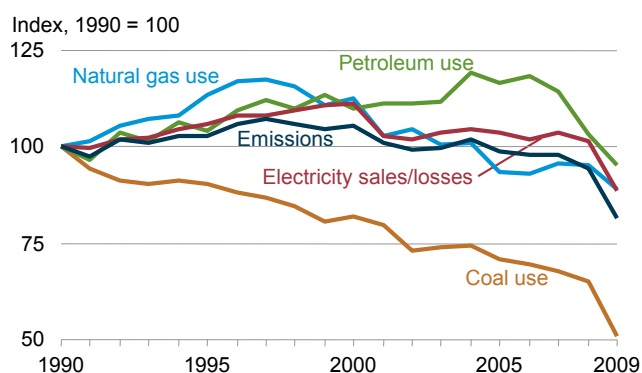
Coke plants consumed 15 million short tons of coal in 2009, down from 39 million short tons in 1990. Other industrial coal consumption declined from 76 million short tons in 1990 to 45 million short tons in 2009, as reflected by a drop in emissions from coal use (Figure 13). From 1990 to 2009, coal use in the industrial sector declined by 47 percent.

Emissions from coal, natural gas, and total petroleum use in 2009 all were below their 1990 levels, although emissions from the combustion of some petroleum products were above their 1990 levels.

### Industrial sector carbon dioxide emissions, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	1,695.1	1,675.2	1,597.6	1,405.4
Change from 1990 (million metric tons)		-19.9	-97.4	-289.6
(percent)		-1.2%	-5.7%	-17.1%
Average annual change from 1990 (percent)		-0.1%	-0.3%	-1.0%
Change from 2005 (million metric tons)			-77.5	-269.7
(percent)			-4.6%	-16.1%
Change from 2008 (million metric tons)				-192.2
(percent)				-12.0%

**Figure 13. U.S. industrial sector carbon dioxide emissions and major industrial fuel use, 1990-2009**



**Table 10. U.S. carbon dioxide emissions from industrial sector energy consumption, 1990-2009 (million metric tons carbon dioxide)**

Fuel	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
<b>Petroleum</b>										
Motor gasoline	13.2	14.1	10.6	22.7	26.0	24.8	26.1	21.2	17.0	16.9
Liquefied petroleum gas	38.9	45.4	56.4	50.0	55.2	51.3	55.7	54.4	41.8	41.1
Distillate fuel	83.9	82.4	87.4	82.6	88.3	91.8	91.7	91.9	92.0	84.4
Residual fuel	30.6	24.5	17.0	15.5	17.5	19.9	16.4	13.2	13.6	11.6
Lubricants	6.9	6.6	7.0	5.9	6.0	5.9	5.8	6.0	5.6	5.0
Kerosene	0.9	1.1	1.1	1.7	2.0	2.8	2.1	1.0	0.3	0.4
Petroleum coke	63.8	66.9	74.1	76.0	82.1	79.7	82.2	80.0	76.2	73.0
Other	127.3	113.6	116.8	139.7	141.6	140.6	150.2	147.6	129.7	110.7
<b>Petroleum subtotal</b>	<b>365.5</b>	<b>354.7</b>	<b>370.4</b>	<b>394.1</b>	<b>418.6</b>	<b>416.8</b>	<b>430.4</b>	<b>415.4</b>	<b>376.2</b>	<b>343.1</b>
Coal	258.4	232.5	210.8	189.9	190.5	182.9	179.4	174.6	168.2	130.9
Coal coke net imports	0.5	7.0	7.5	5.8	15.7	5.0	6.9	2.9	4.7	-2.7
Natural gas	432.4	490.0	480.8	430.0	431.5	397.5	394.2	406.3	406.9	383.1
Electricity <sup>a</sup>	638.3	658.7	718.6	672.0	674.7	672.8	650.2	662.3	641.8	551.0
<b>Total<sup>b</sup></b>	<b>1,695.1</b>	<b>1,742.8</b>	<b>1,788.1</b>	<b>1,691.9</b>	<b>1,731.1</b>	<b>1,675.2</b>	<b>1,661.1</b>	<b>1,661.6</b>	<b>1,597.6</b>	<b>1,405.4</b>

<sup>a</sup>Share of total electric power sector carbon dioxide emissions weighted by sales to the industrial sector.

<sup>b</sup>Includes emissions from nonfuel uses of fossil fuels. See Table 14 for details by fuel category.

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

## 2.6. Transportation sector carbon dioxide emissions

Carbon dioxide emissions from the U.S. transportation sector in 2009 were 81 million metric tons lower than in 2008 but still 267 million metric tons higher than in 1990 (Table 11).

The transportation sector has led all U.S. end-use sectors in emissions of carbon dioxide since 1999; however, with a decline in economic growth in 2009, emissions from the transportation sector fell by 4.3 percent from their 2008 level, which in turn were down from 2007.

Petroleum combustion is by far the largest source of carbon dioxide emissions in the transportation sector.

Increases in the consumption of ethanol fuel 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.)

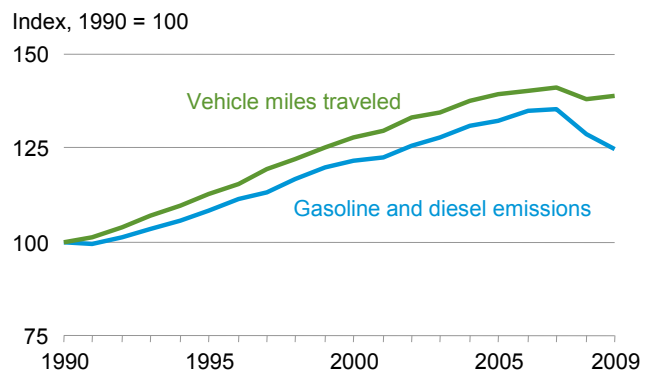
Emissions from gasoline and diesel fuel combustion in the transportation sector generally have paralleled total vehicle miles traveled since 1990 (Figure 14). In 2009, however, vehicles miles traveled rose slightly while combined emissions from gasoline and diesel fuel declined—likely as a result of more efficient vehicles and increased consumption of biofuels.

The transportation sector has dominated the growth in U.S. carbon dioxide emissions since 1990, accounting for 69 percent of the total increase in U.S. energy-related carbon dioxide emissions.

### Transportation sector carbon dioxide emissions, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	1,587.7	1,990.7	1,937.9	1,854.5
Change from 1990 (million metric tons)		403.1	350.2	266.8
(percent)		25.4%	22.1%	16.8%
Average annual change from 1990 (percent)		1.5%	1.1%	0.8%
Change from 2005 (million metric tons)			-52.9	-136.3
(percent)			-2.7%	-6.8%
Change from 2008 (million metric tons)				-83.4
(percent)				-4.3%

**Figure 14. U.S. vehicle miles traveled and carbon dioxide emissions from gasoline and diesel transportation fuel use, 1990-2009**



**Table 11. U.S. carbon dioxide emissions from transportation sector energy consumption, 1990-2009  
(million metric tons carbon dioxide)**

Fuel	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
<b>Petroleum</b>										
Motor gasoline	966.8	1,028.6	1,121.3	1,161.5	1,184.6	1,186.1	1,194.4	1,201.2	1,146.0	1,137.5
Liquefied petroleum gas	1.4	1.1	0.8	1.0	1.2	1.8	1.7	1.4	2.5	2.6
Jet fuel	222.6	222.1	253.8	231.5	239.8	246.3	239.5	238.0	226.3	204.4
Distillate fuel	267.8	306.9	377.8	414.5	433.9	444.4	469.2	472.3	441.8	404.7
Residual fuel	80.1	71.7	69.9	45.0	58.3	66.0	71.4	78.3	72.5	59.9
Lubricants <sup>a</sup>	6.5	6.2	6.7	5.6	5.6	5.6	5.5	5.6	5.2	4.7
Aviation gasoline	3.1	2.7	2.5	2.1	2.2	2.4	2.3	2.2	2.0	1.8
<i>Petroleum subtotal</i>	<i>1,548.4</i>	<i>1,639.3</i>	<i>1,832.8</i>	<i>1,861.1</i>	<i>1,925.6</i>	<i>1,952.7</i>	<i>1,984.0</i>	<i>1,999.0</i>	<i>1,896.3</i>	<i>1,815.7</i>
Coal <sup>b</sup>	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	33.3	31.9	33.1	33.2	35.3	36.7	34.1
Electricity <sup>c</sup>	3.2	3.2	3.6	4.5	4.8	5.0	4.7	5.3	4.9	4.7
<b>Total</b>	<b>1,587.7</b>	<b>1,681.0</b>	<b>1,872.0</b>	<b>1,898.9</b>	<b>1,962.3</b>	<b>1,990.7</b>	<b>2,021.9</b>	<b>2,039.6</b>	<b>1,937.9</b>	<b>1,854.5</b>

<sup>a</sup>Includes emissions from nonfuel uses of fossil fuels. See Table 14 for details by fuel category.

<sup>b</sup>Small amounts of coal consumed for transportation are reported as industrial sector consumption.

<sup>c</sup>Share of total electric power sector carbon dioxide emissions weighted by sales to the transportation sector.

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

## 2.7. Electric power sector carbon dioxide emissions

The electric power sector consists of companies whose primary business is the generation of electricity. Since about 2000, as a result of changes in the fuel mix and efficiency improvements, electricity sales growth has outpaced the growth in emissions from the power sector (Figure 15).

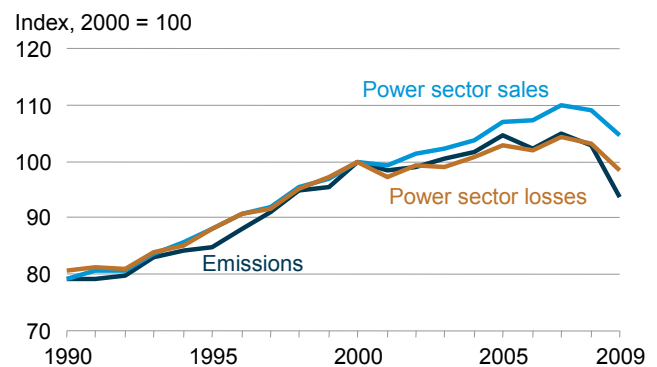
Carbon dioxide emissions from U.S. electric power generation declined by 9.0 percent in 2009 (Table 12). The drop resulted from a 4.1-percent decrease in the sector's total electricity generation and a 5.1-percent reduction in the carbon intensity of the electricity supply. The lower overall carbon intensity of power generation in 2009 was, in part, the result of a 33.5-percent increase (19 billion kilowatthours) in generation from wind resources. Although there was a slight drop in generation from nuclear power plants, hydroelectric generation increased by 7.3 percent, and total generation from all the energy sources that produce no direct carbon dioxide emissions increased by 2.7 percent from 2008.

Although electric power sector generation from all fossil fuels in 2009 was 196 billion kilowatthours lower than in 2008 (7.0 percent), generation from natural gas, the least carbon-intensive fossil fuel, increased by 4.8 percent.

### Electric power sector carbon dioxide emissions, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	1,831.0	2,416.9	2,373.7	2,160.3
Change from 1990 (million metric tons)		585.8	542.7	329.3
(percent)		32.0%	29.6%	18.0%
Average annual change from 1990 (percent)		1.9%	1.5%	0.9%
Change from 2005 (million metric tons)			-43.1	-256.5
(percent)			-1.8%	-10.6%
Change from 2008 (million metric tons)				-213.4
(percent)				-9.0%

**Figure 15. U.S. electric power sector energy sales and losses and carbon dioxide emissions from primary fuel combustion, 1990-2009**



**Table 12. U.S. carbon dioxide emissions from electric power sector energy consumption, 1990-2009 (million metric tons carbon dioxide)**

Fuel	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
<b>Petroleum</b>										
Residual fuel oil	91.6	44.6	68.6	68.5	69.3	69.1	28.4	31.3	18.9	14.3
Distillate fuel oil	7.1	7.9	12.8	11.8	8.1	8.4	5.4	6.5	5.3	5.1
Petroleum coke	3.1	8.2	10.1	17.8	22.7	24.9	21.8	17.5	15.7	14.2
<i>Petroleum subtotal</i>	<i>101.8</i>	<i>60.7</i>	<i>91.5</i>	<i>98.1</i>	<i>100.1</i>	<i>102.3</i>	<i>55.6</i>	<i>55.3</i>	<i>40.0</i>	<i>33.6</i>
Coal	1,547.6	1,660.7	1,927.4	1,931.0	1,943.1	1,983.8	1,953.7	1,987.3	1,959.4	1,742.2
Natural gas	175.5	228.2	280.9	278.3	296.8	319.1	338.2	371.7	362.3	372.6
Municipal solid waste <sup>a</sup>	5.8	10.0	10.1	11.4	11.2	11.2	11.5	11.3	11.6	11.6
Geothermal	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
<b>Total</b>	<b>1,831.0</b>	<b>1,960.1</b>	<b>2,310.2</b>	<b>2,319.2</b>	<b>2,351.5</b>	<b>2,416.9</b>	<b>2,359.5</b>	<b>2,425.9</b>	<b>2,373.7</b>	<b>2,160.3</b>

<sup>a</sup>Emissions from nonbiogenic sources, including fuels derived from recycled tires.

Notes: 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.

## 2.8. Carbon dioxide emissions and carbon sequestration from nonfuel uses of energy inputs

Nonfuel uses of fossil fuels (for purposes other than their energy value) create carbon dioxide emissions and also sequester carbon in nonfuel products, such as plastics.

In 2009, carbon dioxide emissions from nonfuel uses of energy inputs totaled 83 million metric tons—15.3 percent below the 2008 total (Table 13). Carbon sequestration from nonfuel uses of energy inputs in 2009 included 246 million metric tons carbon dioxide equivalent (CO<sub>2</sub>e) that was sequestered in nonfuel products rather than emitted to the atmosphere (Table 14). The 2009 sequestration total was 7.0 percent below the 2008 total.

### Carbon dioxide emissions from nonfuel uses of energy inputs, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	97.1	102.2	97.7	82.8
Change from 1990 (million metric tons)		5.1	0.5	-14.4
(percent)		5.3%	0.6%	-14.8%
Average annual change from 1990 (percent)		0.3%	0.0%	-0.8%
Change from 2005 (million metric tons)			-4.6	-19.5
(percent)			-4.5%	-19.1%
Change from 2008 (million metric tons)				-14.9
(percent)				-15.3%

### Carbon sequestration from nonfuel uses of energy inputs, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated sequestration (million metric tons)	252.8	305.1	264.4	245.7
Change from 1990 (million metric tons)		52.2	11.5	-7.1
(percent)		20.7%	4.6%	-2.8%
Average annual change from 1990 (percent)		1.3%	0.2%	-0.1%
Change from 2005 (million metric tons)			-40.7	-59.3
(percent)			-13.3%	-19.4%
Change from 2008 (million metric tons)				-18.6
(percent)				-7.0%

**Table 13. U.S. carbon dioxide emissions from nonfuel uses of energy fuels, 1990-2009 (million metric tons carbon dioxide)**

End use and type	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
<b>Industrial</b>										
Petroleum										
Liquefied petroleum gas	14.8	19.5	20.4	19.0	19.4	18.3	18.7	18.9	17.7	18.6
Distillate fuel oil	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.6
Residual fuel oil	1.9	2.1	2.0	1.9	2.1	2.3	2.5	2.0	2.1	1.7
Lubricants	6.9	6.6	7.0	5.9	6.0	5.9	5.8	6.0	5.6	5.0
Pentanes plus	1.1	4.1	3.2	2.3	2.3	2.0	1.4	1.8	1.6	1.3
Petrochemical feed	33.6	36.0	36.8	36.5	41.8	38.4	40.1	37.1	32.2	25.1
Petroleum coke	9.1	6.8	7.2	8.2	13.3	11.1	13.1	12.5	12.4	8.5
Special naphtha	7.8	5.2	7.1	5.9	3.7	4.6	5.1	5.7	6.2	3.4
<i>Petroleum subtotal</i>	<i>75.5</i>	<i>80.5</i>	<i>84.1</i>	<i>80.2</i>	<i>89.0</i>	<i>83.2</i>	<i>87.3</i>	<i>84.7</i>	<i>78.4</i>	<i>64.2</i>
Coal	0.5	0.7	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.3
Natural gas	14.7	17.5	16.3	13.0	11.9	12.9	12.4	12.7	13.6	13.5
<i>Industrial subtotal</i>	<i>90.6</i>	<i>98.7</i>	<i>101.0</i>	<i>93.7</i>	<i>101.4</i>	<i>96.6</i>	<i>100.2</i>	<i>97.8</i>	<i>92.4</i>	<i>78.1</i>
<b>Transportation</b>										
Lubricants	6.5	6.2	6.7	5.6	5.6	5.6	5.5	5.6	5.2	4.7
<b>Total</b>	<b>97.1</b>	<b>104.9</b>	<b>107.6</b>	<b>99.3</b>	<b>107.1</b>	<b>102.2</b>	<b>105.7</b>	<b>103.5</b>	<b>97.7</b>	<b>82.8</b>

Notes: Emissions from nonfuel use of energy fuels are included in the energy consumption tables in this chapter. Totals may not equal sum of components due to independent rounding.

**Table 14. U.S. carbon sequestration from nonfuel uses of energy fuels, 1990-2009  
(million metric tons carbon dioxide equivalent)**

End use and type	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
<b>Industrial</b>										
Petroleum										
Liquefied petroleum gas	59.2	78.2	81.7	76.0	77.6	73.2	74.6	75.8	70.9	74.4
Distillate fuel oil	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.6
Residual fuel oil	1.9	2.1	2.0	1.9	2.1	2.3	2.5	2.0	2.1	1.7
Asphalt and road oil	88.5	89.1	96.4	92.2	98.6	100.0	95.4	90.5	76.5	66.0
Lubricants	6.9	6.6	7.0	5.9	6.0	5.9	5.8	6.0	5.6	5.0
Pentanes plus	4.4	16.2	12.7	9.0	9.1	8.0	5.7	7.4	6.3	5.2
Petrochemical feed	46.0	50.0	57.7	59.2	69.1	64.2	63.2	57.5	49.9	46.0
Petroleum coke	9.1	6.8	7.2	8.2	13.3	11.1	13.1	12.5	12.4	8.5
Waxes and miscellaneous	12.6	10.2	11.2	11.6	10.7	10.7	12.0	11.5	12.0	12.2
<i>Petroleum subtotal</i>	<i>228.9</i>	<i>259.3</i>	<i>276.4</i>	<i>264.6</i>	<i>287.0</i>	<i>276.2</i>	<i>273.0</i>	<i>263.8</i>	<i>236.2</i>	<i>219.7</i>
Coal	1.4	2.1	1.8	1.5	1.5	1.5	1.4	1.4	1.4	1.0
Natural gas	16.0	19.0	23.3	20.3	21.4	21.8	22.1	23.0	21.5	20.4
<i>Industrial subtotal</i>	<i>246.3</i>	<i>280.4</i>	<i>301.5</i>	<i>286.4</i>	<i>309.9</i>	<i>299.5</i>	<i>296.6</i>	<i>288.2</i>	<i>259.1</i>	<i>241.0</i>
<b>Transportation</b>										
Lubricants	6.5	6.2	6.7	5.6	5.6	5.6	5.5	5.6	5.2	4.7
<b>Total</b>	<b>252.8</b>	<b>286.6</b>	<b>308.2</b>	<b>292.0</b>	<b>315.5</b>	<b>305.1</b>	<b>302.0</b>	<b>293.8</b>	<b>264.4</b>	<b>245.7</b>

Notes: Emissions from nonfuel use of energy fuels are included in the energy consumption tables in this chapter. Totals may not equal sum of components due to independent rounding.

## 2.9. Adjustments to energy consumption

EIA's greenhouse gas emissions inventory includes two adjustments to energy-related carbon dioxide emissions (Table 15). First, the unadjusted 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, emissions from the Territories are added as an adjustment 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, emissions from military bunker fuels are also subtracted from the U.S. total.

The net adjustment in emissions has been negative in every year from 1990 to 2009, because emissions from international and military bunker fuels have exceeded emissions from U.S. Territories in each of the years. The net negative adjustment for 2009 was 66 million metric tons.

### Carbon dioxide emissions from U.S. territories,\* 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	31.6	58.4	49.5	47.4
Change from 1990 (million metric tons)		26.8	17.9	15.7
(percent)		84.7%	56.6%	49.8%
Average annual change from 1990 (percent)		4.2%	2.5%	2.1%
Change from 2005 (million metric tons)			-8.9	-11.1
(percent)			-15.2%	-18.9%
Change from 2008 (million metric tons)				-2.2
(percent)				-4.4%

\*Added to total U.S. emissions.

### Carbon dioxide emissions from international bunker fuels,\* 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	114.5	103.0	125.6	113.4
Change from 1990 (million metric tons)		-11.5	11.1	-1.1
(percent)		-10.0%	9.7%	-1.0%
Average annual change from 1990 (percent)		-0.7%	0.5%	-0.1%
Change from 2005 (million metric tons)			22.6	10.4
(percent)			21.9%	10.1%
Change from 2008 (million metric tons)				-12.2
(percent)				-9.7%

\*Subtracted from total U.S. emissions.

**Table 15. U.S. carbon dioxide emissions: adjustments for U.S. Territories and international bunker fuels, 1990-2009**  
(million metric tons carbon dioxide)

Adjusted category	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
<b>Emissions from U.S. Territories</b>										
Puerto Rico	20.2	24.3	27.7	37.5	38.2	37.8	37.9	36.6	31.7	30.8
U.S. Virgin Islands	7.5	8.6	9.8	15.3	18.4	16.3	17.3	16.5	13.9	12.7
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	2.4	2.0	2.1	2.3	2.1	1.7	1.7
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	1.3	1.2
<i>U.S. Territories subtotal<sup>a</sup></i>	<i>31.6</i>	<i>38.6</i>	<i>42.6</i>	<i>57.4</i>	<i>60.7</i>	<i>58.4</i>	<i>59.6</i>	<i>57.3</i>	<i>49.5</i>	<i>47.4</i>
<b>Emissions from bunker fuels</b>										
Marine bunkers ( <i>subtotal</i> )	62.7	47.0	37.9	20.0	29.6	29.8	50.3	51.5	56.1	52.0
Distillate fuel	6.3	5.8	2.9	1.5	1.7	2.4	3.1	3.6	4.5	4.3
Residual fuel	56.4	41.2	35.0	18.5	27.9	27.4	47.2	47.9	51.6	47.7
Aviation bunkers ( <i>subtotal</i> )	38.4	45.8	61.3	60.7	66.2	63.9	63.9	64.8	61.3	53.2
U.S. carriers	18.7	21.3	26.2	23.4	26.7	28.6	28.8	29.7	29.6	27.3
Foreign carriers	19.7	24.5	35.1	37.3	39.5	35.3	35.1	35.2	31.7	25.9
Military bunkers ( <i>subtotal</i> )	13.4	9.0	8.0	9.3	10.3	9.3	8.1	8.5	8.2	8.2
<i>Bunker fuels subtotal<sup>b</sup></i>	<i>114.5</i>	<i>101.8</i>	<i>107.3</i>	<i>90.0</i>	<i>106.1</i>	<i>103.0</i>	<i>122.3</i>	<i>124.8</i>	<i>125.6</i>	<i>113.4</i>
<b>Total</b>	<b>-82.9</b>	<b>-63.2</b>	<b>-64.7</b>	<b>-32.6</b>	<b>-45.3</b>	<b>-44.6</b>	<b>-62.7</b>	<b>-67.5</b>	<b>-76.1</b>	<b>-66.0</b>

<sup>a</sup>Added to total U.S. emissions.

<sup>b</sup>Subtracted from total U.S. emissions.

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



## 2.10. Other carbon dioxide emissions sources

“Other emissions sources” in total accounted for 87 million metric tons of carbon dioxide in 2009, or less than 2 percent of the U.S. total.

In 2009, the second-largest source of U.S. carbon dioxide emissions (after fossil fuel consumption) was natural gas production (Figure 16 and Table 16), which includes flaring of natural gas at the wellhead and “scrubbing” of carbon dioxide from natural gas after it has been produced.

Cement manufacture, where most emissions result from the production of clinker (consisting of calcium carbonate sintered with silica in a cement kiln to produce calcium silicate), was the fourth-largest source of U.S. carbon dioxide emissions in 2009, after energy, nonfuel use of fossil fuels, and natural gas production.

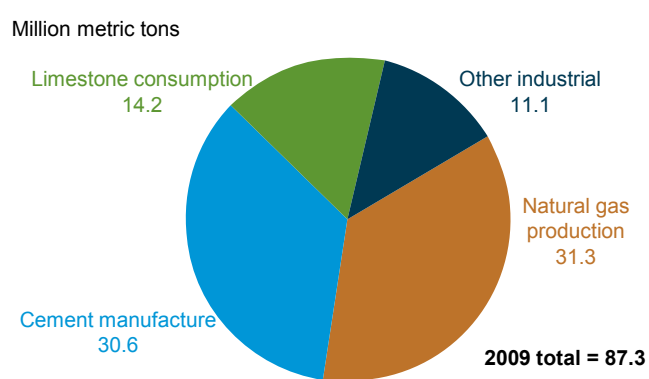
Limestone consumption, especially for lime manufacture, is the source of 14 to 20 million metric tons of carbon dioxide emissions per year.

In addition, “other sources” of U.S. carbon dioxide emissions include soda ash manufacture and consumption; carbon dioxide manufacture; aluminum manufacture; and waste combustion in the commercial and industrial sectors.

### U.S. carbon dioxide emissions from other sources, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons)	85.1	103.5	103.6	87.3
Change from 1990 (million metric tons)		18.4	18.5	2.2
(percent)		21.6%	21.8%	2.6%
Average annual change from 1990 (percent)		1.3%	1.1%	0.1%
Change from 2005 (million metric tons)			0.2	-16.2
(percent)			0.2%	-15.6%
Change from 2008 (million metric tons)				-16.3
(percent)				-15.8%

**Figure 16. U.S. carbon dioxide emissions from other sources, 2009**



**Table 16. U.S. carbon dioxide emissions from other sources, 1990-2009  
(million metric tons carbon dioxide)**

Fuel	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
<b>Cement manufacture</b>										
Clinker production	32.6	36.1	40.4	42.2	44.7	45.1	45.7	44.4	40.4	30.0
Masonry cement	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	0.9	0.9	0.9	0.9	0.8	0.6
<i>Cement manufacture subtotal</i>	<b>33.3</b>	<b>36.9</b>	<b>41.3</b>	<b>43.2</b>	<b>45.7</b>	<b>46.1</b>	<b>46.7</b>	<b>45.4</b>	<b>41.3</b>	<b>30.6</b>
<b>Limestone consumption</b>										
Lime manufacture	12.4	14.5	15.4	15.1	15.7	15.7	16.5	15.9	15.6	11.8
Iron smelting	1.7	1.2	1.1	0.9	1.0	0.8	0.9	0.8	0.8	0.4
Steelmaking	0.3	0.5	0.5	0.4	0.4	0.3	0.4	0.3	0.3	0.2
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	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Flue gas desulfurization	0.7	0.9	1.2	1.3	1.4	1.5	1.5	1.5	1.5	1.5
Dolomite manufacture	0.5	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
<i>Limestone consumption subtotal</i>	<b>15.9</b>	<b>17.8</b>	<b>18.6</b>	<b>18.0</b>	<b>18.9</b>	<b>18.8</b>	<b>19.6</b>	<b>18.9</b>	<b>18.6</b>	<b>14.2</b>
<b>Natural gas production</b>										
Carbon dioxide in natural gas	14.0	16.7	18.3	18.6	18.4	18.1	18.7	19.5	20.5	21.2
Natural gas flaring	9.1	17.2	5.5	5.9	5.8	7.2	7.8	8.7	10.1	10.1
<i>Natural gas production subtotal</i>	<b>23.1</b>	<b>33.9</b>	<b>23.8</b>	<b>24.5</b>	<b>24.3</b>	<b>25.3</b>	<b>26.6</b>	<b>28.2</b>	<b>30.6</b>	<b>31.3</b>
<b>Other</b>										
Soda ash manufacture	3.4	3.8	3.6	3.6	3.8	3.9	3.9	4.0	4.1	3.5
Soda ash consumption	0.5	0.8	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5
Carbon dioxide manufacture	0.9	1.0	1.3	1.5	1.5	1.6	1.6	1.7	1.8	1.9
Aluminum manufacture	5.9	4.9	5.4	4.0	3.7	3.6	3.3	3.7	3.9	2.5
Shale oil production	0.2	*	*	*	*	*	*	*	*	*
Waste combustion	1.9	3.2	3.2	3.6	3.5	3.6	3.6	2.8	2.8	2.8
<i>Other subtotal</i>	<b>12.7</b>	<b>13.8</b>	<b>14.1</b>	<b>13.2</b>	<b>13.1</b>	<b>13.2</b>	<b>13.0</b>	<b>12.9</b>	<b>13.1</b>	<b>11.1</b>
<b>Total</b>	<b>85.1</b>	<b>102.3</b>	<b>97.8</b>	<b>98.9</b>	<b>102.0</b>	<b>103.5</b>	<b>105.9</b>	<b>105.3</b>	<b>103.6</b>	<b>87.3</b>

\*Less than 0.05 million metric tons.

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

## 3. Methane emissions

### 3.1. Total emissions

The major sources of U.S. methane emissions are energy production, distribution, and use; agriculture; and waste management (Figure 17). U.S. methane emissions in 2009 totaled 731 MMTCO<sub>2</sub>e, 0.9 percent higher than the 2008 total of 724 MMTCO<sub>2</sub>e (Table 17).

Methane emissions declined steadily from 1990 to 2001, as emissions from coal mining and landfills fell, then rose from 2002 to 2009 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 303 MMTCO<sub>2</sub>e in 2009. Agricultural emissions (primarily from livestock management) and emissions from waste management (primarily landfills) also are large sources of U.S. methane emissions, contributing 216 and 208 MMTCO<sub>2</sub>e, respectively, in 2009.

#### Total U.S. methane emissions, 1990, 2005, 2008, and 2009

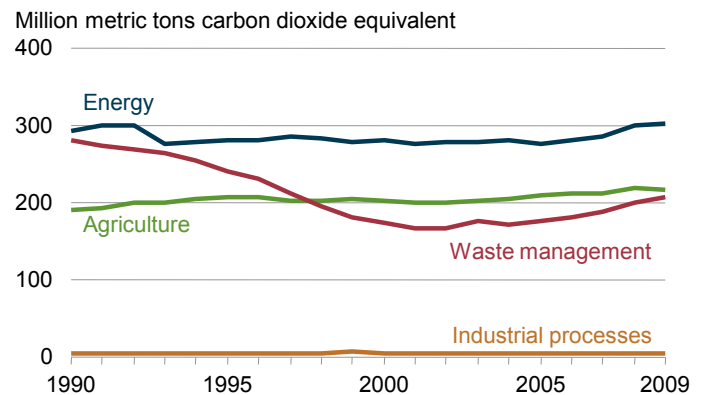
	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	768.8	669.2	724.2	730.9
Change from 1990 (million metric tons CO <sub>2</sub> e)		-99.6	-44.7	-37.9
(percent)		-13.0%	-5.8%	-4.9%
Average annual change from 1990 (percent)		-0.9%	-0.3%	-0.3%
Change from 2005 (million metric tons CO <sub>2</sub> e)			54.9	61.7
(percent)			8.2%	9.2%
Change from 2008 (million metric tons CO <sub>2</sub> e)				6.8
(percent)				0.9%

**Table 17. U.S. methane emissions, 1990-2009 (million metric tons carbon dioxide equivalent)**

Source	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Energy	293.1	279.9	281.7	277.7	280.0	277.0	279.8	285.8	299.3	303.0
Agriculture	190.6	207.1	201.2	202.0	204.0	209.9	211.8	212.3	219.7	215.9
Waste management	280.6	240.3	174.6	175.8	172.0	177.3	181.9	187.6	200.6	207.9
Industrial processes	4.5	5.5	5.6	5.1	5.6	5.0	5.1	5.1	4.6	4.2
<b>Total methane</b>	<b>768.8</b>	<b>732.7</b>	<b>663.1</b>	<b>660.6</b>	<b>661.6</b>	<b>669.2</b>	<b>678.5</b>	<b>690.9</b>	<b>724.2</b>	<b>730.9</b>

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

**Figure 17. U.S. methane emissions by source, 1990-2009**



### 3.2. Energy sources

Natural gas systems and coal mines are the major sources of methane emissions in the energy sector (Figure 18 and Table 18). U.S. methane emissions from natural gas systems grew from 1990 to 2009 by 27 percent (39 MMTCO<sub>2</sub>e), largely because of increases in natural gas consumption. Emissions from coal mines declined from 1990 to 2002 and remained nearly steady through 2007. In 2009, emissions from ventilation and degasification systems at underground mines increased by 9.2 percent, leading to a 4.8-percent increase in total net emissions from coal mining over the 2008 level, despite declines in emissions from both surface mining and post-mining activities.

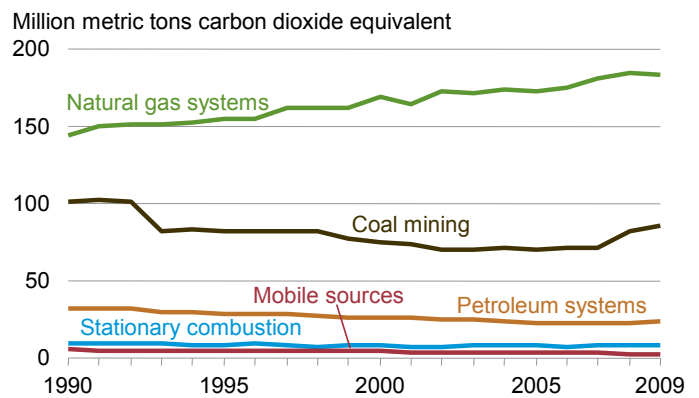
With domestic oil production dropping by 28 percent from 1990 to 2009, methane emissions from petroleum exploration and production have declined by the same percentage.

Residential wood consumption accounted for just over 45 percent of U.S. methane emissions from stationary combustion in 2009. Methane emissions from passenger cars fell by 77 percent from 1990 to 2009, as the use of catalytic converters increased. An 11-percent drop from 2001 to 2009 in annual miles traveled by passenger cars also contributed to the decrease in emissions.

#### Methane emissions from energy sources, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	293.1	277.0	299.3	303.0
Change from 1990 (million metric tons CO <sub>2</sub> e)		-16.1	6.2	9.9
(percent)		-5.5%	2.1%	3.4%
Average annual change from 1990 (percent)		-0.4%	0.1%	0.2%
Change from 2005 (million metric tons CO <sub>2</sub> e)			22.3	26.0
(percent)			8.0%	9.4%
Change from 2008 (million metric tons CO <sub>2</sub> e)				3.7
(percent)				1.2%

Figure 18. U.S. methane emissions from energy sources, 1990-2009



**Table 18. U.S. methane emissions from energy sources, 1990-2009  
(million metric tons carbon dioxide equivalent)**

Source	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Natural gas systems										
Production	39.9	42.7	46.9	50.2	50.9	51.6	52.6	54.6	57.3	57.8
Processing	16.2	18.0	17.9	15.7	16.2	15.9	15.7	16.6	16.3	16.5
Transmission and storage	52.6	53.7	60.4	59.6	58.5	58.3	56.2	60.1	60.2	58.3
Distribution	35.8	40.0	44.0	46.0	47.7	46.9	50.7	50.2	50.4	50.4
<i>Natural gas systems subtotal</i>	<i>144.4</i>	<i>154.3</i>	<i>169.1</i>	<i>171.5</i>	<i>173.2</i>	<i>172.7</i>	<i>175.1</i>	<i>181.4</i>	<i>184.2</i>	<i>183.0</i>
Coal mining										
Surface	11.6	12.3	13.5	13.8	14.3	14.7	15.5	15.3	15.7	14.3
Underground	90.1	70.5	60.9	56.0	57.1	55.5	55.9	55.7	66.4	71.7
<i>Coal mining subtotal</i>	<i>101.7</i>	<i>82.7</i>	<i>74.4</i>	<i>69.8</i>	<i>71.4</i>	<i>70.2</i>	<i>71.4</i>	<i>71.0</i>	<i>82.1</i>	<i>86.0</i>
Petroleum systems										
Refineries	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6
Exploration and production	31.6	28.2	25.0	24.4	23.3	22.3	21.9	21.8	21.3	22.8
Crude oil transportation	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
<i>Petroleum systems subtotal</i>	<i>32.4</i>	<i>29.0</i>	<i>25.8</i>	<i>25.2</i>	<i>24.1</i>	<i>23.0</i>	<i>22.8</i>	<i>22.6</i>	<i>22.1</i>	<i>23.5</i>
Stationary combustion	9.1	8.8	8.1	7.7	7.9	7.9	7.4	7.8	8.1	7.8
Mobile sources	5.5	5.1	4.2	3.4	3.4	3.2	3.1	3.0	2.8	2.7
<b>Total energy sources</b>	<b>293.1</b>	<b>279.9</b>	<b>281.7</b>	<b>277.7</b>	<b>280.0</b>	<b>277.0</b>	<b>279.8</b>	<b>285.8</b>	<b>299.3</b>	<b>303.0</b>

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

### 3.3. Agricultural sources

Livestock management—including emissions from enteric fermentation (67 percent) and management of animal waste (27 percent)—accounts for the largest share of U.S. methane emissions from agricultural activities (Figure 19 and Table 19). 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 fell by 1.7 percent from 2008 to 2009. Swine accounted for 42 percent (25 MMTCO<sub>2</sub>e), and dairy cattle accounted for 49 percent (28 MMTCO<sub>2</sub>e), of total methane emissions from livestock manure in 2009.

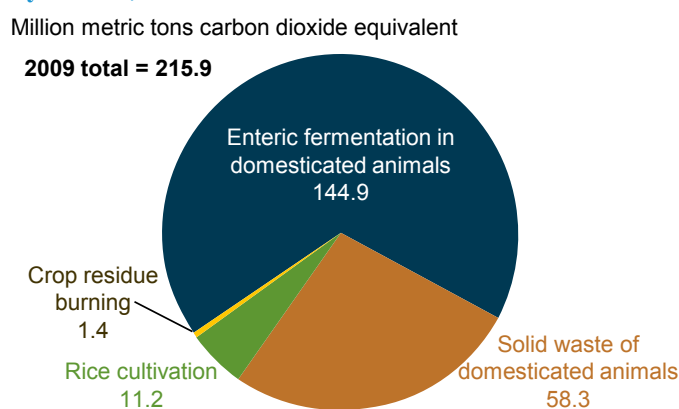
Enteric fermentation (food digestion) in ruminant animals also produces methane emissions, and digestion by cattle accounts for 96 percent of U.S. methane emissions from this source. With little change in the cattle population since 1990, the level of emissions from enteric fermentation has been relatively stable, with a small decrease of 3 MMTCO<sub>2</sub>e (2.2 percent) in 2009 from the 2008 level.

Methane emissions from rice cultivation in the United States increased by almost 4 percent (0.4 MMTCO<sub>2</sub>e) from 2008 to 2009. Emissions from crop residue burning increased by 4 percent from 2008 to 2009. Residue burning remains the smallest contributor to methane emissions from agriculture, representing less than 1 percent of total U.S. methane emissions from agriculture.

#### Methane emissions from agricultural sources, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	190.6	209.9	219.7	215.9
Change from 1990 (million metric tons CO <sub>2</sub> e)		19.3	29.1	25.3
(percent)		10.1%	15.3%	13.3%
Average annual change from 1990 (percent)		0.6%	0.8%	0.7%
Change from 2005 (million metric tons CO <sub>2</sub> e)			9.8	6.0
(percent)			4.7%	2.9%
Change from 2008 (million metric tons CO <sub>2</sub> e)				-3.8
(percent)				-1.7%

#### Figure 19. U.S. methane emissions from agriculture by source, 2009



**Table 19. U.S. methane emissions from agricultural sources, 1990-2009 (million metric tons carbon dioxide equivalent)**

Source	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Enteric fermentation in domesticated animals	139.6	149.0	139.9	140.2	140.4	142.7	144.4	145.0	148.2	144.9
Solid waste of domesticated animals	39.8	45.9	49.0	49.9	50.4	54.4	56.3	56.1	59.3	58.3
Rice cultivation	10.1	11.1	11.1	10.7	11.8	11.5	9.9	9.8	10.8	11.2
Crop residue burning	1.1	1.1	1.3	1.3	1.4	1.3	1.3	1.3	1.4	1.4
<b>Total agricultural sources</b>	<b>190.6</b>	<b>207.1</b>	<b>201.2</b>	<b>202.0</b>	<b>204.0</b>	<b>209.9</b>	<b>211.8</b>	<b>212.3</b>	<b>219.7</b>	<b>215.9</b>

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

### 3.4. Waste management sources

Methane emissions from waste management are dominated by the decomposition of solid waste in municipal and industrial landfills (Figure 20 and Table 20). 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 annual increases in methane emissions. The rapid growth in methane recovery from landfills 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 kilowatthour 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. In addition, the American Recovery and Reinvestment Act of 2009 included a 2-year extension (through December 31, 2012) of the production tax credit for renewable energy, including waste-to-energy and landfill gas combustion.

Wastewater treatment, including both domestic wastewater (about two-thirds) and industrial wastewater (about one-third), is responsible for 14 percent (28 MMTCO<sub>2</sub>e) of methane emissions from waste management. In 2009, emissions from wastewater treatment at pulp and paper manufacturing facilities accounted for 47 percent (5 MMTCO<sub>2</sub>e) of total emissions from industrial wastewater, and emissions from meat and poultry packing facilities accounted for another 41 percent (4 MMTCO<sub>2</sub>e).

#### Methane emissions from waste management sources, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	280.6	177.3	200.6	207.9
Change from 1990 (million metric tons CO <sub>2</sub> e)		-103.3	-80.0	-72.8
(percent)		-36.8%	-28.5%	-25.9%
Average annual change from 1990 (percent)		-3.0%	-1.8%	-1.6%
Change from 2005 (million metric tons CO <sub>2</sub> e)			23.3	30.6
(percent)			13.1%	17.2%
Change from 2008 (million metric tons CO <sub>2</sub> e)				7.3
(percent)				3.6%

Figure 20. U.S. methane emissions from waste management by source, 1990-2009

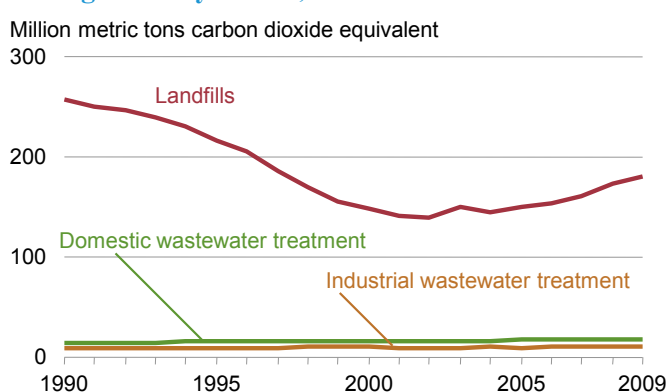


Table 20. U.S. methane emissions from waste management sources, 1990-2009 (million metric tons carbon dioxide equivalent)

Source	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Landfills	257.8	215.4	148.3	149.3	145.1	150.4	154.4	160.0	172.6	179.7
Domestic wastewater treatment	14.4	15.4	16.3	16.8	16.9	17.1	17.3	17.4	17.6	17.8
Industrial wastewater treatment	8.4	9.5	10.0	9.7	9.9	9.8	10.1	10.2	10.4	10.4
<b>Total waste management sources</b>	<b>280.6</b>	<b>240.3</b>	<b>174.6</b>	<b>175.8</b>	<b>172.0</b>	<b>177.3</b>	<b>181.9</b>	<b>187.6</b>	<b>200.6</b>	<b>207.9</b>

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

### 3.5. Industrial process sources

Methane emissions are generated by industrial processes in the production of iron and steel and chemicals (Figure 21 and Table 21). Total methane emissions from industrial processes declined by a net 0.4 MMTCO<sub>2</sub>e (9 percent) from 2008 to 2009, as a result of declines in both chemical production and iron and steel production. Similarly, large decreases during 2009 in production of pig iron, coke, and sinter associated with iron and steel production caused methane emissions from this industrial source to drop by 43.6 percent (0.3 MMTCO<sub>2</sub>e) from the 2008 level.

In 2009, methane emissions from industrial processes dropped below 1990 levels for the first time, resulting in a net decline of 0.3 MMTCO<sub>2</sub>e (7.2 percent) over the past two decades; however, the 2009 decline is associated with the impact of the recession on industrial production in 2009, and emissions from industrial processes can be expected to rebound as the U.S. economy recovers.

#### Methane emissions from industrial process sources, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	4.5	5.0	4.6	4.2
Change from 1990 (million metric tons CO <sub>2</sub> e)		0.5	0.1	-0.3
(percent)		11.7%	1.8%	-7.2%
Average annual change from 1990 (percent)		0.7%	0.1%	-0.4%
Change from 2005 (million metric tons CO <sub>2</sub> e)			-0.4	-0.8
(percent)			-8.8%	-16.8%
Change from 2008 (million metric tons CO <sub>2</sub> e)				-0.4
(percent)				-8.8%

Figure 21. U.S. methane emissions from industrial processes by source, 1990-2009

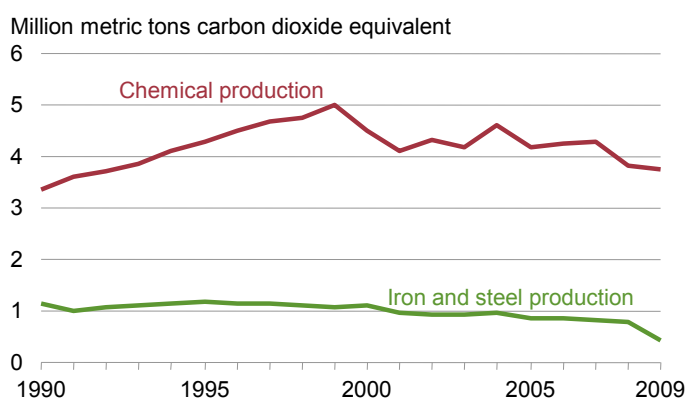


Table 21. U.S. methane emissions from industrial process sources, 1990-2009 (million metric tons carbon dioxide equivalent)

Source	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Chemical production										
Ethylene	2.7	3.5	3.7	3.4	3.8	3.6	3.7	3.8	3.4	3.4
Ethylene dichloride	*	*	*	*	*	*	*	*	*	*
Styrene	*	*	*	*	*	*	*	*	*	*
Methanol	0.2	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1
Carbon black	0.4	0.5	0.5	0.4	0.5	0.5	0.4	0.4	0.4	0.3
<b>Chemical production subtotal</b>	<b>3.4</b>	<b>4.3</b>	<b>4.5</b>	<b>4.2</b>	<b>4.6</b>	<b>4.2</b>	<b>4.2</b>	<b>4.3</b>	<b>3.8</b>	<b>3.8</b>
Iron and steel production										
Coke <sup>a</sup>	*	*	*	*	*	*	*	*	*	*
Sinter	*	*	*	*	*	*	*	*	*	*
Pig iron	1.1	1.1	1.1	0.9	1.0	0.8	0.9	0.8	0.8	0.4
<b>Iron and steel subtotal</b>	<b>1.1</b>	<b>1.2</b>	<b>1.1</b>	<b>0.9</b>	<b>1.0</b>	<b>0.9</b>	<b>0.9</b>	<b>0.8</b>	<b>0.8</b>	<b>0.4</b>
<b>Total industrial processes</b>	<b>4.5</b>	<b>5.5</b>	<b>5.6</b>	<b>5.1</b>	<b>5.6</b>	<b>5.0</b>	<b>5.1</b>	<b>5.1</b>	<b>4.6</b>	<b>4.2</b>

<sup>a</sup>Based on total U.S. production of metallurgical coke, including for uses other than iron and steel manufacture.

\*Less than 0.05 million metric tons.

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



## 4. Nitrous oxide emissions

### 4.1. Total emissions

U.S. nitrous oxide emissions in 2009 were 4 MMTCO<sub>2</sub>e (1.7 percent) below their 2008 total (Table 22). Sources of U.S. nitrous oxide emissions include agriculture, energy use, industrial processes, and waste management (Figure 22). The largest source is agriculture (73 percent), and the majority of agricultural emissions result from nitrogen fertilization of agricultural soils (87 percent of the agriculture total) and management of animal waste (13 percent). U.S. nitrous oxide emissions rose from 1990 to 1994, fell from 1994 to 2002, and returned to an upward trajectory from 2003 to 2007, largely as a result of increased use of synthetic fertilizers. Fertilizers are the primary contributor of emissions from nitrogen fertilization of soils, which grew by more than 30 percent from 2005 to 2008.

#### Total nitrous oxide emissions, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	221.4	223.6	223.5	219.6
Change from 1990 (million metric tons CO <sub>2</sub> e)		2.3	2.1	-1.8
(percent)		1.0%	1.0%	-0.8%
Average annual change from 1990 (percent)		0.1%	0.1%	0.0%
Change from 2005 (million metric tons CO <sub>2</sub> e)			-0.2	-4.0
(percent)			-0.1%	-1.8%
Change from 2008 (million metric tons CO <sub>2</sub> e)				-3.9
(percent)				-1.7%

Figure 22. U.S. nitrous oxide emissions by source, 1990-2009

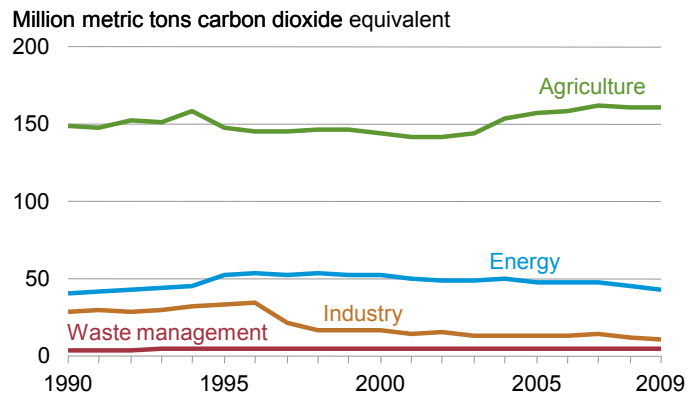


Table 22. U.S. nitrous oxide emissions, 1990-2009 (million metric tons carbon dioxide equivalent)

Source	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Agriculture										
Nitrogen fertilization of soils	128.6	126.2	122.9	123.5	132.9	135.5	136.1	140.2	139.4	139.6
Solid waste of animals	19.6	20.6	20.8	20.5	20.6	20.8	21.2	21.3	21.2	20.8
Crop residue burning	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.5	0.6	0.6
<i>Agriculture subtotal</i>	<i>148.7</i>	<i>147.2</i>	<i>144.3</i>	<i>144.5</i>	<i>154.1</i>	<i>156.9</i>	<i>157.8</i>	<i>162.1</i>	<i>161.1</i>	<i>161.0</i>
Energy										
Mobile combustion	26.3	37.3	36.4	33.9	34.1	32.4	31.8	31.7	30.0	28.8
Stationary combustion	13.9	14.5	15.7	15.3	15.6	15.7	15.4	15.6	15.1	13.6
<i>Energy subtotal</i>	<i>40.2</i>	<i>51.8</i>	<i>52.1</i>	<i>49.2</i>	<i>49.7</i>	<i>48.2</i>	<i>47.2</i>	<i>47.3</i>	<i>45.1</i>	<i>42.5</i>
Industry	28.5	32.8	16.7	13.3	13.3	13.6	13.6	14.1	12.1	10.8
Waste management										
Human sewage in wastewater	3.6	4.0	4.4	4.4	4.5	4.6	4.7	4.7	4.8	4.8
Waste combustion	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4
<i>Waste management subtotal</i>	<i>4.0</i>	<i>4.3</i>	<i>4.7</i>	<i>4.8</i>	<i>4.9</i>	<i>5.0</i>	<i>5.1</i>	<i>5.2</i>	<i>5.2</i>	<i>5.3</i>
<b>Total nitrous oxide</b>	<b>221.4</b>	<b>236.2</b>	<b>217.8</b>	<b>211.8</b>	<b>222.0</b>	<b>223.6</b>	<b>223.7</b>	<b>228.6</b>	<b>223.5</b>	<b>219.6</b>

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

## 4.2. Agricultural sources

Agricultural sources, at 161 MMTCO<sub>2</sub>e, accounted for 73 percent of U.S. nitrous oxide emissions in 2009. Nitrous oxide emissions from agricultural sources decreased by less than 1 percent (less than 0.1 MMTCO<sub>2</sub>e) from 2008 to 2009 (Table 23). More than 85 percent (140 MMTCO<sub>2</sub>e) of U.S. agricultural emissions of nitrous oxide in 2009 is attributable to nitrogen fertilization of soils (Figure 23), including 118 MMTCO<sub>2</sub>e from direct emissions and 21 MMTCO<sub>2</sub>e from indirect emissions.

Microbial denitrification of solid waste from domestic animals in the United States, primarily cattle, emitted 21 MMTCO<sub>2</sub>e of nitrous oxide in 2009. 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. This category no longer includes emissions related to manure deposited by grazing animals.

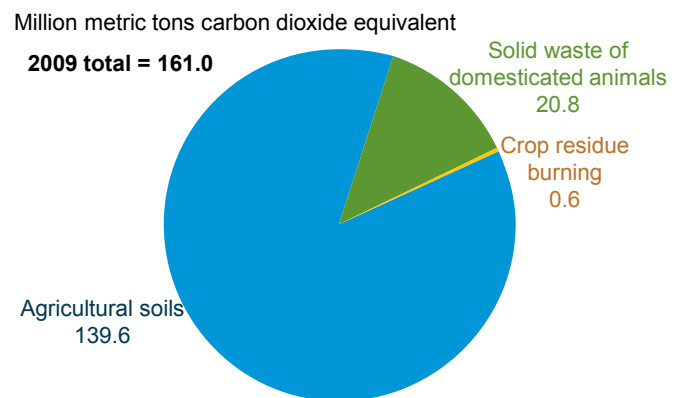
Methods for estimating agricultural emissions from nitrogen fertilization of soils have been updated for the 2009 inventory to correct for the disaggregation of organic and synthetic fertilizers, allow for indirect emissions from leaching of nitrogen only in regions with sufficient rainfall or irrigation, include below-ground crop residues while omitting biological fixation of nitrogen, and transfer emissions from manure deposited by grazing animals to the soil nitrogen amendments total (as opposed to the manure management total).

Emissions from the mineralization of mineral soils are also considered for the first time in this report, although they are zero across the whole time series since 1990 because there has been a net gain in soil carbon in mineral soils over the period at the national level. Mineralization of organic soils (histosols) continues to be a very small source of emissions.

### Nitrous oxide emissions from agricultural sources, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	148.7	156.9	161.1	161.0
Change from 1990 (million metric tons CO <sub>2</sub> e)		8.2	12.4	12.4
(percent)		5.5%	8.4%	8.3%
Average annual change from 1990 (percent)		0.4%	0.4%	0.4%
Change from 2005 (million metric tons CO <sub>2</sub> e)			4.2	4.2
(percent)			2.7%	2.6%
Change from 2008 (million metric tons CO <sub>2</sub> e)				0.0
(percent)				0.0%

**Figure 23. U.S. nitrous oxide emissions from agriculture by source, 2009**



**Table 23. U.S. nitrous oxide emissions from agricultural sources, 1990-2009  
(million metric tons carbon dioxide equivalent)**

Source	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Direct emissions (agricultural soils)										
Synthetic nitrogen fertilizers	47.5	45.8	40.7	42.9	48.5	51.7	53.5	54.6	53.3	53.3
Animal manure	27.8	29.3	26.4	25.6	25.3	25.7	25.7	25.6	25.6	24.9
Sewage sludge and other non-manure organics	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Above- and below-ground crop residues	31.2	29.6	33.8	34.0	36.3	34.8	33.3	35.7	36.3	37.2
Soil mineralization	2.7	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
<i>Direct emissions subtotal</i>	<i>109.2</i>	<i>107.6</i>	<i>103.8</i>	<i>105.3</i>	<i>113.0</i>	<i>115.0</i>	<i>115.3</i>	<i>118.8</i>	<i>118.0</i>	<i>118.2</i>
Indirect emissions (agricultural soils)										
Soil leaching and runoff	11.5	10.8	12.1	11.1	12.3	12.5	12.6	13.2	13.2	13.3
Atmospheric deposition	7.8	7.8	7.0	7.1	7.6	8.0	8.1	8.2	8.1	8.0
<i>Indirect emissions subtotal</i>	<i>19.4</i>	<i>18.6</i>	<i>19.1</i>	<i>18.2</i>	<i>19.9</i>	<i>20.5</i>	<i>20.7</i>	<i>21.5</i>	<i>21.3</i>	<i>21.4</i>
Solid waste of domesticated animals										
Cattle	15.9	16.8	16.9	16.5	16.6	16.8	17.1	17.1	16.9	16.7
Swine	1.5	1.7	1.8	1.8	1.9	1.9	1.9	2.0	2.0	2.0
Poultry	1.9	1.7	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.8
Horses	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2
Sheep	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
Goats	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
<i>Solid waste subtotal</i>	<i>19.6</i>	<i>20.6</i>	<i>20.8</i>	<i>20.5</i>	<i>20.6</i>	<i>20.8</i>	<i>21.2</i>	<i>21.3</i>	<i>21.2</i>	<i>20.8</i>
Crop residue burning	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.5	0.6	0.6
<b>Total agricultural sources</b>	<b>148.7</b>	<b>147.2</b>	<b>144.3</b>	<b>144.5</b>	<b>154.1</b>	<b>156.9</b>	<b>157.8</b>	<b>162.1</b>	<b>161.1</b>	<b>161.0</b>

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

### 4.3. Energy sources

Emissions from energy sources made up about 19 percent of total U.S. nitrous oxide emissions in 2009. Nitrous oxide is a byproduct of fuel combustion in mobile and stationary sources (Figure 24). About two-thirds of U.S. nitrous oxide emissions from energy use can be traced to mobile sources—primarily, passenger cars and light trucks as well as other motor vehicles (Table 24). Emissions from mobile sources dropped by 3.9 percent (1 MMTCO<sub>2</sub>e) from 2008 to 2009, primarily because of a 7.7-percent decrease in emissions from passenger cars and light trucks. Vehicle miles traveled by passenger vehicles were 2.4 percent lower in 2009 than in 2008, in part as the result of the economic recession. Nitrous oxide emissions factors for passenger cars and light-duty vehicles have been revised to the values published in the 2006 IPCC guidelines, resulting in a significant decline in calculated emissions from this source category, as described in previous reports.

Nitrous oxide emissions from stationary combustion sources result predominantly from the burning of coal at electric power plants (8 MMTCO<sub>2</sub>e, or 60 percent of all nitrous oxide emissions from stationary combustion).

#### U.S. nitrous oxide emissions from energy sources, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	40.2	48.2	45.1	42.5
Change from 1990 (million metric tons CO <sub>2</sub> e)		8.0	4.9	2.3
(percent)		19.8%	12.1%	5.6%
Average annual change from 1990 (percent)		1.2%	0.6%	0.3%
Change from 2005 (million metric tons CO <sub>2</sub> e)			-3.1	-5.7
(percent)			-6.4%	-11.8%
Change from 2008 (million metric tons CO <sub>2</sub> e)				-2.6
(percent)				-5.8%

Figure 24. U.S. nitrous oxide emissions from energy use by source, 1990-2009

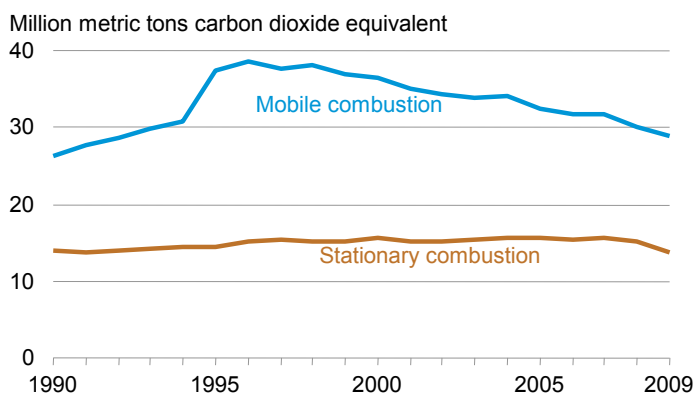


Table 24. U.S. nitrous oxide emissions from energy sources, 1990-2009 (million metric tons carbon dioxide equivalent)

Source	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Mobile combustion										
Motor vehicles	22.7	33.7	32.5	30.5	30.3	28.5	27.8	27.8	26.4	25.7
Passenger cars	13.9	17.9	15.3	12.7	12.1	10.7	10.0	9.6	8.7	8.2
Light-duty trucks	7.0	13.6	14.6	15.0	15.4	15.0	15.1	15.4	14.9	14.6
Other motor vehicles	1.8	2.2	2.6	2.7	2.8	2.8	2.8	2.8	2.8	2.8
Other mobile sources	3.6	3.6	3.9	3.4	3.8	3.9	4.0	4.0	3.6	3.2
<i>Mobile combustion subtotal</i>	<b>26.3</b>	<b>37.3</b>	<b>36.4</b>	<b>33.9</b>	<b>34.1</b>	<b>32.4</b>	<b>31.8</b>	<b>31.7</b>	<b>30.0</b>	<b>28.8</b>
Stationary combustion										
Residential and commercial	1.5	1.4	1.3	1.3	1.3	1.3	1.1	1.2	1.3	1.2
Industrial	4.7	4.9	4.8	4.4	4.7	4.5	4.6	4.5	4.1	3.7
Electric power	7.8	8.3	9.6	9.6	9.7	9.9	9.7	9.9	9.7	8.7
<i>Stationary combustion subtotal</i>	<b>13.9</b>	<b>14.5</b>	<b>15.7</b>	<b>15.3</b>	<b>15.6</b>	<b>15.7</b>	<b>15.4</b>	<b>15.6</b>	<b>15.1</b>	<b>13.6</b>
<b>Total from energy sources</b>	<b>40.2</b>	<b>51.8</b>	<b>52.1</b>	<b>49.2</b>	<b>49.7</b>	<b>48.2</b>	<b>47.2</b>	<b>47.3</b>	<b>45.1</b>	<b>42.5</b>

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

#### 4.4. Industrial sources

U.S. industrial sources emitted 11 MMTCO<sub>2</sub>e of nitrous oxide in 2009, a decrease of 10.8 percent from 2008 (Table 25). 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, 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. There are three companies operating U.S. plants that manufacture adipic acid by oxidizing a ketone-alcohol mixture with nitric acid. The chemical reaction results in nitrous oxide emissions.

The large decline in nitrous oxide emissions from industrial processes since 1996 (Figure 25) is a result of the installation of emissions control technology at three of the four adipic acid plants operating in the United States before 2006 and the closing in 2006 of the only U.S. adipic acid plant without emission control technology. Emission estimates for 2007 and 2008 published in this year's report have been corrected to account for the plant's closing, as indicated by the zero values for uncontrolled sources in 2007, 2008, and 2009. In addition, the nitrous oxide emission factor for adipic acid production has been revised to the value published in the 2006 IPCC guidelines.

#### U.S. nitrous oxide emissions from industrial sources, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	28.5	13.6	12.1	10.8
Change from 1990 (million metric tons CO <sub>2</sub> e)		-14.9	-16.4	-17.7
(percent)		-52.4%	-57.5%	-62.1%
Average annual change from 1990 (percent)		-4.8%	-4.6%	-5.0%
Change from 2005 (million metric tons CO <sub>2</sub> e)			-1.4	-2.8
(percent)			-10.6%	-20.3%
Change from 2008 (million metric tons CO <sub>2</sub> e)				-1.3
(percent)				-10.8%

Figure 25. U.S. nitrous oxide emissions from industry by source, 1990-2009

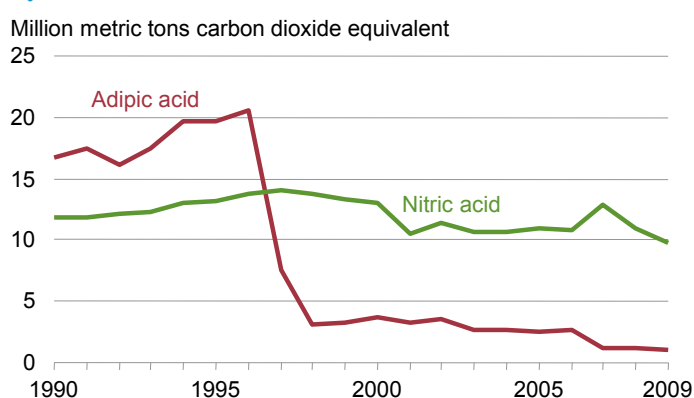


Table 25. U.S. nitrous oxide emissions from industrial sources, 1990-2009 (million metric tons carbon dioxide equivalent)

Source	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Adipic acid										
Controlled sources	0.7	0.8	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.1
Uncontrolled sources	16.0	18.9	2.6	1.4	1.4	1.4	1.5	0.0	0.0	0.0
<i>Adipic acid subtotal</i>	16.7	19.7	3.7	2.6	2.7	2.6	2.7	1.2	1.2	1.1
Nitric acid	11.8	13.1	12.9	10.7	10.6	11.0	10.8	12.8	11.0	9.7
<b>Total industrial sources</b>	<b>28.5</b>	<b>32.8</b>	<b>16.7</b>	<b>13.3</b>	<b>13.3</b>	<b>13.6</b>	<b>13.6</b>	<b>14.1</b>	<b>12.1</b>	<b>10.8</b>

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

#### 4.5. Waste management sources

In 2009, treatment of residential and commercial wastewater produced 92 percent (5 MMTCO<sub>2</sub>e) of all nitrous oxide emissions from waste management. An additional 0.4 MMTCO<sub>2</sub>e was emitted from the combustion of municipal solid waste (Figure 26 and Table 26). Estimates of nitrous oxide emissions from domestic wastewater treatment 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.

#### U.S. nitrous oxide emissions from waste management sources, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	4.0	5.0	5.2	5.3
Change from 1990 (million metric tons CO <sub>2</sub> e)		1.0	1.2	1.3
(percent)		25.9%	30.6%	31.8%
Average annual change from 1990 (percent)		1.5%	1.5%	1.5%
Change from 2005 (million metric tons CO <sub>2</sub> e)			0.2	0.2
(percent)			3.7%	4.7%
Change from 2008 (million metric tons CO <sub>2</sub> e)				0.0
(percent)				0.9%

Figure 26. U.S. nitrous oxide emissions from waste management by source, 1990-2009

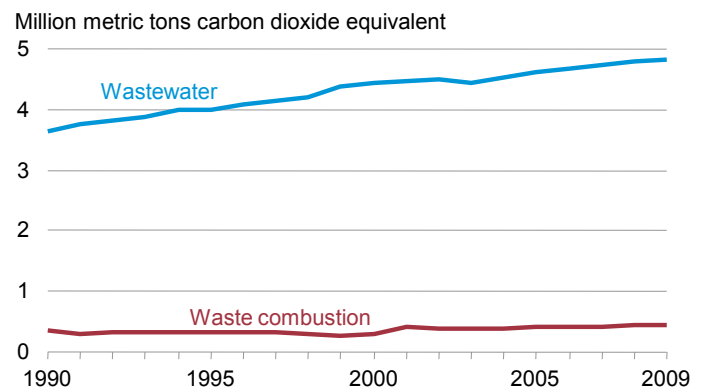


Table 26. U.S. nitrous oxide emissions from waste management sources, 1990-2009 (million metric tons carbon dioxide equivalent)

Source	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Domestic and commercial wastewater	3.6	4.0	4.4	4.4	4.5	4.6	4.7	4.7	4.8	4.8
Waste combustion	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4
<b>Total</b>	<b>4.0</b>	<b>4.3</b>	<b>4.7</b>	<b>4.8</b>	<b>4.9</b>	<b>5.0</b>	<b>5.1</b>	<b>5.2</b>	<b>5.2</b>	<b>5.3</b>

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

## 5. High-GWP gases

### 5.1. Total emissions

Greenhouse gases with high global warming potential (high-GWP gases) are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF<sub>6</sub>), which together represented 3 percent of U.S. greenhouse gas emissions in 2009.

Emissions estimates for the high-GWP gases are provided to EIA by the EPA's Office of Air and Radiation. The estimates for emissions of HFCs not related to industrial processes or electric transmission are derived from the EPA Vintaging Model. Emissions from manufacturing and utilities are derived by the EPA from a mix of public and proprietary data, including from the EPA's voluntary emission reduction partnership programs.

For this year's EIA inventory, 2008 values for HFC-23 from HCFC-22 production and for all industrial emissions of PFCs and SF<sub>6</sub> are used as placeholders for 2009. The updated values will be available when the U.S. inventory is submitted by the EPA to the UNFCCC in April 2011. Emissions of HFCs used as substitutes for ozone-depleting substances and "other" HFCs and PFCs/PFPEs, which are aggregated to protect confidential data, have been updated for 2009, showing a 5.7-percent increase from 2008.

Emissions of high-GWP gases have increased steadily since 1990 (Figure 27 and Table 27), 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.

As part of the global phasedown of HCFCs, according to the U.S. schedule mandated in the Clean Air Act, 2010 was a target year to end production and imports of HCFC-142b and HCFC-22, with the exception of use in equipment manufactured before January 1, 2010. Under the Clean Air Act, U.S. HCFC production and imports will be completely phased out by January 1, 2030, as agreed upon in the Montreal Protocol.

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.

#### U.S. emissions of high-GWP gases, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	102.1	161.3	169.9	178.2
Change from 1990 (million metric tons CO <sub>2</sub> e)		59.2	67.8	76.1
(percent)		57.9%	66.4%	74.5%
Average annual change from 1990 (percent)		3.1%	2.9%	3.0%
Change from 2005 (million metric tons CO <sub>2</sub> e)			8.6	16.9
(percent)			5.4%	10.5%
Change from 2008 (million metric tons CO <sub>2</sub> e)				8.3
(percent)				4.9%

Figure 27. U.S. emissions of high-GWP gases, 1990-2009

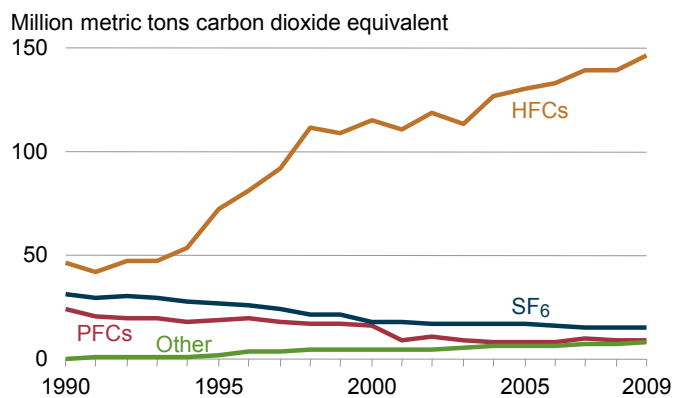


Table 27. U.S. emissions of hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride, 1990-2009 (million metric tons carbon dioxide equivalent)

Gas	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Hydrofluorocarbons	46.3	72.5	115.2	113.6	126.4	130.1	132.8	139.7	138.9	146.3
Perfluorocarbons	24.4	18.6	16.2	9.1	8.0	8.0	8.0	9.6	8.6	8.6
Other HFCs, PFCs/PFPEs	0.3	1.8	4.4	5.4	5.8	6.2	6.5	6.8	7.1	7.9
Sulfur hexafluoride	31.1	26.6	18.2	17.4	16.8	17.0	16.3	15.4	15.4	15.4
<b>Total high-GWP gases</b>	<b>102.1</b>	<b>119.4</b>	<b>154.0</b>	<b>145.4</b>	<b>157.0</b>	<b>161.3</b>	<b>163.6</b>	<b>171.4</b>	<b>169.9</b>	<b>178.2</b>

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.

## 5.2. Hydrofluorocarbons

HFCs are compounds that contain carbon, hydrogen, and fluorine. They are used as solvents, residential and commercial refrigerants, firefighting agents, and propellants for aerosols. Although they do not destroy stratospheric ozone, they are powerful greenhouse gases. For example, HFC-134a, the most prominent substitute for ozone-depleting substances, has a global warming potential of 1,430 according to the IPCC’s Fourth Assessment Report (see Table 5 on page 17 for GWP comparison).

Emissions of substitutes for ozone-depleting substances, including HFC-23, HFC-32, HFC-125, HFC-134a, HFC-143a, and HFC-236fa, have grown from trace amounts in 1990 to 129 MMTCO<sub>2</sub>e in 2009 (Table 28).

All the growth in HFC emissions since 1990 can be attributed to the use of HFCs as replacements for ozone-depleting substances. HFC emissions from industrial and other applications have declined by 45.3 percent over this period. The market for chemicals to replace ozone-depleting substances is still expanding, with HFCs increasingly used in fire protection applications to replace Halon 1301 and Halon 1211.

Since 1997, HFC-134a—used as a replacement for CFCs in air conditioners for passenger vehicles, trains, and buses—has accounted for the largest share of total HFC emissions (Figure 28). In 2009, HFC-134a emissions represented 47 percent of total HFC emissions, including the group of other HFCs/PFCs/PFPEs.

To encourage vehicle manufacturers to reduce emissions of HFC-134a from mobile air conditioners, the EPA has included HFC crediting in the new fuel economy and emission standards for light-duty vehicles that were published in April 2010. The rule includes flexibility provisions by which manufacturers can receive credits toward the CO<sub>2</sub>e emission standard by using air conditioners with low leak rates or alternative refrigerants.<sup>45</sup>

Emissions of HFC-32, HFC-125, and HFC-143a each have more than tripled over the past 8 years. HFC-32 and HFC-125 are components of the refrigerant blend R-410, which is used in many air-conditioning applications. As the prevalence of air-conditioning equipment has grown, the use of R-410 has increased substantially. HFC-143a and HFC-125 are the major constituents of refrigerant blends R-404A and R-507A, which are used in commercial refrigeration applications. As the number of grocery and other stores using refrigeration has grown, so has the demand for refrigeration equipment and, thus, for HFC-143a and HFC-125.

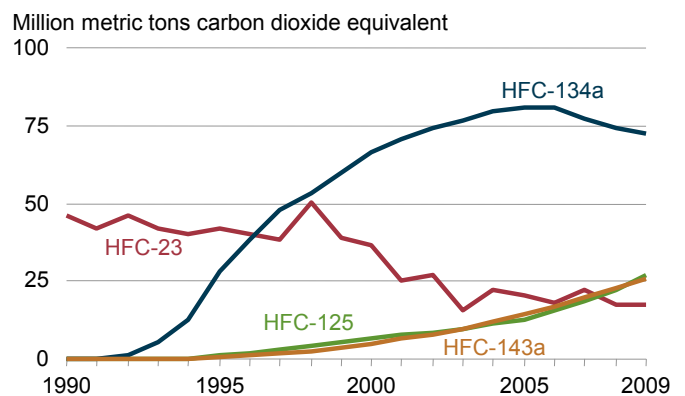
Under the Clean Air Act, manufacture and import of HCFC-22, except for use as a feedstock and in equipment manufactured before 2010, was scheduled to be phased out by January 1, 2010. Manufacturers of HCFC-22 are using cost-effective methods to make voluntary reductions in the amount of HFC-23 created as a byproduct of HCFC-22 manufacture; however, HCFC-22 production remains a steady source of U.S. emissions of HFC-23.

Because the use of HFCs to replace ozone-depleting CFCs and HCFCs increases GHG emissions, multilateral discussions have been ongoing since 2009 to consider adding HFCs to the Montreal Protocol. Negotiations have centered on similar proposals from the Federated States of Micronesia and jointly from the United States, Canada, and Mexico that seek to amend the Montreal Protocol to create a schedule for phasing down consumption of HFCs.

### U.S. emissions of HFCs, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	46.3	130.1	138.9	146.3
Change from 1990 (million metric tons CO <sub>2</sub> e)		83.8	92.6	100.0
(percent)		181.1%	200.0%	216.1%
Average annual change from 1990 (percent)		7.1%	6.3%	6.2%
Change from 2005 (million metric tons CO <sub>2</sub> e)			8.7	16.2
(percent)			6.7%	12.4%
Change from 2008 (million metric tons CO <sub>2</sub> e)				7.5
(percent)				5.4%

Figure 28. U.S. emissions of HFCs, 1990-2009



<sup>45</sup>U.S. Environmental Protection Agency, *EPA and NHTSA Finalize Historic National Program To Reduce Greenhouse Gases and Improve Fuel Economy for Cars and Trucks*, EPA-420-F-10-014 (Washington, DC, April 2010), website [www.epa.gov/otaq/climate/regulations/420f10014.htm](http://www.epa.gov/otaq/climate/regulations/420f10014.htm).



**Table 28. U.S. emissions of hydrofluorocarbons, 1990-2009  
(million metric tons carbon dioxide equivalent)**

Gas	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
HFC-23	46.3	42.1	36.5	15.8	22.1	20.3	17.9	21.9	17.6	17.6
HFC-32	*	*	*	0.2	0.3	0.4	0.6	0.9	1.2	1.7
HFC-125	*	1.0	6.6	9.8	11.3	12.9	15.4	18.4	22.1	27.2
HFC-134a	*	28.4	66.3	76.9	79.8	81.0	80.8	77.5	74.0	72.4
HFC-143a	*	0.6	4.9	9.8	11.9	14.3	16.9	19.7	22.5	25.9
HFC-236fa	*	0.4	0.8	1.1	1.2	1.2	1.3	1.3	1.4	1.4
<b>Total HFCs</b>	<b>46.3</b>	<b>72.5</b>	<b>115.2</b>	<b>113.6</b>	<b>126.4</b>	<b>130.1</b>	<b>132.8</b>	<b>139.7</b>	<b>138.9</b>	<b>146.3</b>

\*Less than 0.05 million metric tons carbon dioxide equivalent.

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

### 5.3. Perfluorocarbons

The two principal sources of U.S. PFC emissions are domestic aluminum production and semiconductor manufacture, which yield perfluoromethane (CF<sub>4</sub>) and perfluoroethane (C<sub>2</sub>F<sub>6</sub>).

Total emissions of PFCs have fallen by two-thirds since 1990 (Figure 29 and Table 29). PFC emissions from aluminum production have declined markedly since 1990 (although 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, and 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. Established in 1996, the PFC Reduction/Climate Partnership for the Semiconductor Industry aims to reduce, via process efficiency upgrades, emissions of several high-GWP gases that result from the manufacture of semiconductors, including perfluoroethane.<sup>46</sup> From 1995 to 2008, total emissions of high-GWP gases (in terms of carbon dioxide equivalents) from the U.S. semiconductor industry fell by 12.6 percent, including a 6.4-percent drop in PFC emissions.

#### U.S. emissions of PFCs, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	24.4	8.0	8.6	8.6
Change from 1990 (million metric tons CO <sub>2</sub> e)		-16.5	-15.9	NA
(percent)		-67.5%	-64.9%	NA
Average annual change from 1990 (percent)		-7.2%	-5.7%	NA
Change from 2005 (million metric tons CO <sub>2</sub> e)			0.6	0.6
(percent)			7.9%	7.9%
Change from 2008 (million metric tons CO <sub>2</sub> e)				NA
(percent)				NA

Figure 29. U.S. emissions of PFCs, 1990-2009

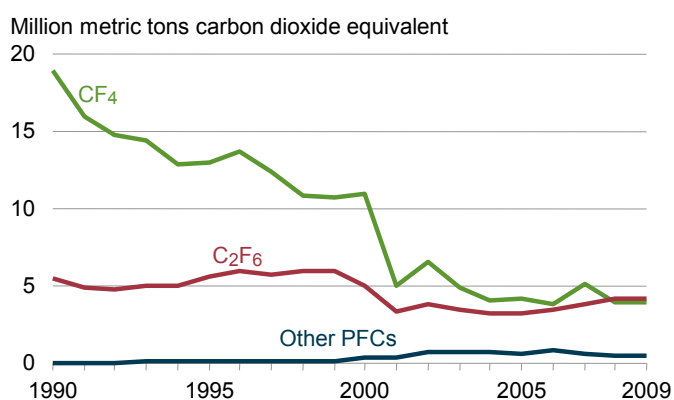


Table 29. U.S. emissions of perfluorocarbons, 1990-2009  
(million metric tons carbon dioxide equivalent)

Gas	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
CF <sub>4</sub>	18.9	13.0	10.9	4.9	4.0	4.1	3.8	5.1	4.0	4.0
C <sub>2</sub> F <sub>6</sub>	5.5	5.5	5.0	3.4	3.3	3.2	3.4	3.8	4.1	4.1
C <sub>3</sub> F <sub>8</sub>	*	*	0.2	0.1	0.1	*	*	0.1	*	*
C <sub>4</sub> F <sub>8</sub>	*	*	*	0.1	0.1	0.1	0.1	0.1	0.1	0.1
NF <sub>3</sub> <sup>a</sup>	*	0.1	0.2	0.5	0.5	0.4	0.7	0.5	0.4	0.4
<b>Total PFCs</b>	<b>24.4</b>	<b>18.6</b>	<b>16.2</b>	<b>9.1</b>	<b>8.0</b>	<b>8.0</b>	<b>8.0</b>	<b>9.6</b>	<b>8.6</b>	<b>8.6</b>

\*Less than 0.05 million metric tons carbon dioxide equivalent.

<sup>a</sup>NF<sub>3</sub> is not a perfluorocarbon, but it is a perfluorinated compound.

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

<sup>46</sup>U.S. Environmental Protection Agency, “PFC Reduction / Climate Partnership for the Semiconductor Industry,” website [www.epa.gov/highgwp/semiconductor-pfc/index.html](http://www.epa.gov/highgwp/semiconductor-pfc/index.html).

## 5.4. Sulfur hexafluoride

SF<sub>6</sub>, an excellent dielectric gas or insulating 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. Other, minor applications of SF<sub>6</sub> include leak detection and the manufacture of loudspeakers and lasers and as an atmospheric tracer for experimental purposes.

Total U.S. emissions of SF<sub>6</sub> have declined by more than 50 percent since 1990 (Figure 30 and Table 30), and industry efforts to reduce emissions of SF<sub>6</sub> from electrical power systems have led to a decline of more than 50 percent in emissions of SF<sub>6</sub> from utility systems since 1990. Seventy-seven members of the electric power industry (about 45 percent of the industry) participate in the SF<sub>6</sub> Emission Reduction Partnership for Electric Power Systems by reporting and reducing SF<sub>6</sub> emissions. Since the establishment of the Partnership, the SF<sub>6</sub> emission leakage rate of participants had dropped from 17 percent to 7 percent annually as of 2006.<sup>47</sup>

SF<sub>6</sub> is also used in the manufacture of semiconductors, where fluorinated gases are used in plasma etching, plasma-enhanced chemical vapor deposition, magnesium metal casting, and in magnesium production as a cover gas. Emissions of SF<sub>6</sub> from the semiconductor industry have more than doubled since 1990. In contrast, emissions from the magnesium industry have fallen over time. Established in 1999, the SF<sub>6</sub> Emission Reduction Partnership for the Magnesium Industry aims to eliminate SF<sub>6</sub> emissions from magnesium production and casting processes by the end of 2010 by optimizing equipment design and operation and improving SF<sub>6</sub> gas management practices.<sup>48</sup> Emissions of SF<sub>6</sub> from the magnesium smelting industry fell by 65 percent from 1995 to 2008 (Table 30).

### U.S. emissions of SF<sub>6</sub>, 1990, 2005, 2008, and 2009

	1990	2005	2008	2009
Estimated emissions (million metric tons CO <sub>2</sub> e)	31.1	17.0	15.4	15.4
Change from 1990 (million metric tons CO <sub>2</sub> e)		-14.1	-15.7	NA
(percent)		-45.3%	-50.5%	NA
Average annual change from 1990 (percent)		-3.9%	-3.8%	NA
Change from 2005 (million metric tons CO <sub>2</sub> e)			-1.6	-1.6
(percent)			-9.5%	-9.5%
Change from 2008 (million metric tons CO <sub>2</sub> e)				NA
(percent)				NA

Figure 30. U.S. emissions of SF<sub>6</sub> by source, 1990-2009

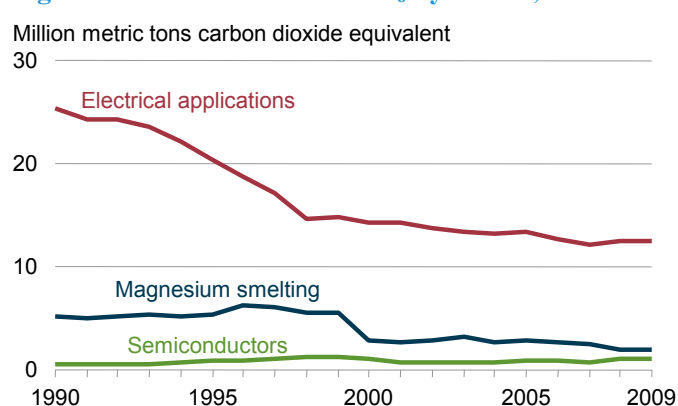


Table 30. U.S. emissions of sulfur hexafluoride by source, 1990-2009 (million metric tons carbon dioxide equivalent)

Source	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009
Electrical applications	25.4	20.4	14.3	13.3	13.3	13.3	12.6	12.1	12.5	12.5
Magnesium smelting	5.2	5.4	2.9	3.3	2.8	2.8	2.7	2.5	1.9	1.9
Semiconductors	0.5	0.9	1.0	0.8	0.8	0.9	0.9	0.8	1.0	1.0
<b>Total SF<sub>6</sub></b>	<b>31.1</b>	<b>26.6</b>	<b>18.2</b>	<b>17.4</b>	<b>16.9</b>	<b>17.0</b>	<b>16.3</b>	<b>15.4</b>	<b>15.4</b>	<b>15.4</b>

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

<sup>47</sup>U.S. Environmental Protection Agency, "SF<sub>6</sub> Emission Reduction Partnership for Electric Power Systems," website [www.epa.gov/highgwp/electricpower-sf6/index.html](http://www.epa.gov/highgwp/electricpower-sf6/index.html).

<sup>48</sup>U.S. Environmental Protection Agency, "SF<sub>6</sub> Emission Reduction Partnership for the Magnesium Industry," website [www.epa.gov/highgwp/magnesium-sf6/index.html](http://www.epa.gov/highgwp/magnesium-sf6/index.html).

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## 6. Land use

### 6.1. Total land use, land use change, and forests

This chapter presents estimates of carbon sequestration (removal from the atmosphere) and emissions (release into the atmosphere) from forests, croplands, grasslands, and residential areas (urban trees, grass clippings, and food scraps) in the United States. In 2008, land use, land use change, and forests were responsible for estimated net carbon sequestration of 940 MMTCO<sub>2</sub>e (Table 31), representing 16 percent of total U.S. CO<sub>2</sub> emissions.

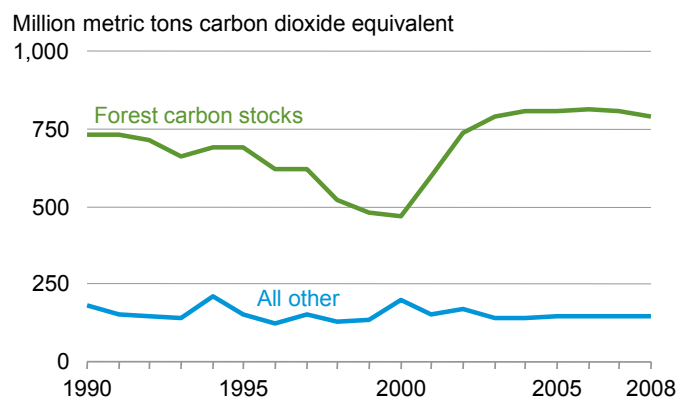
The largest sequestration category in 2008 was forest lands and harvested wood pools,<sup>49</sup> with estimated sequestration increasing from 730 MMTCO<sub>2</sub>e in 1990 to 792 MMTCO<sub>2</sub>e in 2008. The second-largest carbon sequestration category was urban trees,<sup>50</sup> responsible for 57 MMTCO<sub>2</sub>e in 1990 and 94 MMTCO<sub>2</sub>e in 2008. Landfilled yard trimmings and food scraps, both of which also contain carbon, sequestered 10 MMTCO<sub>2</sub>e in 2008. Croplands and grasslands were estimated to have sequestered 18 MMTCO<sub>2</sub>e and 9 MMTCO<sub>2</sub>e, respectively, in 2008.<sup>51</sup> Land converted to grassland sequestered 24 MMTCO<sub>2</sub>e in 2008.

Preparing soils for cultivation involves drainage and tilling, both of which lead to the release of carbon from soil to the atmosphere. In 2008, land that became cropland emitted 6 MMTCO<sub>2</sub>e.

#### U.S. carbon sequestration from land use, land use change and forestry, 1990, 2005, 2007, and 2008

	1990	2005	2007	2008
Estimated sequestration (million metric tons CO <sub>2</sub> e)	909.4	950.4	955.4	940.3
Change from 1990 (million metric tons CO <sub>2</sub> e)		30.9	46.0	30.9
(percent)		3.4%	5.1%	3.4%
Average annual change from 1990 (percent)		0.3%	0.3%	0.2%
Change from 2005 (million metric tons CO <sub>2</sub> e)			5.0	-10.1
(percent)			0.5%	-1.1%
Change from 2007 (million metric tons CO <sub>2</sub> e)				-15.1
(percent)				-1.6%

**Figure 31. U.S. carbon sequestration from land use, land use change, and forestry, 1990-2008**



<sup>49</sup>The IPCC (United Nations Intergovernmental Panel on Climate Change) category is Forest Land Remaining Forest Land (referred to in this chapter as “forest lands and harvested wood pools”), which includes carbon sequestered in forest ecosystems as well as carbon “exported” from forest ecosystems in hardwood products and solid waste disposal sites. Carbon in the latter categories originates in the forest ecosystem and is emitted slowly over decades or even centuries.

<sup>50</sup>Urban trees are included in the IPCC categories “Settlements Remaining Settlements” and “Land Converted to Settlements,” which are essentially forest-like ecosystems but in urbanized areas (such as parks).

<sup>51</sup>These estimates are from the IPCC categories “Croplands Remaining Croplands” and “Grasslands Remaining Grasslands.”

**Table 31. Net U.S. carbon dioxide sequestration from land use, land use change, and forestry, 1990-2008 (million metric tons carbon dioxide equivalent)**

Component	1990	1995	2000	2003	2004	2005	2006	2007	2008
Forest land and harvested wood pools <sup>a</sup>	729.8	692.6	467.7	790.7	805.5	806.6	812.5	806.9	791.9
<b>Croplands and grasslands</b>									
Cropland remaining cropland <sup>b</sup>	29.4	22.9	30.2	17.7	18.1	18.3	19.1	19.7	18.1
Land converted to cropland	-2.2	-2.9	-2.4	-5.9	-5.9	-5.9	-5.9	-5.9	-5.9
Grassland remaining grassland	52	26.7	52.6	9.2	9.1	9	8.9	8.8	8.7
Land converted to grassland	19.8	22.3	27.3	24.9	24.7	24.6	24.5	24.3	24.2
<i>Croplands and grasslands subtotal</i>	<i>99.1</i>	<i>69.0</i>	<i>107.7</i>	<i>45.8</i>	<i>46.0</i>	<i>46.0</i>	<i>46.6</i>	<i>46.9</i>	<i>45.1</i>
<b>Urban trees, yard trimmings, and food scraps</b>									
Urban trees	57.1	67.3	77.5	83.7	85.7	87.8	89.8	91.9	93.9
Yard trimmings	21.2	12.5	8.2	7.1	6.4	6.6	6.8	6.3	6.3
Food scraps	2.2	1.4	3.1	3.1	3.5	3.5	3.6	3.5	3.3
<i>Urban trees, yard trimmings, and food scraps subtotal</i>	<i>80.5</i>	<i>81.2</i>	<i>88.8</i>	<i>93.9</i>	<i>95.6</i>	<i>97.9</i>	<i>100.2</i>	<i>101.7</i>	<i>103.5</i>
<b>Total</b>	<b>909.4</b>	<b>842.9</b>	<b>664.2</b>	<b>930.3</b>	<b>947.1</b>	<b>950.4</b>	<b>959.2</b>	<b>955.4</b>	<b>940.3</b>

<sup>a</sup>Estimates include carbon stock changes in both forest land remaining forest land and land converted to forest land.

<sup>b</sup>Estimates include carbon stock changes in mineral soils and organic soils on cropland remaining cropland and liming emissions from all cropland, grassland, and settlement categories.

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

## 6.2. Forest lands and harvested wood pools

Forest ecosystems constitute the largest source of carbon sequestration in the United States, with the sequestered carbon contained in above-ground or below-ground components of trees and other forest vegetation, as well as dead wood and litter.<sup>52</sup> In 2008, forests and harvested wood products sequestered 792 MMTCO<sub>2</sub>e (Table 32). More than one-half of the forest total (397 out of 704 MMTCO<sub>2</sub>e) was above-ground biomass in the form of tree trunks and branches. Soil organic carbon was the second-largest category of sequestered carbon in 2008, estimated at 146 MMTCO<sub>2</sub>e. Another large category in 2008 was below-ground biomass—i.e., the root systems of trees and other plants—at an estimated total of 79 MMTCO<sub>2</sub>e. Litter and dead wood, which are rich in plant matter that continues to be mainly carbon, accounted for 56 MMTCO<sub>2</sub>e and 26 MMTCO<sub>2</sub>e, respectively, of the carbon sequestered in forests in 2008. Although some of the carbon in litter and dead wood is released through decomposition, the continuing fall of trunks, branches, leaves, and other plant materials adds to the mass of litter and dead wood, leading to an overall increase in carbon stored.

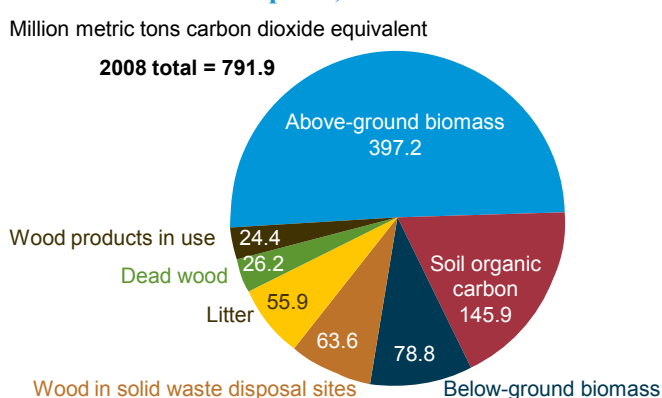
Harvested wood in the form of durable wood products, either in use or in landfills, accounted for 132 MMTCO<sub>2</sub>e of carbon sequestration in 1990. That total dropped to 88 MMTCO<sub>2</sub>e in 2008, primarily as a result of greater use of imported wood, imported wood products, and wood substitutes.<sup>53</sup>

### Carbon sequestration in U.S. forest lands and harvested wood pools, 1990, 2005, 2007, and 2008

	1990	2005	2007	2008
Estimated sequestration (million metric tons CO <sub>2</sub> e)	729.8	806.6	806.9	791.9
Change from 1990 (million metric tons CO <sub>2</sub> e)		76.7	77.1	62.1
(percent)		10.5%	10.6%	8.5%
Average annual change from 1990 (percent)		0.7%	0.6%	0.5%
Change from 2005 (million metric tons CO <sub>2</sub> e)			0.3	-14.7
(percent)			*	-1.8%
Change from 2007 (million metric tons CO <sub>2</sub> e)				-15.0
(percent)				-1.9%

\*Less than 0.5 percent.

**Figure 32. Carbon sequestration in U.S. forest lands and harvested wood pools, 2008**



<sup>52</sup>The term “dead wood” refers to large, non-living woody biomass either standing, lying on the ground (excluding litter), or in the soil. “Litter” (mainly, fallen leaves) refers to smaller fallen and partially decomposed matter on the forest floor.

<sup>53</sup>Wood products originating from forests outside the United States are not included in the U.S. greenhouse gas inventory.

**Table 32. Net carbon dioxide sequestration in U.S. forests and harvested wood pools, 1990-2008  
(million metric tons carbon dioxide equivalent)**

Carbon pool	1990	1995	2000	2003	2004	2005	2006	2007	2008
<b>Forests</b>									
Above-ground biomass	377.7	398.3	309.3	396.8	397.2	397.2	397.2	397.2	397.2
Below-ground biomass	74.5	79.3	61.7	78.7	78.8	78.8	78.8	78.8	78.8
Dead wood	29.4	31.0	15.8	22.4	22.4	23.4	26.2	26.2	26.2
Litter	46.5	28.3	-3.4	54.0	55.9	55.9	55.9	55.9	55.9
Soil organic carbon	70.0	37.2	-28.7	143.9	145.9	145.9	145.9	145.9	145.9
<i>Forests subtotal</i>	<i>598.1</i>	<i>574.2</i>	<i>354.8</i>	<i>695.9</i>	<i>700.2</i>	<i>701.2</i>	<i>703.9</i>	<i>703.9</i>	<i>703.9</i>
<b>Harvested wood</b>									
Wood products	64.8	55.2	47.0	35.5	45.6	45.4	45.1	39.1	24.4
Wood in solid waste disposal sites	67.0	63.2	65.9	59.3	59.8	59.9	63.4	63.8	63.6
<i>Harvested wood subtotal</i>	<i>131.8</i>	<i>118.4</i>	<i>112.9</i>	<i>94.8</i>	<i>105.3</i>	<i>105.4</i>	<i>108.6</i>	<i>103.0</i>	<i>88.0</i>
<b>Total</b>	<b>729.8</b>	<b>692.6</b>	<b>467.7</b>	<b>790.7</b>	<b>805.5</b>	<b>806.6</b>	<b>812.5</b>	<b>806.9</b>	<b>791.9</b>

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. The 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.



### 6.3. Croplands and grasslands

Croplands and grasslands fall into four categories: cropland remaining cropland; land converted to cropland; grassland remaining grassland; and land converted to grassland.

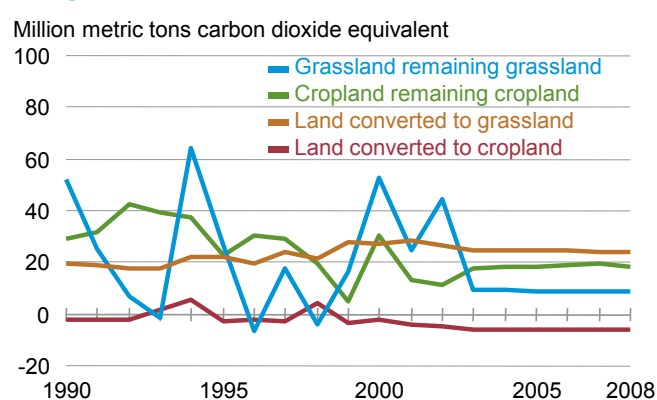
Organic soils contain 12 to 20 percent carbon; mineral soils contain 1 to 6 percent carbon. Soils gain carbon through the decomposition of dead plant matter by soil microorganisms and lose carbon through drainage and agricultural activities, such as tilling. Over time, unless the soil is disturbed repeatedly, its carbon content reaches a balance between sequestration and emissions. Carbon sequestration and emissions from the mineral and organic soils in croplands and grasslands vary, depending on how the lands are maintained or converted. Mineral and organic soils can gain (sequester) or lose (emit) carbon, depending on climate, land use, and soil properties.

As a whole, the estimated aggregate flux of CO<sub>2</sub> for the four categories of croplands and grasslands resulted in the sequestration of 45 MMTCO<sub>2</sub>e in 2008 (Table 33). Land Converted to Grassland, Cropland Remaining Cropland, and Grassland Remaining Grassland sequestered 24, 18, and 9 MMTCO<sub>2</sub>e, respectively, and Land Converted to Cropland emitted 6 MMTCO<sub>2</sub>e. Areas were classified as Cropland Remaining Cropland in a given year between 1990 and 2008 if the land use had been cropland for the previous 20 years. For organic soils, annual fluxes were estimated from the U.S. Department of Agriculture's National Resources Inventory (NRI); the 1990 NRI estimate was applied for 1990-1993, and the 1997 NRI estimate was applied for 1993-2008.

#### Carbon sequestration in U.S. croplands and grasslands, 1990, 2005, 2007, and 2008

	1990	2005	2007	2008
Estimated sequestration (million metric tons CO <sub>2</sub> e)	99.0	46.0	46.9	45.1
Change from 1990 (million metric tons CO <sub>2</sub> e)		-53.0	-52.1	-53.9
(percent)		-53.5%	-52.6%	-54.4%
Average annual change from 1990 (percent)		-5.0%	-4.3%	-4.3%
Change from 2005 (million metric tons CO <sub>2</sub> e)			0.9	-0.9
(percent)			2.0%	-2.0%
Change from 2007 (million metric tons CO <sub>2</sub> e)				-1.8
(percent)				-3.8%

**Figure 33. Carbon sequestration in U.S. croplands and grasslands, 1990-2008**



**Table 33. Net carbon dioxide sequestration in U.S. croplands and grasslands, 1990-2008  
(million metric tons carbon dioxide equivalent)**

Carbon pool	1990	1995	2000	2003	2004	2005	2006	2007	2008
<b>Cropland remaining cropland</b>									
Mineral soils	56.8	50.6	57.9	45.3	45.8	45.9	46.8	47.3	45.7
Organic soils	-27.4	-27.7	-27.7	-27.7	-27.7	-27.7	-27.7	-27.7	-27.7
<i>Cropland remaining cropland subtotal</i>	29.4	22.9	30.2	17.7	18.1	18.3	19.1	19.7	18.1
<b>Land converted to cropland</b>									
Mineral soils	0.3	-0.3	0.3	-3.3	-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
<i>Land converted to cropland subtotal</i>	-2.2	-2.9	-2.4	-5.9	-5.9	-5.9	-5.9	-5.9	-5.9
<b>Grassland remaining grassland</b>									
Mineral soils	55.9	30.4	56.3	12.9	12.8	12.7	12.6	12.5	12.4
Organic soils	-3.9	-3.7	-3.7	-3.7	-3.7	-3.7	-3.7	-3.7	-3.7
<i>Grassland remaining grassland subtotal</i>	52.0	26.7	52.6	9.2	9.1	9.0	8.9	8.8	8.7
<b>Land converted to grassland</b>									
Mineral soils	20.3	23.2	28.1	25.7	25.6	25.5	25.4	25.2	25.1
Organic soils	-0.5	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9
<i>Land converted to grassland subtotal</i>	19.8	22.3	27.3	24.9	24.7	24.6	24.5	24.3	24.2
<b>Total</b>	<b>99.0</b>	<b>69.0</b>	<b>107.7</b>	<b>45.8</b>	<b>46.0</b>	<b>45.9</b>	<b>46.6</b>	<b>46.9</b>	<b>45.1</b>
Liming of soils <sup>a</sup>	-4.7	-4.4	-4.3	-4.6	-3.9	-4.3	-4.2	-4.5	-3.8

<sup>a</sup>Includes emissions from liming on land converted to cropland, grassland remaining grassland, land converted to grassland, and settlements remaining settlements. This value is counted as a carbon dioxide emission under limestone consumption shown in Table 16.

Note: Negative values indicate emissions.

#### 6.4. Urban trees, yard trimmings, and food scraps

In 2008, urban trees, yard trimmings, and food scraps sequestered 104 MMTCO<sub>2</sub>e (Table 34).

Urban trees sequester carbon through photosynthesis, just as forest trees do. Because urban trees often have more space in urban settings such as streets and parks than do trees in forests, they tend to grow bigger and sequester more carbon per tree.

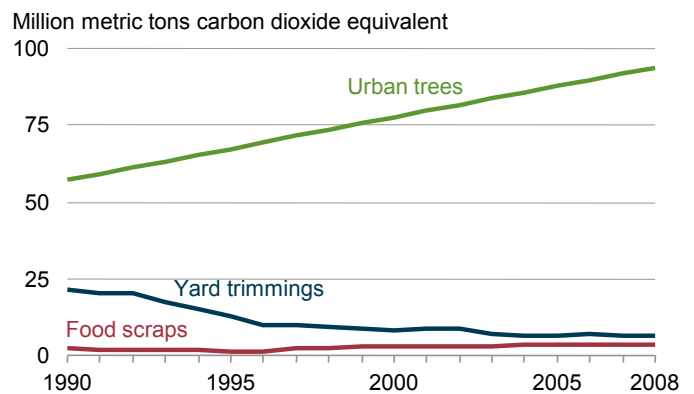
The estimate of carbon sequestration in yard trimmings is for the portion of grass clippings, leaves, and other garden wastes deposited in landfills. Yard trimmings that are composted at individual residences or in municipal composting programs or are used in waste-to-energy activities are not accounted for in this category. From 1990 to 2008, the estimate for carbon sequestration in yard trimmings has changed more than the estimates for the two other categories combined, with a decrease of 70 percent attributed to an increase in municipal composting programs.

From 1990 to 2008, a slight increase in landfill disposal of food scraps was far outweighed by the decrease in disposal of yard trimmings, leading to a net decrease in annual carbon sequestration at landfills from 24 MMTCO<sub>2</sub>e in 1990 to 10 MMTCO<sub>2</sub>e in 2008.

#### Carbon sequestration in U.S. urban trees, yard trimmings, and food scraps, 1990, 2005, 2007, and 2008

	1990	2005	2007	2008
Estimated sequestration (million metric tons CO <sub>2</sub> e)	80.5	97.9	101.7	103.5
Change from 1990 (million metric tons CO <sub>2</sub> e)		17.4	21.2	23.0
(percent)		21.6%	26.3%	28.6%
Average annual change from 1990 (percent)		1.3%	1.5%	1.6%
Change from 2005 (million metric tons CO <sub>2</sub> e)			3.8	5.6
(percent)			3.9%	5.7%
Change from 2007 (million metric tons CO <sub>2</sub> e)				1.8
(percent)				1.8%

**Figure 34. Carbon sequestration in U.S. urban trees, yard trimmings, and food scraps, 1990-2008**



**Table 34. Net carbon dioxide sequestration in U.S. urban trees, yard trimmings, and food scraps, 1990-2008 (million metric tons carbon dioxide equivalent)**

Carbon pool	1990	1995	2000	2003	2004	2005	2006	2007	2008
Urban trees	57.1	67.3	77.5	83.7	85.7	87.8	89.8	91.9	93.9
Yard trimmings									
Grass	1.9	0.8	0.4	0.4	0.3	0.4	0.5	0.4	0.4
Leaves	9.7	6.0	4.0	3.5	3.2	3.3	3.3	3.1	3.1
Branches	9.7	5.8	3.7	3.2	2.9	2.9	3.0	2.8	2.7
Yard trimmings subtotal	21.2	12.5	8.2	7.1	6.4	6.6	6.8	6.3	6.3
Food scraps	2.2	1.4	3.1	3.1	3.5	3.5	3.6	3.5	3.3
<b>Total</b>	<b>80.5</b>	<b>81.2</b>	<b>88.8</b>	<b>93.9</b>	<b>95.6</b>	<b>97.9</b>	<b>100.2</b>	<b>101.7</b>	<b>103.5</b>

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

## 6.5. Carbon dioxide emissions from bioenergy

According to current international convention, CO<sub>2</sub> released through the combustion of energy or fuel derived from plants (bioenergy or biofuels) is excluded from reported energy-related emissions. The related fossil fuel emissions from the transportation and processing of the biological feedstocks are captured within overall energy sector emissions, but currently they are not allocated to the biofuels. Additionally, the CO<sub>2</sub> released from biofuel or bioenergy combustion is assumed to be fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy. However, analysts have debated whether the increased use of biomass energy may result in a loss of terrestrial carbon stocks and foregone future sequestration by natural vegetation. The initial loss of carbon stocks in natural vegetation cleared to grow biomass feedstocks and the foregone future removal of CO<sub>2</sub> are not captured in energy sector emissions. To capture the potential net emissions, the international convention for GHG inventories is to report the net carbon flux from land use change (such as when forests are converted to cropland to grow feedstocks) in the Land Use category. Although accounting for land use emissions is more challenging than for most of the other emissions sources, emissions and sequestration associated with domestic U.S. land use change should in principle be accounted for in this chapter of the inventory report. However, from a global greenhouse gas emissions perspective, the key uncertainty regarding aggregate net biogenic emissions is indirect land use change that occurs abroad. As discussed below, there are many factors that ultimately determine the net effect of biogenic energy sources on CO<sub>2</sub> emissions.

For the first time, this report is providing estimates of direct biogenic CO<sub>2</sub> emissions from combustion of biofuels and bioenergy (see Table 35).<sup>54</sup> Other greenhouse gases, such as methane released from wood that is burned in home fireplaces and woodstoves, are counted in EIA's emissions inventory, because they are not considered part of the natural carbon cycle.

### Direct biogenic combustion emissions by sector

Emissions estimates are provided here for direct emissions from bioenergy consumption in the four end-use sectors (residential, commercial, industrial, and transportation) and for the electric power sector.

**Residential** emissions result from the use of wood and wood-derived fuels, principally for heating and often for aesthetic reasons. As indicated in Table 35, these emissions have fluctuated over time but have decreased overall since 1990.

**Commercial** bioenergy emissions result from the use of wood and wood-derived fuels for heat and electricity generation, including emissions from combined heat and power generation plants that cannot be assigned to either the electric power sector or the industrial sectors according to North American Industry Classification System (NAICS) codes.<sup>55</sup> Energy consumed at municipal landfills in the form of solid biogenic waste and landfill gas also is included in the commercial sector. Finally, small amounts of ethanol and wood consumed directly for their heating value are included. There has been gradual growth of biofuel consumption in the commercial sector.

**Industrial** bioenergy emissions result from the combustion of wood and wood-derived fuels by plants generating process heat and electricity that are assigned to the industrial sector by NAICS codes, including emissions from combined heat and power plants. Most of the biogenic fuel consumption in the industrial sector is in the pulp and paper industry. The industrial sector dominates biogenic emissions, but its share is declining.

**Transportation** bioenergy emissions are principally from ethanol fuel use. Biodiesel emissions include the use of any liquid biofuel suitable as a diesel substitute, additive, or extender. Because of the increase in fuel ethanol consumption (primarily, blended into gasoline), the transportation sector has seen the largest growth in biogenic CO<sub>2</sub> emissions, from 4 million metric tons in 1990 to 64 million metric tons in 2009.

**Electric power** emissions from bioenergy result from the use of wood and wood-derived fuels by plants generating electricity and by combined heat and power plants. In addition, emissions from power generation using solid biogenic waste and landfill gas are included in this category. Biogenic emissions in the electric power sector grew by an average of 2.8 percent per year from 1990 to 2009.

### Emissions by fuel

**Wood** has historically been the largest source of biogenic carbon dioxide emissions. However, emissions from wood burning have dropped from 208 million metric tons in 1990 to 177 million metric tons in 2009, or by nearly 1 percent per year.

**Waste** was the second-largest source of biogenic emissions in 1990, at 24 million metric tons, and emissions from waste combustion have increased by about 3 percent per year since 1990.

**Fuel ethanol**, which was a negligible source of biogenic emissions in 1990, was second only to wood in 2009. Emissions from fuel ethanol combustion have grown by more than 15 percent per year, to a total of 62 million metric tons in 2009.

**Biodiesel** is a relatively new energy source of biogenic emissions, increasing from a negligible level in 2000 to 3.0 million metric tons CO<sub>2</sub> in 2009.

<sup>54</sup>Source: U.S. Energy Information Administration, *Monthly Energy Review* (Washington, DC: October 2010), website [www.eia.gov/FTP/ROOT/multifuel/mer/00351010.pdf](http://www.eia.gov/FTP/ROOT/multifuel/mer/00351010.pdf). MER data are available through 2009. EPA data for other tables in this chapter are available only through 2008.

<sup>55</sup>NAICS is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. economy.

## Life cycle analysis of carbon emissions from bioenergy

The growth of plant material (or feedstock) and its eventual conversion into usable bioenergy involve emissions related to both land use and energy use. However, when a feedstock is grown in an area that doesn't usually support agriculture or natural vegetation, it can lead to additional sequestration of carbon. When sequestration equals or exceeds emissions, the bioenergy source can be considered carbon neutral or better. Analyses of the life-cycle carbon emissions of biofuels or bioenergy have focused on different aspects of their production, transportation, and consumption. As for any other product, their carbon neutrality usually is assessed by considering all the upstream and downstream emissions of greenhouse gases. In addition, indirect changes in land use can be evaluated as a component of biofuel production.

Greenhouse gas emissions from the biofuels or bioenergy life cycle include: (1) emissions associated with the growth of feedstocks (emissions from farm machinery, soils, and the use of fertilizers derived from fossil fuels); (2) emissions from the processing of feedstocks into fuel or energy (including transportation to the processing facility and emissions from processing); (3) emissions from transportation of fuels to end users; and (4) emissions from end uses (combustion in vehicles or in the generation of electricity or heat). On the other hand, however, the growth of biofuel feedstocks (corn, soybeans, tree crops, grasses, etc.) removes CO<sub>2</sub> from the atmosphere as discussed above. Emissions associated with sources (1), (2), and (3) are accounted for elsewhere in this inventory. This section focused on source (4).

The life-cycle emissions associated with bioenergy depends in part on the vegetation displaced by the establishment of feedstock crops. Although the concept that land use change has an impact on carbon stocks is universal, it is a concern primarily in tropical ecosystems. When land is diverted from food production to the production of biofuel feedstock in a given area, and overall food production falls as a result, land in other areas is sometimes converted to cropland to meet market demand. Such indirect land use change can be local, national, or even global and can involve the conversion of forests to cropland. The effects of indirect land use changes on CO<sub>2</sub> emissions are difficult to quantify, because they can occur anywhere in the world, and because estimates depend on assumptions about the supply response to demand for bioenergy feedstocks. Assumptions about supply response in the United States and bilateral trade responses in the rest of the world are critical to evaluating the greenhouse gas emissions impacts of indirect land use change.<sup>56</sup> Whether or not indirect land use change occurs depends on factors such as yield, acreage, and bilateral trade.

<sup>56</sup>R. Keeney and T.W. Hertel, *The Indirect Land Use Impacts of U.S. Biofuel Policies: The Importance of Acreage, Yield, and Bilateral Trade Responses*, GTAP Working Paper No. 52 (2008), website [www.gtap.agecon.purdue.edu/resources/download/4104.pdf](http://www.gtap.agecon.purdue.edu/resources/download/4104.pdf); and J.A. Mathews and H. Tan, "Biofuels and Indirect Land Use Change Effects: The Debate Continues," *Wiley InterScience* (2009), website [www.ncfap.org/documents/biofuels\\_aviation/iLUC%20Searchingcritique%20BioFPR.pdf](http://www.ncfap.org/documents/biofuels_aviation/iLUC%20Searchingcritique%20BioFPR.pdf).

**Table 35. Emissions of carbon dioxide from biofuel/bioenergy use by sector and fuel, 1990-2009**  
(million metric tons carbon dioxide)

Sector	1990	1995	2000	2005	2006	2007	2008	2009	Average annual growth, 1990-2009
<b>Residential</b>									
Wood	54.4	48.8	39.4	40.3	36.6	40.3	42.2	40.3	-1.6%
<i>Subtotal</i>	<i>54.4</i>	<i>48.8</i>	<i>39.4</i>	<i>40.3</i>	<i>36.6</i>	<i>40.3</i>	<i>42.2</i>	<i>40.3</i>	<i>-1.6%</i>
<b>Commercial</b>									
Wood	6.2	6.8	6.7	6.5	6.1	6.5	6.8	6.7	0.5%
Waste (biogenic)	1.7	2.3	2.4	3.1	3.3	2.8	3.1	3.3	3.7%
Fuel ethanol	*	*	*	0.1	0.1	0.1	0.1	0.2	8.7%
<i>Subtotal</i>	<i>7.9</i>	<i>9.1</i>	<i>9.1</i>	<i>9.7</i>	<i>9.5</i>	<i>9.5</i>	<i>10.1</i>	<i>10.2</i>	<i>1.4%</i>
<b>Industrial</b>									
Wood	135.3	155.0	153.4	136.2	138.1	132.5	126.1	114.8	-0.9%
Waste (biogenic)	11.5	11.0	7.4	13.4	11.8	13.1	13.0	14.6	1.3%
Fuel ethanol	0.1	0.1	0.1	0.5	0.7	0.7	0.8	0.9	15.7%
<i>Subtotal</i>	<i>146.8</i>	<i>166.0</i>	<i>160.9</i>	<i>150.1</i>	<i>150.5</i>	<i>146.3</i>	<i>139.9</i>	<i>130.4</i>	<i>-0.6%</i>
<b>Transportation</b>									
Fuel ethanol	4.1	7.7	9.2	22.4	30.2	38.1	53.8	61.2	15.2%
Biodiesel	—	—	—	0.9	2.5	3.4	3.0	3.0	—
<i>Subtotal</i>	<i>4.1</i>	<i>7.7</i>	<i>9.2</i>	<i>23.3</i>	<i>32.7</i>	<i>41.5</i>	<i>56.8</i>	<i>64.2</i>	<i>15.5%</i>
<b>Electric power</b>									
Wood	12.1	11.8	12.6	17.4	17.1	17.4	16.6	16.9	1.8%
Waste (biogenic)	11.3	16.7	16.2	20.0	20.9	21.5	23.4	23.7	4.0%
<i>Subtotal</i>	<i>23.3</i>	<i>28.4</i>	<i>28.8</i>	<i>37.4</i>	<i>38.0</i>	<i>39.0</i>	<i>40.0</i>	<i>40.6</i>	<i>3.0%</i>
<b>Total by sector</b>	<b>236.5</b>	<b>260.0</b>	<b>247.4</b>	<b>260.8</b>	<b>267.2</b>	<b>276.6</b>	<b>289.0</b>	<b>285.6</b>	<b>1.0%</b>
<b>Fuel</b>									
Wood	207.9	222.3	212.1	200.4	197.8	196.8	191.7	178.8	-0.8%
Waste	24.4	29.9	25.9	36.6	36.0	37.4	39.5	41.6	2.8%
Fuel ethanol	4.2	7.8	9.3	22.9	31.0	38.9	54.8	62.3	15.2%
Biodiesel	—	—	—	0.9	2.5	3.4	3.0	3.0	—
<b>Total by fuel</b>	<b>236.5</b>	<b>260.0</b>	<b>247.4</b>	<b>260.8</b>	<b>267.2</b>	<b>276.6</b>	<b>289.0</b>	<b>285.6</b>	<b>1.0%</b>

\*Less than 0.05 million metric tons carbon dioxide equivalent.

Note: Data are from EIA's *Monthly Energy Review*, including 2009 values. EPA data for other tables in this chapter are available only through 2008.

# A1. Notes and sources

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## A1.1. Table Notes and Sources

### Chapter 1: Greenhouse gas emissions overview

**Table 1. U.S. emissions of greenhouse gases, based on global warming potential, 1990-2009: Sources:** Emissions: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009). **Global warming potentials:** Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis: Errata* (Cambridge, UK: Cambridge University Press, 2008), website [www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-errata.pdf](http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-errata.pdf).

**Table 2. U.S. greenhouse gas intensity and related factors, 1990-2009: Sources:** Emissions: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009). **GDP:** U.S. Department of Commerce, Bureau of Economic Analysis, website [www.bea.gov](http://www.bea.gov) (November 2010).

**Table 3. Distribution of total U.S. greenhouse gas emissions by end-use sector, 2009: Source:** Estimates presented in this report. **Notes:** CO<sub>2</sub> emissions by end-use sector are based on EIA's estimates of energy consumption by sector and on industrial process emissions. CO<sub>2</sub> emissions from the electric power sector are allocated to the end-use sectors based on electricity sales to the sector. Non-CO<sub>2</sub> 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. Totals may not equal sum of components due to independent rounding.

**Table 4. World energy-related carbon dioxide emissions by region, 1990-2035: Sources:** History: EIA, International Energy Statistics, website [www.eia.gov/emeu/international](http://www.eia.gov/emeu/international); and U.S. estimates presented in this report. **Projections:** EIA, *Annual Energy Outlook 2011 Early Release Overview*, DOE/EIA-0383ER(2011) (Washington, DC, December 2010), website [www.eia.gov/aeo](http://www.eia.gov/aeo) (U.S. projections); and *International Energy Outlook 2010*, DOE/EIA-0484(2010) (Washington, DC, July 2010), Table A10, website [www.eia.gov/oiaf/ieo](http://www.eia.gov/oiaf/ieo) (world projections). **Note:** Because newer U.S. values are used, the totals for North America, OECD, and the world in this report do not match the corresponding values in *International Energy Outlook 2010*.

**Table 5. Greenhouse gases and 100-year net global warming potentials: Sources:** SAR: Intergovernmental 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. **TAR:** Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), website [www.grida.no/publications/other/ipcc\\_tar/](http://www.grida.no/publications/other/ipcc_tar/). This document was part of the Third Assessment Report (TAR) by the Intergovernmental Panel on Climate Change. **AR4:** Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis: Errata* (Cambridge, UK: Cambridge University Press, 2008), website [www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-errata.pdf](http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-errata.pdf). This document describes errata in parts of the Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change.

### Chapter 2: Carbon dioxide emissions

**Table 6. U.S. carbon dioxide emissions from energy and industry, 1990-2009: Source:** Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 7. U.S. energy-related carbon dioxide emissions by end-use sector, 1990-2009: Source:** Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 8. U.S. carbon dioxide emissions from residential sector energy consumption, 1990-2009: Source:** Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 9. U.S. carbon dioxide emissions from commercial sector energy consumption, 1990-2009: Source:** Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 10. U.S. carbon dioxide emissions from industrial sector energy consumption, 1990-2009: Source:** Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 11. U.S. carbon dioxide emissions from transportation sector energy consumption, 1990-2009: Source:** Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 12. U.S. carbon dioxide emissions from electric power sector energy consumption, 1990-2009: Source:** Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 13. U.S. carbon dioxide emissions from nonfuel uses of energy fuels, 1990-2009:** Source: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 14. U.S. carbon sequestration from nonfuel uses of energy fuels, 1990-2009:** Source: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 15. U.S. carbon dioxide emissions: adjustments for U.S. Territories and international bunker fuels, 1990-2009:** Source: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 16. U.S. carbon dioxide emissions from other sources, 1990-2009:** Source: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

### Chapter 3: Methane emissions

**Table 17. U.S. methane emissions, 1990-2009:** Sources: EIA, published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2009*, DOE/EIA-0573(2009) (Washington, DC, March 2011). Data in this table are revised from the data contained in *Emissions of Greenhouse Gases in the United States 2008*. Emissions calculations based on Intergovernmental Panel on Climate Change, *IPCC Guidelines for National Greenhouse Gas Inventories* (2006 and revised 1996 guidelines), website <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, EPA 430-R-10-006 (Washington, DC, April 2010), website <http://epa.gov/climatechange/emissions/usinventoryreport.html>.

**Table 18. U.S. methane emissions from energy sources, 1990-2009:** Source: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 19. U.S. methane emissions from agricultural sources, 1990-2009:** Source: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 20. U.S. methane emissions from waste management sources, 1990-2009:** Source: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 21. U.S. methane emissions from industrial process sources, 1990-2009:** Source: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

### Chapter 4: Nitrous oxide emissions

**Table 22. U.S. nitrous oxide emissions, 1990-2009:** Sources: EIA, published and unpublished data used to produce *Emissions of Greenhouse Gases in the United States 2009*, DOE/EIA-0573(2009) (Washington, DC, March 2011). Data in this table are revised from the data contained in *Emissions of Greenhouse Gases in the United States 2008*. Emissions calculations based on Intergovernmental Panel on Climate Change, *IPCC Guidelines for National Greenhouse Gas Inventories* (2006 and revised 1996 guidelines), website <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>; and U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, EPA 430-R-10-006 (Washington, DC, April 2010), website <http://epa.gov/climatechange/emissions/usinventoryreport.html>.

**Table 23. U.S. nitrous oxide emissions from agricultural sources, 1990-2009:** Source: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 24. U.S. nitrous oxide emissions from energy sources, 1990-2009:** Source: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 25. U.S. nitrous oxide emissions from industrial sources, 1990-2009:** Source: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).

**Table 26. U.S. nitrous oxide emissions from waste management sources, 1990-2009:** Source: Estimates presented in this report. Data in this table are revised from the data contained in the previous EIA report, *Emissions of Greenhouse Gases in the United States 2008*, DOE/EIA-0573(2008) (Washington, DC, December 2009).



## Chapter 5: High-GWP gases

Table 27. U.S. emissions of hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride, 1990-2009: Source: U.S. Environmental Protection Agency, Office of Air and Radiation, website [www.epa.gov/globalwarming/](http://www.epa.gov/globalwarming/) (preliminary estimates, November 2010).

Table 28. U.S. emissions of hydrofluorocarbons, 1990-2009: Source: U.S. Environmental Protection Agency, Office of Air and Radiation, website [www.epa.gov/globalwarming/](http://www.epa.gov/globalwarming/) (preliminary estimates, November 2010).

Table 29. U.S. emissions of perfluorocarbons, 1990-2009: Source: U.S. Environmental Protection Agency, Office of Air and Radiation, website [www.epa.gov/globalwarming/](http://www.epa.gov/globalwarming/) (estimates, November 2010). 2008 values are used as proxies for 2009.

Table 30. U.S. emissions of sulfur hexafluoride by source, 1990-2009: Source: U.S. Environmental Protection Agency, Office of Air and Radiation, website [www.epa.gov/globalwarming/](http://www.epa.gov/globalwarming/) (estimates, November 2010). 2008 values are used as proxies for 2009.

## Chapter 6: Land use

Table 31. Net U.S. carbon dioxide sequestration from land use, land use change, and forestry, 1990-2008: Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, EPA 430-R-10-006 (Washington, DC, April 2010), website <http://epa.gov/climatechange/emissions/usinventoryreport.html>.

Table 32. Net carbon dioxide sequestration in U.S. forests and harvested wood pools, 1990-2008: Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, EPA 430-R-10-006 (Washington, DC, April 2010), website <http://epa.gov/climatechange/emissions/usinventoryreport.html>.

Table 33. Net carbon dioxide sequestration in U.S. croplands and grasslands, 1990-2008: Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, EPA 430-R-10-006 (Washington, DC, April 2010), website <http://epa.gov/climatechange/emissions/usinventoryreport.html>.

Table 34. Net carbon dioxide sequestration in U.S. urban trees, yard trimmings, and food scraps, 1990-2008: Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, EPA 430-R-10-006 (Washington, DC, April 2010), website <http://epa.gov/climatechange/emissions/usinventoryreport.html>.

Table 35. Emissions of carbon dioxide from biofuel/bioenergy use by sector and fuel, 1990-2009: Sources: U.S. Energy Information Administration, *January 2011 Monthly Energy Review* (Washington, DC: January 31, 2011), website [www.eia.gov/emeu/mer](http://www.eia.gov/emeu/mer); and U.S. Environmental Protection Agency, 40 CFR: Protection of the Environment, Part 98—Mandatory Greenhouse Gas Reporting, “Table C-1 to Subpart C of Part 98—Default CO<sub>2</sub> Emission Factors and High Heat Values for Various Types of Fuel,” Federal Register, Vol. 74, No. 209 (October 30, 2009), p. 56410, website [www.epa.gov/climatechange/emissions/downloads09/GHG-MRR-FinalRule.pdf](http://www.epa.gov/climatechange/emissions/downloads09/GHG-MRR-FinalRule.pdf).

## A1.2. Figure Notes and Sources

### Chapter 1: Greenhouse gas emissions overview

Figure 1. U.S. greenhouse gas emissions by gas, 2009: Source: Estimates presented in this report.

Figure 2. U.S. energy-related carbon dioxide emissions by major fuel, 2009: Source: Estimates presented in this report.

Figure 3. U.S. energy-related carbon dioxide emissions by sector, 2009: Source: Estimates presented in this report.

Figure 4. Annual changes in Kaya identity terms (GDP, Energy/GDP, CO<sub>2</sub>/Energy) and energy-related carbon dioxide emissions, 2005-2009: Sources: Estimates presented in this report; and U.S. Department of Commerce, Bureau of Economic Analysis, website [www.bea.gov](http://www.bea.gov) (GDP, November 2010).

Figure 5. Greenhouse gas emissions in the U.S. economy: Source: Estimates presented in this report. Notes: CO<sub>2</sub> emissions by end-use sector are based on EIA’s estimates of energy consumption by sector and on industrial process emissions. CO<sub>2</sub> emissions from the electric power sector are allocated to the end-use sectors based on electricity sales to the sector. Non-CO<sub>2</sub> 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. Totals may not equal sum of components due to independent rounding.

Figure 6. World carbon dioxide emissions by region, 1990, 2007, 2025, and 2035: Sources: History: Energy Information Administration (EIA), International Energy Statistics, website [www.eia.gov/emeu/international](http://www.eia.gov/emeu/international); and U.S. data presented in this report. Projections: EIA, *Annual Energy Outlook 2011 Early Release Overview*, DOE/EIA-0383ER(2011) (Washington, DC, December 2010), website [www.eia.gov/aeo](http://www.eia.gov/aeo); and *International Energy Outlook 2010*, DOE/EIA-0484(2010) (Washington, DC, July 2010), Table A10, website [www.eia.gov/oiaf/ieo](http://www.eia.gov/oiaf/ieo). Note: Because newer U.S. values are used, the totals for North America, OECD, and the world in this report do not match the corresponding values in International Energy Outlook 2010.

Figure 7. Regional shares of world carbon dioxide emissions, 1990, 2007, 2025, and 2035: Sources: History: Energy Information Administration (EIA), International Energy Statistics, website [www.eia.gov/emeu/international](http://www.eia.gov/emeu/international); and U.S. data presented in this report. Projections: EIA, *Annual Energy Outlook 2011 Early Release Overview*, DOE/EIA-0383ER(2011) (Washington, DC, December 2010), website [www.eia.gov/aeo](http://www.eia.gov/aeo); and *International Energy Outlook 2010*, DOE/EIA-0484(2010) (Washington, DC, July 2010), Table A10, website [www.eia.gov/oiaf/ieo](http://www.eia.gov/oiaf/ieo). Note: Because newer U.S. values are used, the totals for North America, OECD, and the world in this report do not match the corresponding values in International Energy Outlook 2010.

**Figure 8. U.S. emissions of black carbon by source, 2001 and 2020:** Notes: Calculations based on PM<sub>2.5</sub>. Sources: M.A. Bahner, K.A. Weitz, A. Zapata, and B. DeAngelo, "Use of Black Carbon and Organic Carbon Inventories for Projections and Mitigation Analysis," presentation at 16th Annual International Emission Inventory Conference (Raleigh, NC, May 14-17, 2007), website [www.epa.gov/ttn/chief/conference/ei16/session3/k.weitz.pdf](http://www.epa.gov/ttn/chief/conference/ei16/session3/k.weitz.pdf); and U.S. Environmental Protection Agency, "Reducing Particle Pollution," website [www.epa.gov/oar/particlepollution/reducing.html](http://www.epa.gov/oar/particlepollution/reducing.html). It is difficult to compare black carbon with conventional greenhouse gases because of uncertainty related to GWPs. Figure 8 uses a 100-year GWP of 680 in order to be consistent with the GWP time horizon used elsewhere in this report. However, a 20-year GWP may be more appropriate. Year 2020 projections account for reductions due to implementation of existing rules.

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**Figure 9. Annual change in U.S. carbon dioxide emissions, 1991-2009:** Source: Estimates presented in this report.

**Figure 10. Energy-related carbon dioxide emissions for selected sectors 1990-2009:** Source: Estimates presented in this report.

**Figure 11. Annual changes in U.S. heating degree-days and residential sector carbon dioxide emissions from direct fuel combustion, 1990-2009:** Source: Estimates presented in this report.

**Figure 12. U.S. commercial sector carbon dioxide emissions and per capita income, 1990-2009:** Source: Estimates presented in this report.

**Figure 13. U.S. industrial sector carbon dioxide emissions and major industrial fuel use, 1990-2009:** Source: Estimates presented in this report.

**Figure 14. U.S. vehicle miles traveled and carbon dioxide emissions from gasoline and diesel transportation fuel use, 1990-2009:** Source: Estimates presented in this report.

**Figure 15. U.S. electric power sector energy sales and losses and carbon dioxide emissions from primary fuel combustion, 1990-2009:** Source: Estimates presented in this report.

**Figure 16. U.S. carbon dioxide emissions from other sources, 2009:** Source: Estimates presented in this report.

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**Figure 17. U.S. methane emissions by source, 1990-2009:** Source: Estimates presented in this report.

**Figure 18. U.S. methane emissions from energy sources, 1990-2009:** Source: Estimates presented in this report.

**Figure 19. U.S. methane emissions from agriculture by source, 2009:** Source: Estimates presented in this report.

**Figure 20. U.S. methane emissions from waste management by source, 1990-2009:** Source: Estimates presented in this report.

**Figure 21. U.S. methane emissions from industrial processes by source, 1990-2009:** Source: Estimates presented in this report.

## Chapter 4: Nitrous oxide emissions

**Figure 22. U.S. nitrous oxide emissions by source, 1990-2009:** Source: Estimates presented in this report.

**Figure 23. U.S. nitrous oxide emissions from agriculture by source, 2009:** Source: Estimates presented in this report.

**Figure 24. U.S. nitrous oxide emissions from energy use by source, 1990-2009:** Source: Estimates presented in this report.

**Figure 25. U.S. nitrous oxide emissions from industry by source, 1990-2009:** Source: Estimates presented in this report.

**Figure 26. U.S. nitrous oxide emissions from waste management by source, 1990-2009:** Source: Estimates presented in this report.

## Chapter 5: High-GWP gases

**Figure 27. U.S. emissions of high-GWP gases, 1990-2009:** Source: U.S. Environmental Protection Agency estimates.

**Figure 28. U.S. emissions of HFCs, 1990-2009:** Source: U.S. Environmental Protection Agency estimates.

**Figure 29. U.S. emissions of PFCs, 1990-2009:** Source: U.S. Environmental Protection Agency estimates.

**Figure 30. U.S. emissions of SF<sub>6</sub> by source, 1990-2009:** Source: U.S. Environmental Protection Agency estimates.

## Chapter 6: Land use

**Figure 31. U.S. carbon sequestration from land use, land use change, and forestry, 1990-2008:** Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, EPA 430-R-10-006 (Washington, DC, April 2010), website <http://epa.gov/climatechange/emissions/usinventoryreport.html>.

**Figure 32. Carbon sequestration in U.S. forest lands and harvested wood pools, 2008:** Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, EPA 430-R-10-006 (Washington, DC, April 2010), website <http://epa.gov/climatechange/emissions/usinventoryreport.html>.

**Figure 33. Carbon sequestration in U.S. croplands and grasslands, 1990-2008:** Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, EPA 430-R-10-006 (Washington, DC, April 2010), website <http://epa.gov/climatechange/emissions/usinventoryreport.html>.

Figure 34. Carbon sequestration in U.S. urban trees, yard trimmings, and food scraps, 1990-2008: Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, EPA 430-R-10-006 (Washington, DC, April 2010), website <http://epa.gov/climatechange/emissions/usinventoryreport.html>.

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## A2. Glossary

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**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 cutback asphalts. Note: The conversion factor for asphalt is 5.5 barrels per short ton.

**Associated natural gas:** See *Associated-dissolved natural gas* and *Natural gas*.

**Associated-dissolved natural gas:** Natural gas that occurs in crude oil reservoirs either as free gas (associated) or as gas in solution with crude oil (dissolved gas). See *Natural gas*.

**Aviation gasoline (finished):** A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in aviation reciprocating engines. Fuel specifications are provided in ASTM Specification D 910 and Military Specification MIL-G-5572. Note: Data on blending components are not counted in data on finished aviation gasoline.

**Balancing item:** Represents differences between the sum of the components of natural gas supply and the sum of the components of natural gas disposition. These differences may be due to quantities lost or to the effects of data reporting problems. Reporting problems include differences due to the net result of conversions of flow data metered at varying temperature and pressure bases and converted to a standard temperature and pressure base; the effect of variations in company accounting and billing practices; differences between billing cycle and calendar period time frames; and imbalances resulting from the merger of data reporting systems that vary in scope, format, definitions, and type of respondents.

**Biofuels:** Liquid fuels and blending components produced from biomass (plant) feedstocks, used primarily for transportation.

**Biogas:** The gas produced from the anaerobic decomposition of organic material in a landfill.

**Biogenic:** Produced by the actions of living organisms.

**Biomass:** Organic nonfossil material of biological origin constituting a renewable energy source.

**Biosphere:** The portion of the Earth and its atmosphere that can support life. The part of the global carbon cycle that includes living organisms and biogenic organic matter.

**Bituminous coal:** A dense coal, usually black, sometimes dark brown, often with well-defined bands of bright and dull material, used primarily as fuel in steam-electric power generation, with substantial quantities also used for heat and power applications in manufacturing and to make coke. Bituminous coal is the most abundant coal in active U.S. mining regions. Its moisture content usually is less than 20 percent. The heat content of bituminous coal ranges from 21 to 30 million Btu per ton on a moist, mineral-matter-free basis. The heat content of bituminous coal consumed in the United States averages 24 million Btu per ton, on the as-received basis (i.e., containing both inherent moisture and mineral matter).

**BOD<sub>5</sub>:** The biochemical oxygen demand of wastewater during decomposition occurring over a 5-day period. A measure of the organic content of wastewater.

**Bromofluorocarbons (halons):** Inert, nontoxic chemicals that have at least one bromine atom in their chemical makeup. They evaporate without leaving a residue and are used in fire extinguishing systems, especially for large computer installations.

**Bunker fuel:** Fuel supplied to ships and aircraft, both domestic and foreign, consisting primarily of residual and distillate fuel oil for ships and kerosene-based jet fuel for aircraft. The term "international bunker fuels" is used to denote the consumption of fuel for international transport activities. Note: For the purposes of greenhouse gas emissions inventories, data on emissions from combustion of international bunker fuels are subtracted from national emissions totals. Historically, bunker fuels have meant only ship fuel. See *Vessel bunkering*.

**Calcination:** A process in which a material is heated to a high temperature without fusing, so that hydrates, carbonates, or other compounds are decomposed and the volatile material is expelled.

**Calcium sulfate:** A white crystalline salt, insoluble in water. Used in Keene's cement, in pigments, as a paper filler, and as a drying agent.

**Calcium sulfite:** A white powder, soluble in dilute sulfuric acid. Used in the sulfite process for the manufacture of wood pulp.

**Capital stock:** Property, plant and equipment used in the production, processing and distribution of energy resources.

**Carbon black:** An amorphous form of carbon, produced commercially by thermal or oxidative decomposition of hydrocarbons and used principally in rubber goods, pigments, and printer's ink.

**Carbon budget:** Carbon budget: The balance of the exchanges (incomes and losses) of carbon between carbon sinks (e.g., atmosphere and biosphere) in the carbon cycle. See *Carbon cycle* and *Carbon sink*.

**Carbon cycle:** All carbon sinks and exchanges of carbon from one sink to another by various chemical, physical, geological, and biological processes. See *Carbon sink* and *Carbon budget*.

**Carbon dioxide (CO<sub>2</sub>):** A colorless, odorless, non-poisonous 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 25 for methane). "Carbon equivalent units" are defined as carbon dioxide equivalents multiplied by the carbon content of carbon dioxide (i.e., 12/44).

**Carbon flux:** See *Carbon budget*.

**Carbon intensity:** The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) of energy. When there is only one fossil fuel under consideration, the carbon intensity and the emissions coefficient are identical. When there are several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels. See *Emissions coefficient* and *Carbon output rate*.

**Carbon output rate:** The amount of carbon by weight per kilowatthour of electricity produced.

**Carbon sequestration:** The fixation of atmospheric carbon dioxide in a carbon sink through biological or physical processes.

**Carbon sink:** A reservoir that absorbs or takes up released carbon from another part of the carbon cycle. The four sinks, which are regions of the Earth within which carbon behaves in a systematic manner, are the atmosphere, terrestrial biosphere (usually including freshwater systems), oceans, and sediments (including fossil fuels).

**Catalytic converter:** A device containing a catalyst for converting automobile exhaust into mostly harmless products.

**Catalytic hydrocracking:** A refining process that uses hydrogen and catalysts with relatively low temperatures and high pressures for converting middle boiling or residual material to high octane gasoline, reformer charge stock, jet fuel, and/or high grade fuel oil. The process uses one or more catalysts, depending on product output, and can handle high sulfur feedstocks without prior desulfurization.

**Cesspool:** An underground reservoir for liquid waste, typically household sewage.

**Chlorofluorocarbon (CFC):** Any of various compounds consisting of carbon, hydrogen, chlorine, and fluorine used as refrigerants. CFCs are now thought to be harmful to the earth's atmosphere.

**Clean Development Mechanism (CDM):** A Kyoto Protocol program that enables industrialized countries to finance emissions-avoiding projects in developing countries and receive credit for reductions achieved against their own emissions limitation targets. See *Kyoto Protocol*.

**Climate:** The average course or condition of the weather over a period of years as exhibited by temperature, humidity, wind velocity, and precipitation.

**Climate change:** A term 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 (CH<sub>4</sub>) which is the major component of natural gas. It is also an important source of hydrogen in various industrial processes. Methane is a greenhouse gas. See also *Greenhouse gases*.

**Methanogens:** Bacteria that synthesize methane, requiring completely anaerobic conditions for growth.

**Methanol:** A light alcohol that can be used for gasoline blending. See *Oxygenate*.

**Methanotrophs:** Bacteria that use methane as food and oxidize it into carbon dioxide.

**Methyl chloroform (trichloroethane):** An industrial chemical (CH<sub>3</sub>CCl<sub>3</sub>) 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<sub>x</sub>):** Compounds of nitrogen and oxygen produced by the burning of fossil fuels.

**Nitrous oxide (N<sub>2</sub>O):** 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<sub>n</sub>H<sub>2n+2</sub>.

**Perfluorocarbons (PFCs):** A group of man-made chemicals composed of one or two carbon atoms and four to six fluorine atoms, containing no chlorine. PFCs have no commercial uses and are emitted as a byproduct of aluminum smelting and semiconductor manufacturing. PFCs have very high 100-year Global Warming Potentials and are very long-lived in the atmosphere.

**Perfluoromethane:** A compound (CF<sub>4</sub>) emitted as a byproduct of aluminum smelting.

**Petrochemical feedstocks:** Chemical feedstocks derived from petroleum principally for the manufacture of chemicals, synthetic rubber, and a variety of plastics.

**Petroleum:** A broadly defined class of liquid hydrocarbon mixtures. Included are crude oil, lease condensate, unfinished oils, refined products obtained from the processing of crude oil, and natural gas plant liquids. Note: Volumes of finished petroleum products include nonhydrocarbon compounds, such as additives and detergents, after they have been blended into the products.

**Petroleum coke:** See *Coke (petroleum)*.

**Photosynthesis:** The manufacture by plants of carbohydrates and oxygen from carbon dioxide and water in the presence of chlorophyll, with sunlight as the energy source. Carbon is sequestered and oxygen and water vapor are released in the process.

**Pig iron:** Crude, high-carbon iron produced by reduction of iron ore in a blast furnace.

**Pipeline, distribution:** A pipeline that conveys gas from a transmission pipeline to its ultimate consumer.

**Pipeline, gathering:** A pipeline that conveys gas from a production well/field to a gas processing plant or transmission pipeline for eventual delivery to end-use consumers.

**Pipeline, transmission:** A pipeline that conveys gas from a region where it is produced to a region where it is to be distributed.

**Planetary albedo:** The fraction of incident solar radiation that is reflected by the Earth-atmosphere system and returned to space, mostly by backscatter from clouds in the atmosphere.

**Pneumatic device:** A device moved or worked by air pressure.

**Polystyrene:** A polymer of styrene that is a rigid, transparent thermoplastic with good physical and electrical insulating properties, used in molded products, foams, and sheet materials.

**Polyvinyl chloride (PVC):** A polymer of vinyl chloride. Tasteless, odorless, insoluble in most organic solvents. A member of the family vinyl resin, used in soft flexible films for food packaging and in molded rigid products, such as pipes, fibers, upholstery, and bristles.

**Post-mining emissions:** Emissions of methane from coal occurring after the coal has been mined, during transport or pulverization.

**Radiative forcing:** A change in average net radiation at the top of the troposphere (known as the tropopause) because of a change in either incoming solar or exiting infrared radiation. A positive radiative forcing tends on average to warm the earth's surface; a negative radiative forcing on average tends to cool the earth's surface. Greenhouse gases, when emitted into the atmosphere, trap infrared energy radiated from the earth's surface and therefore tend to produce positive radiative forcing. See *Greenhouse gases*.

**Radiatively active gases:** Gases that absorb incoming solar radiation or outgoing infrared radiation, affecting the vertical temperature profile of the atmosphere. See *Radiative forcing*.

**Ratoon crop:** A crop cultivated from the shoots of a perennial plant.

**Redox potential:** A measurement of the state of oxidation of a system.

**Reflectivity:** The ratio of the energy carried by a wave after reflection from a surface to its energy before reflection.

**Reforestation:** Replanting of forests on lands that have recently been harvested or otherwise cleared of trees.

**Reformulated gasoline:** Finished motor gasoline formulated for use in motor vehicles, the composition and properties of which meet the requirements of the reformulated gasoline regulations promulgated by the U.S. Environmental Protection Agency under Section 211(k) of the Clean Air Act. Note: This category includes oxygenated fuels program reformulated gasoline (OPRG) but excludes reformulated gasoline blendstock for oxygenate blending (RBOB).

**Renewable energy resources:** Energy resources that are naturally replenishing but flow-limited. They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable energy resources include: biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action.

**Residual fuel oil:** A general classification for the heavier oils, known as No. 5 and No. 6 fuel oils, that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations. It conforms to ASTM Specifications D 396 and D 975 and Federal Specification VV-F-815C. No. 5, a residual fuel oil of medium viscosity, is also known as Navy Special and is defined in Military Specification MIL-F-859E, including Amendment 2 (NATO Symbol F-770). It is used in steam-powered vessels in government service and inshore powerplants. No. 6 fuel oil includes Bunker C fuel oil and is used for the production of electric power, space heating, vessel bunkering, and various industrial purposes.

**Rumen:** The large first compartment of the stomach of certain animals in which cellulose is broken down by the action of bacteria.

**Sample:** A set of measurements or outcomes selected from a given population.

**Sequestration:** See *Carbon sequestration*.

**Septic tank:** A tank in which the solid matter of continuously flowing sewage is disintegrated by bacteria.

**Sinter:** A chemical sedimentary rock deposited by precipitation from mineral waters, especially siliceous sinter and calcareous sinter.

**Sodium silicate:** A grey-white powder soluble in alkali and water, insoluble in alcohol and acid. Used to fireproof textiles, in petroleum refining and corrugated paperboard manufacture, and as an egg preservative. Also referred to as liquid 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 (SO<sub>2</sub>):** A toxic, irritating, colorless gas soluble in water, alcohol, and ether. Used as a chemical intermediate, in paper pulping and ore refining, and as a solvent.

**Sulfur hexafluoride (SF<sub>6</sub>):** 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<sub>x</sub>):** Compounds containing sulfur and oxygen, such as sulfur dioxide (SO<sub>2</sub>) and sulfur trioxide (SO<sub>3</sub>).

**Tertiary amyl methyl ether ((CH<sub>3</sub>)<sub>2</sub>(C<sub>2</sub>H<sub>5</sub>)COCH<sub>3</sub>):** 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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