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

About This Report

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

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

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

What's New

Carbon Dioxide

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

Methane

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

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

Other Gases: Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride

Difluoromethane (HFC-32). In this annual edition of EIA's greenhouse gas emissions inventory, data on hydrofluorocarbon (HFC) emissions for the first time include emissions of HFC-32, which increasingly is being used to replace HCFC-22 in refrigerant blends. Its inclusion in the inventory, based on data from the U.S. Environmental Protection Agency (EPA), adds 0.4 million metric tons carbon dioxide equivalent ($MMTCO_2e$) to EIA's estimate of total greenhouse gas emissions in 2005.

Electricity Transmission and Distribution. Changes in the calculations of emissions from electricity transmission and distribution resulted in an average annual increase in estimated SF_6 emissions from electric power systems of 0.1 to 0.6 million metric tons carbon dioxide equivalent ($MMTCO_2e$) for the 1990-2003 period.[1]

Magnesium Production and Processing. Emissions estimates from the EPA have been revised to reflect more accurate data on emission factors for sand casting activities and updated historical secondary production data from the U.S. Geological Survey (USGS). The changes resulted in a decrease in estimated SF_6 emissions

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

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

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

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

Land-Use Issues

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

U.S. Emissions in a Global Perspective

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

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

The Greenhouse Effect and Global Climate Change

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

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

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

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

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

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

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

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

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

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

[a]Values adjusted for nonfuel sequestration.
[b]Includes the 50 States and the District of Columbia.
Note: The U.S. numbers include carbon dioxide emissions attributable to renewable energy sources.
Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2003* (May-July 2005), web site www.eia.doe.gov/iea/; and data presented in this report. **Projections:** EIA, *Annual Energy Outlook 2006*, DOE/EIA-0383(2006) (Washington, DC, February, 2006), Table 1, web site www.eia.doe.gov/oiaf/aeo; and *International Energy Outlook 2006*, DOE/EIA-0484(2006) (Washington, DC, June 2006), Table A10.

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

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

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

Greenhouse Gas Sources and Sinks

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

Relative Forcing Effects of Various Gases

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

Table 2. Global Atmospheric Concentrations of Selected Greenhouse Gases

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

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

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

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

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

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

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

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

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

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

Current U.S. Climate Change Initiatives

Federal Initiatives

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

- **International Cooperation:** The United States is engaged in international efforts on climate change, both through multilateral and bilateral activities. Multilaterally, the United States is the largest donor to activities under the UNFCCC and the IPCC. Since 2001, the United States has launched bilateral partnerships with numerous countries on issues ranging from climate change science, to energy and sequestration technologies, to policy approaches.

  - **Asia-Pacific Partnership on Clean Development and Climate:** In June 2005, the United States launched a new international effort, the Asia-Pacific Partnership on Clean Development and Climate, which involves the United States, Australia, China, India, Japan, and South Korea. The partnership will collaborate to promote the development, diffusion, deployment, and transfer of existing and emerging cost-effective, cleaner technologies and practices. Areas for collaboration may include energy efficiency, clean coal, integrated gasification combined cycle, liquefied natural gas, carbon capture and storage, combined heat and power, methane capture and use, civilian nuclear power, geothermal power, rural/village energy systems, advanced transportation, building and home construction and operation, bioenergy, agriculture and forestry, hydropower, wind power, solar power, and other renewables.[17]

  - **Methane to Markets Partnership:** In July 2004, the United States announced the Methane to Markets Partnership. The partnership is an international initiative that advances cost-effective, near-term methane recovery and use as a clean energy source. Its goal is to reduce global methane emissions in order to enhance economic growth, strengthen energy security, improve air quality, improve industrial safety, and reduce emissions of greenhouse gases. Participating countries include Argentina, Australia, Brazil, Canada, China, Colombia, Ecuador, Germany, India, Italy, Japan, Mexico, Nigeria, Republic of Korea, Russia, Ukraine, United Kingdom, and the United States. The United States will commit up to $53 million to the partnership through 2009 for work with the private sector on sharing and expanding the use of profitable technologies to capture methane emissions that are now wasted in the course of industrial processes and use them as a new energy source.[18]

- **Near-Term Greenhouse Gas Reduction Initiatives:** The Federal Government administers a wide array of voluntary, regulatory, and incentive-based programs on energy efficiency, agricultural practices, and greenhouse gas reductions. Major initiatives announced by the Bush Administration include:

  - **Climate VISION Partnership:** In February 2003, President Bush announced that 12 major industrial sectors and the membership of the Business Roundtable had committed to work with the EPA and three Federal departments (Energy, Transportation, and Agriculture) to reduce greenhouse gas emissions in the next decade. Participating industries include electric utilities; petroleum refiners and natural gas producers; automobile, iron and steel, chemical, and magnesium manufacturers; forest and paper producers; railroads; and the cement, mining, aluminum, lime, and semiconductor industries. In May 2005, the Industrial Minerals Association–North America joined the list of participating industries.

    On February 14, 2006, the Climate VISION partners held a workshop to hear from industry sectors on activities they have undertaken to reduce energy usage and greenhouse gas emissions intensity. The purpose of the workshop was to provide an opportunity for current and prospective industry partners to share experiences and lessons learned through case studies and to explore new opportunities for collaboration.[19]

  - **Climate Leaders:** Climate Leaders, established by the EPA in February 2002, is a voluntary partnership that encourages companies to establish and meet clearly defined targets for greenhouse gas emission reductions. Climate Leaders Partners represent a variety of sectors, from heavy manufacturing to banking and retail. As of October 2006, the program had 103 Partners, 59 of which had publicly announced greenhouse gas emission reduction goals. The rest were in the process of completing emissions inventories before setting their reduction goals. (In January 2006, the EPA announced that 5 Partners had achieved their initial reduction goals.) The EPA estimates that emissions reductions by Climate Leaders Partners will prevent emissions equivalent to more than 9 million metric tons of carbon per year—enough to offset annual emissions from more than 6 million cars.[20]

[17]U.S. Department of State, *Vision Statement of Australia, China, India, Japan, the Republic of Korea, and the U.S. for a New Asia-Pacific Partnership on Clean Development and Climate* (Washington, DC, July 28, 2005), web site www.state.gov/g/oes/rls/fs/50335.htm.
[18]U.S. Environmental Protection Agency, "Methane to Markets," web site www.methanetomarkets.org.
[19]Climate Vision, "Climate VISION Partners Highlight Success Stories," web site www.climatevision.gov/events_climate.html.
[20]U.S. Environmental Protection Agency, "Climate Leaders Fact Sheet" (Washington, DC, September 2006), web site www.epa.gov/climateleaders/docs/partnership_fact_sheet.doc.

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

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

Historical Growth Rates for U.S. Carbon Intensity

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

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

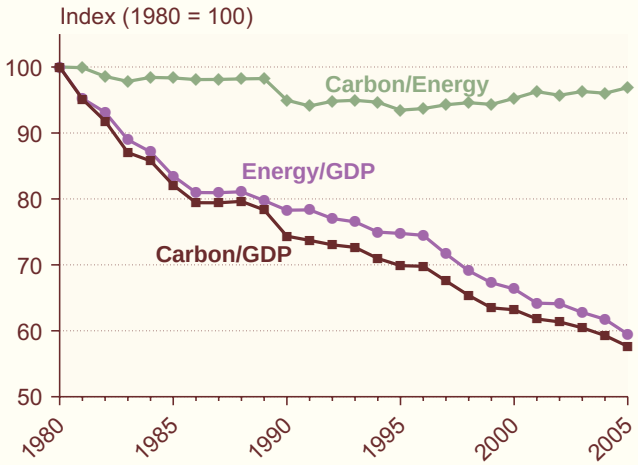
The carbon intensity and greenhouse gas intensity of the U.S. economy move in lockstep, because carbon dioxide emissions make up most of the total for U.S. greenhouse gas emissions. Energy-related carbon dioxide emissions represent approximately 80 percent of total U.S. greenhouse gas emissions. As such,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

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

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

or, algebraically,

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



Source: Historical carbon dioxide emissions data series.

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

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

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

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

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

(continued on page 9)

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

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

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

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

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

California State Initiative

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

International Developments in Global Climate Change

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

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

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

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

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

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

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

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

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

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

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

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

The Kyoto Protocol

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

Recent and Upcoming Conferences of the Parties and Other International Events

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

COP-11 and MOP-1

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

COP-12 and MOP-2

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

G8 Summit in St. Petersburg, Russia

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

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

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

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

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

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

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

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

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

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