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 twelfth annual inventory update, covering national emissions over the period 1990-2003, with preliminary estimates of emissions for 2004.

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," below).

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 engineered gases, 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 this year's report, data on carbon dioxide emissions have been enhanced to include emissions from nonfuel uses of petroleum products, natural gas, and coal (see Table 12 in Chapter 2). Emissions from nonfuel uses of energy fuels were included as part of energy-related carbon dioxide emissions in previous editions of this report but were not shown separately. Emissions from nonfuel uses are now shown separately under energy consumption.

Methane

The method for estimating methane emissions from landfills uses data on total waste generated and waste landfilled, published in *Biocycle* magazine. Before this year, the data from *Biocycle* were available with a one-year time lag, and EIA arrived at an estimate for the current year by scaling the most recent *Biocycle* data year according to changes in annual gross domestic product. For this year's report, *Biocycle* data were unavailable, creating a two-year time lag. Thus, to ensure a more rigorous statistical approach, EIA revised 2003 and 2004 waste generation data by using a regression equation that correlated changes in waste generation since 1988 to changes in gross domestic product over the same period. This change had a negligible impact on the emissions estimates.

In addition, EIA has revised its estimates of methane recovered from landfills and used for energy production. Previous editions of this report erroneously included the avoided emissions of carbon dioxide from fossil fuel combustion displaced by landfill gas-to-energy production in the estimate of methane recovered. This resulted in double counting of the impacts of fossil fuel displacement by landfill-gas-to-energy. For this year's report, avoided emissions have been removed from the estimates of methane emissions from landfills going back to 1990. EIA has also revised estimates of methane emissions from swine waste by adding detail on animal size.

Other Gases: HFCs, PFCs, and SF_6

The U.S. Environmental Protection Agency (EPA), Office of Air and Radiation, has made revisions to the data and estimation methodologies used for other gases—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—in its most recent emissions inventory.[1] Those changes are reflected in the EPA's historical emissions estimates, as described below:

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

- **Electricity Transmission and Distribution.** The changes in calculations of emissions from electricity transmission and distribution are the result of incorporating more up-to-date transmission mileage data and the inclusion of additional historical partner data in the EPA's SF_6 Emissions Reduction Partnership for Electric Power Systems for 2000, 2001, and 2002. Previously, the 2001 Utility Data Institute (UDI) Directory of Electric Power Producers and Distributors was used by the EPA to estimate SF_6 emissions for 2001 and 2002. Those numbers have been revised to account for increases in transmission mileage during 2001 and 2002, primarily as a result of growth in the U.S. transmission system. Accordingly, estimates of non-partner and non-reporting partner emissions have been recalculated in the non-reporting partner regression equations. Because transmission miles are highly correlated with SF_6 emissions, the EPA has used these regression equations to calculate emissions from non-partners and non-reporting partners in the SF_6 emissions reduction partnership.

  In addition to transmission mileage revisions, the electric power system emission estimates have also been recalculated, based on additional historical partner data. Specifically, the regression equations for each respective year of the historical partner submissions have been updated, resulting in new extrapolations to non-reporting partners as well. These revisions resulted in an average annual decrease in estimated SF_6 emissions from electric power systems of 0.2 percent, or less than 0.1 million metric tons carbon dioxide equivalent ($MMTCO_2e$) for the 2000-2002 period.

- **Magnesium Production and Processing.** The emissions estimates in this report have been revised to reflect new historical data supplied by the U.S. Geological Survey and participants in the EPA's SF_6 Emission Reduction Partnership for the Magnesium Industry. This change resulted in an average annual increase in estimated SF_6 emissions from magnesium production and processing of less than 0.1 $MMTCO_2e$ (4.1 percent) for the 2000-2002 period.

- **Substitution of Ozone-Depleting Substances.** The EPA has updated assumptions for its Vintaging Model pertaining to market trends in chemicals and chemical substitutes. These changes resulted in an average annual net increase in estimated HFC and PFC emissions of less than 0.1 $MMTCO_2e$ (4.1 percent) for the 1990-2002 period.

- **Aluminum Production**. As the result of an EPA-funded study, facility-specific slope coefficients for three U.S. aluminum smelters have been reestimated. The new coefficients have been used by the EPA in place of the Intergovernmental Panel on Climate Change (IPCC) defaults for revising the appropriate smelter-specific emission factors. The EPA provided the revised data to EIA, along with additional recently reported data concerning smelter operating parameters by participants in the EPA's Voluntary Aluminum Industrial Partnership Program. These changes resulted in an average annual increase of less than 0.1 $MMTCO_2e$ (0.2 percent) for the 1990-2002 period.

- **HCFC-22 Production.** The EPA has used reports from the Alliance for Responsible Atmospheric Policy to adjust the historical time series for HFC emissions from HCFC-22 production. These changes resulted in an average annual decrease in HFC emissions from HCFC-22 production of less than 0.1 $MMTCO_2e$ (0.01 percent) for the 1990-2002 period.

Land-Use Issues

The carbon sequestration estimates in this year's report reflect several categorical and methodological changes from previous years that have been implemented by the EPA. They include improvements in calculations as well as changes made in accordance with new guidelines from the IPCC, published in its *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (LULUCF GPG).[2] Key changes in this year's inventory include the following:

- As recommended in the LULUCF GPG, carbon stocks are reported according to several land-use types and conversions—for example, forest land remaining forest land, non-forest land becoming forest land, and forest land becoming non-forest land.
- Changes have been made in the definitions of different forest carbon pools. Standing dead trees are now part of the "dead wood" pool. Above- and below-ground portions of various pools are now aggregated as above- and below-ground biomass pools. The soil pool and the forest floor are now classified as "soil organic carbon" and "litter," respectively.
- The estimate of organic carbon in soils in the conterminous United States was calculated from the State Soil Geographic database,[3] and data gaps were filled with representative values for similar soils.

[2]Intergovernmental Panel on Climate Change, *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (Hayama, Japan, 2003), web site www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm.

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

- The newer U.S. Department of Agriculture (USDA) Forestry Inventory and Analysis Database (FIADB) datasets[4] were considered for non-soil forest carbon estimates, along with USDA Resources Planning Act (RPA) data.[5]
- This year, final values for all carbon pools were extrapolated from the last carbon stock change values calculated from the Forest Inventory and Analysis (FIA) survey data.

U.S. Emissions in a Global Perspective

This report estimates that U.S. energy-related carbon dioxide emissions in 2002 totaled 5,746 million metric tons (MMT). To put U.S. emissions in a global perspective, total energy-related carbon dioxide emissions for the world in 2002 are estimated at 24,405 MMT, making U.S. emissions about 24 percent of the world total (Table 1).[6] Emissions for the mature market economies (North America, Western Europe, Japan, and Australia/New Zealand) in 2002 are estimated at 11,872 MMT, or about 49 percent of the world total. In 2002, the remaining 51 percent of worldwide energy-related carbon dioxide emissions came from emerging economies (9,408 MMT) and the transitional economies of the former Soviet Union and Eastern Europe (3,124 MMT). By 2025, however, the U.S. share of total world emissions is projected to fall to 20 percent (7,587 MMT out of a global total of 38,396 MMT). The reason for the expected decline in the U.S. share is that U.S. energy-related carbon dioxide emissions are projected to increase at an annual rate of 1.2 percent, while emissions from the emerging and transitional economies are projected to grow at annual rates of 3.2 and 1.5 percent, respectively.

The Greenhouse Effect and Global Climate Change

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

The most important greenhouse gases are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and several engineered gases, such as HFCs, PFCs, and 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).

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

[5]The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) requires the Secretary of Agriculture to conduct an assessment of the Nation's renewable resources every 10 years. In the most recent assessment, which was done in 2000, the emphasis was expanded from solely economic concerns to resource conditions, ecosystem health, and sustainability. See web site www.fs.fed.us/pl/rpa/what.htm.

[6]Energy Information Administration, *International Energy Outlook 2005*, DOE/EIA-0484(2005) (Washington, DC, July 2005). 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 been revised from those published in the *International Energy Outlook 2005*. Emissions of gases other than energy-related carbon dioxide are difficult to estimate for the developing world; however, emissions related to fossil fuel consumption are likely to make up 80 to 85 percent of total greenhouse gas emissions.

[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.

[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 engineered 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

Table 1. World Carbon Dioxide Emissions by Region, 1990-2025
(Million Metric Tons Carbon Dioxide)

Region/Country	History			Projections				Average Annual Percent Change, 2002-2025
	1990	2001	2002	2010	2015	2020	2025	
Mature Market Economies								
North America	**5,778**	**6,660**	**6,696**	**7,478**	**7,934**	**8,417**	**8,984**	**1.3**
United States[a]	4,997	5,728	5,746	6,365	6,718	7,119	7,587	1.2
Canada	473	573	588	681	726	757	807	1.4
Mexico	308	359	363	432	490	541	591	2.1
Western Europe	**3,413**	**3,585**	**3,549**	**3,674**	**3,761**	**3,812**	**3,952**	**0.5**
Mature Market Asia	**1,284**	**1,610**	**1,627**	**1,731**	**1,780**	**1,822**	**1,852**	**0.6**
Japan	990	1,182	1,179	1,211	1,232	1,240	1,242	0.2
Australia/New Zealand	294	429	448	520	548	582	610	1.4
Total Mature Market	**10,474**	**11,855**	**11,872**	**12,883**	**13,475**	**14,051**	**14,788**	**1.0**
Transitional Economies								
Former Soviet Union	**3,798**	**2,393**	**2,399**	**2,804**	**3,040**	**3,201**	**3,379**	**1.5**
Russia	1,837	1,431	1,409	1,615	1,715	1,799	1,864	1.2
Other FSU	1,962	962	990	1,189	1,325	1,401	1,515	1.9
Eastern Europe	**1,095**	**744**	**726**	**839**	**898**	**951**	**1,006**	**1.4**
Total Transitional	**4,894**	**3,137**	**3,124**	**3,643**	**3,937**	**4,151**	**4,386**	**1.5**
Emerging Economies								
Emerging Asia	**3,890**	**5,967**	**6,205**	**9,306**	**10,863**	**12,263**	**13,540**	**3.5**
China	2,262	3,176	3,322	5,536	6,506	7,373	8,133	4.0
India	583	1,009	1,025	1,369	1,581	1,786	1,994	2.9
South Korea	234	431	451	549	623	676	723	2.1
Other Asia	811	1,351	1,407	1,853	2,154	2,428	2,689	2.9
Middle East	**845**	**1,311**	**1,361**	**1,761**	**1,975**	**2,163**	**2,352**	**2.4**
Africa	**655**	**840**	**854**	**1,122**	**1,283**	**1,415**	**1,524**	**2.5**
Central and South America	**711**	**998**	**988**	**1,289**	**1,480**	**1,639**	**1,806**	**2.7**
Brazil	250	343	342	433	502	583	679	3.0
Other Central/South America	461	655	646	856	979	1,056	1,128	2.5
Total Emerging	**6,101**	**9,116**	**9,408**	**13,478**	**15,602**	**17,480**	**19,222**	**3.2**
Total World	**21,469**	**24,108**	**24,405**	**30,005**	**33,014**	**35,682**	**38,396**	**2.0**

[a]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 2002*, DOE/EIA-0219(2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/; and data presented in this report. **Projections:** EIA, *Annual Energy Outlook 2006 Early Release*, DOE/EIA-0383(2006) (Washington, DC, December 12, 2005), Table 18, web site www.eia.doe.gov/oiaf/aeo/pdf/aeotab_18.pdf; and *International Energy Outlook 2005*, DOE/EIA-0484(2005) (Washington, DC, February 2005), Table A10.

and geologic timeframe. The most recent report of the 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 ± 0.2ºC 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]

In the aftermath of the IPCC report, the Domestic Policy Council, in May 2001 as part of its review of U.S. policy on climate change, requested that the National Academy of Sciences identify areas of uncertainty in the science of climate change, as well as review the IPCC report and summaries.[11] The National Academy of Sciences commissioned the National Research Council to carry out this review. The National Research Council in issuing its findings appeared to agree with some of the IPCC conclusions, but also seemed to suggest that further work needs to be done in identifying the impacts of natural climatic variability and reducing the uncertainty inherent in climate change modeling. Among the National Research Council findings are the following:[12]

> *Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes is also a reflection of natural variability.*
>
> *Because there is considerable uncertainty in current understanding of how the climate system varies naturally and reacts to emissions of greenhouse gases and aerosols, current estimates of the magnitude of future warming should be regarded as tentative and subject to future adjustments (either upward or downward).*
>
> *The committee generally agrees with the assessment of human-caused climate change presented in the IPCC Working Group I (WGI) scientific report, but seeks here to articulate more clearly the level of confidence that can be ascribed to those assessments and the caveats that need to be attached to them.*

Additionally, the U.S. Academy, along with the science academies of 10 other countries, in June 2005 released a joint statement on climate change (see text box on page 6).

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

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.

[11]National Research Council, *Climate Change Science, An Analysis of Some Key Questions* (Washington, DC: National Academy Press, 2001), Appendix A, "Letter from the White House," p. 27, web site http://nap.edu/html/climatechange/.

[12]National Research Council, *Climate Change Science, An Analysis of Some Key Questions* (Washington, DC: National Academy Press, 2001), p. 1, web site http://nap.edu/html/climatechange/.

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.

Water Vapor. Water vapor, as noted above, is the most common greenhouse gas present in the atmosphere. It is emitted into the atmosphere in enormous volumes through natural evaporation from oceans, lakes, and soils and is returned to Earth in the form of rain and snow. The recent IPCC report, however, cites a possible positive feedback from increased water vapor formation due to increased warming caused by rising atmospheric concentrations of carbon dioxide.[13] Elevated atmospheric temperatures increase the water-holding capability of the atmosphere. According to some of the IPCC emission scenarios, higher water vapor content could

Summary of Science Academies' Joint Statement on Global Response to Climate Change

The U.S. National Academy of Sciences and the national science academies of Brazil, Canada, China, France, Germany, India, Italy, Japan, Russia, and the United Kingdom in June 2005 issued a joint statement on the global response to climate change. Their statement stressed the following principles:

- Climate change is real: warming attributable to human activities is taking place and has already led to changes in the Earth's climate.
- The causes of climate change should be reduced: nations should identify cost-effective steps that they can take now to reduce the growth of greenhouse gas emissions.
- Nations should prepare for the consequences of climate change: because large portions of the climate respond slowly, even if steps were taken today to stabilize emissions at current levels the climate would continue to change; therefore, nations should prepare for unavoidable changes.
- An international study should be launched: the G8 nations should develop a science-based approach to targets for greenhouse gas emissions that avoid "unacceptable" impacts.
- There should be cooperation with developing countries: G8 nations should work with developing countries to find solutions that best fit the circumstances of those countries.

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).

[13]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis. Summary for Policymakers* (Cambridge, UK: Cambridge University Press, 2001), p. 49.

double the predicted atmospheric warming from what it would be if the water vapor concentration stayed constant. These scenarios, however, have an element of uncertainty due to the possible countervailing effect of increased cloud formation, which can act to cool the planet by absorbing and reflecting solar radiation or warm the planet through the emission of long-wave radiation. According to the IPCC, increases in atmospheric temperatures would not necessarily result in increased concentrations of water vapor, because most of the atmosphere today is undersaturated.

Carbon Dioxide. Carbon is a common element on the planet, and immense quantities can be found in the atmosphere, in soils, in carbonate rocks, and dissolved in ocean water. All life on Earth participates in the "carbon cycle," by which carbon dioxide is extracted from the air by plants and decomposed into carbon and oxygen, with the carbon being incorporated into plant biomass and the oxygen released to the atmosphere. Plant biomass, in turn, ultimately decays (oxidizes), releasing carbon dioxide back into the atmosphere or storing organic carbon in soil or rock. There are vast exchanges of carbon dioxide between the ocean and the atmosphere, with the ocean absorbing carbon from the atmosphere and plant life in the ocean absorbing carbon from water, dying, and spreading organic carbon on the sea bottom, where it is eventually incorporated into carbonate rocks such as limestone.

Records from Antarctic ice cores indicate that the carbon cycle has been in a state of imbalance for the past 200 years, with emissions of carbon dioxide to the atmosphere exceeding absorption. Consequently, carbon dioxide concentrations in the atmosphere have been rising steadily. Because of its relative abundance, total carbon dioxide in the atmosphere has a radiative forcing value of 1.46 watts per square meter.[14] (See page 10 for a discussion of radiative forcing.) According to the IPCC, before 1750, atmospheric carbon dioxide concentration was around 280 ± 10 parts per million for several thousand years. The IPCC goes on to say that the present carbon dioxide concentration has not been exceeded during the past 420,000 years, and likely not during the past 20 million years.[15]

The most important natural sources of carbon dioxide are releases from the oceans (330 billion metric tons of carbon dioxide per year) and land (440 billion metric tons of carbon dioxide annually), including 220 billion metric tons of carbon dioxide from plant respiration, 202 billion metric tons of carbon dioxide from non-plant respiration (bacteria, fungi, and herbivores), and 15 billion metric tons of carbon dioxide from combustion in natural and human-made fires.[16] Known anthropogenic sources (including deforestation) were estimated to account for about 29 billion metric tons of carbon dioxide per year during the 1989 to 1998 time period.[17] The principal anthropogenic source is the combustion of fossil fuels, which accounts for about 80 percent of total anthropogenic emissions of carbon worldwide. Natural processes—primarily, uptake by the ocean and photosynthesis—absorb substantially all the naturally produced carbon dioxide and some of the anthropogenic carbon dioxide, leading to an annual net increase in carbon dioxide in the atmosphere of 11.4 to 12.1 billion metric tons.[18]

Methane. Methane is also a common compound. The methane cycle is less well understood than the carbon cycle. Natural methane is released primarily by anaerobic decay of vegetation in wetlands, by the digestive tracts of termites in the tropics, by the ocean, and by leakage from methane hydrate deposits. The principal anthropogenic sources are leakages from the production of fossil fuels, human-promoted anaerobic decay in landfills, and the digestive processes of domestic animals. Anthropogenic sources are estimated to account for 60 percent of total methane emissions.[19] The main sources of absorption are thought to be tropospheric reactions with hydroxyl (OH) radicals that break down methane into the methyl radical CH_3 and water vapor (506 MMT methane), stratospheric reactions with hydroxyl radicals and chlorine (40 MMT methane), and decomposition by bacteria in soils (30 MMT methane). Known and unknown sources of methane are estimated to total 598 MMT annually; known sinks (i.e., absorption by natural processes) total about 576 MMT. The annual increase in methane concentration in the atmosphere accounts for the difference of 22 MMT.[20] The radiative

[14]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis. Summary for Policymakers* (Cambridge, UK: Cambridge University Press, 2001), Table 6.1, p. 358.

[15]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis. Summary for Policymakers* (Cambridge, UK: Cambridge University Press, 2001), p. 185.

[16]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), pp. 188, 191.

[17]Intergovernmental Panel on Climate Change, *Land Use, Land-Use Change, and Forestry. A Special Report to the IPCC* (Cambridge, UK: Cambridge University Press, 2000).

[18]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 208.

[19]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 248.

[20]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), Table 4.2, p. 250.

forcing of methane is 0.48 watts per square meter, about one-third that of carbon dioxide.[21]

Nitrous Oxide. The sources and absorption of nitrous oxide are much more speculative than those for other greenhouse gases. The principal natural sources are thought to be bacterial breakdown of nitrogen compounds in soils, particularly forest soils, fluxes from ocean upwellings, and stratospheric photo dissociation and reaction with electronically excited oxygen atoms. The primary human-made sources are enhancement of natural processes through application of nitrogen fertilizers, combustion of fuels (in fossil-fueled power plants and from the catalytic converters in automobiles), certain industrial processes (nylon and nitric acid production), biomass burning, and cattle and feedlots. Worldwide, estimated known sources of nitrous oxide total 16.4 MMT annually (6.9 MMT from anthropogenic sources), and known sinks total 12.6 MMT. The annual increase in concentrations in the atmosphere is thought to total 3.8 MMT.[22] The radiative forcing of nitrous oxide is 0.15 watts per square meter, about one-tenth that of carbon dioxide.[23]

Halocarbons and Other Gases. During the 20th century, human ingenuity created an array of "engineered" chemicals, not normally found in nature, whose special characteristics render them particularly useful. One family of engineered gases is the halocarbons. A halocarbon is a compound containing carbon and either chlorine, bromine, or fluorine. Halocarbons are powerful greenhouse gases. Halocarbons that contain bromine or chlorine also deplete the Earth's ozone layer.

One of the best-known groups of halocarbons is the chlorofluorocarbons (CFCs), particularly CFC-12, often known by its trade name, "Freon-12." CFCs have many desirable features: they are relatively simple to manufacture, inert, nontoxic, and nonflammable. Because CFCs are chemically stable, once emitted, they remain in the atmosphere for hundreds or thousands of years. Because they are not found in nature, these molecules absorb reflected infrared radiation at wavelengths that otherwise would be largely unabsorbed, and they are potent greenhouse gases, with direct global warming potentials hundreds or thousands of times greater, gram-per-gram, than that of carbon dioxide. Because their concentrations in the atmosphere are relatively small, however, their current levels of radiative forcing are low. (See page 10 for a discussion of global warming and radiative forcing.)

Because of their long atmospheric lives, a portion of the CFCs emitted into the atmosphere eventually find their way into the stratosphere, where they can be destroyed by sunlight. This reaction, however, releases free chlorine atoms into the stratosphere, and the free chlorine atoms tend to combine with stratospheric ozone, which protects the surface of the Earth from certain wavelengths of potentially damaging solar ultraviolet radiation (ultraviolet radiation, for example, causes human and animal skin cancers).

The threat posed by CFCs to the ozone layer has caused the United States and many other countries to commit themselves to phasing out the production of CFCs and their chemical cousins, hydrochlorofluorocarbons (HCFCs), pursuant to an international treaty, the 1987 Montreal Protocol. As use of CFCs has declined, many related chemicals have emerged as alternatives, including HCFCs and HFCs. HCFCs are similar to CFCs, but they are more reactive and consequently have shorter atmospheric lives, with less effect on the ozone layer and smaller direct global warming effects. HCFCs are also being phased out, but over a longer time scale. The ozone-depleting substances with the most potential to influence climate—CFC-11, CFC-12, and CFC-113—are beginning to show reduced growth rates in atmospheric concentrations in the aftermath of the Montreal Protocol. The present radiative forcing of CFC-11 is about 0.065 watts per square meter, and that of CFC-12 is around 0.2 watts per square meter.[24]

HFCs have no chlorine and consequently have no effect on the ozone layer, but they are powerful greenhouse gases. The three most prominent HFCs in the atmosphere today are HFC-23, HFC-134a, and HFC-152a.

HFC-23 is formed as a byproduct of HCFC-22 production, which is being phased out under the Montreal Protocol. Although HFC-23 is very long-lived (260 years), the growth rate in its atmospheric concentration has begun to level off in accordance with reductions in HCFC-22 production. HFC-134a production was rare before 1990, but in 1994 HFC-134a was adopted as the standard motor vehicle air conditioning refrigerant in virtually all new cars made in America. HFC-134a has a lifetime of 13.8 years, and emissions have grown rapidly

[21] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis. Summary for Policymakers* (Cambridge, UK: Cambridge University Press, 2001), Table 6.1, p. 358.

[22] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), Table 4.4, p. 252.

[23] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis. Summary for Policymakers* (Cambridge, UK: Cambridge University Press, 2001), Table 6.1, p. 358.

[24] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), Figures 4.6 and 4.7, p. 255.

from near zero in 1990 to 0.034 MMT in 2002.[25] HFC-152a emissions have risen steadily since about 1995, but its short lifetime of 1.4 years has kept concentration levels below 1 part per trillion.

Another new class of engineered halocarbons is the PFCs, which include perfluoromethane (CF_4) and perfluoroethane (C_2F_6). PFCs are emitted as byproducts of aluminum smelting and are increasingly being used in the manufacture of semiconductors. They are powerful greenhouse gases and extremely long-lived. Perfluoromethane has a 100-year global warming potential (GWP) of 5,700 and a lifetime in excess of 50,000 years. Perfluoroethane has a GWP of 11,900 and a lifetime of 10,000 years. Perfluoromethane is a naturally occurring compound in fluorites, and emissions from this source create a natural abundance of 40 parts per trillion in the atmosphere. Increases in anthropogenic emissions, growing at about 1.3 percent annually, have raised atmospheric concentrations to 80 parts per trillion.[26] Perfluoroethane does not occur naturally in the atmosphere, and current concentrations (3.0 parts per trillion) are attributable to anthropogenic emissions, which are growing by 3.2 percent annually. Sinks for PFCs are photolysis and ion reactions in the mesosphere.[27]

Sulfur hexafluoride is used as an insulator in large-scale electrical equipment and as a cover gas in magnesium smelting. It is not a halocarbon, but it is a powerful greenhouse gas. SF_6 has a 100-year GWP of 22,200 and a lifetime of 3,200 years. Like perfluoromethane, SF_6 occurs naturally in fluorites, which produce a natural abundance of 0.01 parts per trillion in the atmosphere. Current atmospheric concentrations (3.0 parts per trillion) can be traced to anthropogenic emissions, which grew by approximately 7 percent annually during the 1980s and 1990s. Also like PFCs, sinks for SF_6 are photolysis and ion reactions in the mesosphere.

There may be other chemicals not yet identified that exhibit radiative properties similar to those of the halocarbons and other gases described above. One recent discovery identified trifluoromethyl sulfur pentafluoride (SF_5CF_3) as a new anthropogenic greenhouse gas in the atmosphere.[28] It is believed that SF_5CF_3 is created by the breakdown of SF_6 in high-voltage equipment, which produces CF_3 that reacts with SF_5 radicals resulting from high-voltage discharges. Its atmospheric concentration has grown from near zero in 1960 to 0.12 parts per trillion in 1999. To date, SF_5CF_3 has the largest radiative forcing on a per-molecule basis of any gas found in the atmosphere.[29] The UNFCCC does not yet specifically address this gas.

A number of chemical solvents are also strong greenhouse gases. The solvents carbon tetrachloride (GWP of 1,800 and lifetime of 35 years) and methyl chloroform (GWP of 140 and lifetime of 4.8 years), however, are regulated in the United States for the purposes of both ozone depletion and toxicity. All these gases have direct radiative forcing effects, which are offset to some degree by their ozone-depleting effects.

With the advent of the United Nations Framework Convention and the Kyoto Protocol, the halocarbon and other industrial chemicals can be grouped into two categories:

- Ozone-depleting chemicals regulated under the Montreal Protocol but excluded from the Framework Convention (CFCs, HCFCs, and others)
- "Kyoto gases" (HFCs, PFCs, and SF_6).

The "Kyoto gases" are deemed to "count" for the purposes of meeting national obligations under the Framework Convention; however, ozone-depleting chemicals regulated by the Montreal Protocol are excluded.

Other Important Radiative Gases. There are a number of additional gases and particles, resulting in part from human sources, that produce radiative forcing of the Earth's climate but are not included under the Framework Convention or the Montreal Protocol. In general, these gases are short-lived, they have only indirect climate effects, or there is a fair amount of uncertainty about their climatic impacts. They can be broken down into three general classes: (1) ozone, both tropospheric and stratospheric; (2) criteria pollutants that are indirect greenhouse gases; and (3) aerosols, including sulfates and black soot.

Ozone (O_3) is present in both the troposphere and the stratosphere. Tropospheric ozone is not directly emitted into the atmosphere but instead forms through the photochemical reactions of various ozone precursors (primarily, nitrogen oxides and volatile organic compounds). In the troposphere, ozone acts as a direct greenhouse gas. The lifetime of ozone in the atmosphere varies from weeks to months, which imparts an element

[25] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 254; and estimates presented in this report.

[26] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 254.

[27] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 254.

[28] W.T. Sturges et al., "A Potent Greenhouse Gas Identified in the Atmosphere: SF_5CF_3," *Science*, Vol. 289 (July 28, 2000), pp. 611-613.

[29] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 254.

of uncertainty in estimating tropospheric ozone's radiative forcing effects. The IPCC estimates that the radiative forcing of tropospheric ozone is 0.35 ± 0.2 watts per square meter.[30] The depletion of stratospheric ozone due to the emission of halocarbons, on the other hand, has tended to cool the planet. The IPCC estimates that the cooling due to stratospheric ozone depletion is on the order of -0.15 ± 0.1 watts per square meter.[31] As the ozone layer recovers, however, due to the impacts of the Montreal Protocol, it is expected that stratospheric ozone will exert a positive radiative forcing effect on the Earth's climate.

Carbon monoxide, nitrogen oxides, and volatile organic compounds are indirect greenhouse gases. Regulated in the United States pursuant to the Clean Air Act, they are often referred to as "criteria pollutants." They are emitted primarily as byproducts of combustion (both of fossil fuels and of biomass), and they influence climate indirectly through the formation of ozone and their effects on the lifetime of methane emissions in the atmosphere. Carbon monoxide, through its effects on hydroxyl radicals, can help promote the abundance of methane in the atmosphere, as well as increase ozone formation. Some IPCC model calculations indicate that 100 metric tons of carbon monoxide emissions is equivalent to emissions of about 5 metric tons of methane.[32]

Nitrogen oxides, including NO and NO_2, influence climate by their impacts on other greenhouse gases. Nitrogen oxides not only promote ozone formation, they also impact (negatively) methane and HFC concentrations in the atmosphere. The deposition of nitrogen oxides could also reduce atmospheric carbon dioxide concentrations by fertilizing the biosphere.[33]

Volatile organic compounds (VOCs), although they have some short-lived direct radiative-forcing properties, primarily influence climate indirectly via their promotion of ozone formation and production of organic aerosols. The main sources of global VOC emissions are vegetation (primarily tropical) (1,382 $MMTCO_2e$), fossil fuels (590 $MMTCO_2e$), and biomass burning (121 $MMTCO_2e$).[34]

Aerosols, which are small airborne particles or droplets, also affect the Earth's climate. Aerosols have both direct effects, through their ability to absorb and scatter solar and thermal radiation, and indirect effects, through their ability to modify the physical properties and amount of clouds. In terms of their potential impacts on climate, the most prominent aerosols are sulfates, fossil fuel black carbon aerosols (black soot), fossil fuel organic carbon aerosols, and biomass-burning aerosols.

One of the primary precursors of sulfates is sulfur dioxide (SO_2), which is emitted largely as a byproduct from the combustion of sulfur-containing fossil fuels, particularly coal. Sulfur dioxide reacts in the air to form sulfate compounds. The major source of anthropogenic black soot and organic carbon aerosols is the burning of fossil fuels, primarily coal and diesel fuels. Biomass-burning aerosols are formed by the incomplete combustion of forest products. The IPCC estimates the direct radiative forcing for aerosols as follows: sulfates, -0.4 watts per square meter; black soot, +0.2 watts per square meter; fossil fuel organic carbon, -0.1 watts per square meter; and biomass-burning aerosols, -0.2 watts per square meter.[35] Although the indirect climate effects of aerosols are uncertain, some preliminary evidence points to an indirect cooling effect due to cloud formation.[36]

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 impact of each additional gram of gas added to the

[30] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis. Summary for Policymakers* (Cambridge, UK: Cambridge University Press, 2001), p. 43.
[31] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis. Summary for Policymakers* (Cambridge, UK: Cambridge University Press, 2001), p. 43.
[32] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis. Summary for Policymakers* (Cambridge, UK: Cambridge University Press, 2001), p. 44.
[33] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis. Summary for Policymakers* (Cambridge, UK: Cambridge University Press, 2001), p. 44.
[34] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), Table 4.7(a), p. 258.
[35] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis. Summary for Policymakers* (Cambridge, UK: Cambridge University Press, 2001), p. 45.
[36] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis. Summary for Policymakers* (Cambridge, UK: Cambridge University Press, 2001), p. 45.

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*,[37] and subsequently updated in *Climate Change 1995*[38] and *Climate Change 2001*.[39] The box on page 12 provides details on the differences in emission calculations using the GWP values from the two assessments.

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. The IPCC, however, has pointed out that there are elements of uncertainty in calculating GWPs.[40] The uncertainty takes several forms:

- The radiative efficiencies of greenhouse gases do not necessarily stay constant over time (as calculated in GWPs), particularly if the abundance of a gas in the atmosphere increases. Each gas absorbs radiation in a particular set of wavelengths, or "window," in the spectrum. In some cases, where concentrations of the gas are low and no other gases block radiation in the same window, small emissions of the gas will have a disproportionate absorptive effect. However, if concentrations of the gas rise over time, a larger and larger portion of the total light passing through the "window" will already have been captured, and the marginal effects of additional emissions will not be as large. Therefore, the effect of an additional unit of emission of a gas that is relatively plentiful in the atmosphere, such as water vapor or carbon dioxide, tends to be less than that of a rare gas, such as sulfur hexafluoride. This "diminishing return" effect implies that increasing the concentration of a particular gas reduces the impact of additional quantities of that gas. Thus, the relative impacts of various gases will change as their relative concentrations in the atmosphere change.
- The residence time of greenhouse gases in the atmosphere (particularly, carbon dioxide) are uncertain. Various natural processes cause many greenhouse gases to decompose into other gases or to be absorbed by the ocean or ground. The amount of time it takes for natural processes to remove a unit of emissions from the atmosphere is often referred to as the "atmospheric lifetime." Some gases, such as CFCs, have very long atmospheric lifetimes, in the hundreds of years. Others, such as carbon monoxide, have lives measured in hours or days. Methane, which decays into carbon dioxide over a period of a few years, has a much larger short-run effect on global warming than does an equivalent amount of carbon dioxide; however, over longer and longer periods—from 10 years to 100 years to 500 years, for example—the differences between the GWPs of methane and carbon dioxide become less significant, because carbon dioxide has a longer atmospheric lifetime than methane.

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.

The GWPs discussed above are direct GWPs in that they consider only the direct impact of the emitted gas. The IPCC has also devoted effort to the study of indirect GWPs. Indirect GWPs are based on the climatic impacts of the atmospheric decomposition of a gas into other gases. A number of gases—including methane, carbon monoxide, halocarbons, and nitrogen oxides—are thought to have indirect climatic effects. Methane indirectly influences the climate through ozone formation and the production of carbon dioxide. Carbon monoxide can promote ozone formation and extend the lifetime of methane in the atmosphere, which results in a positive indirect GWP. Some CFCs and HCFCs produce an indirect cooling effect by removing ozone from the stratosphere. The indirect cooling effect leads to lower net GWPs in a number of cases, but in most cases their net GWPs are still positive. Nitrogen oxides promote the formation of tropospheric ozone and, thus, have a

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

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

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

[40] Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), pp. 385-386.

Comparison of Global Warming Potentials from the IPCC's Second and Third Assessment Reports

Global warming potentials (GWPs) are used to compare the abilities of different greenhouse gases to trap heat in the atmosphere. GWPs are based on the radiative efficiency (heat-absorbing ability) of each gas relative to that of carbon dioxide (CO_2), as well as the decay rate of each gas (the amount removed from the atmosphere over a given number of years) relative to that of CO_2. The GWP provides a construct for converting emissions of various gases into a common measure, which allows climate analysts to aggregate the radiative impacts of various greenhouse gases into a uniform measure denominated in carbon or carbon dioxide equivalents. The table at the right compares the GWPs published in the Second and Third Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC).

In compiling its greenhouse gas emissions estimates, the Energy Information Administration attempts to employ the most current data sources. For that reason, GWP values from the IPCC's Third Assessment Report are used in this report. It is important to point out, however, that countries reporting to the United Nations Framework Convention on Climate Change (UNFCCC), including the United States, have been basing their estimates on GWPs from the IPCC's Second Assessment Report. The UNFCCC Guidelines on Reporting and Review, adopted before the publication of the Third Assessment Report, require emission estimates to be based on the GWPs in the IPCC's Second Assessment Report. This will probably continue in the short term, until the UNFCCC reporting rules are changed. Following the current rules, the U.S. Environmental Protection Agency, which compiles the official U.S. emissions inventory for submission to the UNFCCC, presented estimates based on the GWPs published in the Second Assessment Report in its report, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*, released in April 2005.

Comparison of 100-Year GWP Estimates from the IPCC's Second (1996) and Third (2001) Assessment Reports

Gas	1996 IPCC GWP	2001 IPCC GWP
Methane	21	23
Nitrous Oxide	310	296
HFC-23	11,700	12,000
HFC-125	2,800	3,400
HFC-134a	1,300	1,300
HFC-143a	3,800	4,300
HFC-152a	140	120
HFC-227ea	2,900	3,500
HFC-236fa	6,300	9,400
Perfluoromethane (CF_4)	6,500	5,700
Perfluoroethane (C_2F_6)	9,200	11,900
Sulfur Hexafluoride (SF_6)	23,900	22,200

Sources: UNFCCC, Second Assessment Report (1996) and Third Assessment Report (2001).

The table below shows U.S. carbon dioxide equivalent greenhouse gas emissions calculated using the IPCC's 1996 (Second Assessment Report) and 2001 (Third Assessment Report) GWPs. The estimate for total U.S. emissions in 2004 is 0.7 percent higher when the revised GWPs are used. The estimates for earlier years generally follow the same pattern. Therefore, trends in growth of greenhouse gas emissions are similar for both sets of GWP values. Using the 2001 GWPs, estimates of carbon dioxide equivalent methane emissions are 9.5 percent higher, and carbon-equivalent nitrous oxide emissions are 4.5 percent lower. Carbon dioxide equivalent emissions of HFCs, PFCs, and SF_6 are lower for some years and higher for others, depending on the relative shares of the three gases.

	IPCC GWP		Annual GWP-Weighted Emissions (Million Metric Tons Carbon Dioxide Equivalent)								
			1990			2003			2004		
Gas	1996	2001	1996 GWP	2001 GWP	Percent Difference	1996 GWP	2001 GWP	Percent Difference	1996 GWP	2001 GWP	Percent Difference
Carbon Dioxide	1	1	5,002	5,002	0.0	5,872	5,871	0.0	5,973	5,973	0.0
Methane	21	23	659	721	9.5	579	634	9.5	584	639	9.5
Nitrous Oxide	310	296	353	337	-4.5	351	335	-4.5	370	354	-4.5
HFCs, PFCs, and SF_6	M	M	92	88	-4.0	137	142	4.2	148	156	5.3
Total	—	—	**6,106**	**6,149**	**0.7**	**6,938**	**6,983**	**0.7**	**7,075**	**7,112**	**0.7**

M = mixture of gases.

Sources: Estimates provided in this report; and UNFCCC, Second Assessment Report (1996) and Third Assessment Report (2001).

positive indirect GWP—on the order of 5 for surface emissions and 450 for aircraft emissions.[41]

Current U.S. Climate Change 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 (see box on page 14).

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 Administration has implemented a number of related initiatives, including the following:[42]

- **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. CCTP includes climate change-related technology research, development, and deployment efforts as well as voluntary programs.
- **Climate Change Science Program (CCSP)**: The CCSP is a Federal, multi-agency research program to investigate 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.
- **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. As an example, a new international effort is the Asia-Pacific Partnership on Clean Development, which involves the United States, Australia, China, India, Japan, and South Korea. The partnership focuses on voluntary measures aimed at creating new investment opportunities to build cleaner, more efficient capacity in energy generation and related systems, including methane capture and use, rural energy systems, clean coal, and civilian nuclear power,

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.

[41]Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), pp. 387-390.
[42]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.

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

From 2003 to 2004, the greenhouse gas intensity of the U.S. economy fell from 677 to 662 metric tons per million 2000 dollars of GDP (2.1 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 2004, total U.S. greenhouse gas intensity fell by 23.5 percent, at an average rate of 1.9 percent per year.

Historical Growth Rates for U.S. Carbon Intensity

	Overall Change in Intensity (Percent)		Average Annual Change in Intensity (Percent)	
Decade	Carbon Dioxide	Total GHG	Carbon Dioxide	Total GHG
History				
1950-1960	-12.9	—	-1.4	—
1960-1970	-3.3	—	-0.3	—
1970-1980	-17.7	—	-1.9	—
1980-1990	-25.6	—	-2.7	—
1990-2000	-15.3	-17.9	-1.6	-1.9

Source: Energy Information Administration, *Annual Energy Review 2004*, DOE/EIA-0384(2003) (Washington, DC, August 2005), and estimates presented in Appendix B of this report.

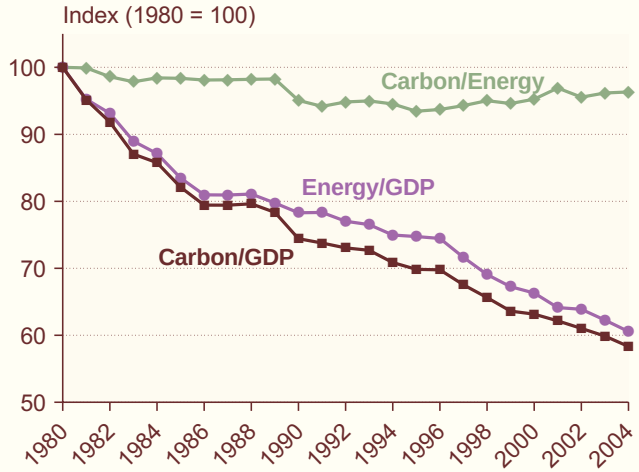
The carbon intensity and greenhouse gas intensity of the U.S. economy move in lockstep, because carbon dioxide emissions make up most of the total for U.S. greenhouse gas emissions. Energy-related carbon dioxide emissions represent approximately 80 percent of total U.S. greenhouse gas emissions. As such, 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: Estimates presented in Appendix B of this report.

(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 15)

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.

as well as advanced transportation and renewable energy systems.

- **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.

  - **Climate Leaders:** Climate Leaders is a voluntary partnership that encourages companies to establish and meet clearly defined targets for greenhouse gas emission reductions. The EPA established Climate Leaders in February 2002 and has recruited 74 partners, 38 of which have established greenhouse gas reduction goals. Climate Leaders partners include companies such as 3M and Alcoa (manufacturing); Baxter International, Johnson & Johnson, and Pfizer, (health services/pharmaceuticals); General Motors, Volvo Trucks North America, and Mack Trucks (automotive); and American Electric Power, Entergy Corporation, and FPL Group (utilities).

    By joining Climate Leaders, the partners commit themselves to document their emissions of the six major greenhouse gases (carbon dioxide, methane, nitrous oxide, HFCs, PFCs, and SF_6) on a company-wide basis (including, at a minimum, all their domestic facilities). Partners are required to develop an Inventory Management Plan (IMP) and report their annual corporate-level emissions by emission source type to the EPA, using the EPA's Annual GHG Inventory Summary and Goal Tracking Form.[43]

    In October 2004, the EPA issued updated guidance for corporate greenhouse gas inventories, based on an existing protocol developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The EPA has finalized guidance covering design principles and cross-sector core guidance covering direct emissions from stationary combustion, indirect emissions from sales and purchases of electricity and steam, direct emissions from mobile combustion sources, direct emissions from municipal solid waste landfilling, and direct emissions of HFCs and PFCs from use of refrigeration and air conditioning equipment. The EPA has also completed draft sector-specific guidance for core emissions from the following industries: cement, manufacture of refrigeration and air conditioning equipment (HFC and PFC emissions), and iron and steel. The EPA is currently developing sector-specific guidance for aluminum production, pulp and paper production, semiconductor manufacturing, and SF_6 from electricity distribution.

  - **Enhanced 1605(b) Voluntary Emissions Reduction Registry:** Pursuant to a key objective of the Global Climate Change Initiative, announced on February 14, 2002, by President George W. Bush, the U.S. Department of Energy (DOE) is working to improve and expand the existing 1605(b) Voluntary Reporting of Greenhouse Gases Program. The primary goal of the DOE effort is to create a credible and transparent program for reporting of real reductions that support the national

[43] U.S. Environmental Protection Agency, Climate Leaders Program, "Annual GHG Inventory Summary and Goal Tracking Form," web site www.epa.gov/climateleaders/docs/summaryform.xls. For information on Climate Leaders Program reporting requirements, see web site www.epa.gov/climateleaders/resources/reporting.html.

greenhouse gas intensity goal laid out in the Global Climate Change Initiative. An additional goal of the enhanced 1605(b) program is to allow businesses and individuals to record their reductions and ensure that reporters are not penalized under any future climate policy. The objective of improving the registry is to help motivate firms to take cost-effective, voluntary actions to reduce greenhouse gas emissions, which would, in part, aid in the achievement of the Initiative's greenhouse gas intensity goal.

An interagency working group has undertaken several actions to improve the Voluntary Reporting Program, including outreach efforts, solicitation of public comments, and review of the existing program. On July 8, 2002, the Secretary of Energy, joined by the Secretary of Commerce, the Secretary of Agriculture, and the EPA Administrator, submitted recommendations to the White House to guide the process for improving and expanding the Voluntary Reporting Program.

In November 2003, DOE released proposed revisions to the General Guidelines, which outline the principles that would govern the revised program. A public workshop on the subject was held in Washington, DC, on January 12, 2004, and DOE continued to collaborate with the USDA, the EPA, and other Federal agencies throughout 2004 in developing revised Guidelines for the Voluntary Reporting of Greenhouse Gases Program and "draft" Technical Guidelines that will specify the methods and factors to be used in measuring and estimating greenhouse gas emissions, emission reductions, and carbon sequestration under the revised program. On March 24, 2005, the Interim Final General Guidelines and a "Notice of Availability" for the Draft Technical Guidelines were published in the *Federal Register* for 60 days of public comment.

Both DOE and the USDA have held workshops to solicit comments on the Interim Final General Guidelines and the Draft Technical Guidelines for the Voluntary Reporting of Greenhouse Gases Program. The DOE workshop, held on April 26-27, 2005, in Arlington, Virginia, was attended by more than 150 individuals, most of whom were participants in the existing 1605(b) program.[44]

The USDA workshop was held on May 5, 2005, in Riverdale, Maryland, to address technical and methodological issues associated with preparing estimates of greenhouse gas emissions and carbon sequestration from agriculture and forestry activities and reporting those emissions under DOE's revised 1605(b) program. USDA invited four organizations to perform technical evaluations of the forestry and agriculture sections of the draft technical guidelines. Evaluators were asked to assess the accuracy, complexity, clarity, consistency, and comprehensiveness of the guidelines as applied to their operations. USDA also requested views on how to streamline and improve the usability of the guidelines.[45]

In a *Federal Register* notice published on May 9, 2005, DOE announced that it had extended the period for public comment on the Interim Final General Guidelines and Draft Technical Guidelines for the Voluntary Reporting of Greenhouse Gases Program to June 22, 2005, with a scheduled "effective date" of September 20, 2005. As this report goes to press, however, DOE still is in the process of making a determination as to whether addressing the comments received will require an extension of the scheduled "effective date" of the revised guidelines beyond September 20, 2005.[46]

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.[47] 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*

[44]For the agenda, a list of attendees, the presentation slides, a transcript, and an audio recording of the proceedings see web site www.pi.energy.gov/enhancingGHGregistry.

[45]The results of these evaluations, as well as other information about the USDA workshop, are available from web site www.usda.gov/agency/oce/gcpo/greenhousegasreporting.htm#Febworkshop.

[46]Comments received by DOE are posted on web site https://ostiweb.osti.gov/pighg/ghgc0202.idc.

[47]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.

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.[48]

The Framework Convention divided its signatories into three groups: the countries listed in Annex I; Annex II, 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 Organization for Economic Cooperation and Development (OECD) (including the United States), the European Union, and 14 countries with economies in transition (Russia, Ukraine, and Eastern Europe).[49]

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.[50] Developing country signatories do not have quantified targets.[51] 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 signatory countries to 118, with Annex I countries representing 61.2 percent of total Annex I carbon dioxide emissions in 1990. The Protocol entered into force in February 2005. While the United States remains a participant in the Framework Convention, it is not a participant in 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-10

COP-10, held in Buenos Aires, Argentina, from December 6 through December 17, 2004, marked the 10th anniversary of the entry into force of the UNFCCC, which was a central theme for the meeting.[52] In addition to the accomplishments of the first 10 years of the Convention and future challenges, discussions at COP-10 highlighted a range of climate-related issues, including the impacts of climate change and adaptation measures, mitigation policies and their impacts, and technology. Participants also considered the entry into force of the Kyoto Protocol, which was enabled by Russia's ratification.

COP-11 and MOP-1

Canada recently 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.

G8 Summit in Gleneagles, Scotland

In a communiqué on climate change and the related topics of clean energy and sustainable development, the leaders of the G8 who met July 6-8, 2005, in Gleneagles, Scotland, outlined several key points that summarize their position:

- They declared that, "climate change is a serious and long-term challenge that has the potential to affect every part of the globe."
- They acknowledged that ". . . use of energy from fossil fuels, and other human activities, contribute in

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

[49]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.

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

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

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

large part to increases in greenhouse gases associated with the warming of our Earth's surface."

- The communiqué further stated that, "While uncertainties remain in our understanding of climate science, we know enough to act now to put ourselves on a path to slow and, as the science justifies, stop and then reverse the growth of greenhouse gases."

Other points further stressed the relationship between climate change, clean energy, and sustainable development. A Dialogue on Climate Change, Clean Energy and Sustainable Development was proposed, which would:

- Address the strategic challenge of transforming our energy systems to create a more secure and sustainable future
- Monitor implementation of the commitments made in the Gleneagles Plan of Action
- Share best practice between participating governments
- Produce a report due at the 2008 G8 Summit, to be hosted by Japan.

The leaders also reaffirmed their commitment to the UNFCCC and the importance of the IPCC. They emphasized the UNFCCC objective of stabilizing atmospheric concentrations of greenhouse gases at a level that "prevents dangerous anthropogenic interference with the climate system." They agreed to support efforts at COP-11 to "move forward in that forum the global discussion on long-term cooperative action to address climate change."

The importance of sustainable development in emerging economies was stressed, and to that end the leaders of Brazil, China, India, Mexico, and South Africa also participated in the Summit. Collectively they called for stronger efforts by developed countries to reduce emissions and agreed to provide financial and technical assistance to developing countries. Additionally, the World Bank and the International Energy Agency were highlighted for their potentially important roles in the process of clean and sustainable development.

The Gleneagles Plan of Action adopted by the G8 leaders identifies a range of activities to promote research, information exchange, and cooperation on energy efficiency, renewable and other clean energy sources, and adaptation to climate change.

Key elements of the Plan include:

- A review of building codes and appliance and vehicle standards to identify best practices and opportunities for coordination
- An extension of the use of labeling on vehicles and appliances to raise consumer awareness of energy consumption
- Encouragement of multilateral development banks to expand the use of voluntary energy savings assessments of proposed investments in energy-intensive sectors; to explore opportunities to increase investments in renewable energy and energy efficiency technologies; and to work with borrower countries to identify less greenhouse gas-intensive growth options.[53]

[53]This summary of the G8 Summit is based on a Pew Center synopsis, available from web site www.pewclimate.org/policy_center/international_policy/summary_of_g8.cfm.