United States Environmental Protection Agency

April 2010

Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008

Executive Summary

An emissions inventory that identifies and quantifies a country's primary anthropogenic[1] sources and sinks of greenhouse gases is essential for addressing climate change. This inventory adheres to both (1) a comprehensive and detailed set of methodologies for estimating sources and sinks of anthropogenic greenhouse gases, and (2) a common and consistent mechanism that enables Parties to the United Nations Framework Convention on Climate Change (UNFCCC) to compare the relative contribution of different emission sources and greenhouse gases to climate change.

In 1992, the United States signed and ratified the UNFCCC. As stated in Article 2 of the UNFCCC, "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. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."[2]

Parties to the Convention, by ratifying, "shall develop, periodically update, publish and make available…national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies…"[3] The United States views the Inventory report as an opportunity to fulfill these commitments.

All material taken from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008*, U.S. Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-10-006, April 2010. You may electronically download the full Inventory report from U.S. EPA's Climate Change web page at: **www.epa.gov/climatechange/emissions/usinventoryreport.html.**

This chapter summarizes the latest information on U.S. anthropogenic greenhouse gas emission trends from 1990 through 2008. To ensure that the U.S. emissions inventory is comparable to those of other UNFCCC Parties, the estimates presented here were calculated using methodologies consistent with those recommended in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997), the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), and the *IPCC Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (IPCC 2003). Additionally, the U.S. emissions inventory has begun to incorporate new methodologies and data from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC

[1] The term "anthropogenic", in this context, refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities (IPCC/UNEP/OECD/IEA 1997).

[2] Article 2 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change. See <http://unfccc.int>.

[3] Article 4(1)(a) of the United Nations Framework Convention on Climate Change (also identified in Article 12). Subsequent decisions by the Conference of the Parties elaborated the role of Annex I Parties in preparing national inventories. See <http://unfccc.int>.

Box ES- 1: Recalculations of Inventory Estimates

Each year, emission and sink estimates are recalculated and revised for all years in the Inventory of U.S. Greenhouse Gas Emissions and Sinks as attempts are made to improve both the analyses themselves, through the use of better methods or data, and the overall usefulness of the report. In this effort, the United States follows the *IPCC Good Practice Guidance* (IPCC 2000), which states, regarding recalculations of the time series, "It is good practice to recalculate historic emissions when methods are changed or refined, when new source categories are included in the national inventory, or when errors in the estimates are identified and corrected." In general, recalculations are made to the U.S. greenhouse gas emission estimates either to incorporate new methodologies or, most commonly, to update recent historical data.

In each Inventory report, the results of all methodology changes and historical data updates are presented in the "Recalculations and Improvements" chapter; detailed descriptions of each recalculation are contained within each source's description contained in the report, if applicable. In general, when methodological changes have been implemented, the entire time series (in the case of the most recent inventory report, 1990 through 2007) has been recalculated to reflect the change, per *IPCC Good Practice Guidance*. Changes in historical data are generally the result of changes in statistical data supplied by other agencies. References for the data are provided for additional information.

2006). The structure of this report is consistent with the UNFCCC guidelines for inventory reporting.[4] For most source categories, the Intergovernmental Panel on Climate Change (IPCC) methodologies were expanded, resulting in a more comprehensive and detailed estimate of emissions.

ES.1. Background Information

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as bromofluorocarbons (i.e., halons). As stratospheric ozone depleting substances, CFCs, HCFCs, and halons are covered under the *Montreal Protocol on Substances that Deplete the Ozone Layer*. The UNFCCC defers to this earlier international treaty. Consequently, Parties to the UNFCCC are not required to include these gases in their national greenhouse gas emission inventories.[5] Some other fluorine-containing halogenated substances—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—do not deplete stratospheric ozone but are potent greenhouse gases. These latter substances are addressed by the UNFCCC and accounted for in national greenhouse gas emission inventories.

There are also several gases that do not have a direct global warming effect but indirectly affect terrestrial and/or solar radiation absorption by influencing the formation or destruction of greenhouse gases, including tropospheric and stratospheric ozone. These gases include carbon monoxide (CO), oxides of nitrogen (NO_x), and non-CH_4 volatile organic compounds (NMVOCs). Aerosols, which are extremely small particles or liquid droplets, such as those produced by sulfur dioxide (SO_2) or elemental carbon emissions, can also affect the absorptive characteristics of the atmosphere.

Although the direct greenhouse gases CO_2, CH_4, and N_2O occur naturally in the atmosphere, human activities have changed their atmospheric concentrations. From the pre-industrial era (i.e., ending about 1750) to 2005, concentrations of these greenhouse gases have increased globally by 36, 148, and 18 percent, respectively (IPCC 2007).

Beginning in the 1950s, the use of CFCs and other stratospheric ozone depleting substances (ODS) increased by nearly 10 percent per year until the mid-1980s, when international concern about ozone depletion led to the entry into force of the Montreal Protocol. Since then, the production of ODS is being phased out. In recent years, use of ODS substitutes such as HFCs and PFCs has grown as they begin to be phased in as replacements for CFCs and HCFCs. Accordingly, atmospheric concentrations of these substitutes have been growing (IPCC 2007).

Global Warming Potentials

Gases in the atmosphere can contribute to the greenhouse effect both directly and indirectly. Direct effects occur when the gas itself absorbs radiation. Indirect radiative forcing occurs when chemical transformations of the substance

[4] See <http://unfccc.int/resource/docs/cop8/08.pdf>.

[5] Emissions estimates of CFCs, HCFCs, halons and other ozone-depleting substances are included in the annexes of the Inventory report for informational purposes.

produce other greenhouse gases, when a gas influences the atmospheric lifetimes of other gases, and/or when a gas affects atmospheric processes that alter the radiative balance of the earth (e.g., affect cloud formation or albedo).[6] The IPCC developed the Global Warming Potential (GWP) concept to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to another gas.

The GWP of a greenhouse gas is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kilogram (kg) of a trace substance relative to that of 1 kg of a reference gas (IPCC 2001). Direct radiative effects occur when the gas itself is a greenhouse gas. The reference gas used is CO_2, and therefore GWP-weighted emissions are measured in teragrams (or million metric tons) of CO_2 equivalent (Tg CO_2 Eq.).[7,8] All gases in this Executive Summary are presented in units of Tg CO_2 Eq.

The UNFCCC reporting guidelines for national inventories were updated in 2006,[9] but continue to require the use of GWPs from the IPCC Second Assessment Report (SAR) (IPCC 1996). This requirement ensures that current estimates of aggregate greenhouse gas emissions for 1990 to 2008 are consistent with estimates developed prior to the publication of the IPCC Third Assessment Report (TAR) and the IPCC Fourth Assessment Report (AR4). Therefore, to comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using SAR GWP values. All estimates are provided throughout the inventory report in both CO_2 equivalents and unweighted units. A comparison of emission values using the SAR GWPs versus the TAR and AR4 GWPs can be found in Chapter 1 and, in more detail, in Annex 6.1 of the inventory report. The GWP values used in the inventory report are listed in Table ES-1.

Global warming potentials are not provided for CO, NO_x, NMVOCs, SO_2, and aerosols because there is no agreed-upon method to estimate the contribution of gases that are short-lived in the atmosphere, spatially variable, or have only indirect effects on radiative forcing (IPCC 1996).

Table ES-1: Global Warming Potentials (100-Year Time Horizon) Used in the Inventory Report

Gas	GWP
CO_2	1
CH_4*	21
N_2O	310
HFC-23	11,700
HFC-32	650
HFC-125	2,800
HFC-134a	1,300
HFC-143a	3,800
HFC-152a	140
HFC-227ea	2,900
HFC-236fa	6,300
HFC-4310mee	1,300
CF_4	6,500
C_2F_6	9,200
C_4F_{10}	7,000
C_6F_{14}	7,400
SF_6	23,900

Source: IPCC (1996)

* The CH_4 GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

ES.2. Recent Trends in U.S. Greenhouse Gas Emissions and Sinks

In 2008, total U.S. greenhouse gas emissions were 6,956.8 Tg CO_2 Eq. Overall, total U.S. emissions have risen by approximately 14 percent from 1990 to 2008. Emissions declined from 2007 to 2008, decreasing by 2.9 percent (211.3 Tg CO_2 Eq.). This decrease is primarily a result of a decrease in demand for transportation fuels associated with the record high costs of these fuels that occurred in 2008. Additionally, electricity demand declined in 2008 in part due to a significant increase in the cost of fuels used to generate electricity. In 2008, temperatures were cooler in the United States than in 2007, both in the summer and the winter. This lead to an increase in heating related energy demand in the winter; however, much of this increase was offset by a decrease in cooling-related electricity demand in the summer.

[6] Albedo is a measure of the Earth's reflectivity, and is defined as the fraction of the total solar radiation incident on a body that is reflected by it.

[7] Carbon comprises 12/44ths of carbon dioxide by weight.

[8] One teragram is equal to 10^{12} grams or one million metric tons.

[9] See <http://unfccc.int/resource/docs/2006/sbsta/eng/09.pdf>.

Figure ES-1 through Figure ES-3 illustrate the overall trends in total U.S. emissions by gas, annual changes, and absolute change since 1990. Table ES-2 provides a detailed summary of U.S. greenhouse gas emissions and sinks for 1990 through 2008.

Figure ES-4 illustrates the relative contribution of the direct greenhouse gases to total U.S. emissions in 2008. The primary greenhouse gas emitted by human activities in the United States was CO_2, representing approximately 85.1 percent of total greenhouse gas emissions. The largest source of CO_2, and of overall greenhouse gas emissions, was fossil fuel combustion. CH_4 emissions, which have declined by 5.5 percent since 1990, resulted primarily from enteric fermentation associated with domestic livestock, decomposition of wastes in landfills, and natural gas systems. Agricultural soil management and mobile source fuel combustion were the major sources of N_2O emissions. Ozone depleting substance substitute emissions and emissions of HFC-23 during the production of HCFC-22 were the primary contributors to aggregate HFC emissions. PFC emissions resulted as a by-product of primary aluminum production and from semiconductor manufacturing, while electrical transmission and distribution systems accounted for most SF_6 emissions.

Overall, from 1990 to 2008 total emissions of CO_2 increased by 820.4 Tg CO_2 Eq. (16.1 percent), while CH_4 and N_2O emissions decreased by 45.8 Tg CO_2 Eq. (7.5 percent) and 4.1 Tg CO_2 Eq. (1.3 percent), respectively. During the same period, aggregate weighted emissions of HFCs, PFCs, and SF_6 rose by 59.4 Tg CO_2 Eq. (65.9 percent). From 1990 to 2008, HFCs increased by 90.0 Tg CO_2 Eq. (243.7 percent), PFCs decreased by 14.1 Tg CO_2 Eq. (67.8 percent), and SF_6 decreased by 16.5 Tg CO_2 Eq. (50.5 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, and SF_6 are significant because many of these gases have extremely high global warming potentials and, in the cases of PFCs and SF_6, long atmospheric lifetimes. Conversely, U.S. greenhouse gas emissions were partly offset by carbon sequestration in forests, trees in urban areas, agricultural soils, and landfilled yard trimmings and food scraps, which, in aggregate, offset 13.5 percent of total emissions in 2008. The following sections describe each gas' contribution to total U.S. greenhouse gas emissions in more detail.

Figure ES-1

U.S. Greenhouse Gas Emissions by Gas

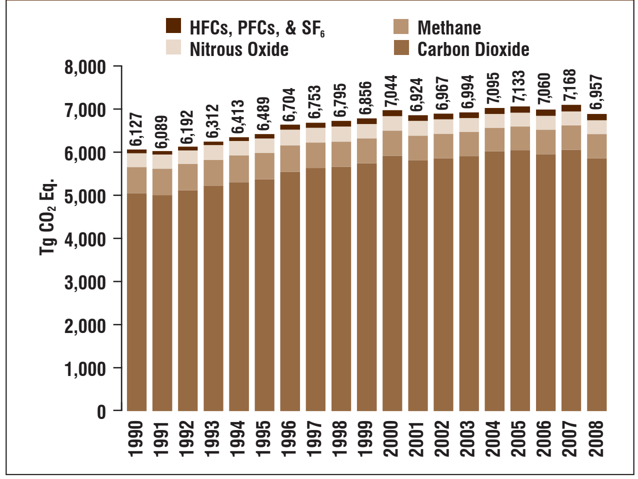


Figure ES-2

Annual Percent Change in U.S. Greenhouse Gas Emissions

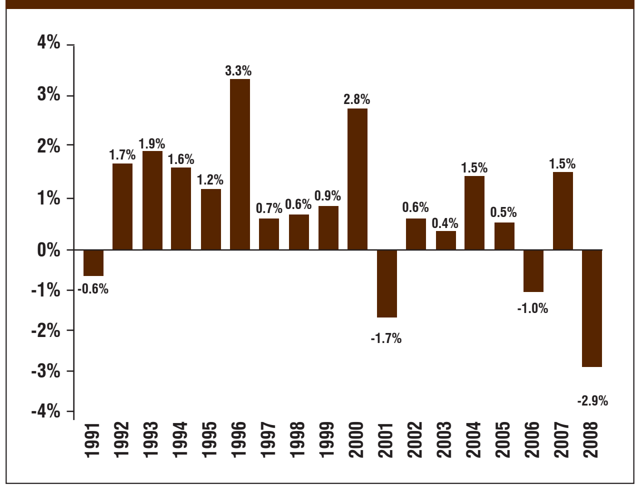


Figure ES-3

Cumulative Change in Annual U.S. Greenhouse Gas Emissions Relative to 1990

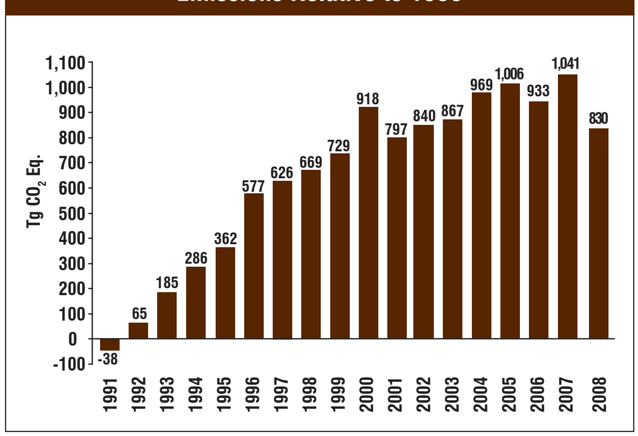


Table ES-2: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Tg CO_2 Eq. or million metric tons CO_2 Eq.)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
CO_2	**5,100.8**	**5,427.3**	**5,977.2**	**6,108.4**	**6,017.2**	**6,120.2**	**5,921.2**
Fossil Fuel Combustion	4,735.7	5,029.5	5,593.4	5,753.3	5,652.8	5,757.0	5,572.8
Electricity Generation	1,820.8	1,947.9	2,296.9	2,402.1	2,346.4	2,412.8	2,363.5
Transportation	1,485.8	1,608.0	1,809.5	1,895.3	1,876.7	1,893.7	1,785.3
Industrial	845.4	862.6	852.2	825.6	850.7	842.2	819.3
Residential	339.1	353.3	371.2	358.4	322.1	341.7	342.7
Commercial	216.7	223.2	227.7	221.3	206.0	217.4	219.5
U.S. Territories	27.9	34.5	35.9	50.6	50.9	49.1	42.5
Non-Energy Use of Fuels	119.6	142.9	146.1	136.5	141.4	135.3	134.2
Iron and Steel Production & Metallurgical Coke Production	102.6	95.7	88.1	67.7	70.5	72.8	69.0
Cement Production	33.3	36.8	41.2	45.9	46.6	45.2	41.1
Natural Gas Systems	37.3	42.2	29.4	29.5	29.5	30.8	30.0
Lime Production	11.5	13.3	14.1	14.4	15.1	14.6	14.3
Incineration of Waste	8.0	11.5	11.3	12.6	12.7	13.3	13.1
Ammonia Production and Urea Consumption	16.8	17.8	16.4	12.8	12.3	14.0	11.8
Cropland Remaining Cropland	7.1	7.0	7.5	7.9	7.9	8.3	7.6
Limestone and Dolomite Use	5.1	6.7	5.1	6.8	8.0	7.7	6.6
Aluminum Production	6.8	5.7	6.1	4.1	3.8	4.3	4.5
Soda Ash Production and Consumption	4.1	4.3	4.2	4.2	4.2	4.1	4.1
Petrochemical Production	3.3	4.1	4.5	4.2	3.8	3.9	3.4
Titanium Dioxide Production	1.2	1.5	1.8	1.8	1.8	1.9	1.8
Carbon Dioxide Consumption	1.4	1.4	1.4	1.3	1.7	1.9	1.8
Ferroalloy Production	2.2	2.0	1.9	1.4	1.5	1.6	1.6
Phosphoric Acid Production	1.5	1.5	1.4	1.4	1.2	1.2	1.2
Wetlands Remaining Wetlands	1.0	1.0	1.2	1.1	0.9	1.0	0.9
Petroleum Systems	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Zinc Production	0.9	1.0	1.1	0.5	0.5	0.4	0.4
Lead Production	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Silicon Carbide Production and Consumption	0.4	0.3	0.2	0.2	0.2	0.2	0.2
Land Use, Land-Use Change, and Forestry (Sink)[a]	*(909.4)*	*(842.9)*	*(664.2)*	*(950.4)*	*(959.2)*	*(955.4)*	*(940.3)*
Biomass - Wood[b]	*215.2*	*229.1*	*218.1*	*206.9*	*207.9*	*207.4*	*198.4*
International Bunker Fuels[b]	*111.8*	*99.8*	*98.5*	*110.5*	*129.1*	*127.1*	*135.2*
Biomass - Ethanol[b]	*4.2*	*7.7*	*9.2*	*22.6*	*30.5*	*38.3*	*53.3*
CH_4	**613.4**	**613.2**	**586.0**	**553.2**	**568.2**	**569.2**	**567.6**
Enteric Fermentation	132.4	143.7	136.8	136.7	139.0	141.2	140.8
Landfills	149.3	144.1	120.7	125.6	127.1	126.5	126.3
Natural Gas Systems	129.5	132.6	130.7	103.6	103.1	99.5	96.4
Coal Mining	84.1	67.1	60.4	56.9	58.3	58.1	67.6
Manure Management	29.3	33.9	38.6	42.2	42.3	45.9	45.0
Petroleum Systems	33.9	32.0	30.2	28.2	28.2	28.8	29.1
Wastewater Treatment	23.5	24.8	25.2	24.3	24.5	24.4	24.3
Forest Land Remaining Forest Land	3.2	4.3	14.3	9.8	21.6	20.0	11.9
Rice Cultivation	7.1	7.6	7.5	6.8	5.9	6.2	7.2
Stationary Combustion	7.4	7.1	6.6	6.6	6.2	6.5	6.7
Abandoned Underground Coal Mines	6.0	8.2	7.4	5.6	5.5	5.7	5.9
Mobile Combustion	4.7	4.3	3.4	2.5	2.3	2.2	2.0

Table ES-2: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Tg CO_2 Eq. or million metric tons CO_2 Eq.) (continued)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
Composting	0.3	0.7	1.3	1.6	1.6	1.7	1.7
Field Burning of Agricultural Residues	0.8	0.7	0.9	0.9	0.9	1.0	1.0
Petrochemical Production	0.9	1.1	1.2	1.1	1.0	1.0	0.9
Iron and Steel Production & Metallurgical Coke Production	1.0	1.0	0.9	0.7	0.7	0.7	0.6
Ferroalloy Production	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.1*	*0.2*	*0.2*	*0.2*
N_2O	**322.3**	**342.5**	**345.5**	**328.3**	**329.5**	**327.7**	**318.2**
Agricultural Soil Management	203.5	205.9	210.1	215.8	211.2	211.0	215.9
Mobile Combustion	43.9	54.0	53.2	36.9	33.6	30.3	26.1
Nitric Acid Production	18.9	21.0	20.7	17.6	17.2	20.5	19.0
Manure Management	14.4	15.5	16.7	16.6	17.3	17.3	17.1
Stationary Combustion	12.8	13.3	14.5	14.7	14.5	14.6	14.2
Forest Land Remaining Forest Land	2.7	3.7	12.1	8.4	18.0	16.7	10.1
Wastewater Treatment	3.7	4.0	4.5	4.7	4.8	4.9	4.9
N_2O from Product Uses	4.4	4.6	4.9	4.4	4.4	4.4	4.4
Adipic Acid Production	15.8	17.6	5.5	5.0	4.3	3.7	2.0
Composting	0.4	0.8	1.4	1.7	1.8	1.8	1.8
Settlements Remaining Settlements	1.0	1.2	1.1	1.5	1.5	1.6	1.6
Field Burning of Agricultural Residues	0.4	0.4	0.5	0.5	0.5	0.5	0.5
Incineration of Waste	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Wetlands Remaining Wetlands	+	+	+	+	+	+	+
International Bunker Fuels[b]	*1.1*	*0.9*	*0.9*	*1.0*	*1.2*	*1.2*	*1.2*
HFCs	**36.9**	**62.2**	**103.2**	**119.3**	**121.8**	**127.4**	**126.9**
Substitution of Ozone Depleting Substances[c]	0.3	29.0	74.3	103.2	107.7	110.1	113.0
HCFC-22 Production	36.4	33.0	28.6	15.8	13.8	17.0	13.6
Semiconductor Manufacture	0.2	0.3	0.3	0.2	0.3	0.3	0.3
PFCs	**20.8**	**15.6**	**13.5**	**6.2**	**6.0**	**7.5**	**6.7**
Aluminum Production	18.5	11.8	8.6	3.0	2.5	3.8	2.7
Semiconductor Manufacture	2.2	3.8	4.9	3.2	3.5	3.6	4.0
SF_6	**32.6**	**27.9**	**19.1**	**17.8**	**17.0**	**16.1**	**16.1**
Electrical Transmission and Distribution	26.6	21.4	15.0	14.0	13.2	12.7	13.1
Magnesium Production and Processing	5.4	5.6	3.0	2.9	2.9	2.6	2.0
Semiconductor Manufacture	0.5	0.9	1.1	1.0	1.0	0.8	1.1
Total	**6,126.8**	**6,488.8**	**7,044.5**	**7,133.2**	**7,059.9**	**7,168.1**	**6,956.8**
Net Emissions (Sources and Sinks)	**5,217.3**	**5,646.0**	**6,380.2**	**6,182.8**	**6,100.7**	**6,212.7**	**6,016.4**

+ Does not exceed 0.05 Tg CO_2 Eq.

[a] Parentheses indicate negative values or sequestration. The net CO_2 flux total includes both emissions and sequestration, and constitutes a sink in the United States. Sinks are only included in net emissions total.

[b] Emissions from International Bunker Fuels and Biomass Combustion are not included in totals.

[c] Small amounts of PFC emissions also result from this source.

Note: Totals may not sum due to independent rounding.

Figure ES-4

2008 Greenhouse Gas Emissions by Gas (percents based on Tg CO_2 Eq.)

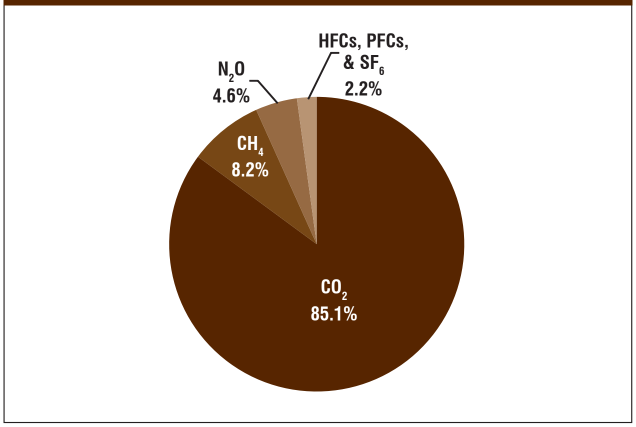
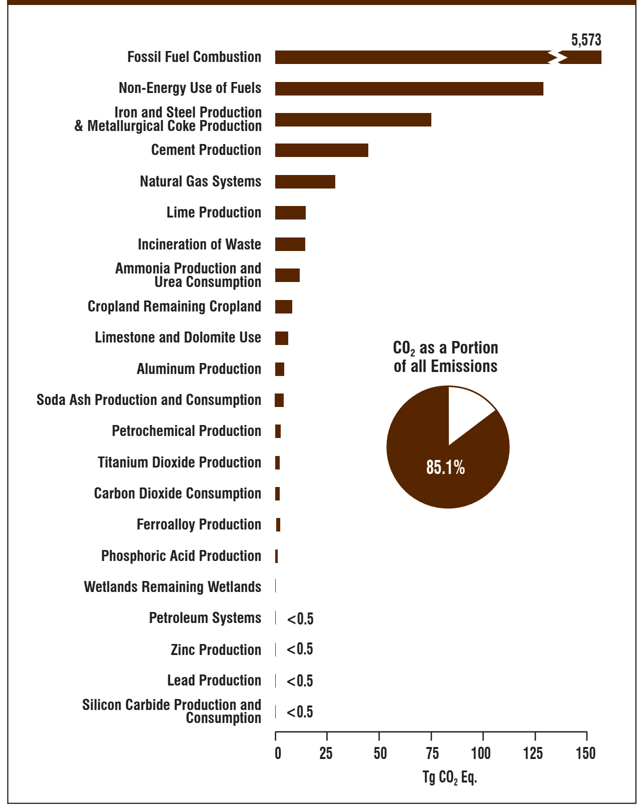


Figure ES-5

2008 Sources of CO_2 Emissions



Carbon Dioxide Emissions

The global carbon cycle is made up of large carbon flows and reservoirs. Billions of tons of carbon in the form of CO_2 are absorbed by oceans and living biomass (i.e., sinks) and are emitted to the atmosphere annually through natural processes (i.e., sources). When in equilibrium, carbon fluxes among these various reservoirs are roughly balanced. Since the Industrial Revolution (i.e., about 1750), global atmospheric concentrations of CO_2 have risen about 36 percent (IPCC 2007), principally due to the combustion of fossil fuels. Within the United States, fossil fuel combustion accounted for 94.1 percent of CO_2 emissions in 2008. Globally, approximately 30,377 Tg of CO_2 were added to the atmosphere through the combustion of fossil fuels in 2008, of which the United States accounted for about 19 percent.[10] Changes in land use and forestry practices can also emit CO_2 (e.g., through conversion of forest land to agricultural or urban use) or can act as a sink for CO_2 (e.g., through net additions to forest biomass). In addition to fossil-fuel combustion, several other sources emit significant quantities of CO_2. These sources include, but are not limited to non-energy use of fuels, iron and steel production and cement production (Figure ES-5).

As the largest source of U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion has accounted for approximately 79 percent of GWP-weighted emissions since 1990, growing slowly from 77 percent of total GWP-weighted emissions in 1990 to 80 percent in 2008. Emissions of CO_2 from fossil fuel combustion increased at an average annual rate of 1 percent from 1990 to 2008. The fundamental factors influencing this trend include: (1) a generally growing domestic economy over the last 19 years, and (2) significant overall growth in emissions from electricity generation and transportation activities. Between 1990 and 2008, CO_2 emissions from fossil fuel combustion increased from 4,735.7 Tg CO_2 Eq. to 5,572.8 Tg CO_2 Eq.—an 18 percent total increase over the nineteen-year period. From 2007 to 2008, these emissions decreased by 184.2 Tg CO_2 Eq. (3.2 percent).

Historically, changes in emissions from fossil fuel combustion have been the dominant factor affecting U.S. emission trends. Changes in CO_2 emissions from fossil fuel combustion are influenced by many long-term and short-term factors, including population and economic growth, energy price fluctuations, technological changes, and seasonal temperatures. On an annual basis, the overall consumption of fossil fuels in the United States generally fluctuates in response to changes in general economic conditions, energy prices, weather, and the availability of non-fossil alternatives. For example, in a year with increased consumption of goods and services, low fuel prices, severe summer and

[10] Global CO_2 emissions from fossil fuel combustion were taken from Energy Information Administration *International Energy Statistics 2009* < http://tonto.eia.doe.gov/cfapps/ipdbproject/IEDIndex3.cfm> EIA (2009).

winter weather conditions, nuclear plant closures, and lower precipitation feeding hydroelectric dams, there would likely be proportionally greater fossil fuel consumption than a year with poor economic performance, high fuel prices, mild temperatures, and increased output from nuclear and hydroelectric plants.

The five major fuel consuming sectors contributing to CO_2 emissions from fossil fuel combustion are electricity generation, transportation, industrial, residential, and commercial. CO_2 emissions are produced by the electricity generation sector as they consume fossil fuel to provide electricity to one of the other four sectors, or "end-use" sectors. For the discussion below, electricity generation emissions have been distributed to each end-use sector on the basis of each sector's share of aggregate electricity consumption. This method of distributing emissions assumes that each end-use sector consumes electricity that is generated from the national average mix of fuels according to their carbon intensity. Emissions from electricity generation are also addressed separately after the end-use sectors have been discussed.

Note that emissions from U.S. territories are calculated separately due to a lack of specific consumption data for the individual end-use sectors.

Figure ES- 6, Figure ES- 7, and Table ES-3 summarize CO_2 emissions from fossil fuel combustion by end-use sector.

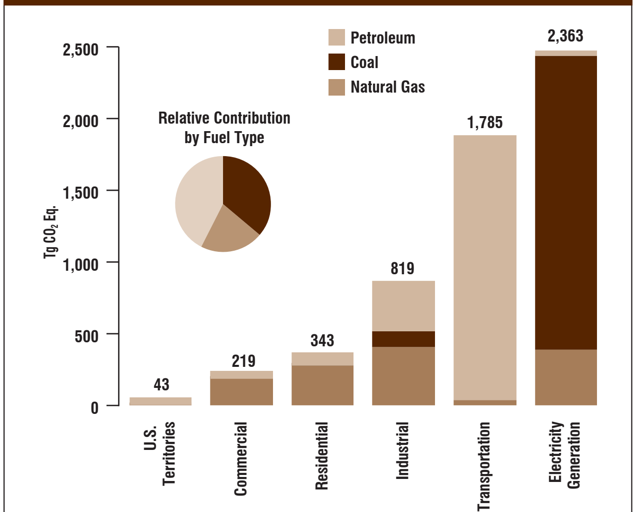
Transportation End-Use Sector. Transportation activities (excluding international bunker fuels) accounted for 32 percent of CO_2 emissions from fossil fuel combustion in 2008.[11] Virtually all of the energy consumed in this end-use sector came from petroleum products. Nearly 53 percent of the emissions resulted from gasoline consumption for personal vehicle use. The remaining emissions came from other transportation activities, including the combustion of diesel fuel in heavy-duty vehicles and jet fuel in aircraft.

Industrial End-Use Sector. Industrial CO_2 emissions, resulting both directly from the combustion of fossil fuels and indirectly from the generation of electricity that is consumed by industry, accounted for 27 percent of CO_2 from fossil fuel combustion in 2008. Approximately 54 percent of these emissions resulted from direct fossil fuel combustion to produce steam and/or heat for industrial processes. The remaining emissions resulted from consuming electricity for motors, electric furnaces, ovens, lighting, and other applications.

Residential and Commercial End-Use Sectors. The residential and commercial end-use sectors accounted for 21 and 19 percent, respectively, of CO_2 emissions from fossil fuel combustion in 2008. Both sectors relied heavily on electricity for meeting energy demands, with 71 and 79 percent, respectively, of their emissions attributable to electricity consumption for lighting, heating, cooling, and

Figure ES-6

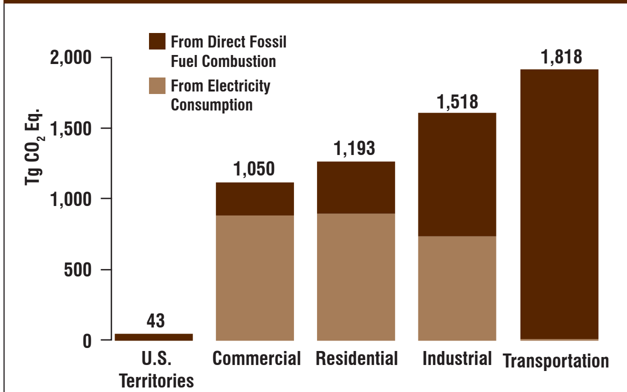
2008 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type



Note: Electricity generation also includes emissions of less than 0.5 Tg CO_2 Eq. from geothermal-based electricity generation.

Figure ES-7

2008 End-Use Sector Emissions of CO_2, CH_4, and N_2O from Fossil Fuel Combustion



[11] If emissions from international bunker fuels are included, the transportation end-use sector accounted for 35 percent of U.S. emissions from fossil fuel combustion in 2008.

Table ES-3: CO_2 Emissions from Fossil Fuel Combustion by Fuel Consuming End-Use Sector (Tg CO_2 Eq.)

End-Use Sector	1990	1995	2000	2005	2006	2007	2008
Transportation	**1,488.8**	**1,611.0**	**1,813.0**	**1,900.1**	**1,881.2**	**1,898.8**	**1,789.9**
Combustion	1,485.8	1,608.0	1,809.5	1,895.3	1,876.7	1,893.7	1,785.3
Electricity	3.0	3.1	3.4	4.7	4.5	5.0	4.7
Industrial	**1,532.2**	**1,578.8**	**1,642.0**	**1,562.5**	**1,562.8**	**1,572.2**	**1,510.9**
Combustion	845.4	862.6	852.2	825.6	850.7	842.2	819.3
Electricity	686.8	716.2	789.8	737.0	712.0	730.0	691.6
Residential	**932.2**	**995.1**	**1,133.6**	**1,215.1**	**1,152.9**	**1,197.9**	**1,184.5**
Combustion	339.1	353.3	371.2	358.4	322.1	341.7	342.7
Electricity	593.0	641.8	762.4	856.7	830.8	856.1	841.8
Commercial	**754.6**	**810.0**	**968.9**	**1,025.0**	**1,005.0**	**1,039.1**	**1,044.9**
Combustion	216.7	223.2	227.7	221.3	206.0	217.4	219.5
Electricity	538.0	586.8	741.3	803.7	799.0	821.7	825.4
U.S. Territories[a]	**27.9**	**34.5**	**35.9**	**50.6**	**50.9**	**49.1**	**42.5**
Total	**4,735.7**	**5,029.5**	**5,593.4**	**5,753.3**	**5,652.8**	**5,757.0**	**5,572.8**
Electricity Generation	**1,820.8**	**1,947.9**	**2,296.9**	**2,402.1**	**2,346.4**	**2,412.8**	**2,363.5**

Note: Totals may not sum due to independent rounding. Combustion-related emissions from electricity generation are allocated based on aggregate national electricity consumption by each end-use sector.
[a] Fuel consumption by U.S. territories (i.e., American Samoa, Guam, Puerto Rico, U.S. Virgin Islands, Wake Island, and other U.S. Pacific Islands) is included in this report.

operating appliances. The remaining emissions were due to the consumption of natural gas and petroleum for heating and cooking.

Electricity Generation. The United States relies on electricity to meet a significant portion of its energy demands, especially for lighting, electric motors, heating, and air conditioning. Electricity generators consumed 37 percent of U.S. energy from fossil fuels and emitted 42 percent of the CO_2 from fossil fuel combustion in 2008. The type of fuel combusted by electricity generators has a significant effect on their emissions. For example, some electricity is generated with low CO_2 emitting energy technologies, particularly non-fossil options such as nuclear, hydroelectric, or geothermal energy. However, electricity generators rely on coal for over half of their total energy requirements and accounted for 95 percent of all coal consumed for energy in the United States in 2008. Consequently, changes in electricity demand have a significant impact on coal consumption and associated CO_2 emissions.

Other significant CO_2 trends included the following:

- CO_2 emissions from non-energy use of fossil fuels have increased 14.6 Tg CO_2 Eq. (12.2 percent) from 1990 through 2008. Emissions from non-energy uses of fossil fuels were 134.2 Tg CO_2 Eq. in 2008, which constituted 2.3 percent of total national CO_2 emissions, approximately the same proportion as in 1990.
- CO_2 emissions from iron and steel production and metallurgical coke production decreased from 2007 to 2008 (3.8 Tg CO_2 Eq.), continuing a trend of decreasing emissions from 1990 through 2008 of 33 percent. This decline is due to the restructuring of the industry, technological improvements, and increased scrap utilization.
- In 2008, CO_2 emissions from cement production decreased by 4.1 Tg CO_2 Eq. (9.0 percent) from 2007. After decreasing in 1991 by two percent from 1990 levels, cement production emissions grew every year through 2006; emissions decreased in the last two years. Overall, from 1990 to 2008, emissions from cement production increased by 24 percent, an increase of 7.9 Tg CO_2 Eq.
- Net CO_2 flux from Land Use, Land-Use Change, and Forestry increased by 30.9 Tg CO_2 Eq. (3 percent) from 1990 through 2008. This increase was primarily due to an increase in the rate of net carbon accumulation in forest carbon stocks, particularly in aboveground and belowground tree biomass, and harvested wood pools. Annual carbon accumulation in landfilled yard trimmings and food scraps slowed over this period, while the rate of carbon accumulation in urban trees increased.

Methane Emissions

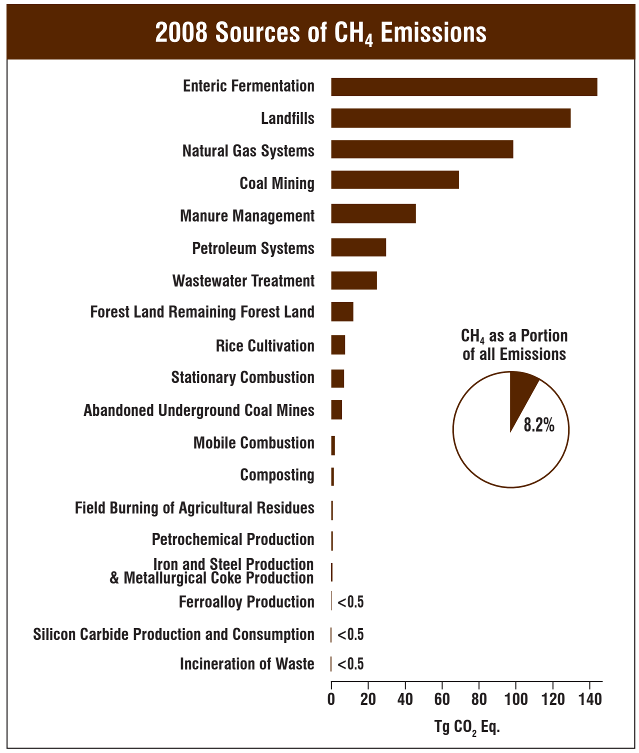
According to the IPCC, CH_4 is more than 20 times as effective as CO_2 at trapping heat in the atmosphere. Over the last two hundred and fifty years, the concentration of CH_4 in the atmosphere increased by 148 percent (IPCC 2007). Anthropogenic sources of CH_4 include landfills, natural gas and petroleum systems, agricultural activities, coal mining, wastewater treatment, stationary and mobile combustion, and certain industrial processes (see Figure ES- 8).

Some significant trends in U.S. emissions of CH_4 include the following:

- Enteric Fermentation is the largest anthropogenic source of CH_4 emissions in the United States. In 2008, enteric fermentation CH_4 emissions were 140.8 Tg CO_2 Eq. (25 percent of total CH_4 emissions), which represents an increase of 8.5 Tg CO_2 Eq. (6.4 percent) since 1990.
- Landfills are the second largest anthropogenic source of CH_4 emissions in the United States, accounting for 22 percent of total CH_4 emissions (126.3 Tg CO_2 Eq.) in 2008. From 1990 to 2008, net CH_4 emissions from landfills decreased by 23.0 Tg CO_2 Eq. (15 percent), with small increases occurring in some interim years. This downward trend in overall emissions is the result of increases in the amount of landfill gas collected and combusted,[12] which has more than offset the additional CH_4 emissions resulting from an increase in the amount of municipal solid waste landfilled.
- CH_4 emissions from natural gas systems were 96.4 Tg CO_2 Eq. in 2008; emissions have declined by 33.1 Tg CO_2 Eq. (26 percent) since 1990. This decline is due to improvements in technology and management practices, as well as some replacement of old equipment.
- In 2008, CH_4 emissions from coal mining were 67.6 Tg CO_2 Eq., a 9.6 Tg CO_2 Eq. (16 percent) increase over 2007 emission levels. The overall decline of 16.4 Tg CO_2 Eq. (20 percent) from 1990 results from the mining of less gassy coal from underground mines and the increased use of CH_4 collected from degasification systems.
- CH_4 emissions from manure management increased by 54 percent since 1990, from 29.3 Tg CO_2 Eq. in 1990 to 45.0 Tg CO_2 Eq. in 2008. The majority of this increase was from swine and dairy cow manure, since the general trend in manure management is one of increasing use of liquid systems, which tends to produce greater CH_4 emissions. The increase in liquid systems is the combined result of a shift to larger facilities, and to facilities in the West and Southwest, all of which tend to use liquid systems. Also, new regulations limiting the application of manure nutrients have shifted manure management practices at smaller dairies from daily spread to manure managed and stored on site.

[12] The CO_2 produced from combusted landfill CH_4 at landfills is not counted in national inventories as it is considered part of the natural C cycle of decomposition.

Figure ES-8



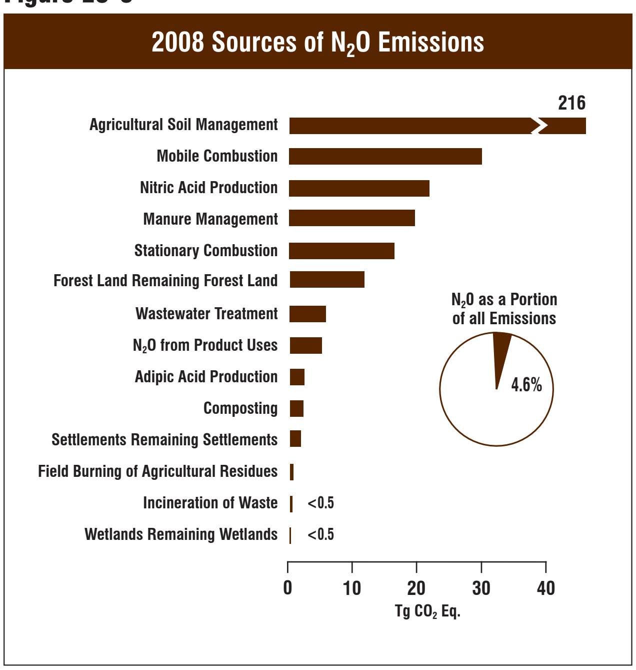
Nitrous Oxide Emissions

N_2O is produced by biological processes that occur in soil and water and by a variety of anthropogenic activities in the agricultural, energy-related, industrial, and waste management fields. While total N_2O emissions are much lower than CO_2 emissions, N_2O is approximately 300 times more powerful than CO_2 at trapping heat in the atmosphere. Since 1750, the global atmospheric concentration of N_2O has risen by approximately 18 percent (IPCC 2007). The main anthropogenic activities producing N_2O in the United States are agricultural soil management, fuel combustion in motor vehicles, nitric acid production, stationary fuel combustion, manure management, and adipic acid production (see Figure ES-9).

Some significant trends in U.S. emissions of N_2O include the following:

- Agricultural soils accounted for approximately 68 percent of N_2O emissions in the United States in 2008. Estimated emissions from this source in 2008 were 215.9 Tg CO_2 Eq. Annual N_2O emissions from agricultural soils fluctuated between 1990 and 2008, although overall emissions were 6.1 percent higher in 2008 than in 1990. N_2O emissions from this source have not shown any significant long-term trend, as they are highly sensitive to the amount of N applied to soils (which has not changed significantly over the time-period), and to weather patterns and crop type.
- In 2008, N_2O emissions from mobile combustion were 26.1 Tg CO_2 Eq. (approximately 8 percent of U.S. N_2O emissions). From 1990 to 2008, N_2O emissions from mobile combustion decreased by 40 percent. However, from 1990 to 1998 emissions increased by 26 percent, due to control technologies that reduced NO_x emissions while increasing N_2O emissions. Since 1998, newer control technologies have led to a steady decline in N_2O from this source.

Figure ES-9



- N_2O emissions from adipic acid production were 2.0 Tg CO_2 Eq. in 2008, and have decreased significantly since 1996 from the widespread installation of pollution control measures. Emissions from adipic acid production have decreased by 87 percent since 1990, and emissions from adipic acid production have remained consistently lower than pre-1996 levels since 1998.

HFC, PFC, and SF_6 Emissions

HFCs and PFCs are families of synthetic chemicals that are used as alternatives to ODS, which are being phased out under the Montreal Protocol and Clean Air Act Amendments of 1990. HFCs and PFCs do not deplete the stratospheric ozone layer, and are therefore acceptable alternatives under the Montreal Protocol.

These compounds, however, along with SF_6, are potent greenhouse gases. In addition to having high global warming potentials, SF_6 and PFCs have extremely long atmospheric lifetimes, resulting in their essentially irreversible accumulation in the atmosphere once emitted. Sulfur hexafluoride is the most potent greenhouse gas the IPCC has evaluated.

Other emissive sources of these gases include HCFC-22 production, electrical transmission and distribution systems, semiconductor manufacturing, aluminum production, and magnesium production and processing (see Figure ES-10).

Some significant trends in U.S. HFC, PFC, and SF_6 emissions include the following:

- Emissions resulting from the substitution of ODS (e.g., CFCs) have been consistently increasing, from small amounts in 1990 to 113.0 Tg CO_2 Eq. in 2008. Emissions from ODS substitutes are both the largest and the fastest growing source of HFC, PFC, and SF_6 emissions. These emissions have been increasing as phase-outs required under the Montreal Protocol come into effect, especially after 1994, when full market penetration was made for the first generation of new technologies featuring ODS substitutes.
- HFC emissions from the production of HCFC-22 decreased by 63 percent (22.8 Tg CO_2 Eq.) from 1990 through 2008, due to a steady decline in the emission rate of HFC-23 (i.e., the amount of HFC-23 emitted per kilogram of HCFC-22 manufactured) and the use

Figure ES-10

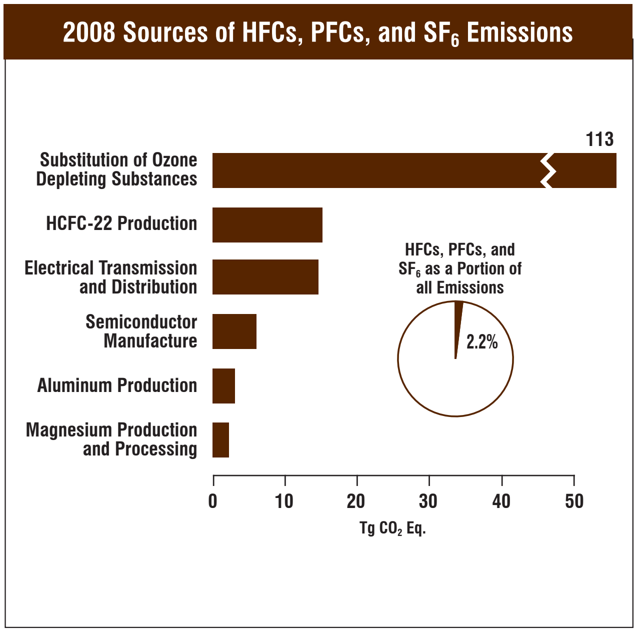
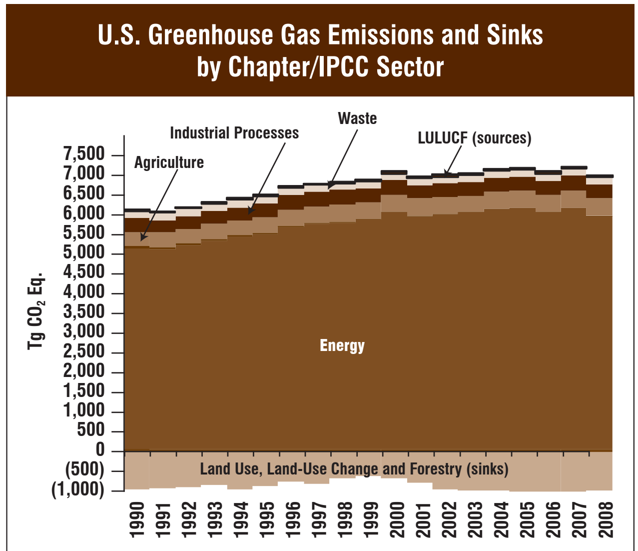


Figure ES-11



Note: Relatively smaller amounts of GWP-weighted emissions are also emitted from the Solvent and Other Product Use Sector.

of thermal oxidation at some plants to reduce HFC-23 emissions.

- SF_6 emissions from electric power transmission and distribution systems decreased by 51 percent (13.6 Tg CO_2 Eq.) from 1990 to 2008, primarily because of higher purchase prices for SF_6 and efforts by industry to reduce emissions.
- PFC emissions from aluminum production decreased by 85 percent (15.8 Tg CO_2 Eq.) from 1990 to 2008, due to both industry emission reduction efforts and lower domestic aluminum production.

ES.3. Overview of Sector Emissions and Trends

In accordance with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997), and the 2003 *UNFCCC Guidelines on Reporting and Review* (UNFCCC 2003), Figure ES-11 and Table ES-4 aggregate emissions and sinks by these chapters. Emissions of all gases can be summed from each source category from IPCC guidance. Over the nineteen-year period of 1990 to 2008, total emissions in the Energy, Industrial Processes, and Agriculture sectors climbed by 775.0 Tg CO_2

Table ES-4: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (Tg CO_2 Eq.)

Chapter/IPCC Sector	1990	1995	2000	2005	2006	2007	2008
Energy	5,224.1	5,545.8	6,087.5	6,187.9	6,089.1	6,182.9	5,999.0
Industrial Processes	318.3	339.1	351.9	334.7	339.7	350.9	334.5
Solvent and Other Product Use	4.4	4.6	4.9	4.4	4.4	4.4	4.4
Agriculture	387.8	407.7	410.9	419.7	417.2	423.0	427.5
Land Use, Land-Use Change, and Forestry (Emissions)	15.0	17.2	36.3	28.6	49.8	47.6	32.2
Waste	177.2	174.5	153.0	158.0	159.7	159.3	159.1
Total Emissions	**6,126.8**	**6,488.8**	**7,044.5**	**7,133.2**	**7,059.9**	**7,168.1**	**6,956.8**
Net CO_2 Flux from Land Use, Land-Use Change, and Forestry (Sinks)[a]	(909.4)	(842.9)	(664.2)	(950.4)	(959.2)	(955.4)	(940.3)
Net Emissions (Sources and Sinks)	**5,217.3**	**5,646.0**	**6,380.2**	**6,182.8**	**6,100.7**	**6,212.7**	**6,016.4**

[a] The net CO_2 flux total includes both emissions and sequestration, and constitutes a sink in the United States. Sinks are only included in net emissions total.
Note: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

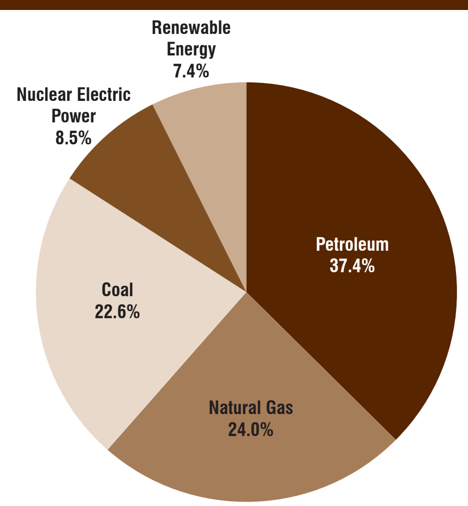
Eq. (15 percent), 16.2 Tg CO_2 Eq. (5 percent), and 39.7 Tg CO_2 Eq. (10 percent), respectively. Emissions decreased in the Waste and Solvent and Other Product Use sectors by 18.1 Tg CO_2 Eq. (10 percent) and less than 0.1 Tg CO_2 Eq. (0.4 percent), respectively. Over the same period, estimates of net C sequestration in the Land Use, Land-Use Change, and Forestry sector (magnitude of emissions plus CO_2 flux from all LULUCF source categories) increased by 13.7 Tg CO_2 Eq. (1.5 percent).

Energy

The Energy chapter contains emissions of all greenhouse gases resulting from stationary and mobile energy activities including fuel combustion and fugitive fuel emissions. Energy-related activities, primarily fossil fuel combustion, accounted for the vast majority of U.S. CO_2 emissions for the period of 1990 through 2008. In 2008, approximately 84 percent of the energy consumed in the United States (on a Btu basis) was produced through the combustion of fossil fuels. The remaining 16 percent came from other energy sources such as hydropower, biomass, nuclear, wind, and solar energy (see Figure ES-12). Energy-related activities are also responsible for CH_4 and N_2O emissions (37 percent and 13 percent of total U.S. emissions of each gas, respectively). Overall, emission sources in the Energy chapter account for a combined 86 percent of total U.S. greenhouse gas emissions in 2008.

Figure ES-12

2008 U.S. Energy Consumption by Energy Source



Industrial Processes

The Industrial Processes chapter contains byproduct or fugitive emissions of greenhouse gases from industrial processes not directly related to energy activities such as fossil fuel combustion. For example, industrial processes can chemically transform raw materials, which often release waste gases such as CO_2, CH_4, and N_2O. These processes include iron and steel production and metallurgical coke production, cement production, ammonia production and urea consumption, lime production, limestone and dolomite use (e.g., flux stone, flue gas desulfurization, and glass manufacturing), soda ash production and consumption, titanium dioxide production, phosphoric acid production, ferroalloy production, CO_2 consumption, silicon carbide production and consumption, aluminum production, petrochemical production, nitric acid production, adipic acid production, lead production, and zinc production. Additionally, emissions from industrial processes release HFCs, PFCs, and SF_6. Overall, emission sources in the Industrial Process chapter account for 5 percent of U.S. greenhouse gas emissions in 2008.

Solvent and Other Product Use

The Solvent and Other Product Use chapter contains greenhouse gas emissions that are produced as a by-product of various solvent and other product uses. In the United States, emissions from N_2O from product uses, the only source of greenhouse gas emissions from this sector, accounted for about 0.1 percent of total U.S. anthropogenic greenhouse gas emissions on a carbon equivalent basis in 2008.

Agriculture

The Agriculture chapter contains anthropogenic emissions from agricultural activities (except fuel combustion, which is addressed in the Energy chapter, and agricultural CO_2 fluxes, which are addressed in the Land Use, Land-Use Change, and Forestry Chapter). Agricultural activities contribute directly to emissions of greenhouse gases through a variety of processes, including the following source categories: enteric fermentation in domestic livestock, livestock manure management, rice cultivation, agricultural soil management, and field burning of agricultural residues. CH_4 and N_2O were the primary greenhouse gases emitted by agricultural activities. CH_4 emissions from enteric fermentation and manure management represented 25 percent and 8 percent of total CH_4 emissions from anthropogenic activities, respectively, in 2008. Agricultural soil management activities such as fertilizer application and other cropping practices were the largest source of U.S. N_2O emissions in 2008, accounting for 68 percent. In 2008, emission sources accounted for in the Agriculture chapter were responsible for 6.1 percent of total U.S. greenhouse gas emissions.

Land Use, Land-Use Change, and Forestry

The Land Use, Land-Use Change, and Forestry chapter contains emissions of CH_4 and N_2O, and emissions and removals of CO_2 from forest management, other land-use activities, and land-use change. Forest management practices, tree planting in urban areas, the management of agricultural soils, and the landfilling of yard trimmings and food scraps have resulted in a net uptake (sequestration) of C in the United States. Forests (including vegetation, soils, and harvested wood) accounted for 84 percent of total 2008 net CO_2 flux, urban trees accounted for 10 percent, mineral and organic soil carbon stock changes accounted for 5 percent, and landfilled yard trimmings and food scraps accounted for 1 percent of the total net flux in 2008. The net forest sequestration is a result of net forest growth and increasing forest area, as well as a net accumulation of carbon stocks in harvested wood pools. The net sequestration in urban forests is a result of net tree growth in these areas. In agricultural soils, mineral and organic soils sequester approximately 5.9 times as much C as is emitted from these soils through liming and urea fertilization. The mineral soil C sequestration is largely due to the conversion of cropland to permanent pastures and hay production, a reduction in summer fallow areas in semi-arid areas, an increase in the adoption of conservation tillage practices, and an increase in the amounts of organic fertilizers (i.e., manure and sewage sludge) applied to agriculture lands. The landfilled yard trimmings and food scraps net sequestration is due to the long-term accumulation of yard trimming carbon and food scraps in landfills.

Land use, land-use change, and forestry activities in 2008 resulted in a net C sequestration of 940.3 Tg CO_2 Eq. (Table ES- 5). This represents an offset of 16 percent of total U.S. CO_2 emissions, or 14 percent of total greenhouse gas emissions in 2008. Between 1990 and 2008, total land use, land-use change, and forestry net C flux resulted in a 3.4 percent increase in CO_2 sequestration, primarily due to an increase in the rate of net C accumulation in forest C stocks, particularly in aboveground and belowground tree biomass, and harvested wood pools. Annual C accumulation in landfilled yard trimmings and food scraps slowed over this period, while the rate of annual C accumulation increased in urban trees.

Table ES- 5: Net CO_2 Flux from Land Use, Land-Use Change, and Forestry (Tg CO_2 Eq.)

Sink Category	1990	1995	2005	2005	2006	2007	2008
Forest Land Remaining Forest Land	(729.8)	(692.6)	(467.7)	(806.6)	(812.5)	(806.9)	(791.9)
Cropland Remaining Cropland	(29.4)	(22.9)	(30.2)	(18.3)	(19.1)	(19.7)	(18.1)
Land Converted to Cropland	2.2	2.9	(2.4)	5.9	5.9	5.9	5.9
Grassland Remaining Grassland	(52.0)	(26.7)	(52.6)	(9.0)	(8.9)	(8.8)	(8.7)
Land Converted to Grassland	(19.8)	(22.3)	(27.3)	(24.6)	(24.5)	(24.3)	(24.2)
Settlements Remaining Settlements	(57.1)	(67.3)	(77.5)	(87.8)	(89.8)	(91.9)	(93.9)
Other (Landfilled Yard Trimmings and Food Scraps)	(23.5)	(13.9)	(11.3)	(10.1)	(10.3)	(9.8)	(9.5)
Total	**(909.4)**	**(842.9)**	**(664.2)**	**(950.4)**	**(959.2)**	**(955.4)**	**(940.3)**

Note: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table ES-6. Emissions from Land Use, Land-Use Change, and Forestry (Tg CO_2 Eq.)

Source Category	1990	1995	2000	2005	2006	2007	2008
CO_2	**8.1**	**8.1**	**8.8**	**8.9**	**8.8**	**9.3**	**8.6**
Cropland Remaining Cropland: Liming of Agricultural Soils	4.7	4.4	4.3	4.3	4.2	4.5	3.8
Urea Fertilization	2.4	2.7	3.2	3.5	3.7	3.8	3.8
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	1.0	1.0	1.2	1.1	0.9	1.0	0.9
CH_4	**3.2**	**4.3**	**14.3**	**9.8**	**21.6**	**20.0**	**11.9**
Forest Land Remaining Forest Land: Forest Fires	3.2	4.3	14.3	9.8	21.6	20.0	11.9
N_2O	**3.7**	**4.9**	**13.2**	**9.8**	**19.5**	**18.3**	**11.7**
Forest Land Remaining Forest Land: Forest Fires	2.6	3.5	11.7	8.0	17.6	16.3	9.7
Forest Land Remaining Forest Land: Forest Soils	0.1	0.2	0.4	0.4	0.4	0.4	0.4
Settlements Remaining Settlements: Settlement Soils	1.0	1.2	1.1	1.5	1.5	1.6	1.6
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
Total	**15.0**	**17.2**	**36.3**	**28.6**	**49.8**	**47.6**	**32.2**

+ Less than 0.05 Tg CO_2 Eq.
Note: Totals may not sum due to independent rounding.

Emissions from Land Use, Land-Use Change, and Forestry are shown in Table ES-6. The application of crushed limestone and dolomite to managed land (i.e., liming of agricultural soils) and urea fertilization resulted in CO_2 emissions of 7.6 Tg CO_2 Eq. in 2008, an increase of 8 percent relative to 1990. The application of synthetic fertilizers to forest and settlement soils in 2008 resulted in direct N_2O emissions of 1.9 Tg CO_2 Eq. Direct N_2O emissions from fertilizer application to forest soils have increased by 422 percent since 1990, but still account for a relatively small portion of overall emissions. Additionally, direct N_2O emissions from fertilizer application to settlement soils increased of 62 percent since 1990. Non-CO_2 emissions from forest fires in 2008 resulted in CH_4 emissions of 11.9 Tg CO_2 Eq., and in N_2O emissions of 9.7 Tg CO_2 Eq. CO_2 and N_2O emissions from peatlands totaled 0.9 Tg CO_2 Eq. and less than 0.01 Tg CO_2 Eq. in 2008, respectively.

Waste

The Waste chapter contains emissions from waste management activities (except incineration of waste, which is addressed in the Energy chapter). Landfills were the largest source of anthropogenic greenhouse gas emissions in the Waste chapter, accounting for just over 79 percent of this chapter's emissions, and 22 percent of total U.S. CH_4 emissions.[13] Additionally, wastewater treatment accounts for 18 percent of Waste emissions, 4 percent of U.S. CH_4 emissions, and 2 percent of U.S. N_2O emissions. Emissions of CH_4 and N_2O from composting are also accounted for in this chapter; generating emissions of 1.7 Tg CO_2 Eq. and 1.8 Tg CO_2 Eq., respectively. Overall, emission sources accounted for in the Waste chapter generated 2.3 percent of total U.S. greenhouse gas emissions in 2008.

[13] Landfills also store carbon, due to incomplete degradation of organic materials such as wood products and yard trimmings, as described in the Land-Use, Land-Use Change, and Forestry chapter of the Inventory report.

ES.4. Other Information

Emissions by Economic Sector

Throughout the Inventory of U.S. Greenhouse Gas Emissions and Sinks report, emission estimates are grouped into six sectors (i.e., chapters) defined by the IPCC: Energy; Industrial Processes; Solvent Use; Agriculture; Land Use, Land-Use Change, and Forestry; and Waste. While it is important to use this characterization for consistency with UNFCCC reporting guidelines, it is also useful to allocate emissions into more commonly used sectoral categories. This section reports emissions by the following economic sectors: Residential, Commercial, Industry, Transportation, Electricity Generation, Agriculture, and U.S. Territories.

Table ES-7 summarizes emissions from each of these sectors, and Figure ES-13 shows the trend in emissions by sector from 1990 to 2008.

Table ES-7: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (Tg CO_2 Eq.)

Implied Sectors	1990	1995	2000	2005	2006	2007	2008
Electric Power Industry	1,867.2	1,993.7	2,336.8	2,443.5	2,387.5	2,454.0	2,404.2
Transportation	1,545.0	1,695.2	1,932.3	2,016.1	1,993.0	2,003.5	1,886.1
Industry	1,506.6	1,531.3	1,469.1	1,350.9	1,380.2	1,374.2	1,342.4
Agriculture	433.2	460.8	485.3	494.1	515.1	518.0	504.1
Commercial	395.1	399.6	387.3	399.0	389.2	404.4	410.9
Residential	345.9	367.6	386.7	370.7	334.9	356.2	359.3
U.S. Territories	33.7	40.7	46.9	58.9	60.0	57.8	49.9
Total Emissions	**6,126.8**	**6,488.8**	**7,044.5**	**7,133.2**	**7,059.9**	**7,168.1**	**6,956.8**
Land Use, Land-Use Change, and Forestry (Sinks)	(909.4)	(842.9)	(664.2)	(950.4)	(959.2)	(955.4)	(940.3)
Net Emissions (Sources and Sinks)	**5,217.3**	**5,646.0**	**6,380.2**	**6,182.8**	**6,100.7**	**6,212.7**	**6,016.4**

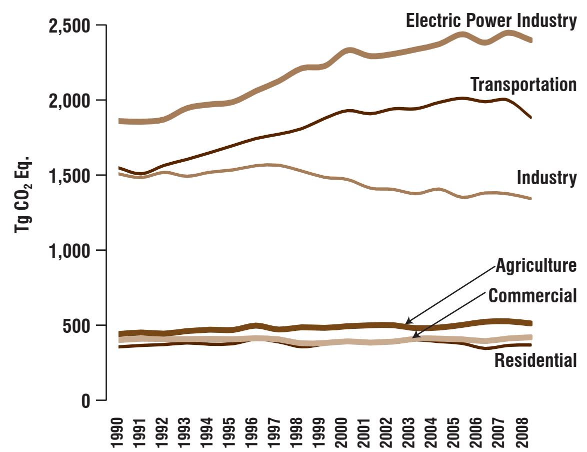
Note: Totals may not sum due to independent rounding. Emissions include CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6.
See Table 2-12 of the Inventory report for more detailed data.

Using this categorization, emissions from electricity generation accounted for the largest portion (35 percent) of U.S. greenhouse gas emissions in 2008. Transportation activities, in aggregate, accounted for the second largest portion (27 percent), while emissions from industry accounted for the third largest portion (19 percent) of U.S. greenhouse gas emissions in 2008. In contrast to electricity generation and transportation, emissions from industry have in general declined over the past decade. The long-term decline in these emissions has been due to structural changes in the U.S. economy (i.e., shifts from a manufacturing-based to a service-based economy), fuel switching, and energy efficiency improvements. The remaining 19 percent of U.S. greenhouse gas emissions were contributed by, in order of importance, the agriculture, commercial, and residential sectors, plus emissions from U.S. territories. Activities related to agriculture accounted for 7 percent of U.S. emissions; unlike other economic sectors, agricultural sector emissions were dominated by N_2O emissions from agricultural soil management and CH_4 emissions from enteric fermentation. The commercial sector accounted for 6 percent of emissions while the residential sector accounted for 5 percent of emissions and U.S. territories accounted for 1 percent of emissions; emissions from these sectors primarily consisted of CO_2 emissions from fossil fuel combustion.

CO_2 was also emitted and sequestered by a variety of activities related to forest management practices, tree planting in urban areas, the management of agricultural soils, and landfilling of yard trimmings.

Figure ES-13

Emissions Allocated to Economic Sectors



Note: Does not include U.S. Territories.

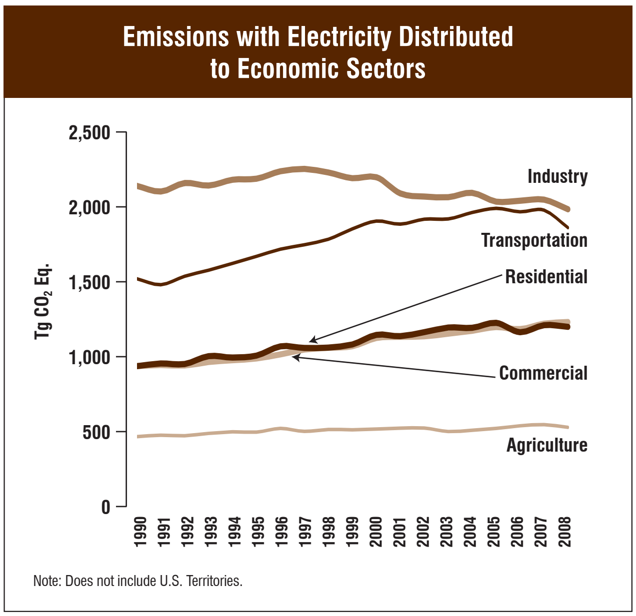
Electricity is ultimately consumed in the economic sectors described above. Table ES-8 presents greenhouse gas emissions from economic sectors with emissions related to electricity generation distributed into end-use categories (i.e., emissions from electricity generation are allocated to the economic sectors in which the electricity is consumed). To distribute electricity emissions among end-use sectors, emissions from the source categories assigned to electricity generation were allocated to the residential, commercial,

Table ES-8: U.S Greenhouse Gas Emissions by Economic Sector with Electricity-Related Emissions Distributed (Tg CO_2 Eq.)

Implied Sectors	1990	1995	2000	2005	2006	2007	2008
Industry	2,179.8	2,228.0	2,239.2	2,071.1	2,077.3	2,084.2	2,018.4
Transportation	1,548.2	1,698.3	1,935.8	2,020.9	1,997.6	2,008.6	1,890.8
Commercial	946.8	1,000.2	1,141.5	1,216.5	1,202.2	1,240.1	1,250.6
Residential	954.0	1,024.5	1,162.4	1,242.2	1,180.3	1,226.9	1,215.6
Agriculture	464.2	497.1	518.7	523.5	542.5	550.5	531.6
U.S. Territories	33.7	40.7	46.9	58.9	60.0	57.8	49.9
Total Emissions	**6,126.8**	**6,488.8**	**7,044.5**	**7,133.2**	**7,059.9**	**7,168.1**	**6,956.8**
Land Use, Land-Use Change, and Forestry (Sinks)	(909.4)	(842.9)	(664.2)	(950.4)	(959.2)	(955.4)	(940.3)
Net Emissions (Sources and Sinks)	**5,217.3**	**5,646.0**	**6,380.2**	**6,182.8**	**6,100.7**	**6,212.7**	**6,016.4**

See Table 2-14 of the Inventory report for more detailed data.

Figure ES-14



industry, transportation, and agriculture economic sectors according to retail sales of electricity.[14] These source categories include CO_2 from fossil fuel combustion and the use of limestone and dolomite for flue gas desulfurization, CO_2 and N_2O from incineration of waste, CH_4 and N_2O from stationary sources, and SF_6 from electrical transmission and distribution systems.

When emissions from electricity are distributed among these sectors, industry accounts for the largest share of U.S. greenhouse gas emissions (29 percent) in 2008. Emissions from the residential and commercial sectors also increase substantially when emissions from electricity are included, due to their relatively large share of electricity consumption (e.g., lighting, appliances, etc.). Transportation activities remain the second largest contributor to total U.S. emissions (27 percent) despite the considerable decline in emissions from this sector during the past year. In all sectors except agriculture, CO_2 accounts for more than 80 percent of greenhouse gas emissions, primarily from the combustion of fossil fuels. Figure ES-14 shows the trend in these emissions by sector from 1990 to 2008.

Indirect Greenhouse Gases (CO, NO_x, NMVOCs, and SO_2)

The reporting requirements of the UNFCCC[15] request that information be provided on indirect greenhouse gases, which include CO, NO_x, NMVOCs, and SO_2. These gases do not have a direct global warming effect, but indirectly affect terrestrial radiation absorption by influencing the formation and destruction of tropospheric and stratospheric ozone, or, in the case of SO_2, by affecting the absorptive characteristics of the atmosphere. Additionally, some of these gases may react with other chemical compounds in the atmosphere to form compounds that are greenhouse gases.

Since 1970, the United States has published estimates of annual emissions of CO, NO_x, NMVOCs, and SO_2 (EPA

[14] Emissions were not distributed to U.S. territories, since the electricity generation sector only includes emissions related to the generation of electricity in the 50 states and the District of Columbia.

[15] See <http://unfccc.int/resource/docs/cop8/08.pdf>.

Box ES-2: Recent Trends in Various U.S. Greenhouse Gas Emissions-Related Data

Total emissions can be compared to other economic and social indices to highlight changes over time. These comparisons include: (1) emissions per unit of aggregate energy consumption, because energy-related activities are the largest sources of emissions; (2) emissions per unit of fossil fuel consumption, because almost all energy-related emissions involve the combustion of fossil fuels; (3) emissions per unit of electricity consumption, because the electric power industry—utilities and nonutilities combined—was the largest source of U.S. greenhouse gas emissions in 2008; (4) emissions per unit of total gross domestic product as a measure of national economic activity; and (5) emissions per capita.

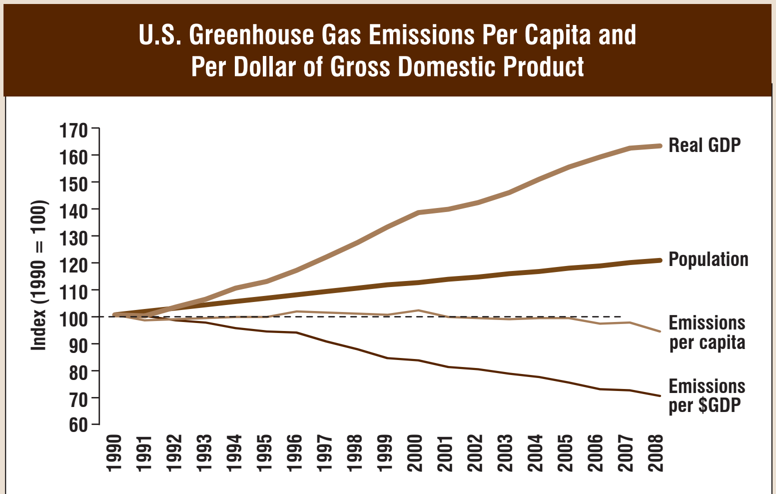
Table ES-9 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. Greenhouse gas emissions in the United States have grown at an average annual rate of 0.7 percent since 1990. This rate is slightly slower than that for total energy, approximately the same as for fossil fuel consumption, and much slower than that for either electricity consumption or overall gross domestic product. Total U.S. greenhouse gas emissions have also grown slightly slower than national population since 1990 (see Figure ES-15).

Table ES-9: Recent Trends in Various U.S. Data (Index 1990 = 100)

Variable	1990	1995	2000	2005	2006	2007	2008	Growth Rate[a]
GDP[b]	100	113	140	157	162	165	166	2.9%
Electricity Consumption[c]	100	112	127	134	135	138	136	1.8%
Fossil Fuel Consumption[c]	100	107	117	119	117	119	115	0.8%
Energy Consumption[c]	100	107	116	119	118	120	118	0.9%
Population[d]	100	107	113	118	119	120	121	1.1%
Greenhouse Gas Emissions[e]	100	106	115	116	115	117	114	0.7%

[a] Average annual growth rate
[b] Gross Domestic Product in chained 2000 dollars (BEA 2009)
[c] Energy content-weighted values (EIA 2009)
[d] U.S. Census Bureau (2009)
[e] GWP-weighted values

Figure ES-15



Source: BEA (2009), U.S. Census Bureau (2009), and emission estimates in the Inventory report.
Note: Does not include U.S. Territories.

Table ES-10: Emissions of NOx, CO, NMVOCs, and SO_2 (Gg)

Gas/Activity	1990	1995	2000	2005	2006	2007	2008
NO_x	**21,728**	**21,227**	**19,145**	**15,933**	**15,071**	**14,410**	**13,578**
Mobile Fossil Fuel Combustion	10,862	10,536	10,199	9,012	8,488	7,965	7,441
Stationary Fossil Fuel Combustion	10,023	9,862	8,053	5,858	5,545	5,432	5,148
Industrial Processes	591	607	626	569	553	537	520
Oil and Gas Activities	139	100	111	321	319	318	318
Incineration of Waste	82	88	114	129	121	114	106
Agricultural Burning	30	30	37	40	40	38	40
Solvent Use	1	3	3	3	4	4	4
Waste	0	1	2	2	2	2	2
CO	**130,536**	**109,114**	**92,872**	**71,555**	**67,909**	**64,348**	**60,739**
Mobile Fossil Fuel Combustion	119,360	97,630	83,559	62,692	58,972	55,253	51,533
Stationary Fossil Fuel Combustion	5,000	5,383	4,340	4,649	4,695	4,744	4,792
Industrial Processes	4,125	3,959	2,126	1,555	1,597	1,640	1,682
Incineration of Waste	978	1,073	1,670	1,403	1,412	1,421	1,430
Agricultural Burning	766	745	888	930	905	960	970
Oil and Gas Activities	302	316	146	318	319	320	322
Waste	1	2	8	7	7	7	7
Solvent Use	5	5	45	2	2	2	2
NMVOCs	**20,930**	**19,520**	**15,227**	**13,761**	**13,594**	**13,423**	**13,254**
Mobile Fossil Fuel Combustion	10,932	8,745	7,229	6,330	6,037	5,742	5,447
Solvent Use	5,216	5,609	4,384	3,851	3,846	3,839	3,834
Industrial Processes	2,422	2,642	1,773	1,997	1,933	1,869	1,804
Stationary Fossil Fuel Combustion	912	973	1,077	716	918	1,120	1,321
Oil and Gas Activities	554	582	388	510	510	509	509
Incineration of Waste	222	237	257	241	238	234	230
Waste	673	731	119	114	113	111	109
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA
SO_2	**20,935**	**16,891**	**14,830**	**13,466**	**12,388**	**11,799**	**10,368**
Stationary Fossil Fuel Combustion	18,407	14,724	12,849	11,541	10,612	10,172	8,891
Industrial Processes	1,307	1,117	1,031	831	818	807	795
Mobile Fossil Fuel Combustion	793	672	632	889	750	611	472
Oil and Gas Activities	390	335	287	181	182	184	187
Incineration of Waste	38	42	29	24	24	24	23
Waste	0	1	1	1	1	1	1
Solvent Use	0	1	1	0	0	0	0
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA

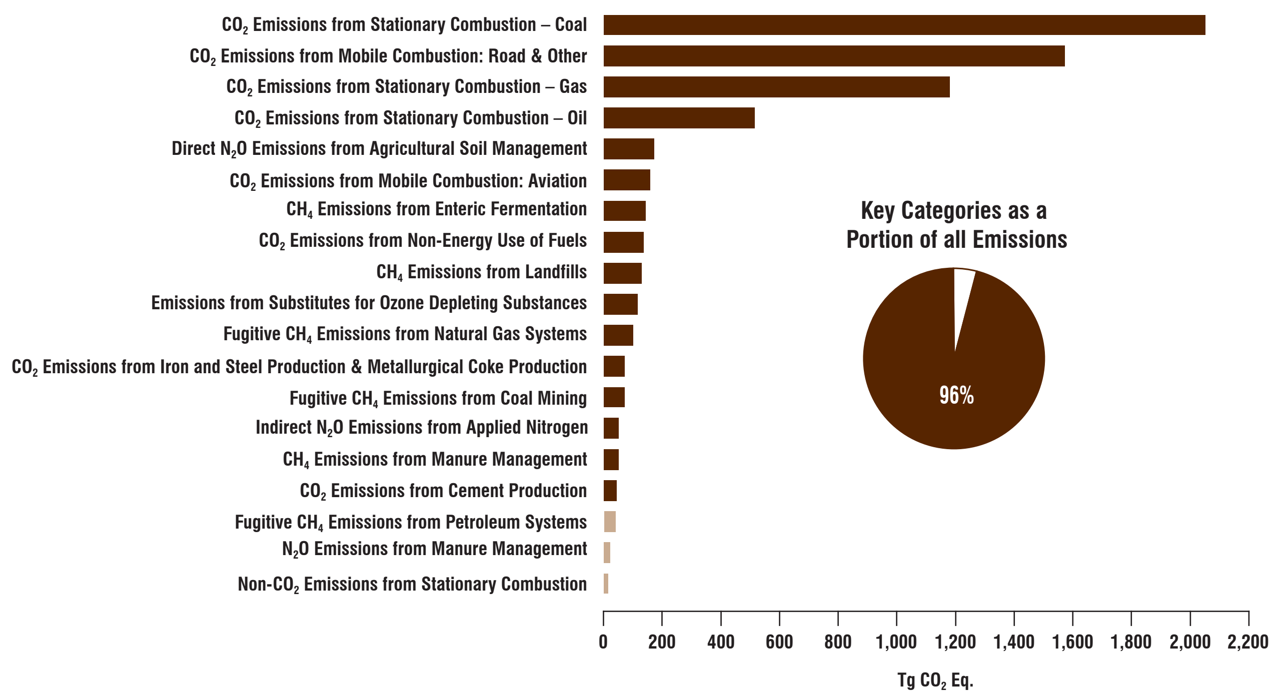
Source: EPA (2009), disaggregated based on EPA (2003) except for estimates from field burning of agricultural residues.
NA (Not Available)
Note: Totals may not sum due to independent rounding.

2008),[16] which are regulated under the Clean Air Act. Table ES- 10 shows that fuel combustion accounts for the majority of emissions of these indirect greenhouse gases. Industrial processes—such as the manufacture of chemical and allied products, metals processing, and industrial uses of solvents—are also significant sources of CO, NO_x, and NMVOCs.

[16] NO_x and CO emission estimates from field burning of agricultural residues were estimated separately, and therefore not taken from EPA (2008).

Figure ES-16

2008 Key Categories



Note: For a complete discussion of the key category analysis, see Annex 1 of the Inventory report. Darker bars indicate a Tier 1 level assessment key category. Lighter bars indicate a Tier 2 level assessment key category.

Key Categories

The *IPCC's Good Practice Guidance* (IPCC 2000) defines a key category as a "[source or sink category] that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both."[17] By definition, key categories are sources or sinks that have the greatest contribution to the absolute overall level of national emissions in any of the years covered by the time series. In addition, when an entire time series of emission estimates is prepared, a thorough investigation of key categories must also account for the influence of trends of individual source and sink categories. Finally, a qualitative evaluation of key categories should be performed, in order to capture any key categories that were not identified in either of the quantitative analyses.

Figure ES-16 presents 2008 emission estimates for the key categories as defined by a level analysis (i.e., the contribution of each source or sink category to the total inventory level). The UNFCCC reporting guidelines request that key category analyses be reported at an appropriate level of disaggregation, which may lead to source and sink category names which differ from those used elsewhere in the inventory report. For more information regarding key categories, see section 1.5 and Annex 1 of the inventory report.

Quality Assurance and Quality Control (QA/QC)

The United States seeks to continually improve the quality, transparency, and credibility of the Inventory of U.S. Greenhouse Gas Emissions and Sinks. To assist in these efforts, the United States implemented a systematic approach to QA/QC. While QA/QC has always been an integral part

[17] See Chapter 7 "Methodological Choice and Recalculation" in IPCC (2000). <http://www.ipcc-nggip.iges.or.jp/public/gp/gpgaum.htm>

of the U.S. national system for inventory development, the procedures followed for the current inventory have been formalized in accordance with the QA/QC plan and the UNFCCC reporting guidelines.

Uncertainty Analysis of Emission Estimates

While the current U.S. emissions inventory provides a solid foundation for the development of a more detailed and comprehensive national inventory, there are uncertainties associated with the emission estimates. Some of the current estimates, such as those for CO_2 emissions from energy-related activities and cement processing, are considered to have low uncertainties. For some other categories of emissions, however, a lack of data or an incomplete understanding of how emissions are generated increases the uncertainty associated with the estimates presented. Acquiring a better understanding of the uncertainty associated with inventory estimates is an important step in helping to prioritize future work and improve the overall quality of the Inventory report. Recognizing the benefit of conducting an uncertainty analysis, the UNFCCC reporting guidelines follow the recommendations of the *IPCC Good Practice Guidance* (IPCC 2000) and require that countries provide single estimates of uncertainty for source and sink categories.

Currently, a qualitative discussion of uncertainty is presented for all source and sink categories. Within the discussion of each emission source, specific factors affecting the uncertainty surrounding the estimates are discussed. Most sources also contain a quantitative uncertainty assessment, in accordance with UNFCCC reporting guidelines.

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