



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



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For more information regarding climate change and greenhouse gas emissions, see the EPA web site at <<http://www.epa.gov/climatechange>>.

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Energy Consumption—Stationary and Mobile Combustion Sources

The photos on the front and back cover of this report depict the energy consuming sources responsible for the most greenhouse gas emissions, as calculated by the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008: stationary and mobile sources combusting fossil fuels. In 2008, these sources made up approximately 81 percent of gross U.S. greenhouse gas emissions. Despite their large contribution, both sources experienced a drop in emissions from 2007 to 2008. Carbon dioxide, methane, and nitrous oxide emissions from fossil fuel combustion at stationary sources decreased by 2.0 percent from 2007-2008 as a result of decreases in energy consumption. In 2008, electricity demand decreased in response to higher energy prices, and a cooler summer. In addition, higher gasoline prices led to a 5.9 percent decrease in overall emissions from the transportation sector, or mobile sources from 2007 to 2008.

**INVENTORY OF U.S. GREENHOUSE GAS
EMISSIONS AND SINKS:
1990–2008**

April 15, 2010

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Preface

The United States Environmental Protection Agency (EPA) prepares the official U.S. Inventory of Greenhouse Gas Emissions and Sinks to comply with existing commitments under the United Nations Framework Convention on Climate Change (UNFCCC). Under decision 3/CP.5 of the UNFCCC Conference of the Parties, national inventories for UNFCCC Annex I parties should be provided to the UNFCCC Secretariat each year by April 15.

In an effort to engage the public and researchers across the country, the EPA has instituted an annual public review and comment process for this document. The availability of the draft document is announced via Federal Register Notice and is posted on the EPA web site. Copies are also mailed upon request. The public comment period is generally limited to 30 days; however, comments received after the closure of the public comment period are accepted and considered for the next edition of this annual report.

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Executive Summary

An emissions inventory that identifies and quantifies a country's primary anthropogenic¹ 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.

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 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.

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>>.

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

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.

ES.1. Background Information

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and ozone (O₃). 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 (SF₆)—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-CH₄ volatile organic

compounds (NMVOCs). Aerosols, which are extremely small particles or liquid droplets, such as those produced by sulfur dioxide (SO₂) or elemental carbon emissions, can also affect the absorptive characteristics of the atmosphere.

Although the direct greenhouse gases CO₂, CH₄, and N₂O 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 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

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

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 CO₂, and therefore GWP-weighted emissions are measured in teragrams (or million metric tons) of CO₂ equivalent (Tg CO₂ Eq.).^{7,8} All gases in this Executive Summary are presented in units of Tg CO₂ 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 this report in both CO₂ 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 this report. The GWP values used in this report are listed in Table ES-1.

Global warming potentials are not provided for CO, NO_x, NMVOCs, SO₂, 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).

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 12/44^{ths} of carbon dioxide by weight.

⁸ One teragram is equal to 10¹² grams or one million metric tons.

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

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

Gas	GWP
CO ₂	1
CH ₄ *	21
N ₂ O	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 ₂ F ₆	9,200
C ₄ F ₁₀	7,000
C ₆ F ₁₄	7,400
SF ₆	23,900

Source: IPCC (1996).

* The CH₄ 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 CO₂ 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 CO₂ 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 CO₂ 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 led 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.

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 CO₂, representing approximately 85.1 percent of total greenhouse gas emissions. The largest source of CO₂, and of overall greenhouse gas emissions, was fossil fuel combustion. CH₄ 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 N₂O 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 SF₆ emissions.

Overall, from 1990 to 2008 total emissions of CO₂ increased by 820.4 Tg CO₂ Eq. (16.1 percent), while CH₄ and N₂O emissions decreased by 45.8 Tg CO₂ Eq. (7.5 percent) and 4.1 Tg CO₂ Eq. (1.3 percent), respectively. During the same period, aggregate weighted emissions of HFCs, PFCs, and SF₆ rose by 59.4 Tg CO₂ Eq. (65.9 percent). From 1990 to 2008, HFCs increased by 90.0 Tg CO₂ Eq. (243.7 percent), PFCs decreased by 14.1 Tg CO₂ Eq. (67.8 percent), and SF₆ decreased by 16.5 Tg CO₂ Eq. (50.5 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, and SF₆ are significant because many of these gases have extremely high global warming potentials and, in the cases of PFCs and SF₆, 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

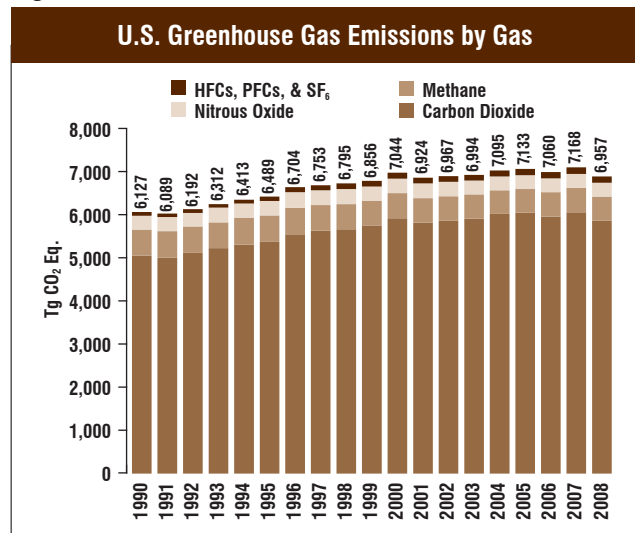


Figure ES-2

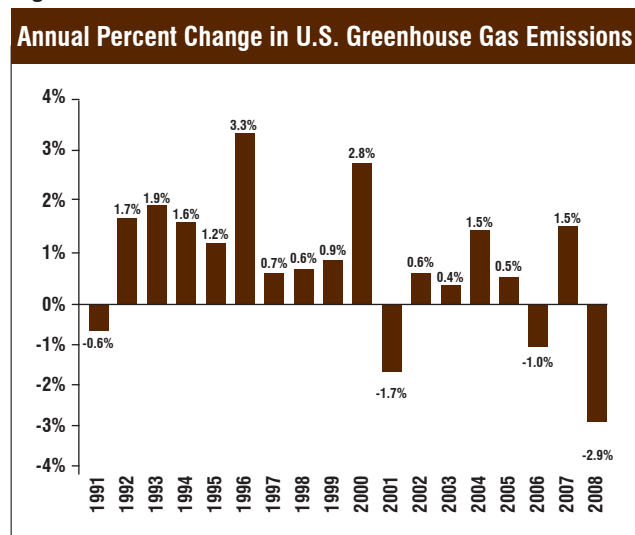


Figure ES-3

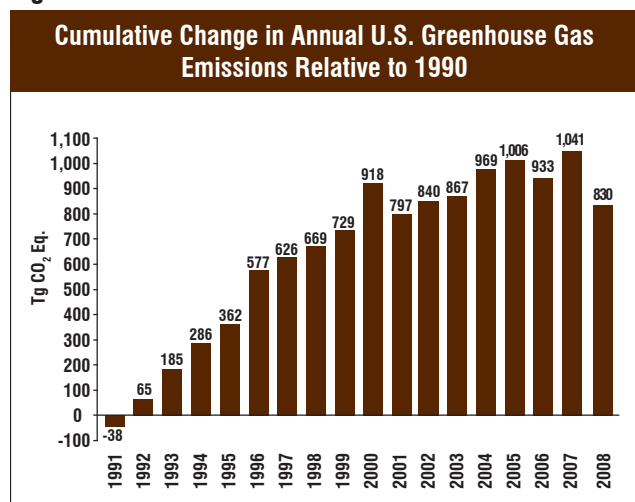


Table ES-2: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Tg CO₂ Eq. or million metric tons CO₂ Eq.)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
CO₂	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
<i>Land Use, Land-Use Change, and Forestry (Sink)^a</i>	<i>(909.4)</i>	<i>(842.9)</i>	<i>(664.2)</i>	<i>(950.4)</i>	<i>(959.2)</i>	<i>(955.4)</i>	<i>(940.3)</i>
<i>Biomass - Wood^b</i>	<i>215.2</i>	<i>229.1</i>	<i>218.1</i>	<i>206.9</i>	<i>207.9</i>	<i>207.4</i>	<i>198.4</i>
<i>International Bunker Fuels^b</i>	<i>111.8</i>	<i>99.8</i>	<i>98.5</i>	<i>110.5</i>	<i>129.1</i>	<i>127.1</i>	<i>135.2</i>
<i>Biomass - Ethanol^b</i>	<i>4.2</i>	<i>7.7</i>	<i>9.2</i>	<i>22.6</i>	<i>30.5</i>	<i>38.3</i>	<i>53.3</i>
CH₄	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 CO₂ Eq. or million metric tons CO₂ Eq.)

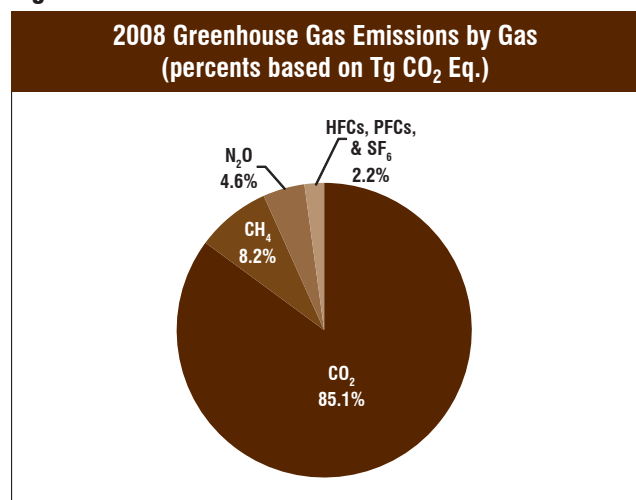
(continued)

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	+	+	+	+	+	+	+
<i>International Bunker Fuels^b</i>	<i>0.2</i>	<i>0.1</i>	<i>0.1</i>	<i>0.1</i>	<i>0.2</i>	<i>0.2</i>	<i>0.2</i>
N₂O	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 ₂ O 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	+	+	+	+	+	+	+
<i>International Bunker Fuels^b</i>	<i>1.1</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.2</i>	<i>1.2</i>	<i>1.2</i>
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
SF₆	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 CO₂ Eq.^a Parentheses indicate negative values or sequestration. The net CO₂ 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



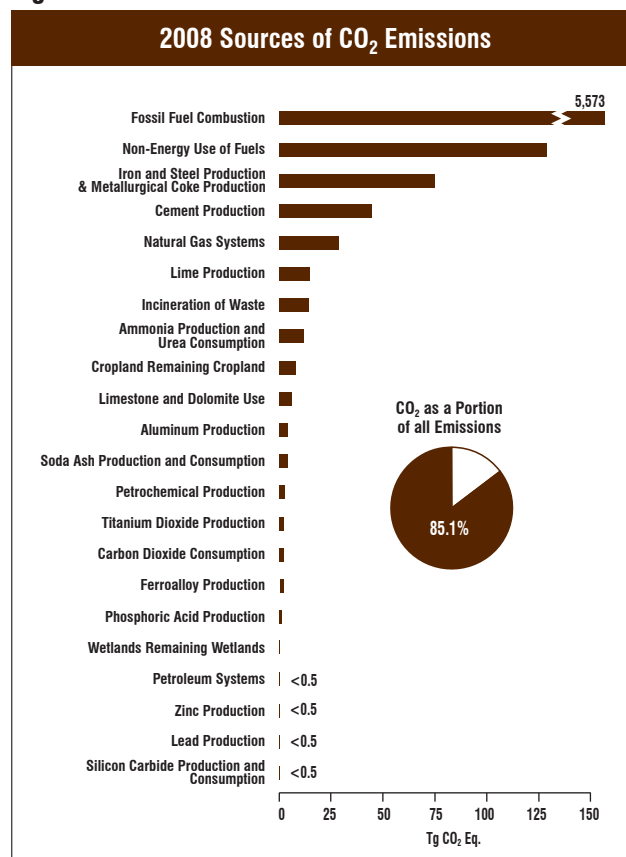
Carbon Dioxide Emissions

The global carbon cycle is made up of large carbon flows and reservoirs. Billions of tons of carbon in the form of CO₂ 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 CO₂ 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 CO₂ emissions in 2008. Globally, approximately 30,377 Tg of CO₂ 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 CO₂ (e.g., through conversion of forest land to agricultural or urban use) or can act as a sink for CO₂ (e.g., through net additions to forest biomass). In addition to fossil-fuel combustion, several other sources emit significant quantities of CO₂. 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, CO₂ 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

¹⁰ Global CO₂ 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).

Figure ES-5



of CO₂ 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, CO₂ emissions from fossil fuel combustion increased from 4,735.7 Tg CO₂ Eq. to 5,572.8 Tg CO₂ Eq.—an 18 percent total increase over the nineteen-year period. From 2007 to 2008, these emissions decreased by 184.2 Tg CO₂ Eq. (3.2 percent).

Historically, changes in emissions from fossil fuel combustion have been the dominant factor affecting U.S. emission trends. Changes in CO₂ 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

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 CO₂ emissions from fossil fuel combustion are electricity generation, transportation, industrial, residential, and commercial. Carbon dioxide 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 CO₂ emissions from fossil fuel combustion by end-use sector.

Transportation End-Use Sector: Transportation activities (excluding international bunker fuels) accounted for 32 percent of CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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

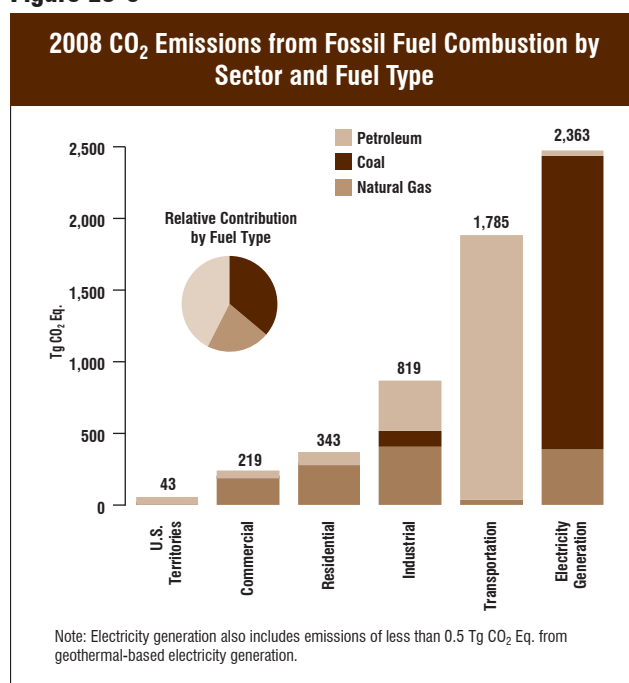
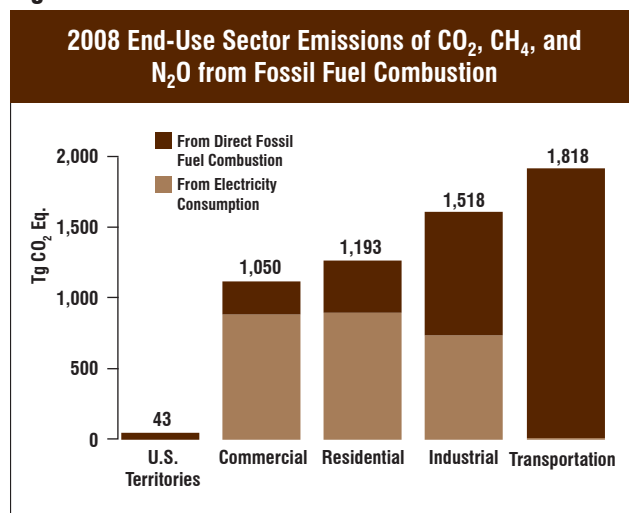


Figure ES-7



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: CO₂ Emissions from Fossil Fuel Combustion by Fuel Consuming End-Use Sector (Tg CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emissions.

Other significant CO₂ trends included the following:

- Carbon dioxide emissions from non-energy use of fossil fuels have increased 14.6 Tg CO₂ Eq. (12.2 percent) from 1990 through 2008. Emissions from non-energy uses of fossil fuels were 134.2 Tg CO₂ Eq. in 2008, which constituted 2.3 percent of total national CO₂ emissions, approximately the same proportion as in 1990.
- Carbon dioxide emissions from iron and steel production and metallurgical coke production decreased from 2007 to 2008 (3.8 Tg CO₂ 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, CO₂ emissions from cement production decreased by 4.1 Tg CO₂ 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 CO₂ Eq.
- Net CO₂ flux from Land Use, Land-Use Change, and Forestry increased by 30.9 Tg CO₂ 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

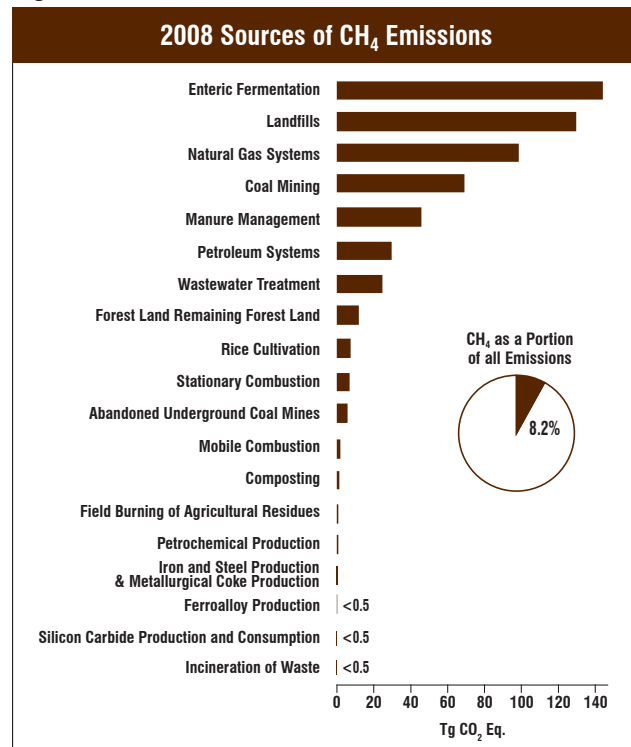
According to the IPCC, CH₄ is more than 20 times as effective as CO₂ at trapping heat in the atmosphere. Over the last two hundred and fifty years, the concentration of CH₄ in the atmosphere increased by 148 percent (IPCC 2007). Anthropogenic sources of CH₄ include landfills, natural gas and petroleum 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 CH₄ include the following:

- Enteric Fermentation is the largest anthropogenic source of CH₄ emissions in the United States. In 2008, enteric fermentation CH₄ emissions were 140.8 Tg CO₂ Eq. (25 percent of total CH₄ emissions), which represents an increase of 8.5 Tg CO₂ Eq. (6.4 percent) since 1990.
- Landfills are the second largest anthropogenic source of CH₄ emissions in the United States, accounting for 22 percent of total CH₄ emissions (126.3 Tg CO₂ Eq.) in 2008. From 1990 to 2008, net CH₄ emissions from landfills decreased by 23.0 Tg CO₂ 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 CH₄ emissions resulting from an increase in the amount of municipal solid waste landfilled.
- Methane emissions from natural gas systems were 96.4 Tg CO₂ Eq. in 2008; emissions have declined by 33.1 Tg CO₂ 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, CH₄ emissions from coal mining were 67.6 Tg CO₂ Eq., a 9.6 Tg CO₂ Eq. (16 percent) increase over 2007 emission levels. The overall decline of 16.4 Tg CO₂ Eq. (20 percent) from 1990 results from the mining of less gassy coal from underground mines and the increased use of CH₄ collected from degasification systems.
- Methane emissions from manure management increased by 54 percent since 1990, from 29.3 Tg CO₂ Eq. in

¹²The CO₂ produced from combusted landfill CH₄ at landfills is not counted in national inventories as it is considered part of the natural C cycle of decomposition.

Figure ES-8



1990 to 45.0 Tg CO₂ 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 CH₄ 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.

Nitrous Oxide Emissions

Nitrous oxide 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 N₂O emissions are much lower than CO₂ emissions, N₂O is approximately 300 times more powerful than CO₂ at trapping heat in the atmosphere. Since 1750, the global atmospheric concentration of N₂O has risen by approximately 18 percent (IPCC 2007). The main anthropogenic activities producing N₂O 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 N₂O include the following:

- Agricultural soils accounted for approximately 68 percent of N₂O emissions in the United States in 2008. Estimated emissions from this source in 2008 were 215.9 Tg CO₂ Eq. Annual N₂O emissions from agricultural soils fluctuated between 1990 and 2008, although overall emissions were 6.1 percent higher in 2008 than in 1990. N₂O 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, N₂O emissions from mobile combustion were 26.1 Tg CO₂ Eq. (approximately 8 percent of U.S. N₂O emissions). From 1990 to 2008, N₂O 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 N₂O emissions. Since 1998, newer control technologies have led to a steady decline in N₂O from this source.

- Nitrous oxide emissions from adipic acid production were 2.0 Tg CO₂ 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 SF₆ 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 SF₆, are potent greenhouse gases. In addition to having high global warming potentials, SF₆ 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 SF₆ 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 CO₂ Eq. in 2008. Emissions from ODS substitutes are both the largest and the fastest growing source of HFC, PFC, and SF₆ 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 CO₂ 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-9

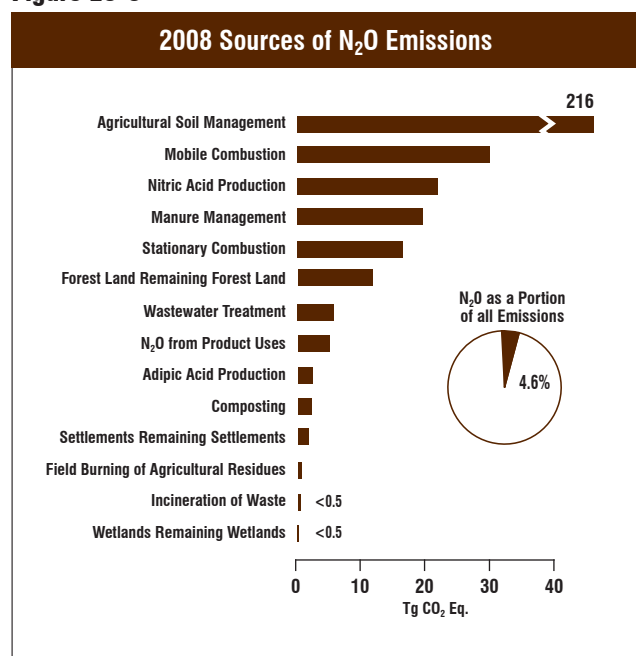


Figure ES-10

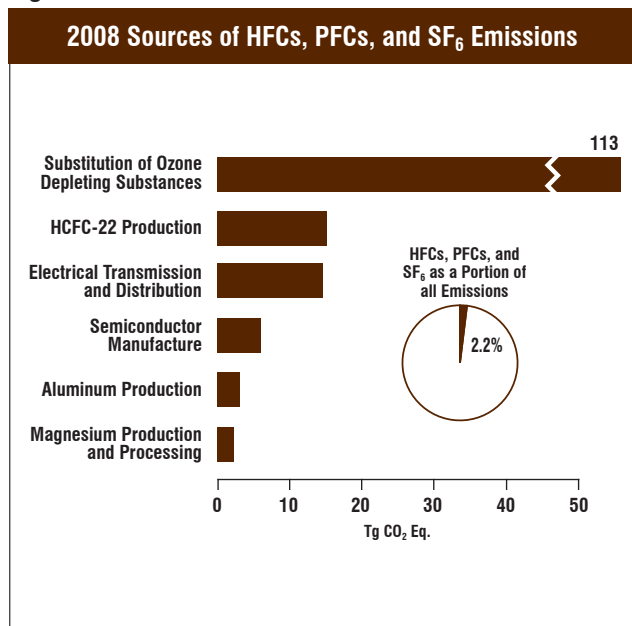
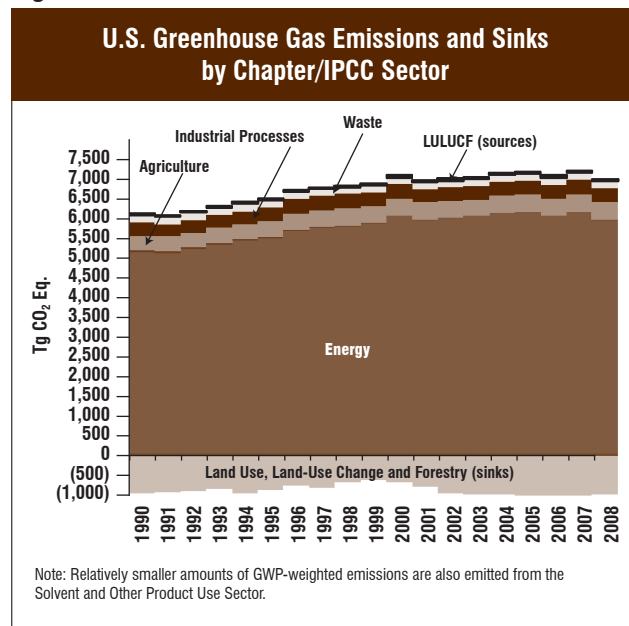


Figure ES-11



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

- Sulfur hexafluoride emissions from electric power transmission and distribution systems decreased by 51 percent (13.6 Tg CO₂ Eq.) from 1990 to 2008, primarily because of higher purchase prices for SF₆ and efforts by industry to reduce emissions.
- PFC emissions from aluminum production decreased by 85 percent (15.8 Tg CO₂ 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 CO₂

Table ES-4: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (Tg CO₂ 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

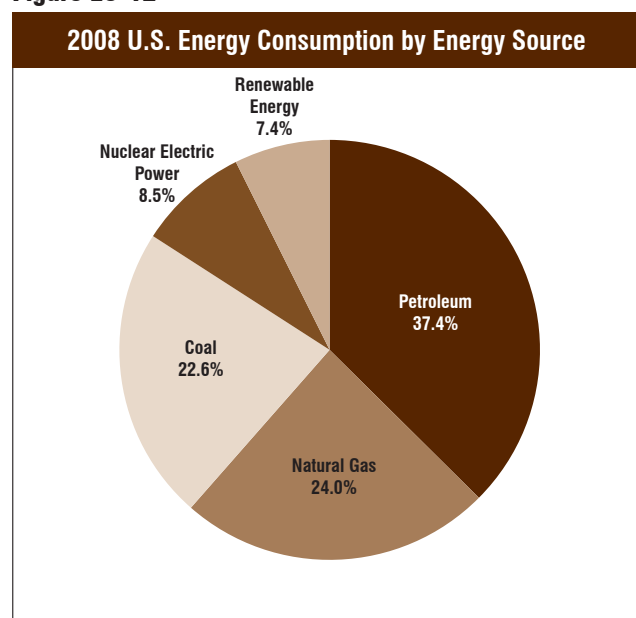
^a The net CO₂ flux total includes both emissions and sequestration, and constitutes a sink in the United States. Sinks are only included in net emissions total. Note: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Eq. (15 percent), 16.2 Tg CO₂ Eq. (5 percent), and 39.7 Tg CO₂ Eq. (10 percent), respectively. Emissions decreased in the Waste and Solvent and Other Product Use sectors by 18.1 Tg CO₂ Eq. (10 percent) and less than 0.1 Tg CO₂ 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 CO₂ flux from all LULUCF source categories) increased by 13.7 Tg CO₂ 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. CO₂ 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 CH₄ and N₂O 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



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 CO₂, CH₄, and N₂O. 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, CO₂ 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 SF₆. 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 N₂O 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 CO₂ 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. Methane and N₂O were the primary greenhouse gases emitted by agricultural activities. Methane emissions from

enteric fermentation and manure management represented 25 percent and 8 percent of total CH₄ 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. N₂O 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 CH₄ and N₂O, and emissions and removals of CO₂ 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 CO₂ 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 CO₂ Eq. (Table ES- 5). This represents an offset of 16 percent of total U.S. CO₂ 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 CO₂ 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 CO₂ Flux from Land Use, Land-Use Change, and Forestry (Tg CO₂ 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 CO₂ Eq.)

Source Category	1990	1995	2000	2005	2006	2007	2008
CO₂	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
CH₄	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
N₂O	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 CO₂ 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 CO₂ emissions of 7.6 Tg CO₂ 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 N₂O emissions of 1.9 Tg CO₂ Eq. Direct N₂O 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 N₂O emissions from fertilizer application to settlement soils increased of 62 percent since 1990. Non-CO₂ emissions from forest fires in 2008 resulted in CH₄ emissions of 11.9 Tg CO₂ Eq., and in N₂O emissions of 9.7 Tg CO₂ Eq. CO₂ and N₂O emissions from peatlands totaled 0.9 Tg CO₂ Eq. and less than 0.01 Tg CO₂ 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. CH₄ emissions.¹³ Additionally, wastewater treatment accounts

for 18 percent of Waste emissions, 4 percent of U.S. CH₄ emissions, and 2 percent of U.S. N₂O emissions. Emissions of CH₄ and N₂O from composting are also accounted for in this chapter; generating emissions of 1.7 Tg CO₂ Eq. and 1.8 Tg CO₂ Eq., respectively. Overall, emission sources accounted for in the Waste chapter generated 2.3 percent of total U.S. greenhouse gas emissions in 2008.

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.

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 this report.

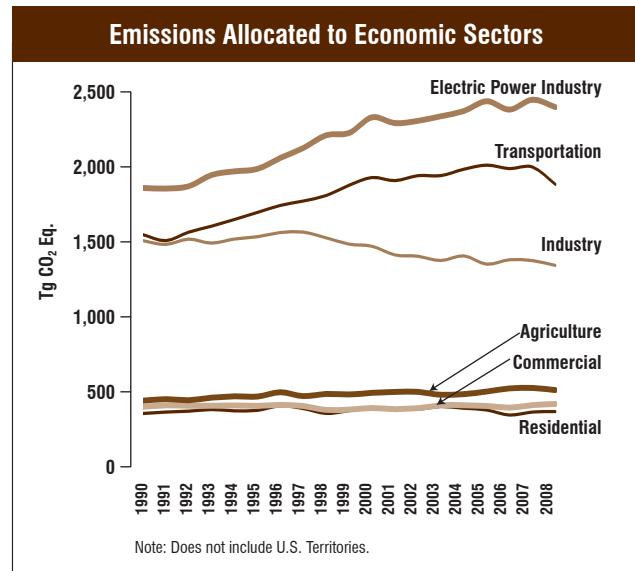
Table ES-7: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (Tg CO₂ Eq.)

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 CO₂, CH₄, N₂O, HFCs, PFCs, and SF₆. See Table 2-12 of this 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 N₂O emissions from agricultural soil management and CH₄ 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 CO₂ emissions from fossil fuel combustion.

Carbon dioxide was also emitted and sequestered by a variety of activities related to forest management practices,

Figure ES-13

tree planting in urban areas, the management of agricultural soils, and landfilling of yard trimmings.

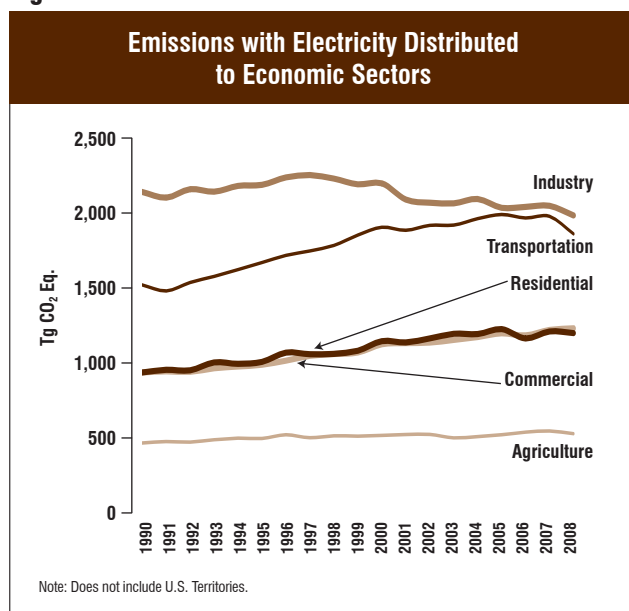
Electricity is ultimately consumed in the economic sectors described above. Table ES-8 presents greenhouse gas emissions from economic sectors with emissions related to electricity generation distributed into end-use categories (i.e., emissions from electricity generation are allocated to the economic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

Table ES-8: U.S. Greenhouse Gas Emissions by Economic Sector with Electricity-Related Emissions Distributed (Tg CO₂ 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 this report for more detailed data.

Figure ES-14



generation were allocated to the residential, commercial, industry, transportation, and agriculture economic sectors according to retail sales of electricity.¹⁴ These source categories include CO₂ from fossil fuel combustion and the use of limestone and dolomite for flue gas desulfurization, CO₂ and N₂O from incineration of waste, CH₄ and N₂O from stationary sources, and SF₆ from electrical transmission and distribution systems.

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.

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, CO₂ 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 SO₂)

The reporting requirements of the UNFCCC¹⁵ request that information be provided on indirect greenhouse gases, which include CO, NO_x, NMVOCs, and SO₂. 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 SO₂, 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.

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

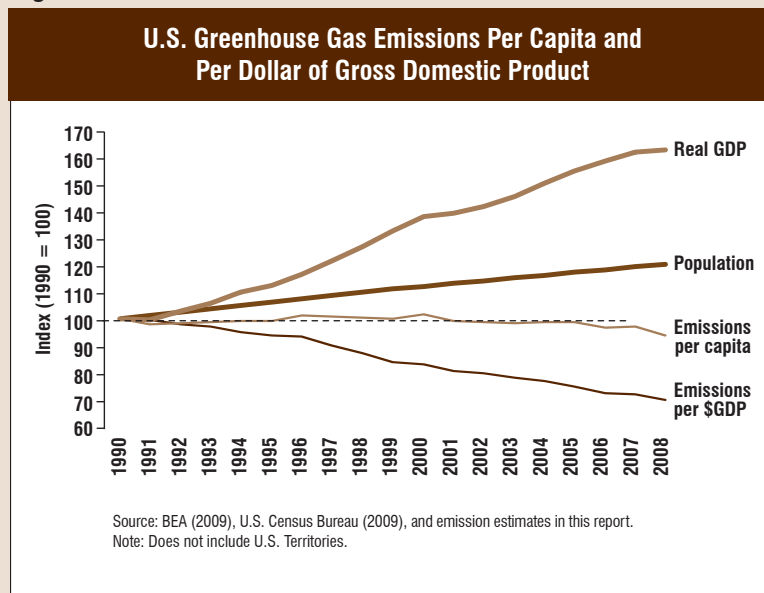


Table ES-10: Emissions of NO_x, CO, NMVOCs, and SO₂ (Gg)

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
SO₂	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).

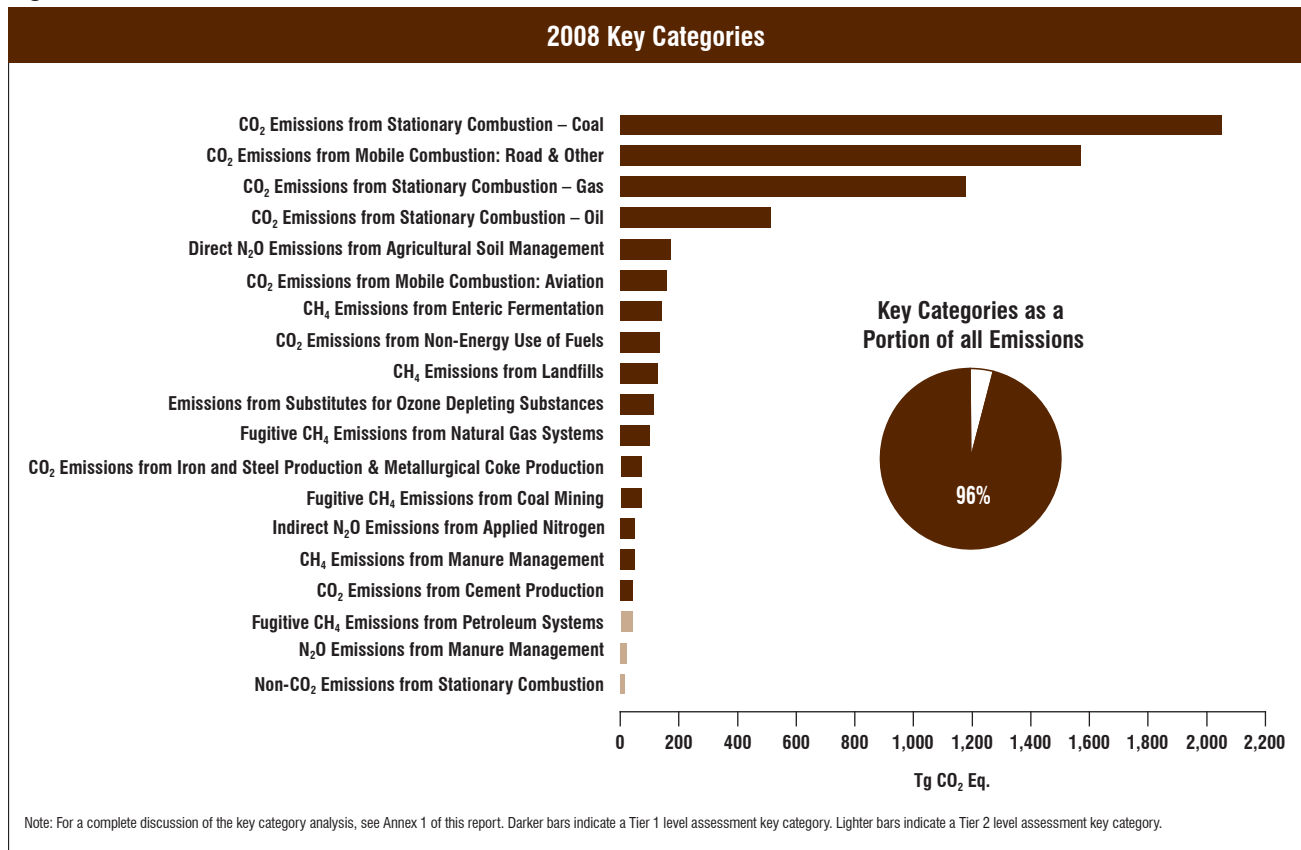
Note: Totals may not sum due to independent rounding.

Since 1970, the United States has published estimates of annual emissions of CO, NO_x, NMVOCs, and SO₂ (EPA 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



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.

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

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 this report. For more information regarding key categories, see section 1.5 and Annex 1 of this 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 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 CO₂ 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 this 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.

1. Introduction

This report presents estimates by the United States government of U.S. anthropogenic greenhouse gas emissions and sinks for the years 1990 through 2008. A summary of these estimates is provided in Table 2.1 and Table 2.2 by gas and source category in the Trends in Greenhouse Gas Emissions chapter. The emission estimates in these tables are presented on both a full molecular mass basis and on a global warming potential (GWP) weighted basis in order to show the relative contribution of each gas to global average radiative forcing.¹ This report also discusses the methods and data used to calculate these emission estimates.

In 1992, the United States signed and ratified the United Nations Framework Convention on Climate Change (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.”^{2,3}

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...”⁴ The United States views this report as an opportunity to fulfill these commitments under the UNFCCC.

In 1988, preceding the creation of the UNFCCC, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) jointly established the Intergovernmental Panel on Climate Change (IPCC). The role of the IPCC is to assess on a comprehensive, objective, open, and transparent basis the scientific, technical, and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation (IPCC 2003). Under Working Group 1 of the IPCC, nearly 140 scientists and national experts from more than thirty countries collaborated in the creation of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) to ensure that the emission inventories submitted to the UNFCCC are consistent and comparable between nations. The IPCC accepted the Revised 1996 IPCC Guidelines at its Twelfth Session (Mexico City, September 11-13, 1996). This report presents information in accordance with these guidelines. In addition, this Inventory is in accordance with the *IPCC Good Practice Guidance and Uncertainty Management*

¹ See the section below entitled *Global Warming Potentials* for an explanation of GWP values.

² 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).

³ Article 2 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change. See <<http://unfccc.int>>. (UNEP/WMO 2000).

⁴ 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>>.

in *National Greenhouse Gas Inventories* and the *Good Practice Guidance for Land Use, Land-Use Change, and Forestry*, which further expanded upon the methodologies in the *Revised 1996 IPCC Guidelines*. The IPCC has also accepted the *2006 Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) at its Twenty-Fifth Session (Mauritius, April 2006). The *2006 IPCC Guidelines* build on the previous bodies of work and include new sources and gases "...as well as updates to the previously published methods whenever scientific and technical knowledge have improved since the previous guidelines were issued." Many of the methodological improvements presented in the *2006 Guidelines* have been adopted in this Inventory.

Overall, this Inventory of anthropogenic greenhouse gas emissions provides a common and consistent mechanism through which Parties to the UNFCCC can estimate emissions and compare the relative contribution of individual sources, gases, and nations to climate change. The structure of this report is consistent with the current *UNFCCC Guidelines on Annual Inventories* (UNFCCC 2006).

1.1. Background Information

Greenhouse Gases

Although the earth's atmosphere consists mainly of oxygen and nitrogen, neither plays a significant role in enhancing the greenhouse effect because both are essentially transparent to terrestrial radiation. The greenhouse effect is primarily a function of the concentration of water vapor, carbon dioxide (CO₂), and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the earth (IPCC 2001). Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans.⁵ A gauge of these changes is called radiative forcing, which is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the earth-atmosphere system (IPCC 2001). Holding everything else constant, increases in greenhouse gas concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the earth).

⁵ For more on the science of climate change, see NRC (2001).

Climate change can be driven by changes in the atmospheric concentrations of a number of radiatively active gases and aerosols. We have clear evidence that human activities have affected concentrations, distributions and life cycles of these gases (IPCC 1996).

Naturally occurring greenhouse gases include water vapor, CO₂, methane (CH₄), nitrous oxide (N₂O), and ozone (O₃). 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 national greenhouse gas inventories.⁶ Some other fluorine-containing halogenated substances—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆)—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 inventories.

There are also several gases that, although they do not have a commonly agreed upon direct radiative forcing effect, do influence the global radiation budget. These tropospheric gases include carbon monoxide (CO), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and tropospheric (ground level) ozone O₃. Tropospheric ozone is formed by two precursor pollutants, volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of ultraviolet light (sunlight). Aerosols are extremely small particles or liquid droplets that are often composed of sulfur compounds, carbonaceous combustion products, crustal materials and other human-induced pollutants. They can affect the absorptive characteristics of the atmosphere. Comparatively, however, the level of scientific understanding of aerosols is still very low (IPCC 2001).

⁶ Emission estimates of CFCs, HCFCs, halons and other ozone-depleting substances are included in this document for informational purposes.

Table 1-1: Global Atmospheric Concentration, Rate of Concentration Change, and Atmospheric Lifetime (years) of Selected Greenhouse Gases

Atmospheric Variable	CO ₂	CH ₄	N ₂ O	SF ₆	CF ₄
Pre-industrial atmospheric concentration	278 ppm	0.715 ppm	0.270 ppm	0 ppt	40 ppt
Atmospheric concentration ^a	385 ppm	1.741-1.865 ppm ^b	0.321-0.322 ppm ^b	5.6 ppt	74 ppt
Rate of concentration change	1.4 ppm/yr	0.005 ppm/yr ^a	0.26%/yr	Linear ^c	Linear ^c
Atmospheric lifetime ^d	50-200 ^e	12 ^f	114 ^f	3,200	>50,000

Source: Pre-industrial atmospheric concentrations and rate of concentration changes for all gases are from IPCC (2007). The current atmospheric concentration for CO₂ is from NOAA/ESRL (2009).

^a The growth rate for atmospheric CH₄ has been decreasing from 14 ppb/yr in 1984 to almost 0 ppb/yr in 2001, 2004, and 2005 (IPCC 2007).

^b The range is the annual arithmetic averages from a mid-latitude Northern-Hemisphere site and a mid-latitude Southern-Hemisphere site for October 2006 through September 2007 (CDIAC 2009).

^c IPCC (2007) identifies the rate of concentration change for SF₆ and CF₄ as linear.

^d Source: IPCC (1996).

^e No single lifetime can be defined for CO₂ because of the different rates of uptake by different removal processes.

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

Note: ppt (parts per thousand), ppm (parts per million), ppb (parts per billion).

Carbon dioxide, CH₄, and N₂O are continuously emitted to and removed from the atmosphere by natural processes on earth. Anthropogenic activities, however, can cause additional quantities of these and other greenhouse gases to be emitted or sequestered, thereby changing their global average atmospheric concentrations. Natural activities such as respiration by plants or animals and seasonal cycles of plant growth and decay are examples of processes that only cycle carbon or nitrogen between the atmosphere and organic biomass. Such processes, except when directly or indirectly perturbed out of equilibrium by anthropogenic activities, generally do not alter average atmospheric greenhouse gas concentrations over decadal timeframes. Climatic changes resulting from anthropogenic activities, however, could have positive or negative feedback effects on these natural systems. Atmospheric concentrations of these gases, along with their rates of growth and atmospheric lifetimes, are presented in Table 1-1.

A brief description of each greenhouse gas, its sources, and its role in the atmosphere is given below. The following section then explains the concept of GWPs, which are assigned to individual gases as a measure of their relative average global radiative forcing effect.

Water Vapor (H₂O). Overall, the most abundant and dominant greenhouse gas in the atmosphere is water vapor. Water vapor is neither long-lived nor well mixed in the atmosphere, varying spatially from 0 to 2 percent (IPCC 1996). In addition, atmospheric water can exist in several physical states including gaseous, liquid, and solid. Human

activities are not believed to affect directly the average global concentration of water vapor, but, the radiative forcing produced by the increased concentrations of other greenhouse gases may indirectly affect the hydrologic cycle. While a warmer atmosphere has an increased water holding capacity, increased concentrations of water vapor affect the formation of clouds, which can both absorb and reflect solar and terrestrial radiation. Aircraft contrails, which consist of water vapor and other aircraft emittants, are similar to clouds in their radiative forcing effects (IPCC 1999).

Carbon Dioxide. In nature, carbon is cycled between various atmospheric, oceanic, land biotic, marine biotic, and mineral reservoirs. The largest fluxes occur between the atmosphere and terrestrial biota, and between the atmosphere and surface water of the oceans. In the atmosphere, carbon predominantly exists in its oxidized form as CO₂. Atmospheric CO₂ is part of this global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. Carbon dioxide concentrations in the atmosphere increased from approximately 280 parts per million by volume (ppmv) in pre-industrial times to 385 ppmv in 2008, a 37.5 percent increase (IPCC 2007 and NOAA/ESRL 2009).^{7,8} The IPCC definitively states that "the present atmospheric CO₂ increase is caused by anthropogenic

⁷ The pre-industrial period is considered as the time preceding the year 1750 (IPCC 2001).

⁸ Carbon dioxide concentrations during the last 1,000 years of the pre-industrial period (i.e., 750-1750), a time of relative climate stability, fluctuated by about 10 ppmv around 280 ppmv (IPCC 2001).

emissions of CO₂” (IPCC 2001). The predominant source of anthropogenic CO₂ emissions is the combustion of fossil fuels. Forest clearing, other biomass burning, and some non-energy production processes (e.g., cement production) also emit notable quantities of CO₂. In its fourth assessment, the IPCC stated that “most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increased in anthropogenic greenhouse gas concentrations,” of which CO₂ is the most important (IPCC 2007).

Methane. Methane is primarily produced through anaerobic decomposition of organic matter in biological systems. Agricultural processes such as wetland rice cultivation, enteric fermentation in animals, and the decomposition of animal wastes emit CH₄, as does the decomposition of municipal solid wastes. CH₄ is also emitted during the production and distribution of natural gas and petroleum, and is released as a by-product of coal mining and incomplete fossil fuel combustion. Atmospheric concentrations of CH₄ have increased by about 143 percent since 1750, from a pre-industrial value of about 722 ppb to 1,741-1,865 ppb in 2007,⁹ although the rate of increase has been declining. The IPCC has estimated that slightly more than half of the current CH₄ flux to the atmosphere is anthropogenic, from human activities such as agriculture, fossil fuel use, and waste disposal (IPCC 2007).

Methane is removed from the atmosphere through a reaction with the hydroxyl radical (OH) and is ultimately converted to CO₂. Minor removal processes also include reaction with chlorine in the marine boundary layer, a soil sink, and stratospheric reactions. Increasing emissions of CH₄ reduce the concentration of OH, a feedback that may increase the atmospheric lifetime of CH₄ (IPCC 2001).

Nitrous Oxide. Anthropogenic sources of N₂O emissions include agricultural soils, especially production of nitrogen-fixing crops and forages, the use of synthetic and manure fertilizers, and manure deposition by livestock; fossil fuel combustion, especially from mobile combustion; adipic (nylon) and nitric acid production; wastewater treatment and waste incineration; and biomass burning. The atmospheric concentration of N₂O has increased by 18 percent since 1750, from a pre-industrial value of about 270 ppb to 321-322 ppb

⁹ The range is the annual arithmetic averages from a mid-latitude Northern-Hemisphere site and a mid-latitude Southern-Hemisphere site for October 2006 through September 2007 (CDIAC 2009).

in 2007,¹⁰ a concentration that has not been exceeded during the last thousand years. Nitrous oxide is primarily removed from the atmosphere by the photolytic action of sunlight in the stratosphere (IPCC 2007).

Ozone. Ozone is present in both the upper stratosphere,¹¹ where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,¹² where it is the main component of anthropogenic photochemical “smog.” During the last two decades, emissions of anthropogenic chlorine and bromine-containing halocarbons, such as CFCs, have depleted stratospheric ozone concentrations. This loss of ozone in the stratosphere has resulted in negative radiative forcing, representing an indirect effect of anthropogenic emissions of chlorine and bromine compounds (IPCC 1996). The depletion of stratospheric ozone and its radiative forcing was expected to reach a maximum in about 2000 before starting to recover. As of the date of publication of IPCC’s *Fourth Assessment Report*, “whether or not recently observed changes in ozone trends are already indicative of recovery of the global ozone layer is not yet clear” (IPCC 2007).

The past increase in tropospheric ozone, which is also a greenhouse gas, is estimated to provide the third largest increase in direct radiative forcing since the pre-industrial era, behind CO₂ and CH₄. Tropospheric ozone is produced from complex chemical reactions of volatile organic compounds mixing with NO_x in the presence of sunlight. The tropospheric concentrations of ozone and these other pollutants are short-lived and, therefore, spatially variable (IPCC 2001).

Halocarbons, Perfluorocarbons, and Sulfur Hexafluoride. Halocarbons are, for the most part, man-made chemicals that have both direct and indirect radiative forcing effects. Halocarbons that contain chlorine (CFCs, HCFCs, methyl

¹⁰ The range is the annual arithmetic averages from a mid-latitude Northern-Hemisphere site and a mid-latitude Southern-Hemisphere site for October 2006 through September 2007 (CDIAC 2009).

¹¹ The stratosphere is the layer from the troposphere up to roughly 50 kilometers. In the lower regions the temperature is nearly constant but in the upper layer the temperature increases rapidly because of sunlight absorption by the ozone layer. The ozone layer is the part of the stratosphere from 19 kilometers up to 48 kilometers where the concentration of ozone reaches up to 10 parts per million.

¹² The troposphere is the layer from the ground up to 11 kilometers near the poles and up to 16 kilometers in equatorial regions (i.e., the lowest layer of the atmosphere, where people live). It contains roughly 80 percent of the mass of all gases in the atmosphere and is the site for most weather processes, including most of the water vapor and clouds.

chloroform, and carbon tetrachloride) and bromine (halons, methyl bromide, and hydrobromofluorocarbons [HBFCs]) result in stratospheric ozone depletion and are therefore controlled under the Montreal Protocol on Substances that Deplete the Ozone Layer. Although CFCs and HCFCs include potent global warming gases, their net radiative forcing effect on the atmosphere is reduced because they cause stratospheric ozone depletion, which itself is an important greenhouse gas in addition to shielding the earth from harmful levels of ultraviolet radiation. Under the Montreal Protocol, the United States phased out the production and importation of halons by 1994 and of CFCs by 1996. Under the Copenhagen Amendments to the Protocol, a cap was placed on the production and importation of HCFCs by non-Article 5 countries¹³ beginning in 1996, and then followed by a complete phase-out by the year 2030. While ozone depleting gases covered under the Montreal Protocol and its Amendments are not covered by the UNFCCC; they are reported in this Inventory under Annex 6.2 of this report for informational purposes.

HFCs, PFCs, and SF₆ are not ozone depleting substances, and therefore are not covered under the Montreal Protocol. They are, however, powerful greenhouse gases. HFCs are primarily used as replacements for ozone depleting substances but also emitted as a by-product of the HCFC-22 manufacturing process. Currently, they have a small aggregate radiative forcing impact, but it is anticipated that their contribution to overall radiative forcing will increase (IPCC 2001). PFCs and SF₆ are predominantly emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. Currently, the radiative forcing impact of PFCs and SF₆ is also small, but they have a significant growth rate, extremely long atmospheric lifetimes, and are strong absorbers of infrared radiation, and therefore have the potential to influence climate far into the future (IPCC 2001).

Carbon Monoxide. Carbon monoxide has an indirect radiative forcing effect by elevating concentrations of CH₄

¹³ Article 5 of the Montreal Protocol covers several groups of countries, especially developing countries, with low consumption rates of ozone depleting substances. Developing countries with per capita consumption of less than 0.3 kg of certain ozone depleting substances (weighted by their ozone depleting potential) receive financial assistance and a grace period of ten additional years in the phase-out of ozone depleting substances.

and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g., the hydroxyl radical, OH) that would otherwise assist in destroying CH₄ and tropospheric ozone. Carbon monoxide is created when carbon-containing fuels are burned incompletely. Through natural processes in the atmosphere, it is eventually oxidized to CO₂. Carbon monoxide concentrations are both short-lived in the atmosphere and spatially variable.

Nitrogen Oxides. The primary climate change effects of nitrogen oxides (i.e., NO and NO₂) are indirect and result from their role in promoting the formation of ozone in the troposphere and, to a lesser degree, lower stratosphere, where it has positive radiative forcing effects.¹⁴ Additionally, NO_x emissions from aircraft are also likely to decrease CH₄ concentrations, thus having a negative radiative forcing effect (IPCC 1999). Nitrogen oxides are created from lightning, soil microbial activity, biomass burning (both natural and anthropogenic fires), fuel combustion, and, in the stratosphere, from the photo-degradation of N₂O. Concentrations of NO_x are both relatively short-lived in the atmosphere and spatially variable.

Nonmethane Volatile Organic Compounds (NMVOCs). Non-CH₄ volatile organic compounds include substances such as propane, butane, and ethane. These compounds participate, along with NO_x, in the formation of tropospheric ozone and other photochemical oxidants. NMVOCs are emitted primarily from transportation and industrial processes, as well as biomass burning and non-industrial consumption of organic solvents. Concentrations of NMVOCs tend to be both short-lived in the atmosphere and spatially variable.

Aerosols. Aerosols are extremely small particles or liquid droplets found in the atmosphere. They can be produced by natural events such as dust storms and volcanic activity, or by anthropogenic processes such as fuel combustion and biomass burning. Aerosols affect radiative forcing differently than greenhouse gases, and their radiative effects occur through direct and indirect mechanisms: directly by scattering and absorbing solar radiation; and indirectly by increasing droplet counts that modify the formation, precipitation efficiency, and radiative properties of clouds. Aerosols are removed from the atmosphere relatively rapidly by precipitation. Because aerosols generally have short atmospheric lifetimes, and

¹⁴ NO_x emissions injected higher in the stratosphere, primarily from fuel combustion emissions from high altitude supersonic aircraft, can lead to stratospheric ozone depletion.

have concentrations and compositions that vary regionally, spatially, and temporally, their contributions to radiative forcing are difficult to quantify (IPCC 2001).

The indirect radiative forcing from aerosols is typically divided into two effects. The first effect involves decreased droplet size and increased droplet concentration resulting from an increase in airborne aerosols. The second effect involves an increase in the water content and lifetime of clouds due to the effect of reduced droplet size on precipitation efficiency (IPCC 2001). Recent research has placed a greater focus on the second indirect radiative forcing effect of aerosols.

Various categories of aerosols exist, including naturally produced aerosols such as soil dust, sea salt, biogenic aerosols, sulfates, and volcanic aerosols, and anthropogenically manufactured aerosols such as industrial dust and carbonaceous aerosols¹⁵ (e.g., black carbon, organic carbon) from transportation, coal combustion, cement manufacturing, waste incineration, and biomass burning.

The net effect of aerosols on radiative forcing is believed to be negative (i.e., net cooling effect on the climate), although because they remain in the atmosphere for only days to weeks, their concentrations respond rapidly to changes in emissions.¹⁶ Locally, the negative radiative forcing effects of aerosols can offset the positive forcing of greenhouse gases (IPCC 1996). “However, the aerosol effects do not cancel the global-scale effects of the much longer-lived greenhouse gases, and significant climate changes can still result” (IPCC 1996).

The IPCC’s *Third Assessment Report* notes that “the indirect radiative effect of aerosols is now understood to also encompass effects on ice and mixed-phase clouds, but the magnitude of any such indirect effect is not known, although it is likely to be positive” (IPCC 2001). Additionally, current research suggests that another constituent of aerosols, black carbon, has a positive radiative forcing, and that its presence “in the atmosphere above highly reflective surfaces such as snow and ice, or clouds, may cause a significant positive

radiative forcing” (IPCC 2007). The primary anthropogenic emission sources of black carbon include diesel exhaust and open biomass burning.

Global Warming Potentials

A global warming potential is a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas (see Table 1-2). It 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 absorbs radiation. Indirect radiative forcing occurs when chemical transformations involving the original gas produce a gas or gases that are greenhouse gases, or when a gas influences other radiatively important processes such as the atmospheric lifetimes of other gases. The reference gas used is CO₂, and therefore GWP weighted emissions are measured in teragrams of CO₂ equivalent (Tg CO₂ Eq.).¹⁷ The relationship between gigagrams (Gg) of a gas and Tg CO₂ Eq. can be expressed as follows:

$$\text{Tg CO}_2 \text{ Eq.} = (\text{Gg of gas}) \times (\text{GWP}) \times \left(\frac{\text{Tg}}{1,000 \text{ Gg}} \right)$$

where,

- Tg CO₂ Eq. = Teragrams of CO₂ equivalent
- Gg = Gigagrams (equivalent to a thousand metric tons)
- GWP = Global warming potential
- Tg = Teragrams

GWP values allow for a comparison of the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of ±35 percent. The parties to the UNFCCC have also agreed to use GWPs based upon a 100-year time horizon although other time horizon values are available.

Greenhouse gas emissions and removals should be presented on a gas-by-gas basis in units of mass... In addition, consistent with decision 2/CP.3, Parties should report aggregate emissions and removals of greenhouse gases, expressed in CO₂ equivalent terms at summary inventory level,

¹⁵ Carbonaceous aerosols are aerosols that are comprised mainly of organic substances and forms of black carbon (or soot) (IPCC 2001).

¹⁶ Volcanic activity can inject significant quantities of aerosol-producing sulfur dioxide and other sulfur compounds into the stratosphere, which can result in a longer negative forcing effect (i.e., a few years) (IPCC 1996).

¹⁷ Carbon comprises 12/44^{ths} of carbon dioxide by weight.

Table 1-2: Global Warming Potentials and Atmospheric Lifetimes (Years) Used in this Report

Gas	Atmospheric Lifetime	GWP ^a
CO ₂	50-200	1
CH ₄ ^b	12±3	21
N ₂ O	120	310
HFC-23	264	11,700
HFC-32	5.6	650
HFC-125	32.6	2,800
HFC-134a	14.6	1,300
HFC-143a	48.3	3,800
HFC-152a	1.5	140
HFC-227ea	36.5	2,900
HFC-236fa	209	6,300
HFC-4310mee	17.1	1,300
CF ₄	50,000	6,500
C ₂ F ₆	10,000	9,200
C ₄ F ₁₀	2,600	7,000
C ₆ F ₁₄	3,200	7,400
SF ₆	3,200	23,900

Source: (IPCC 1996).

^a 100-year time horizon.

^b The GWP of CH₄ 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 CO₂ is not included.

*using GWP values provided by the IPCC in its Second Assessment Report... based on the effects of greenhouse gases over a 100-year time horizon.*¹⁸

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO₂, CH₄, N₂O, HFCs, PFCs, and SF₆) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. The short-lived gases such as water vapor, carbon monoxide, tropospheric ozone, ozone precursors (e.g., NO_x and NMVOCs), and tropospheric aerosols (e.g., SO₂ products and carbonaceous particles), however, vary regionally, and consequently it is difficult to quantify their global radiative forcing impacts. No GWP values are attributed to these

¹⁸ Framework Convention on Climate Change; <<http://unfccc.int/resource/docs/cop8/08.pdf>>; 1 November 2002; Report of the Conference of the Parties at its eighth session; held at New Delhi from 23 October to 1 November 2002; Addendum; Part One: Action taken by the Conference of the Parties at its eighth session; Decision -/CP.8; Communications from Parties included in Annex I to the Convention: Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention, Part 1: UNFCCC reporting guidelines on annual inventories; p. 7 (UNFCCC 2003).

gases that are short-lived and spatially inhomogeneous in the atmosphere.

1.2. Institutional Arrangements

The U.S. Environmental Protection Agency (EPA), in cooperation with other U.S. government agencies, prepares the Inventory of U.S. Greenhouse Gas Emissions and Sinks. A wide range of agencies and individuals are involved in supplying data to, reviewing, or preparing portions of the U.S. Inventory—including federal and state government authorities, research and academic institutions, industry associations, and private consultants.

Within EPA, the Office of Atmospheric Programs (OAP) is the lead office responsible for the emission calculations provided in the Inventory, as well as the completion of the National Inventory Report and the Common Reporting Format tables. The Office of Transportation and Air Quality (OTAQ) is also involved in calculating emissions for the Inventory. While the U.S. Department of State officially submits the annual Inventory to the UNFCCC, EPA's OAP serves as the focal point for technical questions and comments on the U.S. Inventory. The staff of OAP and OTAQ coordinates the annual methodological choice, activity data collection, and emission calculations at the individual source category level. Within OAP, an inventory coordinator compiles the entire Inventory into the proper reporting format for submission to the UNFCCC, and is responsible for the collection and consistency of cross-cutting issues in the Inventory.

Several other government agencies contribute to the collection and analysis of the underlying activity data used in the Inventory calculations. Formal relationships exist between EPA and other U.S. agencies that provide official data for use in the Inventory. The U.S. Department of Energy's Energy Information Administration provides national fuel consumption data and the U.S. Department of Defense provides military fuel consumption and bunker fuels. Informal relationships also exist with other U.S. agencies to provide activity data for use in EPA's emission calculations. These include: the U.S. Department of Agriculture, the U.S. Geological Survey, the Federal Highway Administration, the Department of Transportation, the Bureau of Transportation Statistics, the Department of Commerce, the National Agricultural Statistics Service, and the Federal Aviation

Box 1-1: The IPCC Fourth Assessment Report and Global Warming Potentials

In 2007, the IPCC published its *Fourth Assessment Report* (AR4), which provided an updated and more comprehensive scientific assessment of climate change. Within this report, the GWPs of several gases were revised relative to the SAR and the IPCC's *Third Assessment Report* (TAR) (IPCC 2001). Thus the GWPs used in this report have been updated twice by the IPCC; although the SAR GWPs are used throughout this report, it is interesting to review the changes to the GWPs and the impact such improved understanding has on the total GWP-weighted emissions of the United States. Since the SAR and TAR, the IPCC has applied an improved calculation of CO₂ radiative forcing and an improved CO₂ response function. The GWPs are drawn from IPCC/TEAP (2005) and the TAR, with updates for those cases where new laboratory or radiative transfer results have been published. Additionally, the atmospheric lifetimes of some gases have been recalculated. In addition, the values for radiative forcing and lifetimes have been recalculated for a variety of halocarbons, which were not presented in the SAR. Table 1-3 presents the new GWPs, relative to those presented in the SAR.

Table 1-3: Comparison of 100-Year GWPs

Gas	SAR	TAR	AR4	Change from SAR	
				TAR	AR4
CO ₂	1	1	1	NC	0
CH ₄ *	21	23	25	2	4
N ₂ O	310	296	298	(14)	(12)
HFC-23	11,700	12,000	14,800	300	3,100
HFC-32	650	550	675	(100)	25
HFC-125	2,800	3,400	3,500	600	700
HFC-134a	1,300	1,300	1,430	NC	130
HFC-143a	3,800	4,300	4,470	500	670
HFC-152a	140	120	124	(20)	(16)
HFC-227ea	2,900	3,500	3,220	600	320
HFC-236fa	6,300	9,400	9,810	3,100	3,510
HFC-4310mee	1,300	1,500	1,640	200	340
CF ₄	6,500	5,700	7,390	(800)	890
C ₂ F ₆	9,200	11,900	12,200	2,700	3,000
C ₄ F ₁₀	7,000	8,600	8,860	1,600	1,860
C ₆ F ₁₄	7,400	9,000	9,300	1,600	1,900
SF ₆	23,900	22,200	22,800	(1,700)	(1,100)

Source: (IPCC 2007, IPCC 2001).

NC (No Change).

Note: Parentheses indicate negative values.

* The GWP of CH₄ 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 CO₂ is not included.

To comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using SAR GWP values. The UNFCCC reporting guidelines for national inventories¹⁹ were updated in 2002 but continue to require the use of GWPs from the SAR so that current estimates of aggregate greenhouse gas emissions for 1990 through 2008 are consistent and comparable with estimates developed prior to the publication of the TAR and AR4. For informational purposes, emission estimates that use the updated GWPs are presented in detail in Annex 6.1 of this report. All estimates provided throughout this report are also presented in unweighted units.

¹⁹ See <<http://unfccc.int/resource/docs/cop8/08.pdf>>

Administration. Academic and research centers also provide activity data and calculations to EPA, as well as individual companies participating in voluntary outreach efforts with EPA. Finally, the U.S. Department of State officially submits the Inventory to the UNFCCC each April.

1.3. Inventory Process

EPA has a decentralized approach to preparing the annual U.S. Inventory, which consists of a National Inventory Report (NIR) and Common Reporting Format (CRF) tables. The Inventory coordinator at EPA is responsible for compiling all emission estimates, and ensuring consistency

and quality throughout the NIR and CRF tables. Emission calculations for individual sources are the responsibility of individual source leads, who are most familiar with each source category and the unique characteristics of its emissions profile. The individual source leads determine the most appropriate methodology and collect the best activity data to use in the emission calculations, based upon their expertise in the source category, as well as coordinating with researchers and contractors familiar with the sources. A multi-stage process for collecting information from the individual source leads and producing the Inventory is undertaken annually to compile all information and data.

Methodology Development, Data Collection, and Emissions and Sink Estimation

Source leads at EPA collect input data and, as necessary, evaluate or develop the estimation methodology for the individual source categories. For most source categories, the methodology for the previous year is applied to the new “current” year of the Inventory, and inventory analysts collect any new data or update data that have changed from the previous year. If estimates for a new source category are being developed for the first time, or if the methodology is changing for an existing source category (e.g., the United States is implementing a higher tiered approach for that source category), then the source category lead will develop a new methodology, gather the most appropriate activity data and emission factors (or in some cases direct emission measurements) for the entire time series, and conduct a special source-specific peer review process involving relevant experts from industry, government, and universities.

Once the methodology is in place and the data are collected, the individual source leads calculate emissions and sink estimates. The source leads then update or create the relevant text and accompanying annexes for the Inventory. Source leads are also responsible for completing the relevant sectoral background tables of the Common Reporting Format, conducting quality assurance and quality control (QA/QC) checks, and uncertainty analyses.

Summary Spreadsheet Compilation and Data Storage

The inventory coordinator at EPA collects the source categories’ descriptive text and Annexes, and also aggregates the emission estimates into a summary spreadsheet that links the individual source category spreadsheets together. This summary sheet contains all of the essential data in one central location, in formats commonly used in the Inventory document. In addition to the data from each source category, national trend and related data are also gathered in the summary sheet for use in the Executive Summary, Introduction, and Recent Trends sections of the inventory report. Electronic copies of each year’s summary spreadsheet, which contains all the emission and sink estimates for the United States, are kept on a central server at EPA under the jurisdiction of the inventory coordinator.

National Inventory Report Preparation

The NIR is compiled from the sections developed by each individual source lead. In addition, the inventory coordinator prepares a brief overview of each chapter that summarizes the emissions from all sources discussed in the chapters. The inventory coordinator then carries out a key category analysis for the Inventory, consistent with the IPCC *Good Practice Guidance*, IPCC *Good Practice Guidance for Land Use, Land Use Change and Forestry*, and in accordance with the reporting requirements of the UNFCCC. Also at this time, the Introduction, Executive Summary, and Recent Trends sections are drafted, to reflect the trends for the most recent year of the current Inventory. The analysis of trends necessitates gathering supplemental data, including weather and temperature conditions, economic activity and gross domestic product, population, atmospheric conditions, and the annual consumption of electricity, energy, and fossil fuels. Changes in these data are used to explain the trends observed in greenhouse gas emissions in the United States. Furthermore, specific factors that affect individual sectors are researched and discussed. Many of the factors that affect emissions are included in the inventory document as separate analyses or side discussions in boxes within the text. Text boxes are also created to examine the data aggregated in different ways than in the remainder of the document, such as a focus on transportation activities or emissions from

electricity generation. The document is prepared to match the specification of the UNFCCC reporting guidelines for National Inventory Reports.

Common Reporting Format Table Compilation

The CRF tables are compiled from individual tables completed by each individual source lead, which contain source emissions and activity data. The inventory coordinator integrates the source data into the UNFCCC's "CRF Reporter" for the United States, assuring consistency across all sectoral tables. The summary reports for emissions, methods, and emission factors used, the overview tables for completeness and quality of estimates, the recalculation tables, the notation key completion tables, and the emission trends tables are then completed by the inventory coordinator. Internal automated quality checks on the CRF Reporter, as well as reviews by the source leads, are completed for the entire time series of CRF tables before submission.

QA/QC and Uncertainty

QA/QC and uncertainty analyses are supervised by the QA/QC and Uncertainty coordinators, who have general oversight over the implementation of the QA/QC plan and the overall uncertainty analysis for the Inventory (see sections on QA/QC and Uncertainty, below). These coordinators work closely with the source leads to ensure that a consistent QA/QC plan and uncertainty analysis is implemented across all inventory sources. The inventory QA/QC plan, detailed in a following section, is consistent with the quality assurance procedures outlined by EPA and IPCC.

Expert and Public Review Periods

During the Expert Review period, a first draft of the document is sent to a select list of technical experts outside of EPA. The purpose of the Expert Review is to encourage feedback on the methodological and data sources used in the current Inventory, especially for sources which have experienced any changes since the previous Inventory.

Once comments are received and addressed, a second draft of the document is released for public review by publishing a notice in the U.S. Federal Register and posting the document on the EPA Web site. The Public Review period allows for a 30 day comment period and is open to the entire U.S. public.

Final Submittal to UNFCCC and Document Printing

After the final revisions to incorporate any comments from the Expert Review and Public Review periods, EPA prepares the final National Inventory Report and the accompanying Common Reporting Format Reporter database. The U.S. Department of State sends the official submission of the U.S. Inventory to the UNFCCC. The document is then formatted for printing, posted online, printed by the U.S. Government Printing Office, and made available for the public.

1.4. Methodology and Data Sources

Emissions of greenhouse gases from various source and sink categories have been estimated using methodologies that are consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997). In addition, the United States references the additional guidance provided in the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC 2000), the *IPCC Good Practice Guidance for Land Use, Land-Use Change, and Forestry* (IPCC 2003), and the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). To the extent possible, the present report relies on published activity and emission factor data. Depending on the emission source category, activity data can include fuel consumption or deliveries, vehicle-miles traveled, raw material processed, etc. Emission factors are factors that relate quantities of emissions to an activity.

The IPCC methodologies provided in the *Revised 1996 IPCC Guidelines* represent baseline methodologies for a variety of source categories, and many of these methodologies continue to be improved and refined as new research and data become available. This report uses the IPCC methodologies when applicable, and supplements them with other available methodologies and data where possible. Choices made regarding the methodologies and data sources used are provided in conjunction with the discussion of each source category in the main body of the report. Complete documentation is provided in the annexes on the detailed methodologies and data sources utilized in the calculation of each source category.

Box 1-2: IPCC Reference Approach

The UNFCCC reporting guidelines require countries to complete a “top-down” reference approach for estimating CO₂ emissions from fossil fuel combustion in addition to their “bottom-up” sectoral methodology. This estimation method uses alternative methodologies and different data sources than those contained in that section of the Energy chapter. The reference approach estimates fossil fuel consumption by adjusting national aggregate fuel production data for imports, exports, and stock changes rather than relying on end-user consumption surveys (see Annex 4 of this report). The reference approach assumes that once carbon-based fuels are brought into a national economy, they are either saved in some way (e.g., stored in products, kept in fuel stocks, or left unoxidized in ash) or combusted, and therefore the carbon in them is oxidized and released into the atmosphere. Accounting for actual consumption of fuels at the sectoral or sub-national level is not required.

1.5. 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.”²⁰ By definition, key categories include those sources that have the greatest contribution to the absolute level of national emissions. 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 and uncertainties of individual source and sink categories. This analysis culls out source and sink categories that diverge from the overall trend in national emissions. Finally, a qualitative evaluation of key categories is performed to capture any categories that were not identified in any of the quantitative analyses.

A Tier 1 approach, as defined in the IPCC’s *Good Practice Guidance* (IPCC 2000), was implemented to identify the key categories for the United States. This analysis

was performed twice; one analysis included sources and sinks from the Land Use, Land-Use Change, and Forestry (LULUCF) sector, the other analysis did not include the LULUCF categories. Following the Tier 1 approach, a Tier 2 approach, as defined in the IPCC’s *Good Practice Guidance* (IPCC 2000), was then implemented to identify any additional key categories not already identified in the Tier 1 assessment. This analysis, which includes each source category’s uncertainty assessments (or proxies) in its calculations, was also performed twice to include or exclude LULUCF sources.

In addition to conducting Tier 1 and 2 level and trend assessments, a qualitative assessment of the source categories, as described in the IPCC’s *Good Practice Guidance* (IPCC 2000), was conducted to capture any key categories that were not identified by either quantitative method. One additional key category, international bunker fuels, was identified using this qualitative assessment. International bunker fuels are fuels consumed for aviation or marine international transport activities, and emissions from these fuels are reported separately from totals in accordance with IPCC guidelines. If these emissions were included in the totals, bunker fuels would qualify as a key category according to the Tier 1 approach. The amount of uncertainty associated with estimation of emissions from international bunker fuels also supports the qualification of this source category as key, because it would qualify bunker fuels as a key category according to the Tier 2 approach.

Table 1-4 presents the key categories for the United States (including and excluding LULUCF categories) using emissions and uncertainty data in this report, and ranked according to their sector and global warming potential-weighted emissions in 2008. The table also indicates the criteria used in identifying these categories (i.e., level, trend, Tier 1, Tier 2, and/or qualitative assessments). Annex 1 of this report provides additional information regarding the key categories in the United States and the methodologies used to identify them.

²⁰ See Chapter 7 “Methodological Choice and Recalculation” in IPCC (2000). <<http://www.ipcc-nggip.iges.or.jp/public/gp/gpgaum.htm>>

Table 1-4: Key Categories for the United States (1990-2008)

IPCC Source Categories	Gas	Tier 1				Tier 2				Qual ^a	2008 Emissions (Tg CO ₂ Eq.)
		Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF		
Energy											
CO ₂ Emissions from Stationary Combustion - Coal	CO ₂	✓	✓	✓	✓	✓	✓	✓	✓		2,076.6
CO ₂ Emissions from Mobile Combustion: Road & Other	CO ₂	✓	✓	✓	✓	✓	✓	✓	✓		1,591.6
CO ₂ Emissions from Stationary Combustion - Gas	CO ₂	✓	✓	✓	✓	✓	✓	✓	✓		1,191.2
CO ₂ Emissions from Stationary Combustion - Oil	CO ₂	✓	✓	✓	✓	✓	✓	✓	✓		519.4
CO ₂ Emissions from Mobile Combustion: Aviation	CO ₂	✓	✓	✓	✓		✓	✓			155.5
CO ₂ Emissions from Non-Energy Use of Fuels	CO ₂	✓		✓	✓	✓		✓			134.2
CO ₂ Emissions from Mobile Combustion: Marine	CO ₂	✓	✓	✓							38.1
CO ₂ Emissions from Natural Gas Systems	CO ₂	✓	✓	✓		✓	✓	✓	✓		30.0
Fugitive CH ₄ Emissions from Natural Gas Systems	CH ₄	✓	✓	✓	✓	✓	✓	✓	✓		96.4
Fugitive CH ₄ Emissions from Coal Mining	CH ₄	✓	✓	✓	✓	✓	✓	✓	✓		67.6
Fugitive CH ₄ Emissions from Petroleum Systems	CH ₄	✓	✓	✓		✓	✓	✓	✓		29.1
N ₂ O Emissions from Mobile Combustion: Road & Other	N ₂ O	✓	✓	✓			✓		✓		24.1
Non-CO ₂ Emissions from Stationary Combustion	N ₂ O					✓		✓			14.2
International Bunker Fuels ^b	Several									✓	136.6
Industrial Processes											
CO ₂ Emissions from Iron and Steel Production & Metallurgical Coke Production	CO ₂	✓	✓	✓	✓	✓	✓	✓	✓		69.0
CO ₂ Emissions from Cement Production	CO ₂	✓		✓	✓						41.1
CO ₂ Emissions from Ammonia Production and Urea Consumption	CO ₂		✓								11.8
N ₂ O Emissions from Adipic Acid Production	N ₂ O		✓				✓		✓		2.0
Emissions from Substitutes for Ozone Depleting Substances	Several	✓	✓	✓	✓	✓	✓	✓	✓		113.0
HFC-23 Emissions from HCFC-22 Production	HFCs	✓	✓	✓							13.6
SF ₆ Emissions from Electrical Transmission and Distribution	SF ₆		✓				✓		✓		13.1
PFC Emissions from Aluminum Production	PFCs		✓								2.7
Agriculture											
CH ₄ Emissions from Enteric Fermentation	CH ₄	✓	✓	✓	✓	✓		✓			140.8
CH ₄ Emissions from Manure Management	CH ₄	✓	✓	✓	✓	✓	✓	✓	✓		45.0
Direct N ₂ O Emissions from Agricultural Soil Management	N ₂ O	✓		✓	✓	✓	✓	✓			170.4
Indirect N ₂ O Emissions from Applied Nitrogen	N ₂ O	✓	✓	✓	✓	✓	✓	✓	✓		45.5
N ₂ O Emissions from Manure Management	N ₂ O					✓		✓			17.1
Waste											
CH ₄ Emissions from Landfills	CH ₄	✓	✓	✓	✓	✓	✓	✓	✓		126.3
Land Use, Land Use Change, and Forestry											
CO ₂ from Changes in Forest Carbon Stocks	CO ₂			✓	✓			✓	✓		(791.9)
CO ₂ Emissions from Urban Trees	CO ₂			✓	✓			✓	✓		(93.9)

Table 1-4: Key Categories for the United States (1990-2008) (continued)

IPCC Source Categories	Gas	Tier 1				Tier 2				Qual ^a	2008 Emissions (Tg CO ₂ Eq.)
		Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF		
CO ₂ Emissions from Cropland Remaining Cropland	CO ₂			✓				✓	✓		(18.1)
CO ₂ Emissions from Landfilled Yard Trimmings and Food Scraps	CO ₂							✓	✓		(9.5)
CO ₂ Emissions from Grassland Remaining Grassland	CO ₂			✓	✓			✓	✓		(8.7)
CH ₄ Emissions from Forest Fires	CH ₄							✓	✓		11.9
N ₂ O Emissions from Forest Fires	N ₂ O							✓	✓		9.7
Subtotal Without LULUCF											6,762.4
Total Emissions Without LULUCF											6,924.6
Percent of Total Without LULUCF											98%
Subtotal With LULUCF											5,862.0
Total Emissions With LULUCF											6,016.4
Percent of Total With LULUCF											98%

^aQualitative criteria.

^bEmissions from this source not included in totals.

Note: Parentheses indicate negative values (or sequestration).

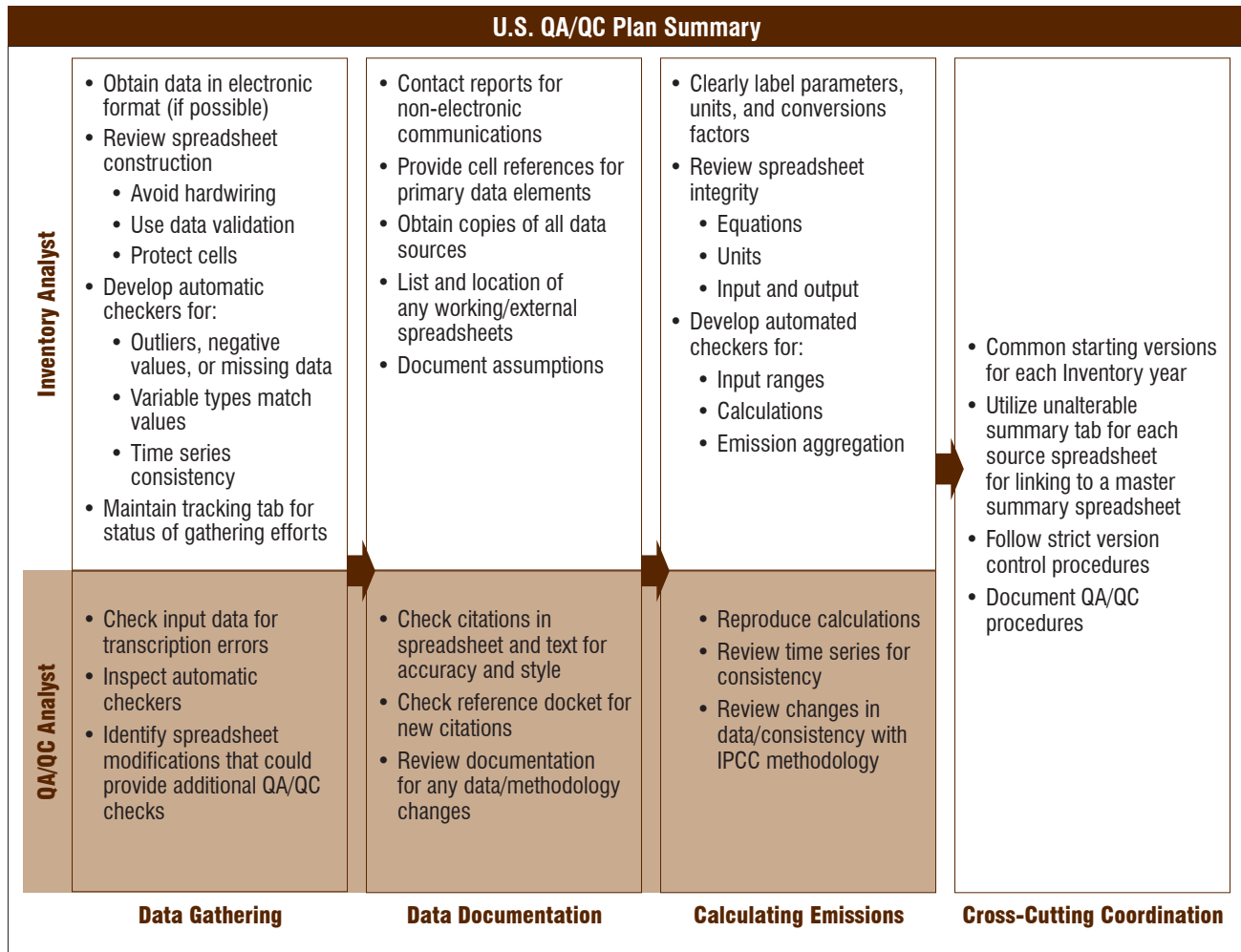
1.6. Quality Assurance and Quality Control (QA/QC)

As part of efforts to achieve its stated goals for inventory quality, transparency, and credibility, the United States has developed a quality assurance and quality control plan designed to check, document and improve the quality of its inventory over time. QA/QC activities on the Inventory are undertaken within the framework of the U.S. QA/QC plan, *Quality Assurance/Quality Control and Uncertainty Management Plan for the U.S. Greenhouse Gas Inventory: Procedures Manual for QA/QC and Uncertainty Analysis*.

Key attributes of the QA/QC plan are summarized in Figure 1-1. These attributes include:

- specific detailed procedures and forms that serve to standardize the process of documenting and archiving information, as well as to guide the implementation of QA/QC and the analysis of the uncertainty of the inventory estimates;
- expert review as well as QC—for both the inventory estimates and the Inventory (which is the primary vehicle for disseminating the results of the inventory development process). In addition, the plan provides for public review of the Inventory;
- both Tier 1 (general) and Tier 2 (source-specific) quality controls and checks, as recommended by IPCC *Good Practice Guidance*;
- consideration of secondary data quality and source-specific quality checks (Tier 2 QC) in parallel and coordination with the uncertainty assessment; the development of protocols and templates provides for more structured communication and integration with the suppliers of secondary information;
- record-keeping provisions to track which procedures have been followed, and the results of the QA/QC and uncertainty analysis, and contains feedback mechanisms for corrective action based on the results of the investigations, thereby providing for continual data quality improvement and guided research efforts;
- implementation of QA/QC procedures throughout the whole inventory development process—from initial data collection, through preparation of the emission estimates, to publication of the Inventory;
- a schedule for multi-year implementation; and
- promotion of coordination and interaction within the EPA, across Federal agencies and departments, state government programs, and research institutions and consulting firms involved in supplying data or preparing

Figure 1-1



estimates for the inventory. The QA/QC plan itself is intended to be revised and reflect new information that becomes available as the program develops, methods are improved, or additional supporting documents become necessary.

In addition, based on the national QA/QC plan for the Inventory, source-specific QA/QC plans have been developed for a number of sources. These plans follow the procedures outlined in the national QA/QC plan, tailoring the procedures to the specific text and spreadsheets of the individual sources. For each greenhouse gas emissions source or sink included in this Inventory, a minimum of a Tier 1 QA/QC analysis has been undertaken. Where QA/QC activities for a particular source go beyond the minimum Tier 1 level, further explanation is provided within the respective source category text.

The quality control activities described in the U.S. QA/QC plan occur throughout the inventory process; QA/QC is not separate from, but is an integral part of, preparing the Inventory. Quality control—in the form of both good practices (such as documentation procedures) and checks on whether good practices and procedures are being followed—is applied at every stage of inventory development and document preparation. In addition, quality assurance occurs at two stages—an expert review and a public review. While both phases can significantly contribute to inventory quality, the public review phase is also essential for promoting the openness of the inventory development process and the transparency of the inventory data and methods.

The QA/QC plan guides the process of ensuring inventory quality by describing data and methodology checks, developing processes governing peer review and public comments, and developing guidance on conducting

an analysis of the uncertainty surrounding the emission estimates. The QA/QC procedures also include feedback loops and provide for corrective actions that are designed to improve the inventory estimates over time.

1.7. Uncertainty Analysis of Emission Estimates

Uncertainty estimates are an essential element of a complete and transparent emissions inventory. Uncertainty information is not intended to dispute the validity of the inventory estimates, but to help prioritize efforts to improve the accuracy of future inventories and guide future decisions on methodological choice. While the U.S. Inventory calculates its emission estimates with the highest possible accuracy, uncertainties are associated to a varying degree with the development of emission estimates for any inventory. Some of the current estimates, such as those for CO₂ emissions from energy-related activities, are considered to have minimal uncertainty associated with them. For some other categories of emissions, however, a lack of data or an incomplete understanding of how emissions are generated increases the uncertainty surrounding the estimates presented. Despite these uncertainties, the UNFCCC reporting guidelines follow the recommendation in the *1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997) and require that countries provide single point estimates for each gas and emission or removal source category. Within the discussion of each emission source, specific factors affecting the uncertainty associated with the estimates are discussed.

Additional research in the following areas could help reduce uncertainty in the U.S. Inventory:

- Incorporating excluded emission sources. Quantitative estimates for some of the sources and sinks of greenhouse gas emissions are not available at this time. In particular, emissions from some land-use activities and industrial processes are not included in the Inventory either because data are incomplete or because methodologies do not exist for estimating emissions from these source categories. See Annex 5 of this report for a discussion of the sources of greenhouse gas emissions and sinks excluded from this report.

- Improving the accuracy of emission factors. Further research is needed in some cases to improve the accuracy of emission factors used to calculate emissions from a variety of sources. For example, the accuracy of current emission factors applied to CH₄ and N₂O emissions from stationary and mobile combustion is highly uncertain.
- Collecting detailed activity data. Although methodologies exist for estimating emissions for some sources, problems arise in obtaining activity data at a level of detail in which aggregate emission factors can be applied. For example, the ability to estimate emissions of SF₆ from electrical transmission and distribution is limited due to a lack of activity data regarding national SF₆ consumption or average equipment leak rates.

The overall uncertainty estimate for the U.S. greenhouse gas emissions Inventory was developed using the IPCC Tier 2 uncertainty estimation methodology. Estimates of quantitative uncertainty for the overall greenhouse gas emissions inventory are shown below, in Table 1-5.

The IPCC provides good practice guidance on two approaches—Tier 1 and Tier 2—to estimating uncertainty for individual source categories. Tier 2 uncertainty analysis, employing the Monte Carlo Stochastic Simulation technique, was applied wherever data and resources permitted; further explanation is provided within the respective source category text and in Annex 7. Consistent with the *IPCC Good Practice Guidance* (IPCC 2000), over a multi-year timeframe, the United States expects to continue to improve the uncertainty estimates presented in this report.

Emissions calculated for the U.S. Inventory reflect current best estimates; in some cases, however, estimates are based on approximate methodologies, assumptions, and incomplete data. As new information becomes available in the future, the United States will continue to improve and revise its emission estimates. See Annex 7 of this report for further details on the U.S. process for estimating uncertainty associated with the emission estimates and for a more detailed discussion of the limitations of the current analysis and plans for improvement. Annex 7 also includes details on the uncertainty analysis performed for selected source categories.

Table 1-5: Estimated Overall Inventory Quantitative Uncertainty (Tg CO₂ Eq. and Percent)

Gas	2008 Emission Estimate ^a	Uncertainty Range Relative to Emission Estimate ^b				Mean ^c	Standard Deviation ^c
	(Tg CO ₂ Eq.)	(Tg CO ₂ Eq.)		(%)		(Tg CO ₂ Eq.)	
		Lower Bound ^d	Upper Bound ^d	Lower Bound	Upper Bound		
CO ₂	5,920.8	5,828.0	6,234.1	-2%	+5%	6,027.2	104.0
CH ₄ ^e	567.1	503.8	662.9	-11%	+17%	576.4	39.6
N ₂ O ^e	314.3	280.3	460.3	-11%	+46%	360.8	46.1
PFC, HFC & SF ₆ ^e	146.7	144.0	162.2	-2%	+11%	153.1	4.6
Total	6,949.0	6,887.2	7,360.4	-1%	+6%	7,117.5	120.9
Net Emissions (Sources and Sinks)	6,008.6	5,898.9	6,448.4	-2%	+7%	6,174.1	142.1

^a Emission estimates reported in this table correspond to emissions from only those source categories for which quantitative uncertainty was performed this year. Thus, the totals reported in this table exclude approximately 7.8 Tg CO₂ Eq. of emissions for which quantitative uncertainty was not assessed. Hence, these emission estimates do not match the final total U.S. greenhouse gas emission estimates presented in this Inventory.

^b The lower and upper bounds for emission estimates correspond to a 95 percent confidence interval, with the lower bound corresponding to 2.5th percentile and the 95th percentile corresponding to 97.5th percentile.

^c Mean value indicates the arithmetic average of the simulated emission estimates; standard deviation indicates the extent of deviation of the simulated values from the mean.

^d The lower and upper bound emission estimates for the sub-source categories do not sum to total emissions because the low and high estimates for total emissions were calculated separately through simulations.

^e The overall uncertainty estimates did not take into account the uncertainty in the GWP values for CH₄, N₂O and high GWP gases used in the inventory emission calculations for 2008.

1.8. Completeness

This report, along with its accompanying CRF reporter, serves as a thorough assessment of the anthropogenic sources and sinks of greenhouse gas emissions for the United States for the time series 1990 through 2008. Although this report is intended to be comprehensive, certain sources have been identified yet excluded from the estimates presented for various reasons. Generally speaking, sources not accounted for in this inventory are excluded due to data limitations or a lack of thorough understanding of the emission process. The United States is continually working to improve upon the understanding of such sources and seeking to find the data required to estimate related emissions. As such improvements are implemented, new emission sources are quantified and included in the Inventory. For a complete list of sources excluded, see Annex 5 of this report.

1.9. Organization of Report

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), this Inventory of U.S. Greenhouse Gas Emissions and Sinks is segregated into six sector-specific chapters, listed below in Table 1-6. In addition, chapters on Trends in Greenhouse Gas Emissions and Other information to be considered as part of the U.S. Inventory submission are included.

Within each chapter, emissions are identified by the anthropogenic activity that is the source or sink of the greenhouse gas emissions being estimated (e.g., coal mining). Overall, the following organizational structure is consistently applied throughout this report:

Chapter/IPCC Sector: Overview of emission trends for each IPCC defined sector

Source category: Description of source pathway and emission trends.

Methodology: Description of analytical methods employed to produce emission estimates and identification of data references, primarily for activity data and emission factors.

Uncertainty: A discussion and quantification of the uncertainty in emission estimates and a discussion of time-series consistency.

QA/QC Verification: A discussion on steps taken to QA/QC and verify the emission estimates, where beyond the overall U.S. QA/QC plan, and any key findings.

Recalculations: A discussion of any data or methodological changes that necessitate a recalculation of previous years' emission estimates, and the impact of the recalculation on the emission estimates, if applicable.

Planned Improvements: A discussion on any source-specific planned improvements, if applicable.

Special attention is given to CO₂ from fossil fuel combustion relative to other sources because of its share of emissions and its dominant influence on emission trends. For example, each energy consuming end-use sector (i.e., residential, commercial, industrial, and transportation), as well as the electricity generation sector, is described individually. Additional information for certain source categories and other topics is also provided in several Annexes listed in Table 1-7.

Table 1-6: IPCC Sector Descriptions

Chapter/IPCC Sector	Activities Included
Energy	Emissions of all greenhouse gases resulting from stationary and mobile energy activities including fuel combustion and fugitive fuel emissions.
Industrial Processes	By-product or fugitive emissions of greenhouse gases from industrial processes not directly related to energy activities such as fossil fuel combustion.
Solvent and Other Product Use	Emissions, of primarily NMVOCs, resulting from the use of solvents and N ₂ O from product uses.
Agriculture	Anthropogenic emissions from agricultural activities except fuel combustion, which is addressed under Energy.
Land Use, Land-Use Change, and Forestry	Emissions and removals of CO ₂ , CH ₄ , and N ₂ O from forest management, other land-use activities, and land-use change.
Waste	Emissions from waste management activities.

Source: IPCC/UNEP/OECD/IEA (1997)

Table 1-7: List of Annexes

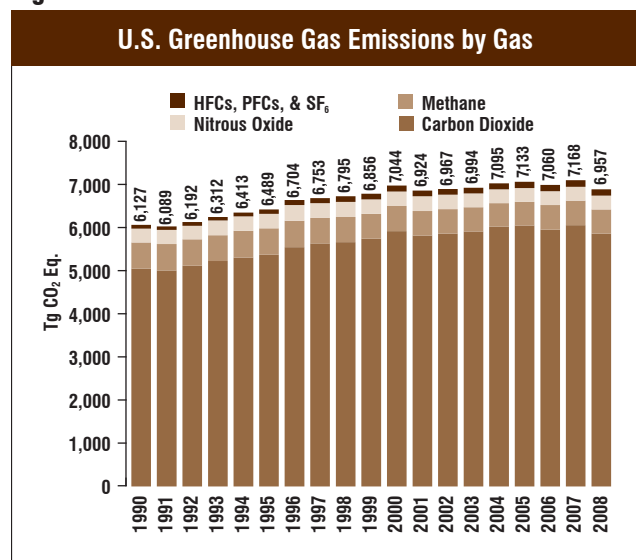
ANNEX 1	Key Category Analysis
ANNEX 2	Methodology and Data for Estimating CO₂ Emissions from Fossil Fuel Combustion 2.1. Methodology for Estimating Emissions of CO ₂ from Fossil Fuel Combustion 2.2. Methodology for Estimating the Carbon Content of Fossil Fuels 2.3. Methodology for Estimating Carbon Emitted from Non-Energy Uses of Fossil Fuels
ANNEX 3	Methodological Descriptions for Additional Source or Sink Categories 3.1. Methodology for Estimating Emissions of CH ₄ , N ₂ O, and Indirect Greenhouse Gases from Stationary Combustion 3.2. Methodology for Estimating Emissions of CH ₄ , N ₂ O, and Indirect Greenhouse Gases from Mobile Combustion and Methodology for and Supplemental Information on Transportation-Related Greenhouse Gas Emissions 3.3. Methodology for Estimating CH ₄ Emissions from Coal Mining 3.4. Methodology for Estimating CH ₄ Emissions from Natural Gas Systems 3.5. Methodology for Estimating CH ₄ and CO ₂ Emissions from Petroleum Systems 3.6. Methodology for Estimating CO ₂ and N ₂ O Emissions from Incineration of Waste 3.7. Methodology for Estimating Emissions from International Bunker Fuels used by the U.S. Military 3.8. Methodology for Estimating HFC and PFC Emissions from Substitution of Ozone Depleting Substances 3.9. Methodology for Estimating CH ₄ Emissions from Enteric Fermentation 3.10. Methodology for Estimating CH ₄ and N ₂ O Emissions from Manure Management 3.11. Methodology for Estimating N ₂ O Emissions from Agricultural Soil Management 3.12. Methodology for Estimating Net Carbon Stock Changes in Forest Lands Remaining Forest Lands 3.13. Methodology for Estimating Net Changes in Carbon Stocks in Mineral and Organic Soils on Croplands and Grasslands 3.14. Methodology for Estimating CH ₄ Emissions from Landfills
ANNEX 4	IPCC Reference Approach for Estimating CO₂ Emissions from Fossil Fuel Combustion
ANNEX 5	Assessment of the Sources and Sinks of Greenhouse Gas Emissions Excluded
ANNEX 6	Additional Information 6.1. Global Warming Potential Values 6.2. Ozone Depleting Substance Emissions 6.3. Sulfur Dioxide Emissions 6.4. Complete List of Source Categories 6.5. Constants, Units, and Conversions 6.6. Abbreviations 6.7. Chemical Formulas
ANNEX 7	Uncertainty 7.1. Overview 7.2. Methodology and Results 7.3. Planned Improvements 7.4. Additional Information on Uncertainty Analyses by Source

2. Trends in Greenhouse Gas Emissions

2.1. Recent Trends in U.S. Greenhouse Gas Emissions and Sinks

In 2008, total U.S. greenhouse gas emissions were 6,956.8 teragrams of carbon dioxide equivalents (Tg CO₂ Eq.); net emissions were 6,016.4 Tg CO₂ Eq. reflecting the influence of sinks (net CO₂ flux from Land Use, Land Use Change, and Forestry).¹ Overall, total U.S. emissions have risen by almost 14 percent from 1990 to 2008. Emissions decreased from 2007 to 2008 by 2.9 percent (211.3 Tg CO₂ Eq.). The following factors were primary contributors to this decrease: (1) a decrease in electricity demand and a resulting decrease in energy consumption, (2) higher energy prices leading to a decrease in energy consumption, and (3) cooler summer conditions in 2008 compared to 2007 reducing energy demand and offsetting the increased energy demand for heating in the colder winter. In addition, the high price of gasoline combined with the economic downturn led to a significant decline in petroleum consumption by the transportation sector in 2008. Figure 2-1 through Figure 2-3 illustrate the overall trend in total U.S. emissions by gas, annual changes, and absolute changes since 1990.

Figure 2-1



As the largest source of U.S. greenhouse gas emissions, carbon dioxide (CO₂) from fossil fuel combustion has accounted for approximately 79 percent of global warming potential (GWP) weighted emissions since 1990, growing slowly from 77 percent of total GWP-weighted emissions in 1990 to 80 percent in 2008. Emissions from this source category grew by 17.7 percent (837.1 Tg CO₂ Eq.) from 1990 to 2008 and were responsible for most of the increase in national emissions during this period. From 2007 to 2008, these emissions decreased by 3.2 percent (184.2 Tg CO₂ Eq.). Historically, changes in emissions from fossil fuel combustion have been the dominant factor affecting U.S. emission trends.

Changes in CO₂ 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

¹ Estimates are presented in units of teragrams of carbon dioxide equivalent (Tg CO₂ Eq.), which weight each gas by its global warming potential, or GWP, value. (See section on global warming potentials, Executive Summary.)

Figure 2-2

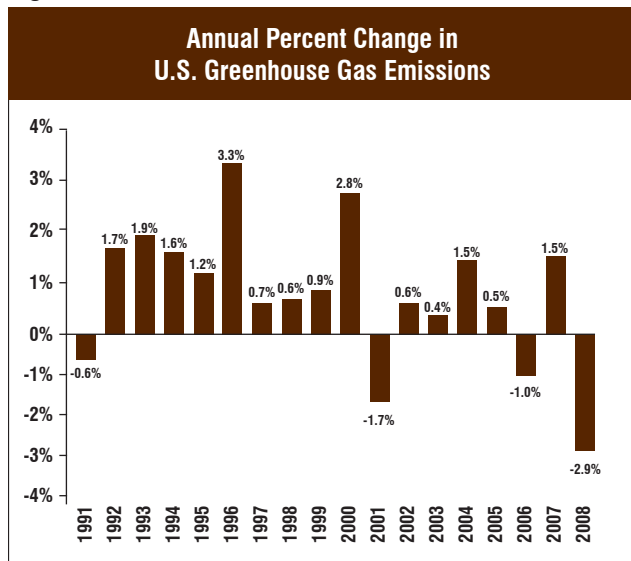
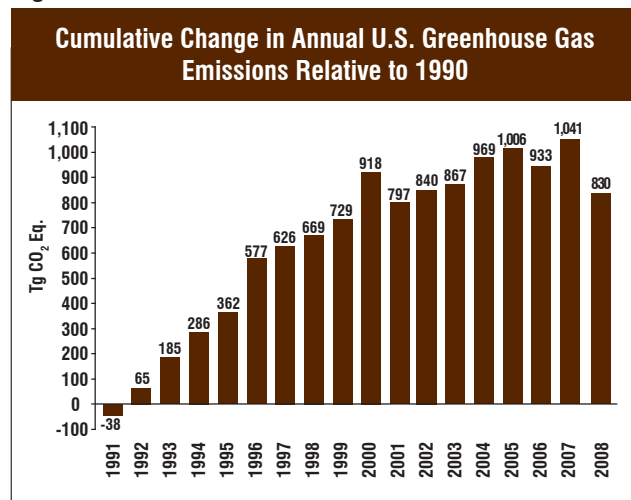


Figure 2-3



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

In the longer-term, energy consumption patterns respond to changes that affect the scale of consumption (e.g., population, number of cars, and size of houses), the efficiency

with which energy is used in equipment (e.g., cars, power plants, steel mills, and light bulbs) and consumer behavior (e.g., walking, bicycling, or telecommuting to work instead of driving).

Energy-related CO₂ emissions also depend on the type of fuel or energy consumed and its carbon (C) intensity. Producing a unit of heat or electricity using natural gas instead of coal, for example, can reduce the CO₂ emissions because of the lower C content of natural gas.

A brief discussion of the year-to-year variability in fuel combustion emissions is provided below, beginning with 2004.

Emissions from fuel combustion increased from 2004 to 2005 at a rate slightly lower than the average annual growth rate since 1990. A number of factors played a role in this slight increase. This small increase is primarily a result of the restraint on fuel consumption, primarily in the transportation sector, caused by rising fuel prices. Although electricity prices increased slightly, there was a significant increase in electricity consumption in the residential and commercial sectors due to warmer summer weather conditions. This led to an increase in emissions in these sectors with the increased use of air-conditioners. As the amount of fuels used to generate electricity increased among all end-use sectors, electricity emissions increased as well. Despite a slight decrease in industrial energy-related emissions, industrial production and manufacturing output actually increased. The price of natural gas escalated dramatically, causing a decrease in consumption of natural gas in the industrial sector. Use of renewable fuels decreased slightly due to decreased use of biofuels and decreased electricity output by hydroelectric power plants.

From 2005 to 2006, emissions from fuel combustion decreased for the first time since 2000 to 2001. This decrease occurred across all sectors, with the exception of the industrial sector, due to a number of factors. The decrease in emissions from electricity generation was a result of a smaller share of electricity generated by coal and a greater share generated by natural gas. Coal and natural gas consumption for electricity generation decreased by 1.3 percent and increased by 6.0 percent in 2006, respectively, and nuclear power increased by less than 1 percent. The transportation decrease was primarily a result of the restraint on fuel consumption caused by rising fuel prices, which directly resulted in a decrease of petroleum consumption within this sector of about 1.3 percent in 2006.

The decrease in emissions from the residential sector was primarily a result of decreased electricity consumption due to increases in the price of electricity, and warmer winter weather conditions. A moderate increase in industrial sector emissions was a result of growth in industrial output and growth in the U.S. economy. Renewable fuels used to generate electricity increased in 2006, with the greatest growth occurring in generation from wind.

After experiencing a decrease from 2005 to 2006, emissions from fuel combustion grew from 2006 to 2007 at a rate somewhat higher than the average growth rate since 1990. There were a number of factors contributing to this increase. Unfavorable weather conditions in both the winter and summer resulted in an increase in consumption of heating fuels, as well as an increase in the demand for electricity. This demand for electricity was met with an increase in coal consumption of 1.7 percent, and with an increase in natural gas consumption of 9.9 percent. This increase in fossil fuel consumption, combined with a 14.7 percent decrease in hydropower generation from 2006 to 2007, resulted in an increase in emissions in 2007. The increase in emissions from the residential and commercial sectors is a result of increased electricity consumption due to warmer summer conditions and cooler winter conditions compared to 2006. In addition to these unfavorable weather conditions, electricity prices remained relatively stable compared to 2006, and natural gas prices decreased slightly. Emissions from the industrial sector increased slightly compared to 2006 as a result of a 1.5 percent increase in industrial production and the increase in fossil fuels used for electricity generation. Despite an overall decrease in electricity generation from renewable energy in 2007 driven by decreases in hydropower generation, wind and solar generation increased significantly.

Emissions from fossil fuel combustion decreased from 2007 to 2008. Several factors contributed to this decrease in emissions. An increase in energy prices coupled with the economic downturn led to a decrease in energy demand and a resulting decrease in emissions from 2007 to 2008. In 2008, the price of coal, natural gas, and petroleum used to generate electricity, as well as the price of fuels used for transportation, increased significantly. As a result of this price increase, coal, natural gas, and petroleum consumption

used for electricity generation decreased by 1.3 percent, 2.6 percent, and 29.5 percent, respectively. The increase in the cost of fuels to generate electricity translated into an increase in the price of electricity, leading to a decrease in electricity consumption across all sectors except the commercial sector. The increase in transportation fuel prices led to a decrease in vehicle miles traveled (VMT) and a decrease of 5.7 percent in transportation fossil fuel combustion emissions from 2007 to 2008. Cooler weather conditions in the summer led to a decrease in cooling degree days by 8.7 percent and a decrease in electricity demand compared to 2007, whereas cooler winter conditions led to a 5.6 percent increase in heating degree days compared to 2007 and a resulting increase in demand for heating fuels. The increased emissions from winter heating energy demand was offset by a decrease in emissions from summer cooling related electricity demand. Lastly, renewable energy² consumption for electricity generation increased by 7.1 percent from 2007 to 2008, driven by a significant increase in solar and wind energy consumption (of 12 percent and 51 percent, respectively). This increase in renewable energy generation contributed to a decrease in the carbon intensity of electricity generation.

Overall, from 1990 to 2008, total emissions of CO₂ increased by 820.4 Tg CO₂ Eq. (16.1 percent), while CH₄ and N₂O emissions decreased by 45.8 Tg CO₂ Eq. (7.5 percent) and 4.1 Tg CO₂ Eq. (about 1.3 percent) respectively. During the same period, aggregate weighted emissions of HFCs, PFCs, and SF₆ rose by 59.4 Tg CO₂ Eq. (65.9 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, and SF₆ are significant because many of them have extremely high GWPs and, in the cases of PFCs and SF₆, long atmospheric lifetimes. Conversely, U.S. greenhouse gas emissions were partly offset by C sequestration in managed forests, trees in urban areas, agricultural soils, and landfilled yard trimmings, which was estimated to be 13.5 percent of total emissions in 2008.

Table 2-1 summarizes emissions and sinks from all U.S. anthropogenic sources in weighted units of Tg CO₂ Eq., while unweighted gas emissions and sinks in gigagrams (Gg) are provided in Table 2-2.

² Renewable energy includes the following energy sources: hydroelectric power, geothermal energy, biofuels, solar energy, and wind energy.

Table 2-1: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Tg CO₂ Eq.)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
CO₂	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
<i>Land Use, Land-Use Change, and Forestry (Sink)^a</i>	<i>(909.4)</i>	<i>(842.9)</i>	<i>(664.2)</i>	<i>(950.4)</i>	<i>(959.2)</i>	<i>(955.4)</i>	<i>(940.3)</i>
<i>Biomass - Wood^b</i>	<i>215.2</i>	<i>229.1</i>	<i>218.1</i>	<i>206.9</i>	<i>207.9</i>	<i>207.4</i>	<i>198.4</i>
<i>International Bunker Fuels^b</i>	<i>111.8</i>	<i>99.8</i>	<i>98.5</i>	<i>110.5</i>	<i>129.1</i>	<i>127.1</i>	<i>135.2</i>
<i>Biomass - Ethanol^b</i>	<i>4.2</i>	<i>7.7</i>	<i>9.2</i>	<i>22.6</i>	<i>30.5</i>	<i>38.3</i>	<i>53.3</i>
CH₄	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 2-1: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Tg CO₂ 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	+	+	+	+	+	+	+
<i>International Bunker Fuels^b</i>	<i>0.2</i>	<i>0.1</i>	<i>0.1</i>	<i>0.1</i>	<i>0.2</i>	<i>0.2</i>	<i>0.2</i>
N₂O	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 ₂ O 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	+	+	+	+	+	+	+
<i>International Bunker Fuels^b</i>	<i>1.1</i>	<i>1.0</i>	<i>0.9</i>	<i>1.0</i>	<i>1.2</i>	<i>1.2</i>	<i>1.2</i>
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
SF₆	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 CO₂ Eq.

^a The net CO₂ flux total includes both emissions and sequestration, and constitutes a sink in the United States. Sinks are only included in net emissions total. Parentheses indicate negative values or sequestration.

^b Emissions from International Bunker Fuels and Wood Biomass and Ethanol 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.

Note: One teragram (Tg) equals one million metric tons.

Table 2-2: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Gg)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
CO₂	5,100,840	5,427,306	5,977,201	6,108,424	6,017,221	6,120,220	5,921,204
Fossil Fuel Combustion	4,735,701	5,029,498	5,593,381	5,753,342	5,652,845	5,756,999	5,572,760
Electricity Generation	1,820,818	1,947,925	2,296,894	2,402,142	2,346,406	2,412,825	2,363,497
Transportation	1,485,773	1,607,972	1,809,537	1,895,323	1,876,678	1,893,749	1,785,252
Industrial	845,429	862,575	852,212	825,590	850,742	842,242	819,297
Residential	339,142	353,308	371,212	358,399	322,053	341,737	342,719
Commercial	216,656	223,204	227,674	221,261	206,024	217,355	219,467
U.S. Territories	27,882	34,513	35,853	50,626	50,941	49,090	42,528
Non-Energy Use of Fuels	119,602	142,922	146,141	136,539	141,382	135,306	134,200
Iron and Steel Production & Metallurgical Coke Production	102,564	95,748	8,110	67,731	70,539	72,802	69,010
Cement Production	33,278	36,847	41,190	45,910	46,562	45,229	41,147
Natural Gas Systems	37,317	42,249	29,394	29,472	29,526	30,816	29,973
Lime Production	11,533	13,325	14,088	14,379	15,100	14,595	14,330
Incineration of Waste	8,049	11,461	11,270	12,616	12,684	13,289	13,128
Ammonia Production and Urea Consumption	16,831	17,796	16,402	12,849	12,300	13,968	11,755
Cropland Remaining Cropland	7,084	7,049	7,541	7,854	7,875	8,319	7,638
Limestone and Dolomite Use	5,127	6,683	5,056	6,768	8,035	7,702	6,617
Aluminum Production	6,831	5,659	6,086	4,142	3,801	4,251	4,477
Soda Ash Production and Consumption	4,141	4,304	4,181	4,228	4,162	4,140	4,111
Petrochemical Production	3,311	4,101	4,479	4,181	3,837	3,931	3,449
Titanium Dioxide Production	1,195	1,526	1,752	1,755	1,836	1,930	1,809
Carbon Dioxide Consumption	1,416	1,422	1,421	1,321	1,709	1,867	1,780
Ferroalloy Production	2,152	2,036	1,893	1,392	1,505	1,552	1,599
Phosphoric Acid Production	1,529	1,513	1,382	1,386	1,167	1,166	1,187
Wetlands Remaining Wetlands	1,033	1,018	1,227	1,079	879	1,012	941
Petroleum Systems	555	528	534	490	488	474	453
Zinc Production	929	993	1,115	506	513	411	402
Lead Production	285	298	311	266	270	267	264
Silicon Carbide Production and Consumption	375	329	248	219	207	196	175
<i>Land Use, Land-Use Change, and Forestry (Sink)^a</i>	<i>(909,422)</i>	<i>(842,852)</i>	<i>(664,247)</i>	<i>(950,396)</i>	<i>(959,158)</i>	<i>(955,410)</i>	<i>(940,349)</i>
<i>Wood Biomass and Ethanol Consumption^b</i>	<i>219,341</i>	<i>236,775</i>	<i>227,276</i>	<i>229,419</i>	<i>238,323</i>	<i>245,706</i>	<i>251,763</i>
<i>International Bunker Fuels^b</i>	<i>111,828</i>	<i>99,817</i>	<i>98,482</i>	<i>110,505</i>	<i>129,104</i>	<i>127,054</i>	<i>135,226</i>
CH₄	29,209	29,202	27,903	26,341	27,058	27,105	27,030
Enteric Fermentation	6,303	6,844	6,513	6,509	6,619	6,723	6,707
Landfills	7,111	6,860	5,747	5,980	6,050	6,023	6,016
Natural Gas Systems	6,169	6,313	6,223	4,935	4,907	4,738	4,591
Coal Mining	4,003	3,193	2,877	2,710	2,776	2,765	3,221
Manure Management	1,395	1,612	1,837	2,011	2,015	2,183	2,144
Petroleum Systems	1,613	1,524	1,439	1,344	1,344	1,372	1,384
Wastewater Treatment	1,120	1,183	1,199	1,158	1,166	1,162	1,158
Forest Land Remaining Forest Land	152	203	681	467	1,027	953	568
Rice Cultivation	339	363	357	326	282	295	343
Stationary Combustion	353	340	315	312	294	309	319
Abandoned Underground Coal Mines	288	392	350	266	264	269	281
Mobile Combustion	223	204	160	119	112	105	97
Composting	15	35	60	75	75	79	80
Field Burning of Agricultural Residues	36	35	42	44	43	46	46

Table 2-2: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Gg) (continued)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
Petrochemical Production	41	52	59	51	48	48	43
Iron and Steel Production & Metallurgical Coke Production	46	47	44	34	35	33	31
Ferroalloy Production	1	1	1	+	+	+	+
Silicon Carbide Production and Consumption	1	1	1	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
<i>International Bunker Fuels^b</i>	8	6	6	7	8	7	8
N₂O	1,040	1,105	1,115	1,059	1,063	1,057	1,026
Agricultural Soil Management	656	664	678	696	681	681	696
Mobile Combustion	142	174	172	119	108	98	84
Nitric Acid Production	61	68	67	57	56	66	61
Manure Management	47	50	54	54	56	56	55
Stationary Combustion	41	43	47	47	47	47	46
Forest Land Remaining Forest Land	9	12	39	27	58	54	33
Wastewater Treatment	12	13	14	15	15	16	16
N ₂ O from Product Uses	14	15	16	14	14	14	14
Adipic Acid Production	51	57	18	16	14	12	7
Composting	1	3	4	6	6	6	6
Settlements Remaining Settlements	3	4	4	5	5	5	5
Field Burning of Agricultural Residues	1	1	2	2	2	2	2
Incineration of Waste	2	1	1	1	1	1	1
Wetlands Remaining Wetlands	+	+	+	+	+	+	+
<i>International Bunker Fuels^b</i>	3	3	3	3	4	4	4
HFCs	M	M	M	M	M	M	M
Substitution of Ozone Depleting Substances ^c	M	M	M	M	M	M	M
HCFC-22 Production	3	3	2	1	1	1	1
Semiconductor Manufacture	+	+	+	+	+	+	+
PFCs	M	M	M	M	M	M	M
Aluminum Production	M	M	M	M	M	M	M
Semiconductor Manufacture	M	M	M	M	M	M	M
SF₆	1	1	1	1	1	1	1
Electrical Transmission and Distribution	1	1	1	1	1	1	1
Magnesium Production and Processing	+	+	+	+	+	+	+
Semiconductor Manufacture	+	+	+	+	+	+	+

+ Does not exceed 0.5 Gg.

M Mixture of multiple gases.

^a The net CO₂ flux total includes both emissions and sequestration, and constitutes a sink in the United States. Sinks are only included in net emissions total. Parentheses indicate negative values or sequestration.

^b Emissions from International Bunker Fuels and Wood Biomass and Ethanol Consumption 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.

Emissions of all gases can be summed from each source category from Intergovernmental Panel on Climate Change (IPCC) guidance. Over the nineteen-year period of 1990 to 2008, total emissions in the Energy, Industrial Processes, and Agriculture sectors grew by 775.0 Tg CO₂ Eq. (15 percent), 16.2 Tg CO₂ Eq. (5 percent), and 39.7 Tg CO₂ Eq.

(10 percent), respectively. Emissions decreased in the Waste and Solvent and Other Product Use sectors by 18.1 Tg CO₂ Eq. (10 percent) and less than 0.1 Tg CO₂ Eq. (less than 0.4 percent), respectively. Over the same period, estimates of net C sequestration in the Land Use, Land-Use Change, and Forestry sector increased by 30.9 Tg CO₂ Eq. (3.4 percent).

Table 2-3: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (Tg CO₂ 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 CO₂ 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.

Figure 2-4

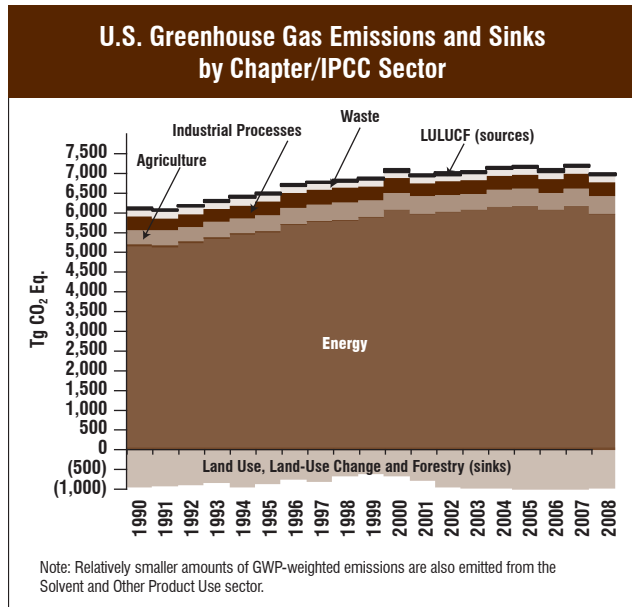
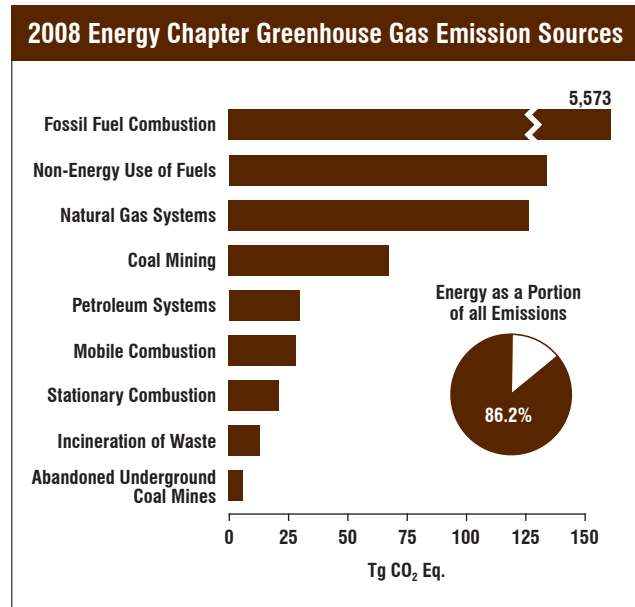


Figure 2-5



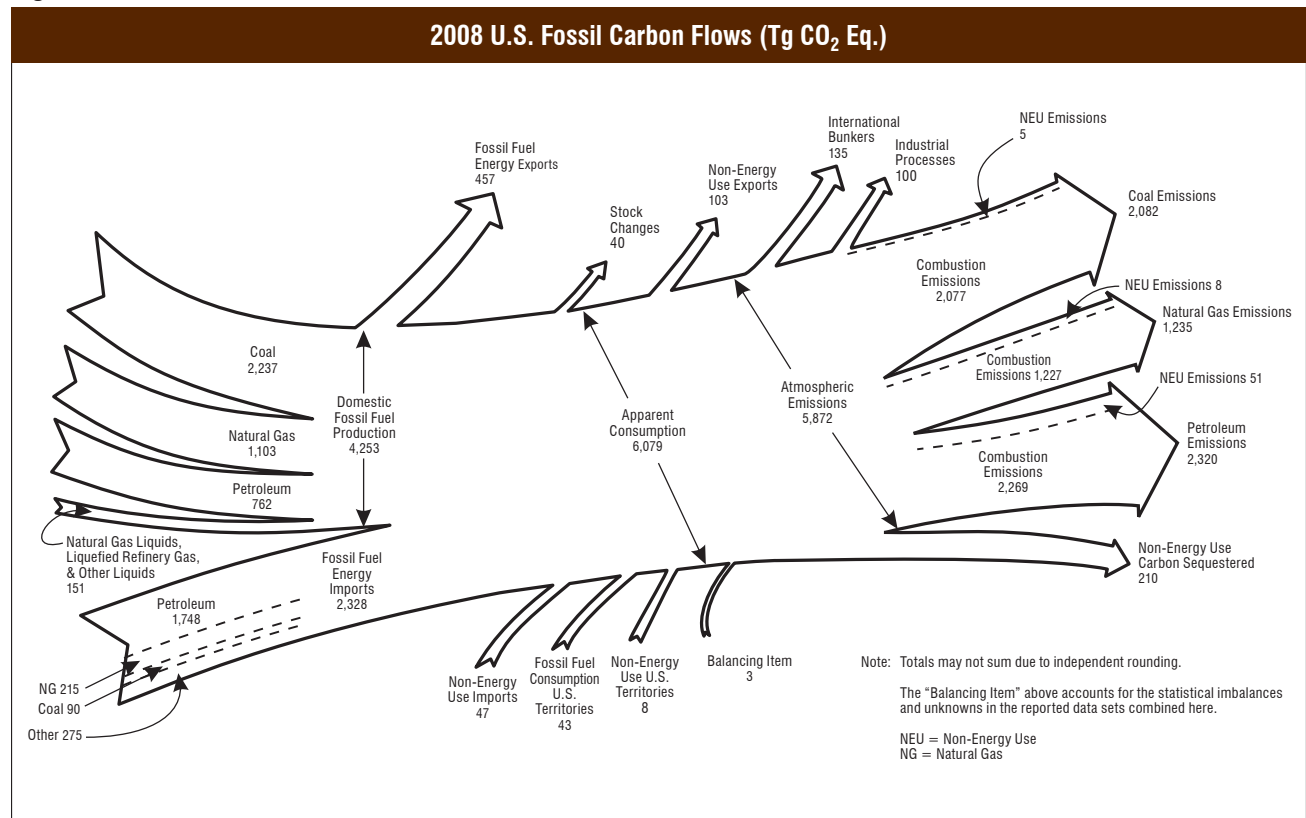
Energy

Energy-related activities, primarily fossil fuel combustion, accounted for the vast majority of U.S. CO₂ 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 2-5 and Figure 2-6). A discussion of specific trends related to CO₂ as well as other greenhouse gas emissions from energy consumption is presented in the Energy chapter. Energy-related activities are also responsible for CH₄ and N₂O emissions (37 percent and 13 percent of total U.S. emissions of each gas, respectively).

Table 2-4 presents greenhouse gas emissions from the Energy chapter, by source and gas.

Carbon dioxide emissions from fossil fuel combustion are presented in Table 2-5 based on the underlying U.S. energy consumer data collected by EIA. Estimates of CO₂ emissions from fossil fuel combustion are calculated from these EIA “end-use sectors” based on total consumption and appropriate fuel properties (any additional analysis and refinement of the EIA data is further explained in the Energy chapter of this report). EIA’s fuel consumption data for the electric power sector comprises electricity-only and combined-heat-and-power (CHP) plants within the NAICS 22 category whose primary business is to sell electricity, or electricity and heat, to the public (nonutility power

Figure 2-6



producers can be included in this sector as long as they meet they electric power sector definition). EIA statistics for the industrial sector include fossil fuel consumption that occurs in the fields of manufacturing, agriculture, mining, and construction. EIA’s fuel consumption data for the transportation sector consists of all vehicles whose primary purpose is transporting people and/or goods from one physical location to another. EIA’s fuel consumption data for the industrial sector consists of all facilities and equipment used for producing, processing, or assembling goods (EIA includes generators that produce electricity and/or useful thermal output primarily to support on-site industrial activities in this sector). EIA’s fuel consumption data for the residential sector consists of living quarters for private households. EIA’s fuel consumption data for the commercial sector consists of service-providing facilities and equipment from private and public organizations and businesses (EIA includes generators that produce electricity and/or useful thermal output primarily to support the activities at commercial establishments in this sector). Table 2-5, Figure 2-7, and Figure 2-8 summarize CO₂ emissions from fossil fuel combustion by end-use sector.

The main driver of emissions in the energy sector is CO₂ from fossil fuel combustion. The transportation end-use sector accounted for 1,789.9 Tg CO₂ Eq. in 2008, or approximately 32 percent of total CO₂ emissions from fossil

Figure 2-7

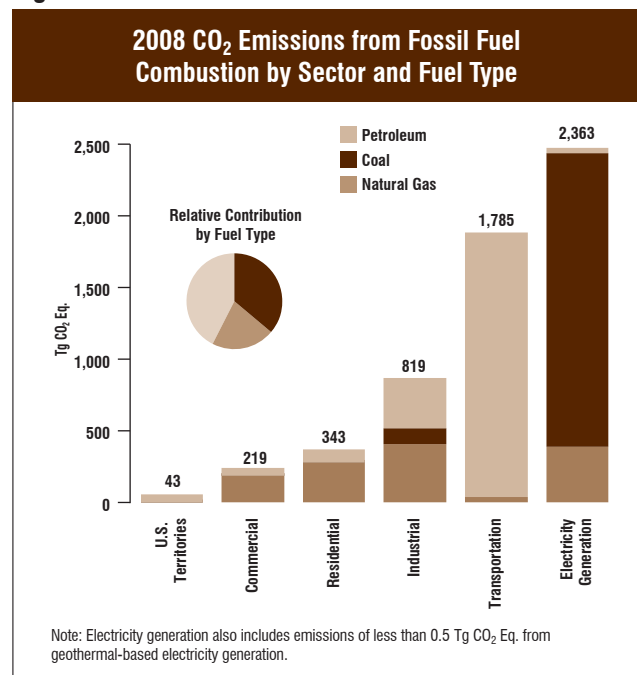


Table 2-4: Emissions from Energy (Tg CO₂ Eq.)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
CO₂	4,901.2	5,226.7	5,780.7	5,932.5	5,836.9	5,936.9	5,750.5
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	845.5	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
Natural Gas Systems	37.3	42.2	29.4	29.5	29.5	30.8	30.0
Incineration of Waste	8.0	11.5	11.3	12.6	12.7	13.3	13.1
Petroleum Systems	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Wood Biomass and Ethanol Consumption ^a	219.3	236.8	227.3	229.4	238.3	245.7	251.8
International Bunker Fuels ^a	111.8	99.8	98.5	110.5	129.1	127.1	135.2
CH₄	265.6	251.3	238.7	203.4	203.6	200.7	207.8
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
Petroleum Systems	33.9	32.0	30.2	28.2	28.2	28.8	29.1
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
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels ^a	0.2	0.1	0.1	0.1	0.2	0.2	0.2
N₂O	57.2	67.8	68.1	52.0	48.5	45.3	40.8
Mobile Combustion	43.9	54.0	53.2	36.9	33.6	30.3	26.1
Stationary Combustion	12.8	13.3	14.5	14.7	14.5	14.6	14.2
Incineration of Waste	0.5	0.5	0.4	0.4	0.4	0.4	0.4
International Bunker Fuels ^a	1.1	0.9	0.9	1.0	1.2	1.2	1.2
Total	5,224.1	5,545.8	6,087.5	6,187.9	6,089.1	6,182.9	5,999.0

+ Does not exceed 0.05 Tg CO₂ Eq.
^a These values are presented for informational purposes only and are not included in totals or are already accounted for in other source categories.
Note: Totals may not sum due to independent rounding.

fuel combustion, the largest share of any end-use sector.³ The industrial end-use sector accounted for 27 percent of CO₂ emissions from fossil fuel combustion. The residential and commercial end-use sectors accounted for an average 21 and 19 percent, respectively, of CO₂ emissions from fossil fuel combustion. Both end-use sectors were heavily reliant on electricity for meeting energy needs, with electricity consumption for lighting, heating, air conditioning, and operating appliances contributing to about 71 and 79 percent of emissions from the residential and commercial end-use sectors, respectively. Significant trends in emissions from

energy source categories over the nineteen-year period from 1990 through 2008 included the following:

- Total CO₂ emissions from fossil fuel combustion increased from 4,735.7 Tg CO₂ Eq. to 5,572.8 Tg CO₂ Eq.—an 18 percent total increase over the nineteen-year period. From 2007 to 2008, these emissions decreased by 184.2 Tg CO₂ Eq. (3.2 percent).
- Carbon dioxide emissions from non-energy use of fossil fuels have increased 14.6 Tg CO₂ Eq. (12.2 percent) from 1990 through 2008. Emissions from non-energy uses of fossil fuels were 134.2 Tg CO₂ Eq. in 2008, which constituted 2.3 percent of total national CO₂ emissions.

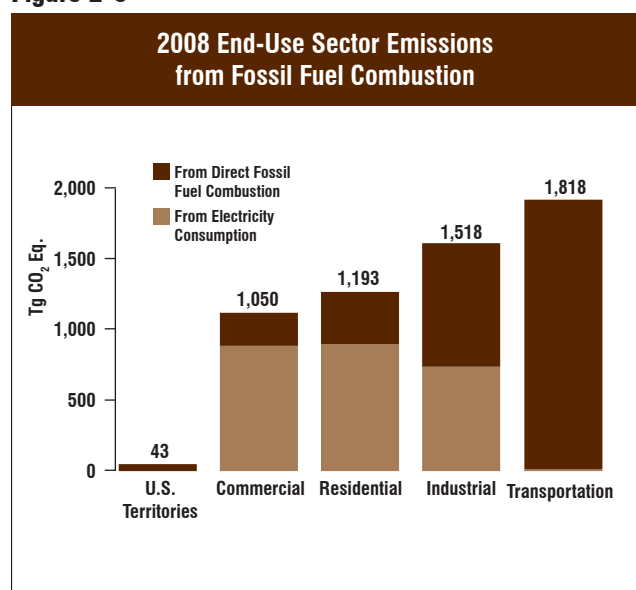
³ Note that electricity generation is the largest emitter of CO₂ when electricity is not distributed among end-use sectors.

Table 2-5: CO₂ Emissions from Fossil Fuel Combustion by Fuel Consuming End-Use Sector (Tg CO₂ 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	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.

Figure 2-8



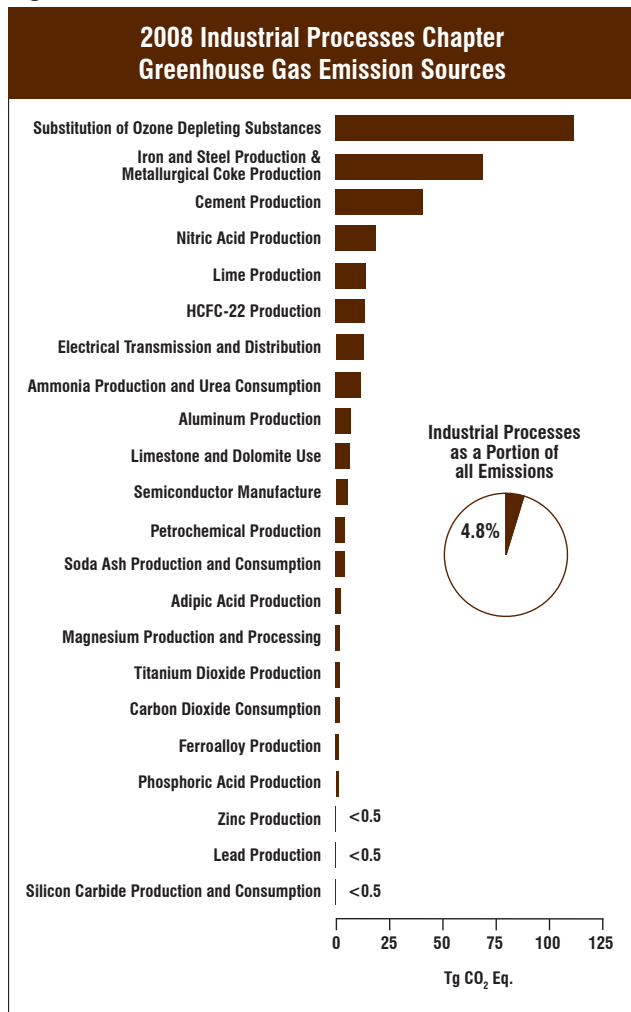
- Methane emissions from natural gas systems were 96.4 Tg CO₂ Eq. in 2008; emissions have declined by 33.1 Tg CO₂ Eq. (25.6 percent) since 1990. This decline has been due to improvements in technology and management practices, as well as replacement of old equipment.
- Methane emissions from coal mining were 67.6 Tg CO₂ Eq. In 2008, a decline in emissions of 16.4 Tg CO₂ Eq. (19.5 percent) from 1990, is a result of the mining of less gassy coal from underground mines and the increased use of CH₄ collected from degasification systems.

- In 2008, N₂O emissions from mobile combustion were 26.1 Tg CO₂ Eq. (approximately 8.2 percent of U.S. N₂O emissions). From 1990 to 2008, N₂O emissions from mobile combustion decreased by 40.5 percent. However, from 1990 to 1998 emissions increased by 26 percent, due to control technologies that reduced NO_x emissions while increasing N₂O emissions. Since 1998, newer control technologies have led to a steady decline in N₂O from this source.
- Carbon dioxide emissions from incineration of waste (13.1 Tg CO₂ Eq. in 2008) increased by 5.1 Tg CO₂ Eq. (63 percent) from 1990 through 2008, as the volume of plastics and other fossil carbon-containing materials in municipal solid waste grew.

Industrial Processes

Greenhouse gas emissions are produced as the byproducts of many non-energy-related industrial activities. For example, industrial processes can chemically transform raw materials, which often release waste gases such as CO₂, CH₄, and N₂O. 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,

Figure 2-9



phosphoric acid production, ferroalloy production, CO₂ consumption, silicon carbide production and consumption, aluminum production, petrochemical production, nitric acid production, adipic acid production, lead production, and zinc production (see Figure 2-9). Industrial processes also release HFCs, PFCs and SF₆. In addition to their use as ODS substitutes, HFCs, PFCs, SF₆, and other fluorinated compounds are employed and emitted by a number of other industrial sources in the United States. These industries include aluminum production, HCFC-22 production, semiconductor manufacture, electric power transmission and distribution, and magnesium metal production and processing. Table 2-6 presents greenhouse gas emissions from industrial processes by source category.

Overall, emissions from industrial processes increased by 5.1 percent from 1990 to 2008 despite decreases in emissions from several industrial processes, such as iron and steel production and metallurgical coke production,

aluminum production, HCFC-22 production, and electrical transmission and distribution. The increase in overall emissions was driven by a rise in the emissions originating from cement manufacture and, primarily, the emissions from the use of substitutes for ozone depleting substances. Significant trends in emissions from industrial processes source categories over the nineteen-year period from 1990 through 2008 included the following:

- HFC emissions from ODS substitutes have been increasing from small amounts in 1990 to 113.0 Tg CO₂ Eq. in 2008. This increase results from efforts to phase out CFCs and other ODSs in the United States. In the short term, this trend is expected to continue, and will likely accelerate over the next decade as HCFCs—which are interim substitutes in many applications—are phased out under the provisions of the Copenhagen Amendments to the Montreal Protocol.
- Carbon dioxide and CH₄ emissions from iron and steel production and metallurgical coke production decreased by 5.2 percent to 69.7 Tg CO₂ Eq. in 2008, and have declined overall by 33.9 Tg CO₂ Eq. (32.7 percent) from 1990 through 2008, due to restructuring of the industry, technological improvements, and increased scrap utilization.
- PFC emissions from aluminum production decreased by about 85 percent (15.8 Tg CO₂ Eq.) from 1990 to 2008, due to both industry emission reduction efforts and lower domestic aluminum production.
- Nitrous oxide emissions from adipic acid production were 2.0 Tg CO₂ Eq. in 2008, and have decreased significantly in recent years from the widespread installation of pollution control measures. These emissions from adipic acid production have decreased nearly 87 percent since 1990, and except for slight increases in 2002 and 2003 these declined by 62 percent from 1998 to 2008.
- Carbon dioxide emissions from ammonia production and urea application (11.8 Tg CO₂ Eq. in 2008) have decreased by 5.1 Tg CO₂ Eq. (30 percent) since 1990, due to a decrease in domestic ammonia production. This decrease in ammonia production can be attributed to market fluctuations and high natural gas prices.

Table 2-6: Emissions from Industrial Processes (Tg CO₂ Eq.)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
CO₂	191.5	192.6	187.7	167.0	171.5	174.0	162.1
Iron and Steel Production & Metallurgical Coke Production	102.6	95.7	88.1	67.7	70.5	72.8	69.0
<i>Iron and Steel Production</i>	97.1	90.7	83.7	63.9	66.9	69.0	63.7
<i>Metallurgical Coke Production</i>	5.5	5.0	4.4	3.8	3.7	3.8	5.3
Cement Production	33.3	36.8	41.2	45.9	46.6	45.2	41.1
Lime Production	11.5	13.3	14.1	14.4	15.1	14.6	14.3
Ammonia Production & Urea Consumption	16.8	17.8	16.4	12.8	12.3	14.0	11.8
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 Manufacture 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
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
CH₄	1.9	2.1	2.2	1.8	1.7	1.7	1.6
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
<i>Iron and Steel Production</i>	1.0	1.0	0.9	0.7	0.7	0.7	0.6
<i>Metallurgical Coke Production</i>	+	+	+	+	+	+	+
Ferroalloy Production	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+
N₂O	34.7	38.6	26.3	22.6	21.5	24.2	21.1
Nitric Acid Production	18.9	21.0	20.7	17.6	17.2	20.5	19.0
Adipic Acid Production	15.8	17.6	5.5	5.0	4.3	3.7	2.0
HFCs	36.9	62.2	103.2	119.3	121.8	127.4	126.9
Substitution of Ozone Depleting Substances ^a	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 Manufacturing HFCs	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
Semiconductor Manufacturing PFCs	2.2	3.8	4.9	3.2	3.5	3.6	4.0
Aluminum Production	18.5	11.8	8.6	3.0	2.5	3.8	2.7
SF₆	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 Manufacturing SF ₆	0.5	0.9	1.1	1.0	1.0	0.8	1.1
Total	318.3	339.1	351.9	334.7	339.7	350.9	334.5

+ Does not exceed 0.05 Tg CO₂ Eq.

^a Small amounts of PFC emissions also result from this source.

Note: Totals may not sum due to independent rounding.

Solvent and Other Product Use

Greenhouse gas emissions are produced as a byproduct of various solvent and other product uses. In the United States, N₂O Emissions from Product Uses, the only source of greenhouse gas emissions from this sector, accounted for 4.4 Tg CO₂ Eq., or less than 0.1 percent of total U.S. emissions in 2008 (see Table 2-7).

In 2008, N₂O emissions from product uses constituted slightly more than 1 percent of U.S. N₂O emissions. From 1990 to 2008, emissions from this source category decreased by less than 0.5 percent, though slight increases occurred in intermediate years.

Agriculture

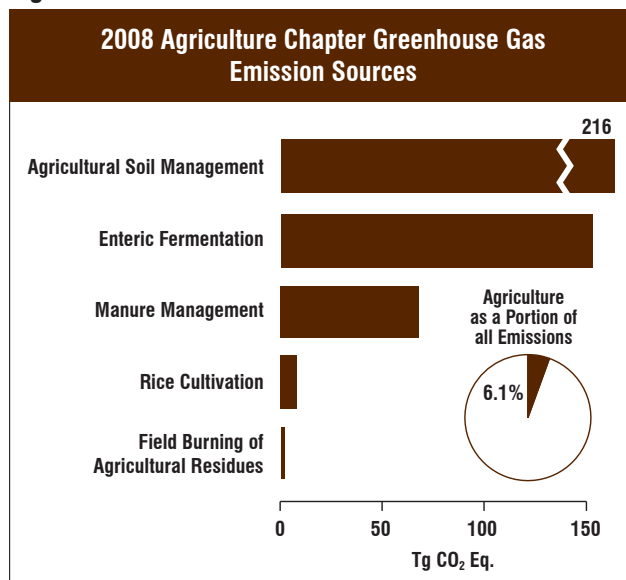
Agricultural activities contribute directly to emissions of greenhouse gases through a variety of processes, including the following source categories: enteric fermentation in domestic livestock, livestock manure management, rice cultivation, agricultural soil management, and field burning of agricultural residues.

In 2008, agricultural activities were responsible for emissions of 427.5 Tg CO₂ Eq., or 6.1 percent of total U.S. greenhouse gas emissions. Methane and N₂O were the primary greenhouse gases emitted by agricultural activities. CH₄ emissions from enteric fermentation and manure management represented about 25 percent and 8 percent of total CH₄ 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. N₂O emissions in 2008, accounting for almost 68 percent.

Some significant trends in U.S. emissions from Agriculture include the following:

- Agricultural soils produced approximately 68 percent of N₂O emissions in the United States in 2008. Estimated emissions from this source in 2008 were 215.9 Tg CO₂ Eq. Annual N₂O emissions from agricultural soils

Figure 2-10



fluctuated between 1990 and 2008, although overall emissions were 6.1 percent higher in 2008 than in 1990. Methane emissions from this source have not shown any significant long-term trend, as their estimation is 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.

- Enteric fermentation was the largest source of CH₄ emissions in 2008, at 140.8 Tg CO₂ Eq. Although emissions from enteric fermentation have increased by 6.4 percent between 1990 and 2008, emissions increased about 9 percent between 1990 and 1995 and decreased about 6 percent from 1995 to 2004, mainly due to decreasing populations of both beef and dairy cattle and improved feed quality for feedlot cattle. Emissions increased by 5 percent from 2004 through 2007, as both dairy and beef populations increased and the literature for dairy cow diets indicated a trend toward a decrease in feed digestibility. Emissions decreased again in 2008 as beef cattle populations decreased again. During this timeframe, populations of sheep have decreased 48 percent since 1990 while horse populations have

Table 2-7: N₂O Emissions from Solvent and Other Product Use (Tg CO₂ Eq.)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
N ₂ O	4.4	4.6	4.9	4.4	4.4	4.4	4.4
N ₂ O from Product Uses	4.4	4.6	4.9	4.4	4.4	4.4	4.4
Total	4.4	4.6	4.9	4.4	4.4	4.4	4.4

Table 2-8: Emissions from Agriculture (Tg CO₂ Eq.)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
CH₄	169.6	185.9	183.7	186.7	188.1	194.2	194.0
Enteric Fermentation	132.4	143.7	136.8	136.7	139.0	141.2	140.8
Manure Management	29.3	33.9	38.6	42.2	42.3	45.9	45.0
Rice Cultivation	7.1	7.6	7.5	6.8	5.9	6.2	7.2
Field Burning of Agricultural Residues	0.8	0.7	0.9	0.9	0.9	1.0	1.0
N₂O	218.3	221.8	227.2	233.0	229.1	228.8	233.5
Agricultural Soil Management	203.5	205.9	210.1	215.8	211.2	211.0	215.9
Manure Management	14.4	15.5	16.7	16.6	17.3	17.3	17.1
Field Burning of Agricultural Residues	0.4	0.4	0.5	0.5	0.5	0.5	0.5
Total	387.8	407.7	410.9	419.7	417.2	423.0	427.5

Note: Totals may not sum due to independent rounding.

increased by almost 87 percent, mostly over the last seven years. Goat and swine populations have increased 1 percent and 25 percent, respectively, during this timeframe.

- Overall, emissions from manure management increased 42 percent between 1990 and 2008. This encompassed an increase of 54 percent for CH₄, from 29.3 Tg CO₂ Eq. in 1990 to 45.0 Tg CO₂ Eq. in 2008; and an increase of almost 19 percent for N₂O, from 14.4 Tg CO₂ Eq. in 1990 to 17.1 Tg CO₂ 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 CH₄ emissions.

Land Use, Land-Use Change, and Forestry

When humans alter the terrestrial biosphere through land use, changes in land use, and land management practices, they also alter the background carbon fluxes between biomass, soils, and the atmosphere. 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 an uptake (sequestration) of carbon in the United States, which offset about 14 percent of total U.S. greenhouse gas emissions in 2008. Forests (including vegetation, soils, and harvested wood) accounted for approximately 84 percent of total 2008 net CO₂ 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, increasing forest area, and a net accumulation of carbon stocks in harvested wood pools. The net sequestration in urban forests is a result of net tree growth and increased urban forest size. 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 hay production fields, the limited use of bare-summer fallow areas in semi-arid areas, and an increase in the adoption of conservation tillage practices. 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 CO₂ Eq. (256.5 Tg C). (Table 2-9). This represents an offset of approximately 16 percent of total U.S. CO₂ 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 CO₂ sequestration.

Land use, land-use change, and forestry source categories also resulted in emissions of CO₂, CH₄, and N₂O that are not included in the net CO₂ flux estimates presented in Table 2-10. The application of crushed limestone and dolomite to managed land (i.e., soil liming) and urea fertilization resulted in CO₂ emissions of 7.6 Tg CO₂ Eq. in 2008, an increase of about 8 percent relative to 1990. Lands undergoing peat extraction resulted in CO₂ emissions of 0.9 Tg CO₂ Eq. (941 Gg), and N₂O emissions of less than 0.01 Tg CO₂ Eq. N₂O emissions from the application of synthetic

Table 2-9: Net CO₂ Flux from Land Use, Land-Use Change, and Forestry (Tg CO₂ 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 2-10: Emissions from Land Use, Land-Use Change, and Forestry (Tg CO₂ Eq.)

Source Category	1990	1995	2000	2005	2006	2007	2008
CO₂	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
Cropland Remaining Cropland: 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
CH₄	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
N₂O	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 CO₂ Eq.

Note: Totals may not sum due to independent rounding.

fertilizers to forest soils have increased from 1990 to 0.4 Tg CO₂ Eq. in 2008. Settlement soils in 2008 resulted in direct N₂O emissions of 1.6 Tg CO₂ Eq., a 61 percent increase relative to 1990. Non-CO₂ emissions from forest fires in 2008 resulted in CH₄ emissions of 11.9 Tg CO₂ Eq., and in N₂O emissions of 9.7 Tg CO₂ Eq. (Table 2-10).

Other significant trends from 1990 to 2008 in land use, land-use change, and forestry emissions include:

- Net C sequestration by forest land has increased by almost 9 percent. This is primarily due to increased forest management and the effects of previous reforestation. The increase in intensive forest management resulted in higher growth rates and higher biomass density. The tree planting and conservation efforts of the 1970s and 1980s continue to have a significant impact on sequestration rates. Finally, the forested area in the United States increased over the past 19 years, although only at an average rate of 0.23 percent per year.
- Net sequestration of C by urban trees has increased by 65 percent over the period from 1990 to 2008. This is primarily due to an increase in urbanized land area in the United States.
- Annual C sequestration in landfilled yard trimmings and food scraps has decreased by 59 percent since 1990. This is due in part to a decrease in the amount of yard trimmings and food scraps generated. In addition, the proportion of yard trimmings and food scraps landfilled has decreased, as there has been a significant rise in the number of municipal composting facilities in the United States.

Waste

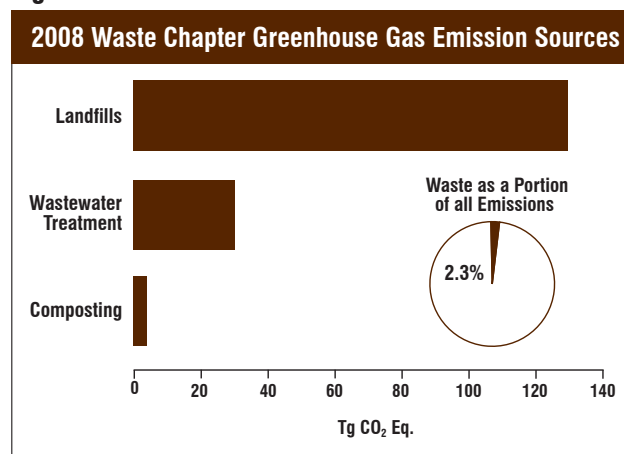
Waste management and treatment activities are sources of greenhouse gas emissions (see Figure 2-11). In 2008, landfills were the second largest source of anthropogenic CH₄ emissions, accounting for 22 percent of total U.S. CH₄ emissions.⁴ Additionally, wastewater treatment accounts for 4 percent of U.S. CH₄ emissions, and 2 percent of N₂O emissions. Emissions of CH₄ and N₂O from composting grew from 1990 to 2008, and resulted in emissions of 3.5 Tg CO₂ Eq. in 2008. A summary of greenhouse gas emissions from the Waste chapter is presented in Table 2-11.

Overall, in 2008, waste activities generated emissions of 159.1 Tg CO₂ Eq., or 2.3 percent of total U.S. greenhouse gas emissions.

Some significant trends in U.S. emissions from Waste include the following:

- From 1990 to 2008, net CH₄ emissions from landfills decreased by 23.0 Tg CO₂ Eq. (15 percent), with small increases occurring in interim years. This downward trend in overall emissions is the result of increases in the amount of landfill gas collected and combusted,⁵ which has more than offset the additional CH₄ emissions resulting from an increase in the amount of municipal solid waste landfilled.
- From 1990 to 2008, CH₄ and N₂O emissions from wastewater treatment increased by 0.8 Tg CO₂ Eq. (3.5 percent) and 1.3 Tg CO₂ Eq. (34 percent), respectively.

Figure 2-11



- Methane and N₂O emissions from composting each increased by less than 0.1 Tg CO₂ Eq. (1 percent) from 2007 to 2008. Emissions from composting have been continually increasing since 1990, from 0.7 Tg CO₂ Eq. to 3.5 Tg CO₂ Eq. in 2008, an over four-fold increase over the time series.

2.2. Emissions by Economic Sector

Throughout this report, emission estimates are grouped into six sectors (i.e., chapters) defined by the IPCC and detailed above: Energy; Industrial Processes; Solvent and Other Product Use; Agriculture; Land Use, Land-Use Change, and Forestry; and Waste. While it is important to use this characterization for consistency with UNFCCC

Table 2-11: Emissions from Waste (Tg CO₂ Eq.)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
CH₄	173.2	169.6	147.1	151.5	153.1	152.5	152.3
Landfills	149.3	144.1	120.7	125.6	127.1	126.5	126.3
Wastewater Treatment	23.5	24.8	25.2	24.3	24.5	24.4	24.3
Composting	0.3	0.7	1.3	1.6	1.6	1.7	1.7
N₂O	4.0	4.8	5.8	6.5	6.6	6.7	6.8
Wastewater Treatment	3.7	4.0	4.5	4.7	4.8	4.9	4.9
Composting	0.4	0.8	1.4	1.7	1.8	1.8	1.8
Total	177.2	174.5	153.0	158.0	159.7	159.3	159.1

Note: Totals may not sum due to independent rounding.

⁴ 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.

⁵ The CO₂ produced from combusted landfill CH₄ at landfills is not counted in national inventories as it is considered part of the natural C cycle of decomposition.

reporting guidelines, it is also useful to allocate emissions into more commonly used sectoral categories. This section reports emissions by the following U.S. economic sectors: residential, commercial, industry, transportation, electricity generation, and agriculture, as well as U.S. territories.

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). Emissions from industry accounted for about 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 efficiency improvements. The remaining 19 percent of U.S. greenhouse gas emissions were contributed by the residential, agriculture, and commercial sectors, plus emissions from U.S. territories. The residential sector accounted for 5 percent, and primarily consisted of CO₂ emissions from fossil fuel combustion. Activities related to agriculture accounted for roughly 7 percent of U.S. emissions; unlike other economic sectors, agricultural sector emissions were dominated by N₂O emissions from agricultural soil management and CH₄ emissions from enteric fermentation, rather than CO₂ from fossil fuel combustion. The commercial sector accounted for roughly 6 percent of emissions, while U.S. territories accounted for about 1 percent.

Table 2-12: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (Tg CO₂ Eq. and Percent of Total in 2008)

Sector/Source	1990	1995	2000	2005	2006	2007	2008	Percent ^a
Electric Power Industry	1,867.2	1,993.7	2,336.8	2,443.5	2,387.5	2,454.0	2,404.2	34.6%
CO ₂ from Fossil Fuel Combustion	1,820.8	1,947.9	2,296.9	2,402.1	2,346.4	2,412.8	2,363.5	34.0%
Incineration of Waste	8.5	11.9	11.7	13.0	13.1	13.7	13.5	0.2%
Electrical Transmission and Distribution	26.6	21.4	15.0	14.0	13.2	12.7	13.1	0.2%
Stationary Combustion	8.6	9.1	10.6	11.0	10.8	11.0	10.8	0.2%
Limestone and Dolomite Use	2.6	3.3	2.5	3.4	4.0	3.9	3.3	0.0%
Transportation	1,545.0	1,695.2	1,932.3	2,016.1	1,993.0	2,003.5	1,886.1	27.1%
CO ₂ from Fossil Fuel Combustion	1,485.8	1,608.0	1,809.5	1,895.3	1,876.7	1,893.7	1,785.3	25.7%
Substitution of Ozone Depleting Substances	+	19.0	55.7	72.9	72.2	68.8	64.9	0.9%
Mobile Combustion	47.4	56.9	55.1	37.6	34.1	30.7	26.4	0.4%
Non-Energy Use of Fuels	11.8	11.3	12.1	10.2	9.9	10.2	9.5	0.1%
Industry	1,506.6	1,531.3	1,469.1	1,350.9	1,380.2	1,374.2	1,342.4	19.3%
CO ₂ from Fossil Fuel Combustion	814.4	826.0	813.4	778.8	801.7	793.8	773.9	11.1%
Natural Gas Systems	166.9	174.8	160.1	133.1	132.6	130.3	126.4	1.8%
Non-Energy Use of Fuels	102.0	125.6	123.1	118.3	122.6	116.6	117.5	1.7%
Iron and Steel & Metallurgical Coke Production	103.5	96.7	89.0	68.4	71.3	73.5	69.7	1.0%
Coal Mining	84.1	67.1	60.4	56.9	58.3	58.1	67.6	1.0%
Cement Production	33.3	36.8	41.2	45.9	46.6	45.2	41.1	0.6%
Petroleum Systems	34.4	32.5	30.7	28.7	28.7	29.3	29.5	0.4%
Nitric Acid Production	18.9	21.0	20.7	17.6	17.2	20.5	19.0	0.3%
Lime Production	11.5	13.3	14.1	14.4	15.1	14.6	14.3	0.2%
HCFC-22 Production	36.4	33.0	28.6	15.8	13.8	17.0	13.6	0.2%
Ammonia Production and Urea Consumption	16.8	17.8	16.4	12.8	12.3	14.0	11.8	0.2%
Aluminum Production	25.4	17.5	14.7	7.1	6.3	8.1	7.2	0.1%
Substitution of Ozone Depleting Substances	+	1.2	3.1	5.2	5.7	6.1	6.6	0.1%

Table 2-12: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (continued)
(Tg CO₂ Eq. and Percent of Total in 2008)

Sector/Source	1990	1995	2000	2005	2006	2007	2008	Percent ^a
Abandoned Underground Coal Mines	6.0	8.2	7.4	5.6	5.5	5.7	5.9	0.1%
Semiconductor Manufacture	2.9	4.9	6.2	4.4	4.7	4.7	5.4	0.1%
N ₂ O from Product Uses	4.4	4.6	4.9	4.4	4.4	4.4	4.4	0.1%
Petrochemical Production	4.2	5.2	5.7	5.3	4.8	4.9	4.4	0.1%
Soda Ash Production and Consumption	4.1	4.3	4.2	4.2	4.2	4.1	4.1	0.1%
Stationary Combustion	4.7	4.9	4.8	4.4	4.6	4.5	4.1	0.1%
Limestone and Dolomite Use	2.6	3.3	2.5	3.4	4.0	3.9	3.3	0.0%
Adipic Acid Production	15.8	17.6	5.5	5.0	4.3	3.7	2.0	0.0%
Magnesium Production and Processing	5.4	5.6	3.0	2.9	2.9	2.6	2.0	0.0%
Titanium Dioxide Production	1.2	1.5	1.8	1.8	1.8	1.9	1.8	0.0%
Carbon Dioxide Consumption	1.4	1.4	1.4	1.3	1.7	1.9	1.8	0.0%
Ferroalloy Production	2.2	2.0	1.9	1.4	1.5	1.6	1.6	0.0%
Mobile Combustion	0.9	1.0	1.1	1.3	1.3	1.3	1.3	0.0%
Phosphoric Acid Production	1.5	1.5	1.4	1.4	1.2	1.2	1.2	0.0%
Zinc Production	0.9	1.0	1.1	0.5	0.5	0.4	0.4	0.0%
Lead Production	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.0%
Silicon Carbide Production and Consumption	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.0%
Agriculture	433.2	460.8	485.3	494.1	515.1	518.0	504.1	7.2%
N ₂ O from Agricultural Soil Management	203.5	205.9	210.1	215.8	211.2	211.0	215.9	3.1%
Enteric Fermentation	132.4	143.7	136.8	136.7	139.0	141.2	140.8	2.0%
Manure Management	43.7	49.3	55.2	58.9	59.6	63.2	62.1	0.9%
CO ₂ from Fossil Fuel Combustion	31.0	36.6	38.7	46.8	49.0	48.4	45.4	0.7%
CH ₄ and N ₂ O from Forest Fires	5.8	7.7	26.0	17.8	39.2	36.3	21.7	0.3%
Rice Cultivation	7.1	7.6	7.5	6.8	5.9	6.2	7.2	0.1%
Liming of Agricultural Soils	4.7	4.4	4.3	4.3	4.2	4.5	3.8	0.1%
Urea Fertilization	2.4	2.7	3.2	3.5	3.7	3.8	3.8	0.1%
Field Burning of Agricultural Residues	1.2	1.1	1.4	1.5	1.4	1.5	1.5	0.0%
CO ₂ and N ₂ O from Managed Peatlands	1.0	1.0	1.2	1.1	0.9	1.0	0.9	0.0%
Mobile Combustion	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.0%
N ₂ O from Forest Soils	0.1	0.2	0.4	0.4	0.4	0.4	0.4	0.0%
Stationary Combustion	+	+	+	+	+	+	+	0.0%
Commercial	395.1	399.6	387.3	399.0	389.2	404.4	410.9	5.9%
CO ₂ from Fossil Fuel Combustion	216.7	223.2	227.7	221.3	206.0	217.4	219.5	3.2%
Landfills	149.3	144.1	120.7	125.6	127.1	126.5	126.3	1.8%
Substitution of Ozone Depleting Substances	+	0.7	5.5	18.5	22.4	26.6	31.1	0.4%
Wastewater Treatment	23.5	24.8	25.2	24.3	24.5	24.4	24.3	0.3%
Human Sewage	3.7	4.0	4.5	4.7	4.8	4.9	4.9	0.1%
Composting	0.7	1.5	2.6	3.3	3.3	3.5	3.5	0.1%
Stationary Combustion	1.2	1.3	1.2	1.2	1.1	1.2	1.2	0.0%
Residential	345.9	367.6	386.7	370.7	334.9	356.2	359.3	5.2%
CO ₂ from Fossil Fuel Combustion	339.1	353.3	371.2	358.4	322.1	341.7	342.7	4.9%
Substitution of Ozone Depleting Substances	0.3	8.1	10.1	6.5	7.5	8.6	10.3	0.1%

Table 2-12: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (Tg CO₂ Eq. and Percent of Total in 2008) (continued)

Sector/Source	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008
Stationary Combustion	5.5	5.0	4.3	4.3	3.9	4.2	4.6	0.1%			
Settlement Soil Fertilization	1.0	1.2	1.1	1.5	1.5	1.6	1.6	0.0%			
U.S. Territories	33.7	40.7	46.9	58.9	60.0	57.8	49.9	0.7%			
CO ₂ from Fossil Fuel Combustion	27.9	34.5	35.9	50.6	50.9	49.1	42.5	0.6%			
Non-Energy Use of Fuels	5.7	6.0	10.9	8.1	8.9	8.5	7.2	0.1%			
Stationary Combustion	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.0%			
Total Emissions	6,126.8	6,488.8	7,044.5	7,133.2	7,059.9	7,168.1	6,956.8	100.0%			
Sinks	(909.4)	(842.9)	(664.2)	(950.4)	(959.2)	(955.4)	(940.3)	-13.5%			
CO ₂ Flux from Forests	(729.8)	(692.6)	(467.7)	(806.6)	(812.5)	(806.9)	(791.9)	-11.4%			
Urban Trees	(57.1)	(67.3)	(77.5)	(87.8)	(89.8)	(91.9)	(93.9)	-1.3%			
CO ₂ Flux from Agricultural Soil											
Carbon Stocks	(99.1)	(69.0)	(107.7)	(45.9)	(46.5)	(46.9)	(45.0)	-0.6%			
Landfilled Yard Trimmings and Food Scraps	(23.5)	(13.9)	(11.3)	(10.1)	(10.3)	(9.8)	(9.5)	-0.1%			
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	86.5%			

+ Does not exceed 0.05 Tg CO₂ Eq. or 0.05 percent.

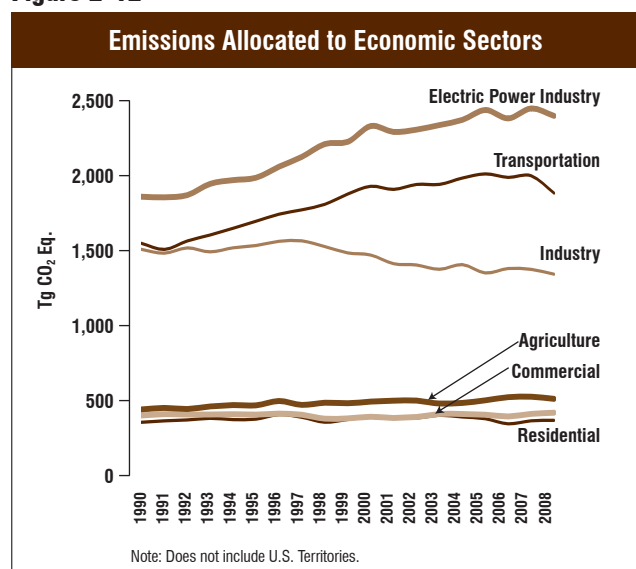
^a Percent of total emissions for year 2008.

Note: Includes all emissions of CO₂, CH₄, N₂O, HFCs, PFCs, and SF₆. Parentheses indicate negative values or sequestration. Totals may not sum due to independent rounding.

Carbon dioxide 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.

Table 2-12 presents a detailed breakdown of emissions from each of these economic sectors by source category, as they are defined in this report. Figure 2-12 shows the trend in emissions by sector from 1990 to 2008.

Figure 2-12



Note: Does not include U.S. Territories.

Emissions with Electricity Distributed to Economic Sectors

It can also be useful to view 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). The generation, transmission, and distribution of electricity, which is the largest economic sector in the United States, accounted for 35 percent of total U.S. greenhouse gas emissions in 2008. Emissions increased by 30 percent since 1990, as electricity demand grew and fossil fuels remained the dominant energy source for generation. Electricity generation-related emissions decreased from 2007 to 2008 by 2 percent, primarily due to decreased CO₂ emissions from fossil fuel combustion. The electricity generation sector in the United States is composed of traditional electric utilities as well as other entities, such as power marketers and non-utility power producers. The majority of electricity generated by these entities was through the combustion of coal in boilers to produce high-pressure steam that is passed through a turbine. Table 2-13 provides a detailed summary of emissions from electricity generation-related activities.

Table 2-13: Electricity Generation-Related Greenhouse Gas Emissions (Tg CO₂ Eq.)

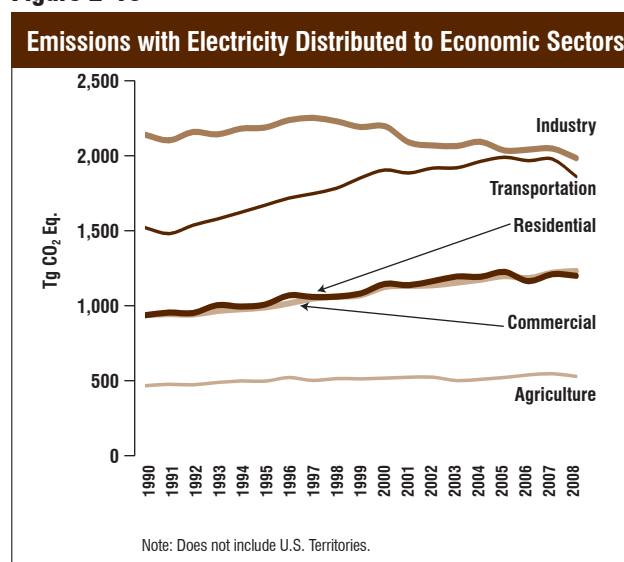
Gas/Fuel Type or Source	1990	1995	2000	2005	2006	2007	2008
CO₂	1,831.4	1,962.7	2,310.7	2,418.1	2,363.1	2,430.0	2,379.9
CO ₂ from Fossil Fuel Combustion	1,820.8	1,947.9	2,296.9	2,402.1	2,346.4	2,412.8	2,363.5
Coal	1,547.6	1,660.7	1,927.4	1,983.8	1,953.7	1,987.3	1,962.6
Natural Gas	175.3	228.1	280.8	318.8	338.0	371.3	361.6
Petroleum	97.5	58.7	88.4	99.2	54.4	53.9	38.9
Geothermal	0.4	0.3	0.4	0.4	0.4	0.4	0.4
Incineration of Waste	8.0	11.5	11.3	12.6	12.7	13.3	13.1
Limestone and Dolomite Use	2.6	3.3	2.5	3.4	4.0	3.9	3.3
CH₄	0.6	0.6	0.7	0.7	0.7	0.7	0.7
Stationary Combustion ^a	0.6	0.6	0.7	0.7	0.7	0.7	0.7
Incineration of Waste	+	+	+	+	+	+	+
N₂O	8.5	9.0	10.4	10.7	10.5	10.6	10.5
Stationary Combustion ^a	8.1	8.6	10.0	10.3	10.1	10.2	10.1
Incineration of Waste	0.5	0.5	0.4	0.4	0.4	0.4	0.4
SF₆	26.6	21.4	15.0	14.0	13.2	12.7	13.1
Electrical Transmission and Distribution	26.6	21.4	15.0	14.0	13.2	12.7	13.1
Total	1,867.2	1,993.7	2,336.8	2,443.5	2,387.5	2,454.0	2,404.2

+ Does not exceed 0.05 Tg CO₂ Eq. or 0.05 percent.
^aIncludes only stationary combustion emissions related to the generation of electricity.
Note: Totals may not sum due to independent rounding.

To distribute electricity emissions among economic end-use sectors, emissions from the source categories assigned to the electricity generation sector were allocated to the residential, commercial, industry, transportation, and agriculture economic sectors according to retail sales of electricity (EIA 2009a and Duffield 2006). These three source categories include CO₂ from Fossil Fuel Combustion, CH₄ and N₂O from Stationary Combustion, and SF₆ from Electrical Transmission and Distribution Systems.⁶

When emissions from electricity are distributed among these sectors, industry accounts for the largest share of U.S. greenhouse gas emissions (29 percent), followed closely by emissions from transportation activities, which account for 27 percent of total emissions. 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. In all sectors except agriculture, CO₂ accounts for more than 80 percent of greenhouse gas emissions, primarily from the combustion of fossil fuels.

Table 2-14 presents a detailed breakdown of emissions from each of these economic sectors, with emissions from electricity generation distributed to them. Figure 2-13 shows the trend in these emissions by sector from 1990 to 2008.

Figure 2-13

⁶ 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.

Table 2-14: U.S. Greenhouse Gas Emissions by Economic Sector and Gas with Electricity-Related Emissions Distributed (Tg CO₂ Eq.) and Percent of Total in 2008

Sector/Gas	1990	1995	2000	2005	2006	2007	2008	Percent ^a
Industry	2,179.8	2,228.0	2,239.2	2,071.1	2,077.3	2,084.2	2,018.4	29.0%
Direct Emissions	1,506.6	1,531.3	1,469.1	1,350.9	1,380.2	1,374.2	1,342.4	19.3%
CO ₂	1,130.3	1,160.5	1,136.3	1,062.2	1,090.6	1,083.0	1,049.5	15.1%
CH ₄	294.8	286.5	262.5	227.7	228.5	226.6	232.5	3.3%
N ₂ O	32.7	35.4	32.8	29.0	28.8	31.7	29.3	0.4%
HFCs, PFCs, and SF ₆	48.8	48.9	37.5	31.9	32.3	32.9	31.1	0.4%
Electricity-Related	673.3	696.7	770.1	720.2	697.1	710.0	676.0	9.7%
CO ₂	660.4	685.9	761.5	712.8	690.0	703.0	669.2	9.6%
CH ₄	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0%
N ₂ O	3.1	3.2	3.4	3.2	3.1	3.1	2.9	0.0%
SF ₆	9.6	7.5	5.0	4.1	3.9	3.7	3.7	0.1%
Transportation	1,548.2	1,698.3	1,935.8	2,020.9	1,997.6	2,008.6	1,890.8	27.2%
Direct Emissions	1,545.0	1,695.2	1,932.3	2,016.1	1,993.0	2,003.5	1,886.1	27.1%
CO ₂	1,497.6	1,619.3	1,821.6	1,905.5	1,886.6	1,904.0	1,794.8	25.8%
CH ₄	4.5	4.0	3.1	2.2	2.0	1.9	1.7	0.0%
N ₂ O	42.95	52.87	51.95	35.46	32.12	28.78	24.65	0.4%
HFCs ^b	+	19.0	55.7	72.9	72.2	68.8	64.9	0.9%
Electricity-Related	3.1	3.1	3.5	4.8	4.6	5.1	4.8	0.1%
CO ₂	3.1	3.1	3.5	4.8	4.6	5.1	4.7	0.1%
CH ₄	+	+	+	+	+	+	+	0.0%
N ₂ O	+	+	+	+	+	+	+	0.0%
SF ₆	+	+	+	+	+	+	+	0.0%
Commercial	946.8	1,000.2	1,141.5	1,216.5	1,202.2	1,240.1	1,250.6	18.0%
Direct Emissions	395.1	399.6	387.3	399.0	389.2	404.4	410.9	5.9%
CO ₂	216.7	223.2	227.7	221.3	206.0	217.4	219.5	3.2%
CH ₄	174.0	170.5	148.0	152.4	154.0	153.4	153.2	2.2%
N ₂ O	4.4	5.2	6.2	6.8	6.9	7.0	7.1	0.1%
HFCs	+	0.7	5.5	18.5	22.4	26.6	31.1	0.4%
Electricity-Related	551.7	600.6	754.1	817.6	813.0	835.8	839.6	12.1%
CO ₂	541.1	591.3	745.7	809.1	804.7	827.6	831.2	11.9%
CH ₄	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0%
N ₂ O	2.5	2.7	3.3	3.6	3.6	3.6	3.7	0.1%
SF ₆	7.9	6.4	4.8	4.7	4.5	4.3	4.6	0.1%
Residential	954.0	1,024.5	1,162.4	1,242.2	1,180.3	1,226.9	1,215.6	17.5%
Direct Emissions	345.9	367.6	386.7	370.7	334.9	356.2	359.3	5.2%
CO ₂	339.1	353.3	371.2	358.4	322.1	341.7	342.7	4.9%
CH ₄	4.4	4.0	3.4	3.4	3.1	3.4	3.7	0.1%
N ₂ O	2.1	2.2	2.1	2.4	2.3	2.5	2.5	0.0%
HFCs	0.3	8.1	10.1	6.5	7.5	8.6	10.3	0.1%
Electricity-Related	608.1	656.9	775.7	871.5	845.4	870.7	856.3	12.3%
CO ₂	596.5	646.7	767.0	862.5	836.8	862.2	847.7	12.2%
CH ₄	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.0%
N ₂ O	2.8	3.0	3.4	3.8	3.7	3.8	3.7	0.1%
SF ₆	8.7	7.1	5.0	5.0	4.7	4.5	4.7	0.1%
Agriculture	464.2	497.1	518.7	523.5	542.5	550.5	531.6	7.6%
Direct Emissions	433.2	460.8	485.3	494.1	515.1	518.0	504.1	7.2%
CO ₂	39.2	44.7	47.6	55.7	57.8	57.8	54.0	0.8%
CH ₄	172.9	190.3	198.2	196.7	209.9	214.3	206.1	3.0%
N ₂ O	221.2	225.8	239.6	241.7	247.4	245.9	244.0	3.5%

Table 2-14: U.S. Greenhouse Gas Emissions by Economic Sector and Gas with Electricity-Related Emissions Distributed (Tg CO₂ Eq.) and Percent of Total in 2008 (continued)

Sector/Gas	1990	1995	2000	2005	2006	2007	2008	Percent ^a
Electricity-Related	31.0	36.4	33.3	29.4	27.4	32.5	27.5	0.4%
CO ₂	30.4	35.8	33.0	29.1	27.1	32.2	27.2	0.4%
CH ₄	+	+	+	+	+	+	+	0.0%
N ₂ O	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0%
SF ₆	0.4	0.4	0.2	0.2	0.2	0.2	0.1	0.0%
U.S. Territories	33.7	40.7	46.9	58.9	60.0	57.8	49.9	0.7%
Total	6,126.8	6,488.8	7,044.5	7,133.2	7,059.9	7,168.1	6,956.8	100.0%

+ Does not exceed 0.05 Tg CO₂ Eq. or 0.05 percent.

^a Percent of total emissions for year 2008.

^b Includes primarily HFC-134a.

Note: Emissions from electricity generation are allocated based on aggregate electricity consumption in each end-use sector. Totals may not sum due to independent rounding.

Industry

The industrial end-use sector includes CO₂ emissions from fossil fuel combustion from all manufacturing facilities, in aggregate. This sector also includes emissions that are produced as a byproduct of the non-energy-related industrial process activities. The variety of activities producing these non-energy-related emissions, to name a few includes fugitive CH₄ emissions from coal mining, by-product CO₂ emissions from cement manufacture, and HFC, PFC, and SF₆ by-product emissions from semiconductor manufacture. Overall, direct industry sector emissions have declined since 1990, while electricity-related emissions have risen. In theory, emissions from the industrial end-use sector should be highly correlated with economic growth and industrial output, but heating of industrial buildings and agricultural energy consumption are also affected by weather conditions. In addition, structural changes within the U.S. economy that lead to shifts in industrial output away from energy-intensive manufacturing products to less energy-intensive products (e.g., from steel to computer equipment) also have a significant effect on industrial emissions.

Transportation

When electricity-related emissions are distributed to economic end-use sectors, transportation activities accounted for 27 percent of U.S. greenhouse gas emissions in 2008. The largest sources of transportation GHGs in 2008 were passenger cars (33 percent), light duty trucks, which include sport utility vehicles, pickup trucks, and minivans (29 percent), freight trucks (21 percent) and commercial aircraft (7 percent). These figures include direct emissions

from fossil fuel combustion, as well as HFC emissions from mobile air conditioners and refrigerated transport allocated to these vehicle types. Table 2-15 provides a detailed summary of greenhouse gas emissions from transportation-related activities with electricity-related emissions included in the totals.

From 1990 to 2008, transportation emissions rose by 22 percent due, in large part, to increased demand for travel and the stagnation of fuel efficiency across the U.S. vehicle fleet. The number of vehicle miles traveled by light-duty motor vehicles (passenger cars and light-duty trucks) increased 37 percent from 1990 to 2008, as a result of a confluence of factors including population growth, economic growth, urban sprawl, and low fuel prices over much of this period. A similar set of social and economic trends has led to a significant increase in air travel and freight transportation by both air and road modes during the time series.

Although average fuel economy over this period increased slightly due primarily to the retirement of older vehicles, average fuel economy among new vehicles sold annually gradually declined from 1990 to 2004. The decline in new vehicle fuel economy between 1990 and 2004 reflected the increasing market share of light duty trucks, which grew from about one-fifth of new vehicle sales in the 1970s to slightly over half of the market by 2004. Increasing fuel prices have since decreased the momentum of light duty truck sales, and average new vehicle fuel economy has improved since 2005 as the market share of passenger cars increased. VMT growth among all passenger vehicles has also been impacted, remaining stagnant from 2004 to 2007, compared to an average annual growth rate of 2.5 percent

Table 2-15: Transportation-Related Greenhouse Gas Emissions (Tg CO₂ Eq.)

Vehicle Type/Gas	1990	1995	2000	2005	2006	2007	2008
Passenger Cars	657.3	645.9	695.2	709.3	682.6	671.6	632.1
CO ₂	629.2	606.7	644.1	662.0	638.8	632.4	597.5
CH ₄	2.6	2.1	1.6	1.1	1.0	0.9	0.8
N ₂ O	25.4	26.9	25.2	17.8	15.7	13.8	11.7
HFCs	+	10.1	24.3	28.4	27.1	24.6	22.1
Light-Duty Trucks	336.5	436.5	512.0	551.0	563.6	569.9	552.4
CO ₂	321.0	406.4	466.9	505.6	519.2	528.0	513.7
CH ₄	1.4	1.4	1.1	0.7	0.7	0.6	0.6
N ₂ O	14.1	22.1	22.4	13.7	12.6	11.2	9.5
HFCs	+	6.5	21.7	31.0	31.2	30.1	28.6
Medium- and Heavy-Duty Trucks	231.1	277.7	354.5	408.3	418.6	425.2	401.2
CO ₂	230.1	274.8	345.8	396.0	406.0	412.5	388.6
CH ₄	0.2	0.2	0.1	0.1	0.1	0.1	0.1
N ₂ O	0.8	1.0	1.2	1.1	1.1	1.1	1.0
HFCs	+	1.7	7.4	11.1	11.4	11.5	11.6
Buses	8.4	9.2	11.2	12.0	12.3	12.5	12.1
CO ₂	8.4	9.2	11.1	11.8	12.0	12.1	11.7
CH ₄	+	+	+	+	+	+	+
N ₂ O	+	+	+	+	+	+	+
HFCs	+	+	0.1	0.2	0.3	0.3	0.4
Motorcycles	1.8	1.8	1.9	1.7	1.9	2.1	2.2
CO ₂	1.7	1.8	1.8	1.6	1.9	2.1	2.1
CH ₄	+	+	+	+	+	+	+
N ₂ O	+	+	+	+	+	+	+
Commercial Aircraft^a	136.8	143.1	170.9	162.8	138.5	139.5	123.4
CO ₂	135.4	141.6	169.2	161.2	137.1	138.1	122.2
CH ₄	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N ₂ O	1.3	1.4	1.6	1.5	1.3	1.3	1.2
Other Aircraft^b	44.4	32.3	33.5	35.1	34.3	33.7	33.7
CO ₂	43.9	32.0	33.1	34.7	34.0	33.4	33.3
CH ₄	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N ₂ O	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Ships and Boats^c	45.1	58.6	61.3	45.2	48.4	55.2	38.7
CO ₂	44.5	57.7	60.2	44.5	47.7	54.4	38.1
CH ₄	+	+	+	+	+	+	+
N ₂ O	0.6	0.8	0.9	0.6	0.7	0.8	0.5
HFCs	+	+	0.1	+	+	+	+
Rail	39.0	43.7	48.0	53.0	55.1	54.3	50.6
CO ₂	38.5	42.7	45.6	50.3	52.4	51.6	47.9
CH ₄	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N ₂ O	0.3	0.3	0.3	0.4	0.4	0.4	0.4
HFCs	+	0.5	2.0	2.2	2.2	2.2	2.3
Other Emissions from Electricity Generation ^d	0.1	0.1	+	0.1	0.1	0.1	0.1
Pipelines^e	36.0	38.2	35.2	32.3	32.3	34.3	34.9
CO ₂	36.0	38.2	35.2	32.3	32.3	34.3	34.9
Lubricants	11.8	11.3	12.1	10.2	9.9	10.2	9.5
CO ₂	11.8	11.3	12.1	10.2	9.9	10.2	9.5

Table 2-15: Transportation-Related Greenhouse Gas Emissions (Tg CO₂ Eq.) (continued)

Vehicle Type/Gas	1990	1995	2000	2005	2006	2007	2008
Total Transportation	1,548.2	1,698.3	1,935.8	2,020.9	1,997.6	2,008.6	1,890.8
<i>International Bunker Fuels^f</i>	<i>113.0</i>	<i>100.9</i>	<i>99.5</i>	<i>111.7</i>	<i>130.5</i>	<i>128.4</i>	<i>136.6</i>

+ Does not exceed 0.05 Tg CO₂ Eq.
^a Consists of emissions from jet fuel consumed by domestic operations of commercial aircraft (no bunkers).
^b Consists of emissions from jet fuel and aviation gasoline consumption by general aviation and military aircraft.
^c Fluctuations in emission estimates are associated with fluctuations in reported fuel consumption, and may reflect data collection problems.
^d Other emissions from electricity generation are a result of waste incineration (as the majority of municipal solid waste is combusted in “trash-to-steam” electricity generation plants), electrical transmission and distribution, and a portion of limestone and dolomite use (from pollution control equipment installed in electricity generation plants).
^e CO₂ estimates reflect natural gas used to power pipelines, but not electricity. While the operation of pipelines produces CH₄ and N₂O, these emissions are not directly attributed to pipelines in the US Inventory.
^f Emissions from International Bunker Fuels include emissions from both civilian and military activities; these emissions are not included in the transportation totals.

Note: Totals may not sum due to independent rounding. Passenger cars and light-duty trucks include vehicles typically used for personal travel and less than 8500 lbs; medium- and heavy-duty trucks include vehicles 8501 lbs and above. HFC emissions primarily reflect HFC-134a.

over the period 1990 to 2004. The recession supplemented the effect of increasing fuel prices in 2008 and VMT declined by 2.1 percent, the first decrease in annual passenger vehicle VMT since 1990.

Almost all of the energy consumed for transportation was supplied by petroleum-based products, with more than half being related to gasoline consumption in automobiles and other highway vehicles. Other fuel uses, especially diesel fuel for freight trucks and jet fuel for aircraft, accounted for the remainder. The primary driver of transportation-related emissions was CO₂ from fossil fuel combustion, which increased by 20 percent from 1990 to 2008. This rise in CO₂ emissions, combined with an increase in HFCs from virtually no emissions in 1990 to 64.9 Tg CO₂ Eq. in 2008, led to an increase in overall emissions from transportation activities of 22 percent.

Commercial

The commercial sector is heavily reliant on electricity for meeting energy needs, with electricity consumption for lighting, heating, air conditioning, and operating appliances. The remaining emissions were largely due to the direct consumption of natural gas and petroleum products, primarily for heating and cooking needs. Energy-related emissions from the residential and commercial sectors have generally been increasing since 1990, and are often correlated with short-term fluctuations in energy consumption caused by weather conditions, rather than prevailing economic conditions. Landfills and wastewater treatment are included in this

sector, with landfill emissions decreasing since 1990, while wastewater treatment emissions have increased slightly.

Residential

The residential sector is heavily reliant on electricity for meeting energy needs, with electricity consumption for lighting, heating, air conditioning, and operating appliances. The remaining emissions were largely due to the direct consumption of natural gas and petroleum products, primarily for heating and cooking needs. Emissions from the residential sectors have generally been increasing since 1990, and are often correlated with short-term fluctuations in energy consumption caused by weather conditions, rather than prevailing economic conditions. In the long-term, this sector is also affected by population growth, regional migration trends, and changes in housing and building attributes (e.g., size and insulation).

Agriculture

The agricultural sector includes a variety of processes, including enteric fermentation in domestic livestock, livestock manure management, and agricultural soil management. In 2008, enteric fermentation was the largest source of CH₄ emissions in the United States, and agricultural soil management was the largest source of N₂O emissions in the United States. This sector also includes small amounts of CO₂ emissions from fossil fuel combustion by motorized farm equipment like tractors.

Box 2-1: Methodology for Aggregating Emissions by Economic Sector

In presenting the Economic Sectors in the annual *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, EPA expands upon the standard IPCC sectors common for UNFCCC reporting. EPA believes that discussing greenhouse gas emissions relevant to U.S.-specific sectors improves communication of the report's findings.

Electricity Generation: Carbon dioxide emissions from the combustion of fossil fuels included in the EIA electric-utility fuel-consuming sector are apportioned to this economic sector. Stationary combustion emissions of CH₄ and N₂O are also based on the EIA electric-utility sector. Additional sources include CO₂ and N₂O from waste incineration, as the majority of municipal solid waste is combusted in “trash-to-steam” electricity generation plants. The Electricity Generation economic sector also includes SF₆ from electrical transmission and distribution, and a portion of CO₂ from limestone and dolomite use (from pollution control equipment installed in electricity generation plants).

Transportation: Carbon dioxide emissions from the combustion of fossil fuels included in the EIA transportation fuel-consuming sector are apportioned to this economic sector (additional analyses and refinement of the EIA data is further explained in the Energy chapter of this report). Additional emissions are apportioned from CH₄ and N₂O from mobile combustion, based on the EIA transportation sector. Substitutes for ozone depleting substances are apportioned to this economic sector based on their specific end-uses within the source category, along with emissions from transportation refrigeration/air-conditioning systems. Finally, CO₂ emissions from non-energy uses of fossil fuels identified as lubricants for transportation vehicles are included in the Transportation economic sector.

Industry: Carbon dioxide emissions from the combustion of fossil fuels included in the EIA industrial fuel-consuming sector, minus the agricultural use of fuel explained below, are apportioned to this economic sector. Stationary and mobile combustion emissions of CH₄ and N₂O are also based on the EIA industrial sector, minus emissions apportioned to the Agriculture economic sector described below. Substitutes for ozone depleting substances are apportioned based on their specific end-uses within the source category, with most emissions falling within the Industry economic sector (emissions from the other economic sectors are subtracted to avoid double-counting). Additionally, all process-related emissions from sources with methods considered within the IPCC Industrial Process guidance have been apportioned to this economic sector. This includes the process-related emissions (i.e., emissions resulting from the processes used to make materials, and not from burning fuels to provide power or heat) from such activities as cement production, iron and steel production and metallurgical coke production, and ammonia production. Additionally, fugitive emissions from energy production sources, such as natural gas systems, coal mining, and petroleum systems are included in the Industry economic sector. A portion of CO₂ emissions from limestone and dolomite use (from pollution control equipment installed in large industrial facilities) are also included in the Industry economic sector. Finally, all remaining CO₂ emissions from non-energy uses of fossil fuels are assumed to be industrial in nature (besides the lubricants for transportation vehicles specified above), and are attributed to the Industry economic sector.

Agriculture: As agricultural equipment is included in EIA's industrial fuel-consuming sector surveys, additional data is used to separate out the fuel used by agricultural equipment, to allow for accurate reporting in the Agriculture economic sector from all sources of emissions, such as motorized farming equipment. Energy consumption estimates are obtained from Department of Agriculture survey data, in combination with separate EIA fuel sales reports. This supplementary data is used to apportion CO₂ emissions from fossil fuel combustion and CH₄ and N₂O emissions from stationary and mobile combustion (this data is subtracted from the Industry economic sector to avoid double-counting). The other emission sources included in this economic sector are non-combustion sources of emissions that are included in the Agriculture and Land Use, Land-Use Change and Forestry chapters: N₂O emissions from agricultural soils, CH₄ from enteric fermentation (i.e., exhalation from the digestive tracts of domesticated animals), CH₄ and N₂O from manure management, CH₄ from rice cultivation, CO₂ emissions from liming of agricultural soils and urea application, and CH₄ and N₂O from forest fires. Nitrous oxide emissions from the application of fertilizers to tree plantations (termed “forest land” by the IPCC) are also included in the Agriculture economic sector.

Residential: This economic sector includes the CO₂ emissions from the combustion of fossil fuels reported for the EIA residential sector. Stationary combustion emissions of CH₄ and N₂O are also based on the EIA residential fuel-consuming sector. Substitutes for ozone depleting substances are apportioned based on their specific end-uses within the source category, with emissions from residential air-conditioning systems distributed to this economic sector. Nitrous oxide emissions from the application of fertilizers to developed land (termed “settlements” by the IPCC) are also included in the Residential economic sector.

Commercial: This economic sector includes the CO₂ emissions from the combustion of fossil fuels reported in the EIA commercial fuel-consuming sector data. Stationary combustion emissions of CH₄ and N₂O are also based on the EIA commercial sector. Substitutes for ozone depleting substances are apportioned based on their specific end-uses within the source category, with emissions from commercial refrigeration/air-conditioning systems distributed to this economic sector. Public works sources including direct CH₄ from landfills and CH₄ and N₂O from wastewater treatment and composting are included in this economic sector.

Electricity Generation

The process of generating electricity, for consumption in the above sectors, is the single largest source of greenhouse gas emissions in the United States, representing 35 percent of total U.S. emissions. Electricity generation also accounted

for the largest share of CO₂ emissions from fossil fuel combustion, approximately 42 percent in 2008. Electricity was consumed primarily in the residential, commercial, and industrial end-use sectors for lighting, heating, electric motors, appliances, electronics, and air conditioning.

Box 2-2: 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; or (5) emissions per capita.

Table 2-16 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 0.9 percent since 1990. This rate is slightly slower than that for total energy or 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 2-14).

Table 2-16: 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.

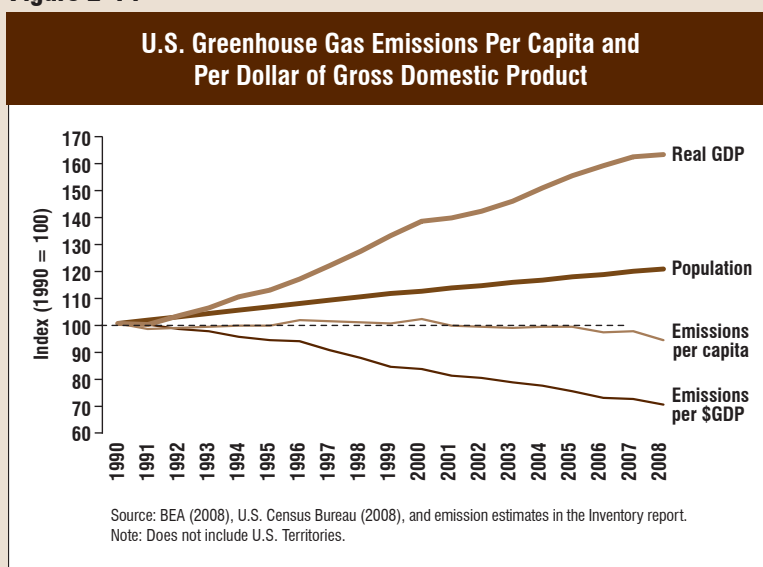
^b Gross Domestic Product in chained 2000 dollars (BEA 2008).

^c Energy content-weighted values (EIA 2008a).

^d U.S. Census Bureau (2008).

^e GWP-weighted values.

Figure 2-14



2.3. Indirect Greenhouse Gas Emissions (CO, NO_x, NMVOCs, and SO₂)

The reporting requirements of the UNFCCC⁷ request that information be provided on indirect greenhouse gases, which include CO, NO_x, NMVOCs, and SO₂. 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 SO₂, 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. Carbon monoxide is produced when carbon-containing fuels are combusted incompletely. Nitrogen oxides (i.e., NO and NO₂) are created by lightning, fires, fossil fuel combustion, and in the stratosphere from N₂O. Non-CH₄ volatile organic compounds—which include hundreds of organic compounds that participate in atmospheric chemical reactions (i.e., propane, butane, xylene, toluene, ethane, and many others)—are emitted primarily from transportation, industrial processes, and non-industrial consumption of

organic solvents. In the United States, SO₂ is primarily emitted from coal combustion for electric power generation and the metals industry. Sulfur-containing compounds emitted into the atmosphere tend to exert a negative radiative forcing (i.e., cooling) and therefore are discussed separately.

One important indirect climate change effect of NMVOCs and NO_x is their role as precursors for tropospheric ozone formation. They can also alter the atmospheric lifetimes of other greenhouse gases. Another example of indirect greenhouse gas formation into greenhouse gases is CO's interaction with the hydroxyl radical—the major atmospheric sink for CH₄ emissions—to form CO₂. Therefore, increased atmospheric concentrations of CO limit the number of hydroxyl molecules (OH) available to destroy CH₄.

Since 1970, the United States has published estimates of annual emissions of CO, NO_x, NMVOCs, and SO₂ (EPA 2009),⁸ which are regulated under the Clean Air Act. Table 2-17 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.

Box 2-3: Sources and Effects of Sulfur Dioxide

Sulfur dioxide (SO₂) emitted into the atmosphere through natural and anthropogenic processes affects the earth's radiative budget through its photochemical transformation into sulfate aerosols that can (1) scatter radiation from the sun back to space, thereby reducing the radiation reaching the earth's surface; (2) affect cloud formation; and (3) affect atmospheric chemical composition (e.g., by providing surfaces for heterogeneous chemical reactions). The indirect effect of sulfur-derived aerosols on radiative forcing can be considered in two parts. The first indirect effect is the aerosols' tendency to decrease water droplet size and increase water droplet concentration in the atmosphere. The second indirect effect is the tendency of the reduction in cloud droplet size to affect precipitation by increasing cloud lifetime and thickness. Although still highly uncertain, the radiative forcing estimates from both the first and the second indirect effect are believed to be negative, as is the combined radiative forcing of the two (IPCC 2001). However, because SO₂ is short-lived and unevenly distributed in the atmosphere, its radiative forcing impacts are highly uncertain.

Sulfur dioxide is also a major contributor to the formation of regional haze, which can cause significant increases in acute and chronic respiratory diseases. Once SO₂ is emitted, it is chemically transformed in the atmosphere and returns to the earth as the primary source of acid rain. Because of these harmful effects, the United States has regulated SO₂ emissions in the Clean Air Act.

Electricity generation is the largest anthropogenic source of SO₂ emissions in the United States, accounting for 87 percent in 2007. Coal combustion contributes nearly all of those emissions (approximately 92 percent). Sulfur dioxide emissions have decreased in recent years, primarily as a result of electric power generators switching from high-sulfur to low-sulfur coal and installing flue gas desulfurization equipment.

⁷ See <<http://unfccc.int/resource/docs/cop8/08.pdf>>.

⁸ NO_x and CO emission estimates from field burning of agricultural residues were estimated separately, and therefore not taken from EPA (2009).

Table 2-17: Emissions of NO_x, CO, NMVOCs, and SO₂ (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
SO₂	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

NA (Not Available).

Note: Totals may not sum due to independent rounding.

Source: EPA (2009), disaggregated based on EPA (2003) except for estimates from field burning of agricultural residues.

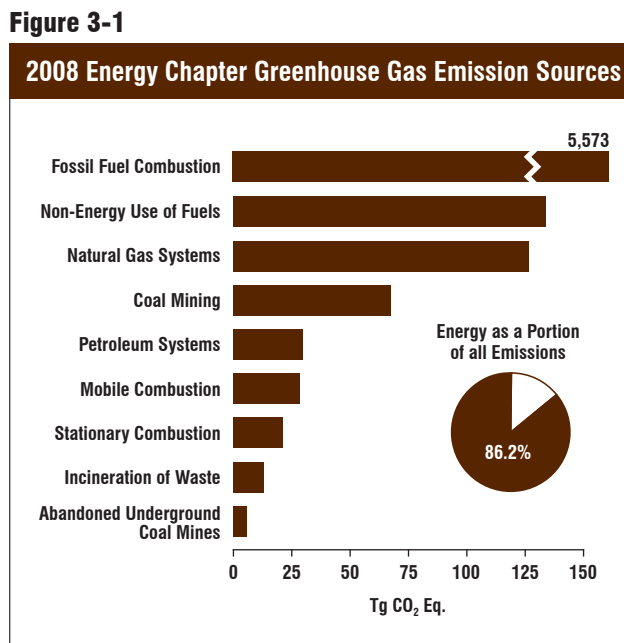
3. Energy

Energy-related activities were the primary sources of U.S. anthropogenic greenhouse gas emissions, accounting for 86.2 percent of total emissions on a carbon dioxide (CO₂) equivalent basis in 2008. This included 97, 37, and 13 percent of the nation’s CO₂, methane (CH₄), and nitrous oxide (N₂O) emissions, respectively. Energy-related CO₂ emissions alone constituted 82.7 percent of national emissions from all sources on a CO₂ equivalent basis, while the non-CO₂ emissions from energy-related activities represented a much smaller portion of total national emissions (3.6 percent collectively).

Emissions from fossil fuel combustion comprise the vast majority of energy-related emissions, with CO₂ being the primary gas emitted (see Figure 3-1). Globally, approximately 30,377 Tg of CO₂ were added to the atmosphere through the combustion of fossil fuels in 2008, of which the United States accounted for about 19 percent.¹ Due to their relative importance, fossil fuel combustion-related CO₂ emissions are considered separately, and in more detail than other energy-related emissions (see Figure 3-2). Fossil fuel combustion also emits CH₄ and N₂O, as well as indirect greenhouse gases such as nitrogen oxides (NO_x), carbon monoxide (CO), and non-CH₄ volatile organic compounds (NMVOCs). Mobile fossil fuel combustion was the second largest source of N₂O emissions in the United States, and overall energy-related activities were collectively the largest source of the indirect greenhouse gas emissions mentioned above.

Energy-related activities other than fuel combustion, such as the production, transmission, storage, and distribution of fossil fuels, also emit greenhouse gases. These emissions consist primarily of fugitive CH₄ from natural gas systems, petroleum systems, and coal mining. Smaller quantities of CO₂, CO, NMVOCs, and NO_x are also emitted.

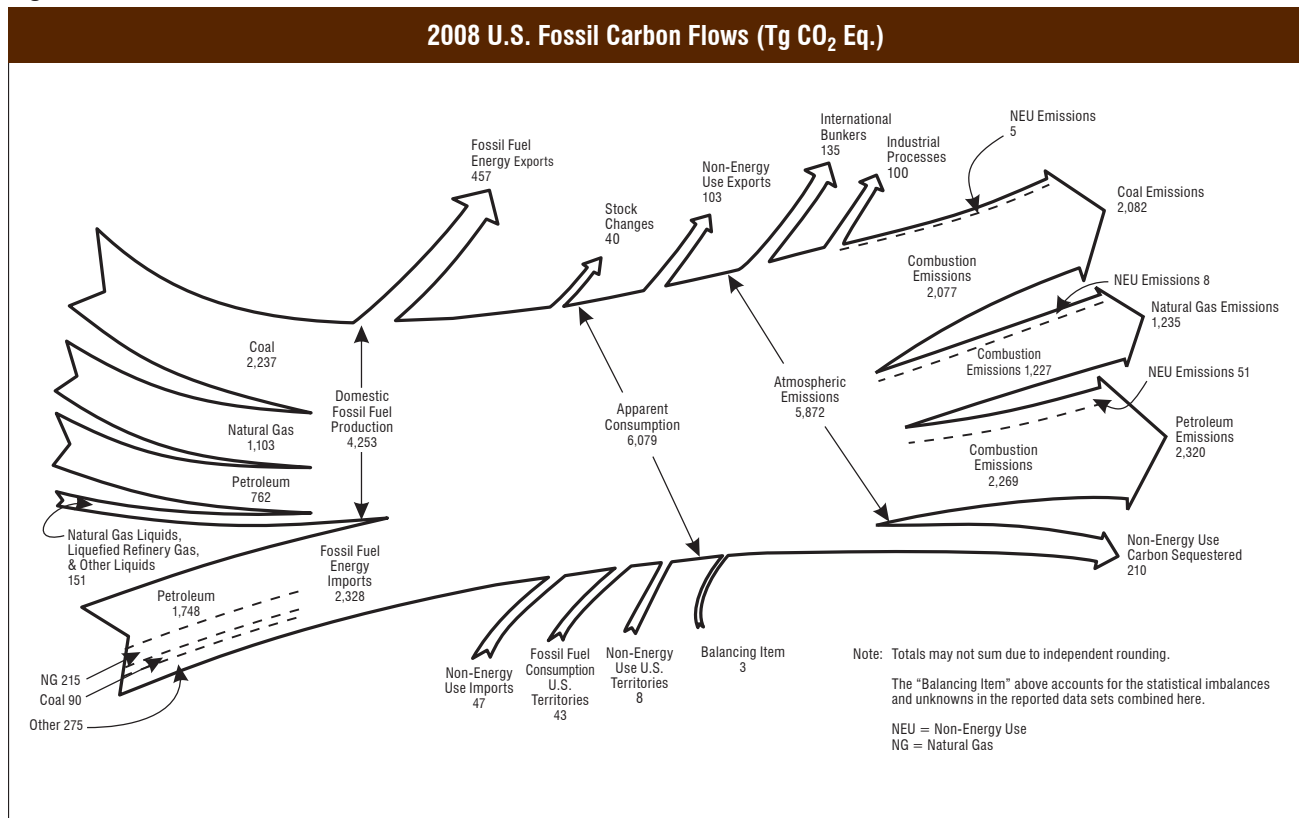
The combustion of biomass and biomass-based fuels also emits greenhouse gases. CO₂ emissions from these activities, however, are not included in national emissions totals because biomass fuels are of biogenic origin.² It is assumed that the carbon (C) released during the consumption of biomass is recycled as U.S. forests and crops regenerate, causing no net addition of CO₂ to the atmosphere. The net impacts of land-use and forestry activities on the C cycle are accounted for separately within the Land Use, Land-Use Change, and Forestry chapter. Emissions of other greenhouse



¹ Global CO₂ 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).

² The 2006 IPCC Guidelines, states that CO₂ from the combustion or decay of short-lived biogenic material removed from where it is grown, is reported as zero in the energy, Industrial Processes Product Use (IPPU) and waste sectors as classified in section 1.1.

Figure 3-2



gases from the combustion of biomass and biomass-based fuels are included in national totals under stationary and mobile combustion.

Table 3-1 summarizes emissions from the Energy sector in units of teragrams of CO₂ equivalents (Tg CO₂ Eq.), while

unweighted gas emissions in gigagrams (Gg) are provided in Table 3-2. Overall, emissions due to energy-related activities were 5,999.0 Tg CO₂ Eq. in 2008, an increase of 15 percent since 1990.

Table 3-1: CO₂, CH₄, and N₂O Emissions from Energy (Tg CO₂ Eq.)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
CO₂	4,901.2	5,226.7	5,780.7	5,932.5	5,836.9	5,936.9	5,750.5
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
Natural Gas Systems	37.3	42.2	29.4	29.5	29.5	30.8	30.0
Incineration of Waste	8.0	11.5	11.3	12.6	12.7	13.3	13.1
Petroleum Systems	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Wood Biomass and Ethanol Consumption ^a	219.3	236.8	227.3	229.4	238.3	245.7	251.8
International Bunker Fuels ^a	111.8	99.8	98.5	110.5	129.1	127.1	135.2

Table 3-1: CO₂, CH₄, and N₂O Emissions from Energy (Tg CO₂ Eq.) (continued)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
CH₄	265.6	251.3	238.7	203.4	203.6	200.7	207.8
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
Petroleum Systems	33.9	32.0	30.2	28.2	28.2	28.8	29.1
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
Incineration of Waste	+	+	+	+	+	+	+
<i>International Bunker Fuels^a</i>	<i>0.2</i>	<i>0.1</i>	<i>0.1</i>	<i>0.1</i>	<i>0.2</i>	<i>0.2</i>	<i>0.2</i>
N₂O	57.2	67.8	68.1	52.0	48.5	45.3	40.8
Mobile Combustion	43.9	54.0	53.2	36.9	33.6	30.3	26.1
Stationary Combustion	12.8	13.3	14.5	14.7	14.5	14.6	14.2
Incineration of Waste	0.5	0.5	0.4	0.4	0.4	0.4	0.4
<i>International Bunker Fuels^a</i>	<i>1.1</i>	<i>0.9</i>	<i>0.9</i>	<i>1.0</i>	<i>1.2</i>	<i>1.2</i>	<i>1.2</i>
Total	5,224.1	5,545.8	6,087.5	6,187.9	6,089.1	6,182.9	5,999.0

+ Does not exceed 0.05 Tg CO₂ Eq.

^a These values are presented for informational purposes only and are not included or are already accounted for in totals.

Note: Totals may not sum due to independent rounding.

Table 3-2: CO₂, CH₄, and N₂O Emissions from Energy (Gg)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
CO₂	4,901,225	5,226,659	5,780,718	5,932,458	5,836,924	5,936,884	5,750,514
Fossil Fuel Combustion	4,735,701	5,029,498	5,593,381	5,753,342	5,652,845	5,756,999	5,572,760
Non-Energy Use of Fuels	119,602	142,922	146,141	136,539	141,382	135,306	134,200
Natural Gas Systems	37,317	42,249	29,394	29,472	29,526	30,816	29,973
Incineration of Waste	8,049	11,461	11,270	12,616	12,684	13,289	13,128
Petroleum Systems	555	528	534	490	488	474	453
<i>Wood Biomass and Ethanol Consumption^a</i>	<i>219,341</i>	<i>236,775</i>	<i>227,276</i>	<i>229,419</i>	<i>238,323</i>	<i>245,706</i>	<i>251,763</i>
<i>International Bunker Fuels^a</i>	<i>111,828</i>	<i>99,817</i>	<i>98,482</i>	<i>110,505</i>	<i>129,104</i>	<i>127,054</i>	<i>135,226</i>
CH₄	12,649	11,966	11,364	9,685	9,697	9,559	9,893
Natural Gas Systems	6,169	6,313	6,223	4,935	4,907	4,738	4,591
Coal Mining	4,003	3,193	2,877	2,710	2,776	2,765	3,221
Petroleum Systems	1,613	1,524	1,439	1,344	1,344	1,372	1,384
Stationary Combustion	353	340	315	312	294	309	319
Abandoned Underground Coal Mines	288	392	350	266	264	269	281
Mobile Combustion	223	204	160	119	112	105	97
Incineration of Waste	+	+	+	+	+	+	+
<i>International Bunker Fuels^a</i>	<i>8</i>	<i>6</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>7</i>	<i>8</i>
N₂O	185	219	220	168	156	146	132
Mobile Combustion	142	174	172	119	108	98	84
Stationary Combustion	41	43	47	47	47	47	46
Incineration of Waste	2	1	1	1	1	1	1
<i>International Bunker Fuels^a</i>	<i>3</i>	<i>3</i>	<i>3</i>	<i>3</i>	<i>4</i>	<i>4</i>	<i>4</i>

+ Does not exceed 0.05 Tg CO₂ Eq.

^a These values are presented for informational purposes only and are not included or are already accounted for in totals.

Note: Totals may not sum due to independent rounding.

3.1. Fossil Fuel Combustion (IPCC Source Category 1A)

Emissions from the combustion of fossil fuels for energy include the gases CO₂, CH₄, and N₂O. Given that CO₂ is the primary gas emitted from fossil fuel combustion and represents the largest share of U.S. total emissions, CO₂ emissions from fossil fuel combustion are discussed at the beginning of this section. Following that is a discussion of emissions of all three gases from fossil fuel combustion presented by sectoral breakdowns. Methodologies for estimating CO₂ from fossil fuel combustion also differ from the estimation of CH₄ and N₂O emissions from stationary combustion and mobile combustion. Thus, three separate descriptions of methodologies, uncertainties, recalculations, and planned improvements are provided at the end of this section. Total CO₂, CH₄, and N₂O emissions from fossil fuel combustion are presented in Table 3-3 and Table 3-4.

CO₂ from Fossil Fuel Combustion

Carbon dioxide is the primary gas emitted from fossil fuel combustion and represents the largest share of U.S. total greenhouse gas emissions. Carbon dioxide emissions from fossil fuel combustion are presented in Table 3-5. In 2008,

CO₂ emissions from fossil fuel combustion decreased by 3.2 percent relative to the previous year. This decrease is primarily a result of a decrease in electricity demand and a decrease in energy consumption, coupled with a significant increase in the cost of fuels used to generate electricity and an increased cost of electricity. In 2008, temperatures were cooler in the United States than in 2007, both in the summer and the winter. This led 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. In addition, the high price of gasoline combined with the economic downturn led to a significant decline in petroleum consumption by the transportation sector in 2008. In 2008, CO₂ emissions from fossil fuel combustion were 5,572.8 Tg CO₂ Eq., or almost 18 percent above emissions in 1990 (see Table 3-5).³

Trends in CO₂ emissions from fossil fuel combustion are influenced by many long-term and short-term factors. On a year-to-year basis, the overall demand for fossil fuels in the United States and other countries 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 winter weather conditions, nuclear plant closures, and lower

Table 3-3: CO₂, CH₄, and N₂O Emissions from Fossil Fuel Combustion (Tg CO₂ Eq.)

Gas	1990	1995	2000	2005	2006	2007	2008
CO ₂	4,735.7	5,029.5	5,593.4	5,753.3	5,652.8	5,757.0	5,572.8
CH ₄	12.1	11.4	10.0	9.1	8.5	8.7	8.7
N ₂ O	56.8	67.4	67.7	51.7	48.1	44.9	40.4
Total	4,804.6	5,108.3	5,671.1	5,814.1	5,709.5	5,810.6	5,621.9

Note: Totals may not sum due to independent rounding.

Table 3-4: CO₂, CH₄, and N₂O Emissions from Fossil Fuel Combustion (Gg)

Gas	1990	1995	2000	2005	2006	2007	2008
CO ₂	4,735,701	5,029,498	5,593,381	5,753,342	5,652,845	5,756,999	5,572,760
CH ₄	576	544	475	431	406	414	416
N ₂ O	183	217	218	167	155	145	130

Note: Totals may not sum due to independent rounding.

³ An additional discussion of fossil fuel emission trends is presented in the Trends in U.S. Greenhouse Gas Emissions chapter.

Table 3-5: CO₂ Emissions from Fossil Fuel Combustion by Fuel Type and Sector (Tg CO₂ Eq.)

Fuel/Sector	1990	1995	2000	2005	2006	2007	2008
Coal	1,718.4	1,819.0	2,065.5	2,112.9	2,077.2	2,105.7	2,076.6
Residential	3.0	1.7	1.1	0.8	0.6	0.7	0.7
Commercial	12.0	11.2	8.8	9.3	6.2	6.7	6.4
Industrial	155.2	144.4	127.3	115.3	112.6	107.0	102.9
Transportation	NE	NE	NE	NE	NE	NE	NE
Electricity Generation	1,547.6	1,660.7	1,927.4	1,983.8	1,953.7	1,987.3	1,962.6
U.S. Territories	0.6	0.9	0.9	3.7	4.1	4.1	4.1
Natural Gas	1,000.7	1,156.6	1,217.4	1,159.9	1,141.4	1,215.0	1,227.0
Residential	238.0	262.7	270.7	262.4	237.3	256.5	264.7
Commercial	142.1	164.2	172.5	163.0	153.8	164.1	169.7
Industrial	409.2	463.3	457.1	381.2	377.8	386.3	393.6
Transportation	36.0	38.4	35.6	33.1	33.1	35.3	35.8
Electricity Generation	175.3	228.1	280.8	318.8	338.0	371.3	361.6
U.S. Territories	NO	NO	0.7	1.3	1.4	1.4	1.6
Petroleum	2,016.3	2,053.5	2,310.2	2,480.2	2,433.8	2,435.9	2,268.8
Residential	98.2	88.9	99.4	95.2	84.1	84.5	77.3
Commercial	62.6	47.8	46.4	48.9	45.9	46.6	43.4
Industrial	281.0	254.9	267.8	329.1	360.3	348.9	322.9
Transportation	1,449.7	1,569.6	1,773.9	1,862.2	1,843.5	1,858.4	1,749.4
Electricity Generation	97.5	58.7	88.4	99.2	54.4	53.9	38.9
U.S. Territories	27.2	33.6	34.2	45.7	45.5	43.6	36.9
Geothermal^a	0.40	0.34	0.36	0.38	0.37	0.38	0.38
Total	4,735.7	5,029.5	5,593.4	5,753.3	5,652.8	5,757.0	5,572.8

NE (Not Estimated)
NO (Not Occurring)
^a Although not technically a fossil fuel, geothermal energy-related CO₂ emissions are included for reporting purposes.
Note: Totals may not sum due to independent rounding.

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.

Longer-term changes in energy consumption patterns, however, tend to be more a function of aggregate societal trends that affect the scale of consumption (e.g., population, number of cars, size of houses, and number of houses), the efficiency with which energy is used in equipment (e.g., cars, power plants, steel mills, and light bulbs), and social planning and consumer behavior (e.g., walking, bicycling, or telecommuting to work instead of driving).

Carbon dioxide emissions also depend on the source of energy and its carbon (C) intensity. The amount of C in fuels varies significantly by fuel type. For example, coal contains the highest amount of C per unit of useful energy. Petroleum has roughly 75 percent of the C per unit of energy as coal, and

natural gas has only about 55 percent.⁴ Producing a unit of heat or electricity using natural gas instead of coal can reduce the CO₂ emissions associated with energy consumption, and using nuclear or renewable energy sources (e.g., wind) can essentially eliminate emissions (see Box 3-2). Table 3-6 shows annual changes in emissions during the last five years for coal, petroleum, and natural gas in selected sectors.

In the United States, 84 percent of the energy consumed in 2008 was produced through the combustion of fossil fuels such as coal, natural gas, and petroleum (see Figure 3-3 and Figure 3-4). The remaining portion was supplied by nuclear electric power (9 percent) and by a variety of renewable energy sources (7 percent), primarily hydroelectric power and biofuels (EIA 2009a). Specifically, petroleum supplied the largest share of domestic energy demands, accounting for an average of 42 percent of total fossil fuel based energy

⁴ Based on national aggregate carbon content of all coal, natural gas, and petroleum fuels combusted in the United States.

Table 3-6: Annual Change in CO₂ Emissions from Fossil Fuel Combustion for Selected Fuels and Sectors (Tg CO₂ Eq. and Percent)

Sector	Fuel Type	2004 to 2005		2005 to 2006		2006 to 2007		2007 to 2008		Total 2008
Electricity Generation	Coal	40.8	2.1%	-30.1	-1.5%	33.6	1.7%	-24.7	-1.2%	1,962.6
Electricity Generation	Natural Gas	22.1	7.5%	19.2	6.0%	33.3	9.9%	-9.6	-2.6%	361.6
Electricity Generation	Petroleum	2.2	2.3%	-44.8	-45.2%	-0.5	-0.9%	-15.0	-27.9%	38.9
Transportation ^a	Petroleum	27.8	1.5%	-18.7	-1.0%	14.9	0.8%	-109.0	-5.9%	1,749.4
Residential	Natural Gas	-2.0	-0.7%	-25.1	-9.6%	19.2	8.1%	8.2	3.2%	264.7
Commercial	Natural Gas	-6.9	-4.0%	-9.2	-5.7%	10.2	6.6%	5.7	3.5%	169.7
Industrial	Coal	-3.0	-2.5%	-2.6	-2.3%	-5.6	-5.0%	-4.1	-3.9%	102.9
Industrial	Natural Gas	-33.0	-8.0%	-3.4	-0.9%	8.5	2.3%	7.2	1.9%	393.6
All Sectors^b	All Fuels^b	44.5	0.8%	-100.5	-1.7%	104.2	1.8%	-184.2	-3.2%	5,572.8

^a Excludes emissions from International Bunker Fuels.
^b Includes fuels and sectors not shown in table.

Figure 3-3

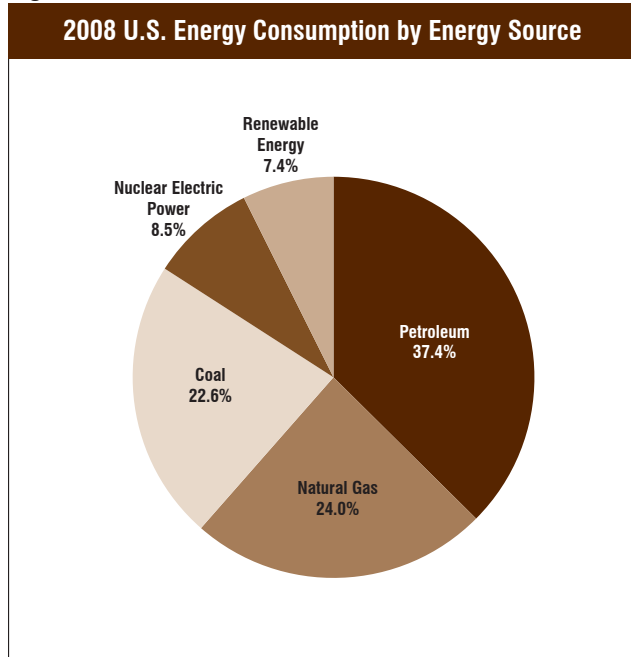


Figure 3-5

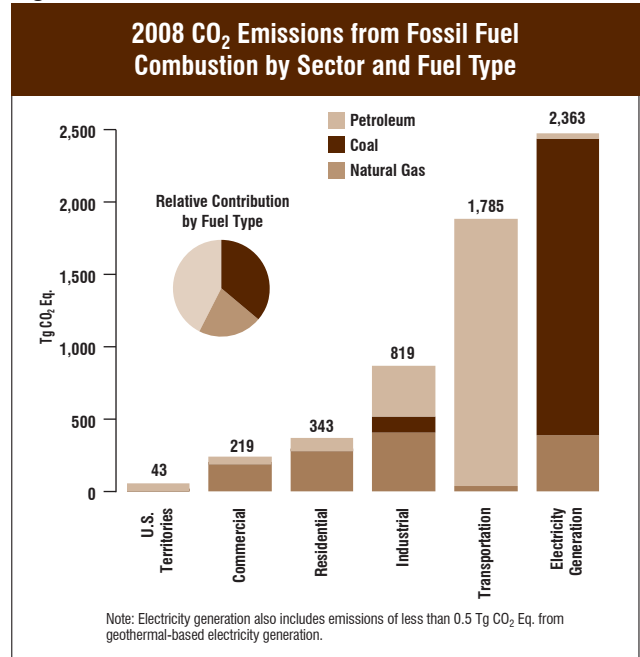
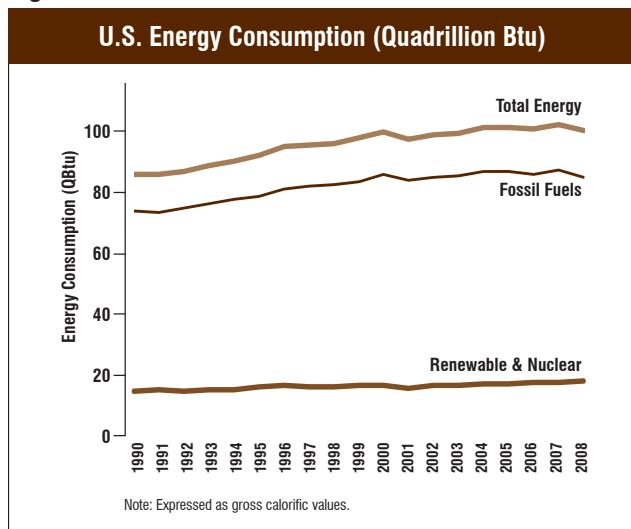


Figure 3-4



consumption in 2008. Natural gas and coal followed in order of importance, accounting for approximately 30 and 28 percent of total consumption, respectively. Petroleum was consumed primarily in the transportation end-use sector, the vast majority of coal was used in electricity generation, and natural gas was broadly consumed in all end-use sectors except transportation (see Figure 3-5) (EIA 2009a).

Fossil fuels are generally combusted for the purpose of producing energy for useful heat and work. During the combustion process, the C stored in the fuels is oxidized and emitted as CO₂ and smaller amounts of other gases, including

Box 3-1: Weather and Non-Fossil Energy Effects on CO₂ from Fossil Fuel Combustion Trends

In 2008, weather conditions were cooler in the winter and much cooler in the summer, as heating degree days increased by 5.6 percent and cooling degree days decreased by 8.7 percent, compared to 2007. Although winter conditions were cooler in 2008 compared to 2007, the winter was slightly warmer than normal, with heating degree days in the United States only 1 percent below normal (see Figure 3-6). Cooler winter conditions compared to 2007 led to an increase in demand for heating fuels. Although summer conditions were slightly cooler in 2008 compared to 2007, summer temperatures were slightly warmer than usual, with cooling degree days 3 percent above normal (see Figure 3-7) (EIA 2009f).⁵ Despite being warmer than normal in 2008, cooling degree days decreased by 8.7% from 2007, which offset the increase in heating related energy demand.

Figure 3-6

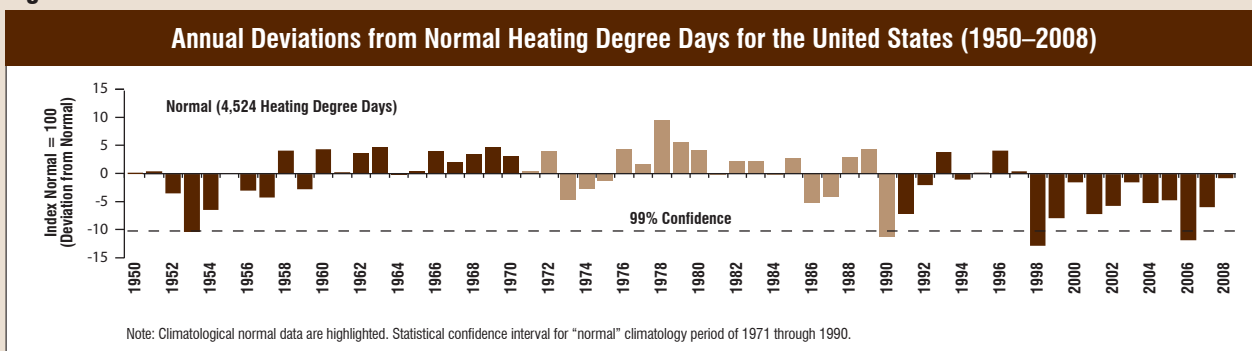


Figure 3-7

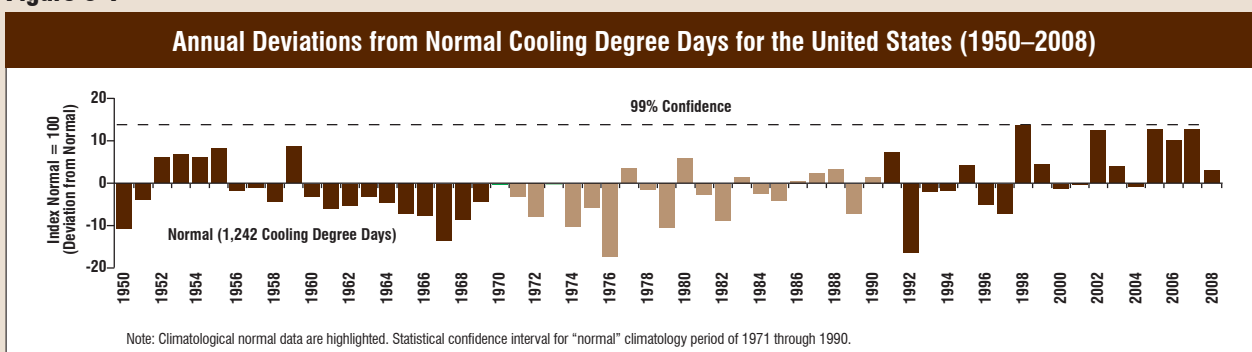
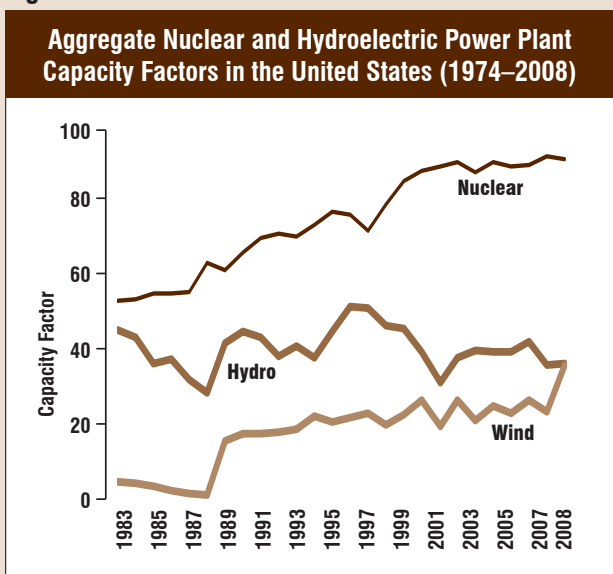


Figure 3-8



Although no new U.S. nuclear power plants have been constructed in recent years, the utilization (i.e., capacity factors)⁶ of existing plants in 2008 remained high at just over 90 percent. Electricity output by hydroelectric power plants increased in 2008 by approximately 0.2 percent. Electricity generated by nuclear plants in 2008 provided just over 3 times as much of the energy consumed in the United States as hydroelectric plants (EIA 2009a). Nuclear, hydroelectric, and wind power capacity factors since 1974 are shown in Figure 3-8.

⁵ Degree days are relative measurements of outdoor air temperature. Heating degree days are deviations of the mean daily temperature below 65° F, while cooling degree days are deviations of the mean daily temperature above 65° F. Heating degree days have a considerably greater affect on energy demand and related emissions than do cooling degree days. Excludes Alaska and Hawaii. Normals are based on data from 1971 through 2000. The variation in these normals during this time period was ±10 percent and ±14 percent for heating and cooling degree days, respectively (99 percent confidence interval).

⁶ The capacity factor equals generation divided by net summer capacity. Summer capacity is defined as "The maximum output that generating equipment can supply to system load, as demonstrated by a multi-hour test, at the time of summer peak demand (period of June 1 through September 30)." Data for both the generation and net summer capacity are from EIA (2009a).

CH₄, CO, and NMVOCs.⁷ These other C containing non-CO₂ gases are emitted as a by-product of incomplete fuel combustion, but are, for the most part, eventually oxidized to CO₂ in the atmosphere. Therefore, it is assumed that all of the C in fossil fuels used to produce energy is eventually converted to atmospheric CO₂.

Fossil Fuel Combustion Emissions by Sector

In addition to the CO₂ emitted from fossil fuel combustion, CH₄ and N₂O are emitted from stationary and mobile combustion as well. Table 3-7 provides an overview of the CO₂, CH₄, and N₂O emissions from fossil fuel combustion by sector.

Other than CO₂, gases emitted from stationary combustion include the greenhouse gases CH₄ and N₂O and the indirect greenhouse gases NO_x, CO, and NMVOCs.⁸ Methane and N₂O emissions from stationary combustion sources depend upon fuel characteristics, size and vintage, along with combustion technology, pollution control equipment, ambient environmental conditions, and operation and maintenance practices. Nitrous oxide emissions from stationary combustion are closely related to air-fuel mixes and combustion temperatures, as well as the characteristics of any pollution control equipment that is employed. Methane emissions from stationary combustion are primarily a function of the CH₄ content of the fuel and combustion efficiency.

Table 3-7: CO₂, CH₄, and N₂O Emissions from Fossil Fuel Combustion by Sector (Tg CO₂ Eq.)

End-Use Sector/Gas	1990	1995	2000	2005	2006	2007	2008
Electricity Generation	1,829.5	1,957.1	2,307.5	2,413.2	2,357.2	2,423.8	2,374.3
CO ₂	1,820.8	1,947.9	2,296.9	2,402.1	2,346.4	2,412.8	2,363.5
CH ₄	0.6	0.6	0.7	0.7	0.7	0.7	0.7
N ₂ O	8.1	8.6	10.0	10.3	10.1	10.3	10.1
Transportation	1,534.4	1,666.3	1,866.1	1,934.7	1,912.6	1,926.2	1,813.4
CO ₂	1,485.8	1,608.0	1,809.5	1,895.3	1,876.7	1,893.7	1,785.3
CH ₄	4.7	4.3	3.4	2.5	2.3	2.2	2.0
N ₂ O	43.9	54.0	53.2	36.9	33.6	30.3	26.1
Industrial	850.2	867.5	857.0	830.1	855.4	846.7	823.4
CO ₂	845.4	862.6	852.2	825.6	850.7	842.2	819.3
CH ₄	1.5	1.6	1.6	1.5	1.5	1.5	1.3
N ₂ O	3.2	3.3	3.2	3.0	3.2	3.0	2.8
Residential	344.6	358.3	375.5	362.7	325.9	346.0	347.4
CO ₂	339.1	353.3	371.2	358.4	322.1	341.7	342.7
CH ₄	4.4	4.0	3.4	3.4	3.1	3.4	3.7
N ₂ O	1.1	1.0	0.9	0.9	0.8	0.9	0.9
Commercial	217.9	224.5	228.9	222.5	207.2	218.6	220.7
CO ₂	216.7	223.2	227.7	221.3	206.0	217.4	219.5
CH ₄	0.9	0.9	0.9	0.9	0.8	0.9	0.9
N ₂ O	0.4	0.4	0.3	0.3	0.3	0.3	0.3
U.S. Territories^a	28.0	34.7	36.0	50.8	51.1	49.3	42.7
Total	4,804.6	5,108.3	5,671.1	5,814.1	5,709.5	5,810.6	5,621.9

^a U.S. Territories are not apportioned by sector, and emissions are total greenhouse gas emissions from all fuel combustion sources.

Note: Totals may not sum due to independent rounding. Emissions from fossil fuel combustion by electricity generation are allocated based on aggregate national electricity consumption by each end-use sector.

⁷ See the sections entitled Stationary Combustion and Mobile Combustion in this chapter for information on non-CO₂ gas emissions from fossil fuel combustion.

⁸ Sulfur dioxide (SO₂) emissions from stationary combustion are addressed in Annex 6.3.

Table 3-8: CO₂, CH₄, and N₂O Emissions from Fossil Fuel Combustion by End-Use Sector (Tg CO₂ Eq.)

End-Use Sector/Gas	1990	1995	2000	2005	2006	2007	2008
Transportation	1,537.5	1,669.3	1,869.5	1,939.5	1,917.2	1,931.3	1,818.1
CO ₂	1,488.8	1,611.0	1,813.0	1,900.1	1,881.2	1,898.8	1,789.9
CH ₄	4.7	4.3	3.4	2.5	2.4	2.2	2.0
N ₂ O	44.0	54.0	53.2	37.0	33.6	30.3	26.2
Industrial	1,540.2	1,587.1	1,650.5	1,570.4	1,570.7	1,580.0	1,518.2
CO ₂	1,532.2	1,578.8	1,642.0	1,562.5	1,562.8	1,572.2	1,510.9
CH ₄	1.8	1.8	1.8	1.7	1.7	1.7	1.5
N ₂ O	6.3	6.5	6.7	6.2	6.2	6.2	5.7
Residential	940.5	1,003.1	1,141.5	1,223.4	1,160.6	1,206.0	1,193.0
CO ₂	932.2	995.1	1,133.6	1,215.1	1,152.9	1,197.9	1,184.5
CH ₄	4.6	4.2	3.6	3.7	3.3	3.6	4.0
N ₂ O	3.7	3.8	4.2	4.6	4.4	4.5	4.5
Commercial	758.4	814.0	973.6	1,029.9	1,009.8	1,044.0	1,049.9
CO ₂	754.6	810.0	968.9	1,025.0	1,005.0	1,039.1	1,044.9
CH ₄	1.0	1.1	1.1	1.1	1.1	1.1	1.1
N ₂ O	2.8	2.9	3.6	3.8	3.7	3.8	3.8
U.S. Territories^a	28.0	34.7	36.0	50.8	51.1	49.3	42.7
Total	4,804.6	5,108.3	5,671.1	5,814.1	5,709.5	5,810.6	5,621.9

^a U.S. Territories are not apportioned by sector, and emissions are total greenhouse gas emissions from all fuel combustion sources.

Note: Totals may not sum due to independent rounding. Emissions from fossil fuel combustion by electricity generation are allocated based on aggregate national electricity consumption by each end-use sector.

Mobile combustion produces greenhouse gases other than CO₂, including CH₄, N₂O, and indirect greenhouse gases including NO_x, CO, and NMVOCs. As with stationary combustion, N₂O and NO_x emissions from mobile combustion are closely related to fuel characteristics, air-fuel mixes, combustion temperatures, and the use of pollution control equipment. N₂O from mobile sources, in particular, can be formed by the catalytic processes used to control NO_x, CO, and hydrocarbon emissions. Carbon monoxide emissions from mobile combustion are significantly affected by combustion efficiency and the presence of post-combustion emission controls. Carbon monoxide emissions are highest when air-fuel mixtures have less oxygen than required for complete combustion. These emissions occur especially in idle, low speed, and cold start conditions. Methane and NMVOC emissions from motor vehicles are a function of the CH₄ content of the motor fuel, the amount of hydrocarbons passing uncombusted through the engine,

and any post-combustion control of hydrocarbon emissions (such as catalytic converters).

An alternative method of presenting combustion emissions is to allocate emissions associated with electricity generation to the sectors in which it is used. Four end-use sectors were defined: industrial, transportation, residential, and commercial. In the table below, electricity generation emissions have been distributed to each end-use sector based upon the sector's share of national electricity consumption, with the exception of CH₄ and N₂O from transportation.⁹ Emissions from U.S. territories are also calculated separately due to a lack of end-use-specific consumption data. This method of distributing emissions assumes that 564 combustion sources focus on the alternative method as presented in Table 3-8.

⁹ Separate calculations were performed for transportation-related CH₄ and N₂O. The methodology used to calculate these emissions are discussed in the mobile combustion section.

Stationary Combustion

The direct combustion of fuels by stationary sources in the electricity generation, industrial, commercial, and residential sectors represent the greatest share of U.S. greenhouse gas emissions. Table 3-9 presents CO₂ emissions from fossil fuel combustion by stationary sources. The CO₂ emitted is closely linked to the type of fuel being combusted in each sector (see Methodology section for CO₂ from fossil fuel combustion). Other than CO₂, gases emitted from stationary combustion include the greenhouse gases CH₄ and N₂O. Table 3-10 and Table 3-11 present CH₄ and N₂O emissions from the combustion of fuels in stationary sources. Methane and N₂O emissions from stationary combustion sources depend upon fuel characteristics, size and vintage, along with combustion technology, pollution control equipment, ambient environmental conditions, and operation and maintenance practices. Nitrous oxide

emissions from stationary combustion are closely related to air-fuel mixes and combustion temperatures, as well as the characteristics of any pollution control equipment that is employed. Methane emissions from stationary combustion are primarily a function of the CH₄ content of the fuel and combustion efficiency. Please refer to Table 3-7 for the corresponding presentation of all direct emission sources of fuel combustion.

Electricity Generation

The process of generating electricity is the single largest source of CO₂ emissions in the United States, representing 40 percent of total CO₂ emissions from all CO₂ emissions sources across the United States. Methane and N₂O accounted for a small portion of emissions from electricity generation, representing less than 0.1 percent and 0.4 percent, respectively.¹⁰ Electricity generation also accounted for the largest share of CO₂ emissions from

Table 3-9: CO₂ Emissions from Stationary Combustion (Tg CO₂ Eq.)

Sector/Fuel Type	1990	1995	2000	2005	2006	2007	2008
Electricity Generation	1,820.8	1,947.9	2,296.9	2,402.1	2,346.4	2,412.8	2,363.5
Coal	1,547.6	1,660.7	1,927.4	1,983.8	1,953.7	1,987.3	1,962.6
Natural Gas	175.3	228.1	280.8	318.8	338.0	371.3	361.6
Fuel Oil	97.5	58.7	88.4	99.2	54.4	53.9	38.9
Geothermal	0.4	0.3	0.4	0.4	0.4	0.4	0.4
Industrial	845.4	862.6	852.2	825.6	850.7	842.2	819.3
Coal	155.2	144.4	127.3	115.3	112.6	107.0	102.9
Natural Gas	409.2	463.3	457.1	381.2	377.8	386.3	393.6
Fuel Oil	281.0	254.9	267.8	329.1	360.3	348.9	322.9
Commercial	216.7	223.2	227.7	221.3	206.0	217.4	219.5
Coal	12.0	11.2	8.8	9.3	6.2	6.7	6.4
Natural Gas	142.1	164.2	172.5	163.0	153.8	164.1	169.7
Fuel Oil	62.6	47.8	46.4	48.9	45.9	46.6	43.4
Residential	339.1	353.3	371.2	358.4	322.1	341.7	342.7
Coal	3.0	1.7	1.1	0.8	0.6	0.7	0.7
Natural Gas	238.0	262.7	270.7	262.4	237.3	256.5	264.7
Fuel Oil	98.2	88.9	99.4	95.2	84.1	84.5	77.3
U.S. Territories^a	27.9	34.5	35.9	50.6	50.9	49.1	42.5
Coal	0.6	0.9	0.9	3.7	4.1	4.1	4.1
Natural Gas	NO	NO	0.7	1.3	1.4	1.4	1.6
Fuel Oil	27.2	33.6	34.2	45.7	45.5	43.6	36.9
Total	3,249.9	3,421.5	3,783.8	3,858.0	3,776.2	3,863.3	3,787.5

^a U.S. Territories are not apportioned by sector, and emissions are from all fuel combustion sources (stationary and mobile) are presented in this table.

¹⁰ Since emissions estimates for U.S. territories cannot be disaggregated by gas in Table 3-7 and Table 3-8, the percentages for CH₄ and N₂O exclude U.S. territory estimates.

Table 3-10: CH₄ Emissions from Stationary Combustion (Tg CO₂ Eq.)

Sector/Fuel Type	1990	1995	2000	2005	2006	2007	2008
Electricity Generation	0.6	0.6	0.7	0.7	0.7	0.7	0.7
Coal	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Fuel Oil	0.1	+	0.1	0.1	+	+	+
Natural Gas	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wood	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Industrial	1.5	1.6	1.6	1.5	1.5	1.5	1.3
Coal	0.3	0.3	0.3	0.3	0.3	0.2	0.2
Fuel Oil	0.2	0.1	0.1	0.2	0.2	0.2	0.2
Natural Gas	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Wood	0.9	1.0	1.0	0.9	0.9	0.9	0.8
Commercial	0.9	0.9	0.9	0.9	0.8	0.9	0.9
Coal	+	+	+	+	+	+	+
Fuel Oil	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Natural Gas	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Wood	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Residential	4.4	4.0	3.4	3.4	3.1	3.4	3.7
Coal	0.2	0.1	0.1	0.1	+	+	+
Fuel Oil	0.3	0.3	0.3	0.3	0.3	0.3	0.2
Natural Gas	0.4	0.5	0.5	0.5	0.4	0.5	0.5
Wood	3.5	3.1	2.5	2.6	2.3	2.6	2.9
U.S. Territories	+	+	0.1	0.1	0.1	0.1	0.1
Coal	+	+	+	+	+	+	+
Fuel Oil	+	+	+	0.1	0.1	0.1	0.1
Natural Gas	+	+	+	+	+	+	+
Wood	+	+	+	+	+	+	+
Total	7.4	7.1	6.6	6.6	6.2	6.5	6.7

+ Does not exceed 0.05 Tg CO₂ Eq.
 Note: Totals may not sum due to independent rounding.

fossil fuel combustion, approximately 42 percent in 2008. Methane and N₂O from electricity generation represented 8 and 25 percent of emissions from fossil fuel combustion in 2008, respectively. Electricity was consumed primarily in the residential, commercial, and industrial end-use sectors for lighting, heating, electric motors, appliances, electronics, and air conditioning (see Figure 3-9).

The electric power industry includes all power producers, consisting of both regulated utilities and nonutilities (e.g. independent power producers, qualifying cogenerators, and other small power producers). For the underlying energy data used in this chapter, the Energy Information Administration (EIA) places electric power generation into three functional categories: the electric power sector, the commercial sector, and the industrial sector. The electric power sector consists of electric utilities and independent power producers whose

Figure 3-9

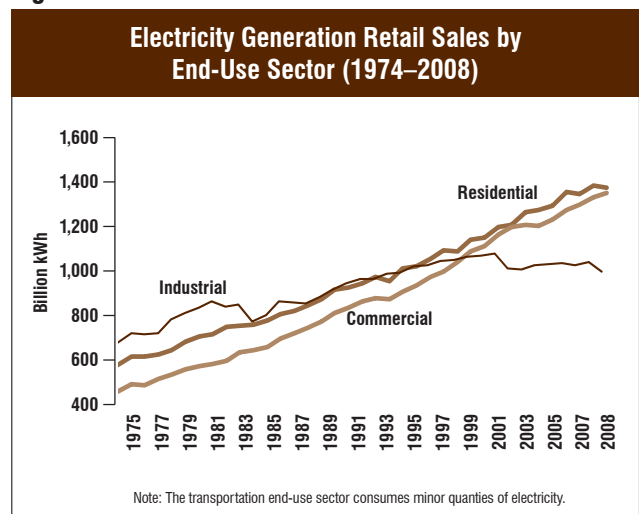


Table 3-11: N₂O Emissions from Stationary Combustion (Tg CO₂ Eq.)

Sector/Fuel Type	1990	1995	2000	2005	2006	2007	2008
Electricity Generation	8.1	8.6	10.0	10.3	10.1	10.2	10.1
Coal	7.6	8.1	9.4	9.7	9.5	9.7	9.6
Fuel Oil	0.2	0.1	0.2	0.2	0.1	0.1	0.1
Natural Gas	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Wood	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Industrial	3.2	3.3	3.2	3.0	3.2	3.0	2.8
Coal	0.8	0.7	0.6	0.6	0.6	0.5	0.5
Fuel Oil	0.5	0.4	0.4	0.5	0.6	0.6	0.5
Natural Gas	0.2	0.3	0.3	0.2	0.2	0.2	0.2
Wood	1.7	1.9	1.9	1.7	1.8	1.7	1.5
Commercial	0.4	0.4	0.3	0.3	0.3	0.3	0.3
Coal	0.1	0.1	+	+	+	+	+
Fuel Oil	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Natural Gas	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wood	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Residential	1.1	1.0	0.9	0.9	0.8	0.9	0.9
Coal	+	+	+	+	+	+	+
Fuel Oil	0.3	0.2	0.3	0.3	0.2	0.2	0.2
Natural Gas	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Wood	0.7	0.6	0.5	0.5	0.5	0.5	0.6
U.S. Territories	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Coal	+	+	+	+	+	+	+
Fuel Oil	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Natural Gas	+	+	+	+	+	+	+
Wood	+	+	+	+	+	+	+
Total	12.8	13.3	14.5	14.7	14.5	14.6	14.2

+ Does not exceed 0.05 Tg CO₂ Eq.
Note: Totals may not sum due to independent rounding.

primary business is the production of electricity,¹¹ while the other sectors consist of those producers that indicate their primary business is something other than the production of electricity.

The industrial, residential, and commercial end-use sectors, as presented in Table 3-8, were reliant on electricity for meeting energy needs. The residential and commercial end-use sectors were especially reliant on electricity consumption for lighting, heating, air conditioning, and operating appliances. Electricity sales to the residential and commercial end-use sectors in 2008 decreased approximately 0.9 percent and increased 1.2 percent, respectively. The trend in the commercial sector can largely be attributed to

slightly positive growth in the U.S. economy that was largely concentrated in non-industrial activity that takes place in the commercial sector. Furthermore, unless entire facilities such as shopping centers are closed, their lights and electronic equipment remain on, even if there are fewer customers using them. The decrease in the residential sector is attributed to a decrease in air conditioning-related electricity consumption in the residential and commercial sectors that occurred as a result of the cooler summer compared to 2007. In 2008, the amount of electricity generated (in kWh) decreased by 1.3 percent from the previous year. This decline was due to the economic downturn, an increase in the cost of electricity, and more favorable weather conditions compared to 2007. As a result, CO₂ emissions from the electric power sector decreased by 2.0 percent as the consumption of coal, natural gas, and petroleum for electricity generation decreased. Consumption of coal, natural gas, and petroleum for

¹¹ Utilities primarily generate power for the U.S. electric grid for sale to retail customers. Nonutilities produce electricity for their own use, to sell to large consumers, or to sell on the wholesale electricity market (e.g., to utilities for distribution and resale to customers).

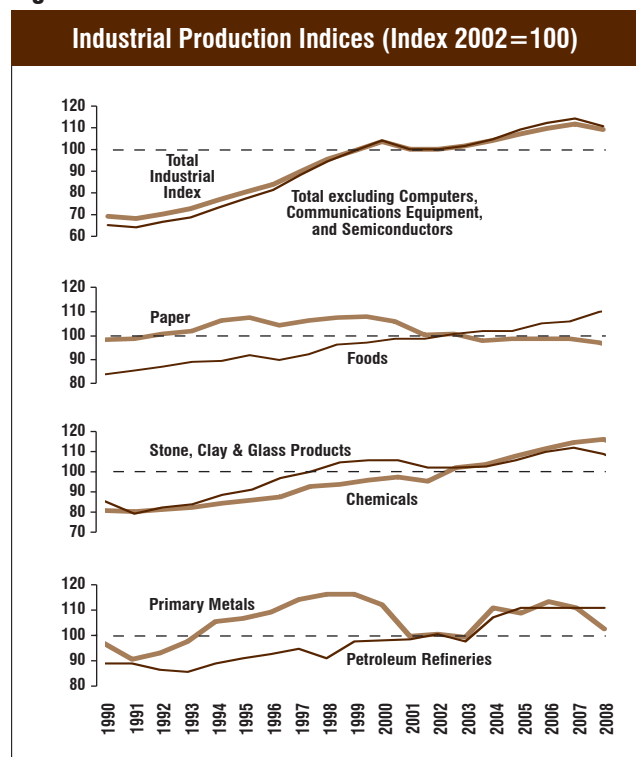
electricity generation, decreased by 1.3 percent, 2.6 percent, and 29.5 percent, respectively, in 2008. While in 2008 the amount of electricity generated decreased by 1.3 percent, CO₂ emissions from the electric power sector decreased by 2.0 percent. The decrease in C intensity of the electricity supply (see Table 3-16) was the result of a decrease in fossil fuels consumed to generate electricity and an increase in renewable generation of 7 percent spurred by a 51 percent increase in wind-generated electricity.

Industrial Sector

The industrial sector accounted for 15 percent of CO₂ emissions from fossil fuel combustion, 15 percent of CH₄ emissions from fossil fuel combustion, and 7 percent of N₂O emissions from fossil fuel combustion. Carbon dioxide, CH₄, and N₂O emissions resulted from the direct consumption of fossil fuels for steam and process heat production.

The industrial sector, per the underlying energy consumption data from EIA, includes activities such as manufacturing, construction, mining, and agriculture. The largest of these activities in terms of energy consumption is manufacturing, of which six industries—Petroleum Refineries, Chemicals, Primary Metals, Paper, Food, and Nonmetallic Mineral Products—represent the vast majority of the energy use (EIA 2009a and EIA 2005).

Figure 3-10



In theory, emissions from the industrial sector should be highly correlated with economic growth and industrial output, but heating of industrial buildings and agricultural energy consumption are also affected by weather conditions.¹² In addition, structural changes within the U.S. economy that lead to shifts in industrial output away from energy-intensive manufacturing products to less energy-intensive products (e.g., from steel to computer equipment) also have a significant effect on industrial emissions.

From 2007 to 2008, total industrial production and manufacturing output decreased by 2.2 and 3.1 percent, respectively (FRB 2008). Over this period, output increased for Food and Petroleum Refineries, and decreased for Chemicals, Paper, Primary Metals, and Nonmetallic Mineral Products (see Figure 3-10).

Despite the growth in industrial output (56 percent) and the overall U.S. economy (66 percent) from 1990 to 2008, CO₂ emissions from fossil fuel combustion in the industrial sector decreased by 3.1 percent over that time. A number of factors are believed to have caused this disparity between growth in industrial output and decrease in industrial emissions, including: (1) more rapid growth in output from less energy-intensive industries relative to traditional manufacturing industries, and (2) energy-intensive industries such as steel are employing new methods, such as electric arc furnaces, that are less carbon intensive than the older methods. In 2008, CO₂, CH₄, and N₂O emissions from fossil fuel combustion and electricity use within the industrial end-use sector totaled 1,518.2 Tg CO₂ Eq., or approximately 3.9 percent below 2007 emissions.

Residential and Commercial Sectors

The residential and commercial sectors accounted for an average 6 and 4 percent of CO₂ emissions from fossil fuel combustion, 43 and 10 percent of CH₄ emissions from fossil fuel combustion, and 2 and 1 percent of N₂O emissions from fossil fuel combustion, respectively. Emissions from these sectors were largely due to the direct consumption of natural gas and petroleum products, primarily for heating and

¹² Some commercial customers are large enough to obtain an industrial price for natural gas and/or electricity and are consequently grouped with the industrial end-use sector in U.S. energy statistics. These misclassifications of large commercial customers likely cause the industrial end-use sector to appear to be more sensitive to weather conditions.

cooking needs. Coal consumption was a minor component of energy use in both of these end-use sectors. In 2008, CO₂, CH₄, and N₂O emissions from fossil fuel combustion and electricity use within the residential and commercial end-use sectors were 1,193.0 Tg CO₂ Eq. and 1,049.9 Tg CO₂ Eq., respectively. Total CO₂, CH₄, and N₂O emissions from the residential sector decreased by 1.1 percent in 2008, with emissions in 2008 from the commercial sector 0.6 percent higher than in 2007.

Emissions from the residential and commercial sectors have generally been increasing since 1990, and are often correlated with short-term fluctuations in energy consumption caused by weather conditions, rather than prevailing economic conditions. In the long-term, both sectors are also affected by population growth, regional migration trends, and changes in housing and building attributes (e.g., size and insulation).

Emissions from natural gas consumption represent over 77 percent of the direct fossil fuel CO₂ emissions from each of these sectors. In 2008, natural gas CO₂ emissions from the residential and commercial sectors increased by 3.2 percent and 3.5 percent, respectively. The increase in natural gas emissions in both sectors is a result of cooler winter conditions in the United States compared to 2007.

U.S. Territories

Emissions from U.S. territories are based on the fuel consumption in American Samoa, Guam, Puerto Rico, U.S. Virgin Islands, Wake Island, and other U.S. Pacific Islands. As described the Methodology section for CO₂ from fossil fuel combustion, this data is collected separately from the sectoral-level data available for the general calculations. As sectoral information is not available for U.S. Territories, CO₂, CH₄, and N₂O emissions are not presented for U.S. Territories in the tables above, though the emissions will include some transportation and mobile combustion sources.

Transportation and Mobile Combustion

This discussion of transportation emissions follows the alternative method of presenting combustion emissions by allocating emissions associated with electricity generation to the transportation end-use sector, as presented in Table 3-8. For direct emissions from transportation (i.e., not including electricity consumption), please see Table 3-7.

Transportation End-Use Sector

The transportation end-use sector accounted for 1,818.1 Tg CO₂ Eq. in 2008, which represented 32 percent of CO₂ emissions, 24 percent of CH₄ emissions, and 65 percent of N₂O emissions from fossil fuel combustion, respectively. Fuel purchased in the U.S. for international aircraft and marine travel accounted for an additional 135.2 Tg CO₂ in 2008; these emissions are recorded as international bunkers and are not included in U.S. totals according to UNFCCC reporting protocols. Among domestic transportation sources, light duty vehicles (including passenger cars and light-duty trucks) represented 62 percent of CO₂ emissions, medium- and heavy-duty trucks 22 percent, commercial aircraft 7 percent, and other sources 9 percent. See Table 3-12 for a detailed breakdown of CO₂ emissions by mode and fuel type.

From 1990 to 2008, transportation emissions rose by 22 percent due, in large part, to increased demand for travel and the stagnation of fuel efficiency across the U.S. vehicle fleet. The number of vehicle miles traveled by light-duty motor vehicles (passenger cars and light-duty trucks) increased 37 percent from 1990 to 2008, as a result of a confluence of factors including population growth, economic growth, urban sprawl, and low fuel prices over much of this period. A similar set of social and economic trends has led to a significant increase in air travel and freight transportation by both air and road modes during the time series.

From 2007 to 2008, CO₂ emissions from transportation sources declined 6 percent (the largest annual change in either absolute or percentage terms recorded between 1990 and 2008). The decrease in emissions can largely be attributed to the decline in economic activity during 2008 and the increased price of transportation fuels. Modes such as medium- and heavy-duty trucks were significantly impacted by the decline in freight transport. Similarly, increased jet fuel prices were a factor in the 12 percent drop in commercial aircraft emissions since 2007.

Almost all of the energy consumed for transportation was supplied by petroleum-based products, with more than half being related to gasoline consumption in automobiles and other highway vehicles. Other fuel uses, especially diesel fuel for freight trucks and jet fuel for aircraft, accounted for the remainder. The primary driver of transportation-related emissions was CO₂ from fossil fuel combustion, which increased by 20 percent from 1990 to 2008. This rise in CO₂ emissions, combined with an increase in HFCs from

Table 3-12: CO₂ Emissions from Fossil Fuel Combustion in Transportation End-Use Sector (Tg CO₂ Eq.)^a

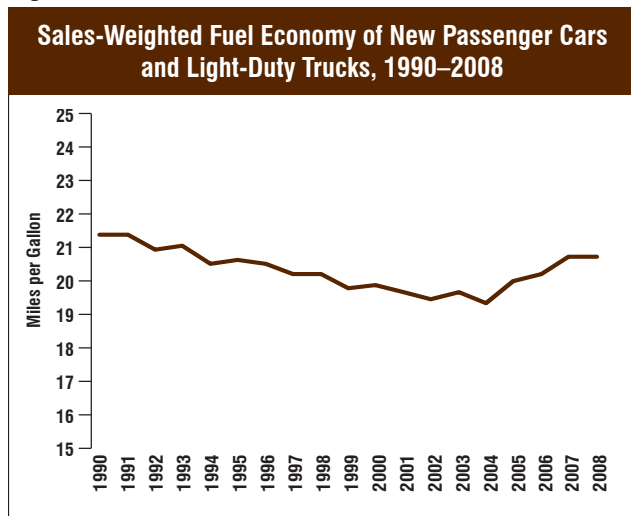
Fuel/Vehicle Type	1990	1995	2000	2005	2006	2007	2008
Gasoline	983.6	1,041.7	1,135.1	1,187.3	1,177.6	1,180.4	1,129.4
Passenger Cars	621.3	598.7	640.5	657.8	634.6	628.3	593.6
Light-Duty Trucks	309.0	391.0	446.3	478.6	491.2	499.8	486.1
Medium- and Heavy-Duty Trucks ^b	38.7	35.9	36.0	34.9	35.5	36.0	33.7
Buses	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Motorcycles	1.7	1.8	1.8	1.6	1.9	2.1	2.1
Recreational Boats	12.4	14.0	10.1	14.1	14.0	13.9	13.5
Distillate Fuel Oil (Diesel)	262.9	324.2	402.5	458.1	470.3	476.3	441.9
Passenger Cars	7.9	7.8	3.7	4.2	4.1	4.1	3.9
Light-Duty Trucks	11.5	14.9	20.1	25.8	26.8	27.3	26.7
Medium- and Heavy-Duty Trucks ^b	190.5	238.4	309.6	360.6	370.1	376.1	354.5
Buses	8.0	8.7	10.2	10.6	10.8	10.8	10.3
Rail	35.5	39.6	42.1	45.6	47.8	46.6	43.2
Recreational Boats	2.0	2.3	2.7	3.1	3.2	3.3	0.9
Ships and Other Boats	7.5	12.4	14.1	8.1	7.5	8.2	2.2
<i>International Bunker Fuels^c</i>	<i>11.7</i>	<i>9.3</i>	<i>6.3</i>	<i>9.4</i>	<i>8.8</i>	<i>8.2</i>	<i>9.0</i>
Jet Fuel	176.2	170.9	199.8	193.5	168.8	169.3	153.6
Commercial Aircraft	135.4	141.6	169.2	161.2	137.1	138.1	122.2
Military Aircraft	34.4	23.9	21.1	18.1	16.4	16.1	16.3
General Aviation Aircraft	6.4	5.4	9.5	14.1	15.3	15.0	15.1
<i>International Bunker Fuels^c</i>	<i>46.4</i>	<i>51.2</i>	<i>58.8</i>	<i>57.5</i>	<i>75.3</i>	<i>73.2</i>	<i>77.0</i>
Aviation Gasoline	3.1	2.7	2.5	2.4	2.3	2.2	2.0
General Aviation Aircraft	3.1	2.7	2.5	2.4	2.3	2.2	2.0
Residual Fuel Oil	22.6	29.1	33.3	19.3	23.0	29.0	21.4
Ships and Other Boats ^d	22.6	29.1	33.3	19.3	23.0	29.0	21.4
<i>International Bunker Fuels^{c, d}</i>	<i>53.7</i>	<i>39.3</i>	<i>33.3</i>	<i>43.6</i>	<i>45.0</i>	<i>45.6</i>	<i>49.2</i>
Natural Gas	36.0	38.4	35.6	33.1	33.1	35.3	35.8
Passenger Cars	-	0.1	-	-	-	-	-
Light-Duty Trucks	-	+	-	-	-	-	-
Buses	-	0.1	0.4	0.8	0.8	1.0	1.0
Pipeline	36.0	38.2	35.2	32.3	32.3	34.3	34.9
LPG	1.3	1.0	0.7	1.6	1.6	1.3	1.2
Light-Duty Trucks	0.5	0.5	0.4	1.2	1.1	0.9	0.9
Medium- and Heavy-Duty Trucks ^b	0.8	0.5	0.2	0.4	0.4	0.4	0.3
Buses	-	+	+	+	+	-	-
Electricity	3.0	3.1	3.4	4.7	4.5	5.0	4.7
Rail	3.0	3.1	3.4	4.7	4.5	5.0	4.7
Total	1,488.8	1,611.0	1,813.0	1,900.1	1,881.2	1,898.8	1,789.9
Total (Including Bunkers)^c	1,600.7	1,710.9	1,911.5	2,010.6	2,010.3	2,025.8	1,925.1

+ Less than 0.05 Tg CO₂ Eq.

- Unreported or zero.

^a This table does not include emissions from non-transportation mobile sources, such as agricultural equipment and construction/mining equipment; it also does not include emissions associated with electricity consumption by pipelines or lubricants used in transportation.^b Includes medium- and heavy-duty trucks over 8,500 lbs.^c Official estimates exclude emissions from the combustion of both aviation and marine international bunker fuels; however, estimates including international bunker fuel-related emissions are presented for informational purposes.^d Fluctuations in emission estimates from the combustion of residual fuel oil are associated with fluctuations in reported fuel consumption and may reflect data collection problems.

Note: Totals may not sum due to independent rounding.

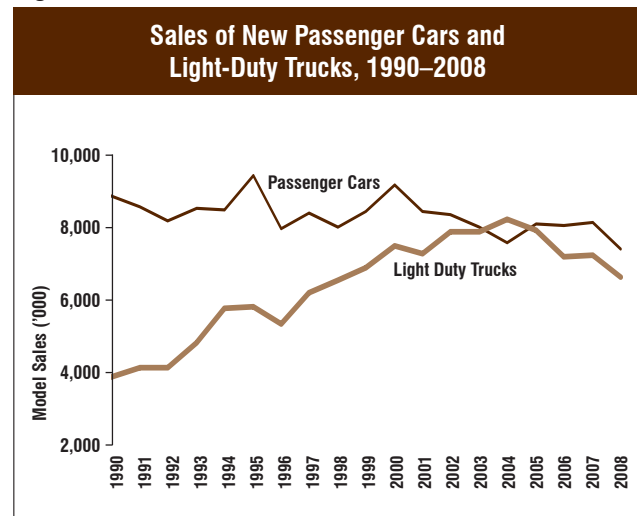
Figure 3-11

close to zero emissions in 1990 to 64.9 Tg CO₂ Eq. in 2008, led to an increase in overall emissions from transportation activities of 22 percent.

Fossil Fuel Combustion CO₂ Emissions from Transportation

Domestic transportation CO₂ emissions increased by 20 percent (301.1 Tg) between 1990 and 2008, an annualized increase of 1.1 percent. The 6 percent decline in emissions between 2007 and 2008 reversed a trend of generally increasing emission since 2001. Almost all of the energy consumed by the transportation sector is petroleum-based, including motor gasoline, diesel fuel, jet fuel, and residual oil. Transportation sources also produce CH₄ and N₂O; these emissions are included in Table 3-13 and Table 3-14 in the “Mobile Combustion” Section. Annex 3.2 presents total emissions from all transportation and mobile sources, including CO₂, N₂O, CH₄, and HFCs.

Carbon dioxide emissions from passenger cars and light-duty trucks totaled 1,111.2 Tg in 2008, an increase of 17 percent (160.9 Tg) from 1990. CO₂ emissions from passenger cars and light-duty trucks peaked at 1,183.9 Tg in 2004, and since then have declined about 6 percent. Over the 1990s through early this decade, growth in vehicle travel substantially outweighed improvements in vehicle fuel economy; however, the rate of vehicle miles traveled (VMT) growth slowed considerably starting in 2005 (and declined rapidly in 2008) while average vehicle fuel economy increased. Among new vehicles sold annually, average fuel economy gradually declined from 1990 to 2004 (Figure 3-11), reflecting substantial growth in sales of light-duty

Figure 3-12

trucks—in particular, growth in the market share of sport utility vehicles—relative to passenger cars (Figure 3-12). New vehicle fuel economy improved beginning in 2005, largely due to higher light-duty truck fuel economy standards, which have risen each year since 2005. The overall increase in fuel economy is also due to a slightly lower light-duty truck market share, which peaked in 2004 at 52 percent and declined to 49 percent in 2008.

General aviation aircraft CO₂ emissions increased by 80 percent (7.6 Tg) from 1990 to 2008, representing the largest percentage increase of any transportation mode. Among on-road vehicles, CO₂ emissions from medium- and heavy-duty trucks¹³ increased by the largest percentage, 69 percent (158.5 Tg) from 1990 to 2008. This increase was largely due to a substantial increase in truck freight movement, as medium- and heavy-duty truck VMT increased by 54 percent. Carbon dioxide from the domestic operation of commercial aircraft decreased by 10 percent (13.2 Tg) from 1990 to 2008 in large part because of the economic recession in 2008. Additionally, commercial aircraft have substantially improved operational efficiency because of a growing percentage of seats occupied per flight, improvements in the fuel efficiency of new aircraft, and the accelerated retirement of older, less fuel efficient aircraft. Across all categories of aviation,¹⁴ CO₂ emissions decreased by 13.3 percent (23.8

¹³Includes “medium- and heavy-duty trucks” fueled by gasoline, diesel and LPG.

¹⁴Includes consumption of jet fuel and aviation gasoline. Does not include aircraft bunkers, which are not accounted for in national emission totals.

Tg) between 1990 and 2008. This includes a 53 percent (18.2 Tg) decrease in emissions from domestic military operations. For further information on all greenhouse gas emissions from transportation sources, please refer to Annex 3.2.

Fossil Fuel Combustion CH₄ and N₂O Emissions from Mobile Sources

Mobile combustion includes emissions of CH₄ and N₂O from all transportation sources identified in the U.S. Inventory with the exception of pipelines, which are stationary; mobile sources also include non-transportation sources such as construction/mining equipment, agricultural equipment, vehicles used off-road, and other sources (e.g., snowmobiles, lawnmowers, etc.). Annex 3.2 includes a summary of all emissions from both transportation and mobile sources. Table 3-13 and Table 3-14 provide CH₄ and N₂O emission estimates in Tg CO₂ Eq.¹⁵

Mobile combustion was responsible for a small portion of national CH₄ emissions (0.4 percent) but was the second largest source of U.S. N₂O emissions (8 percent). From 1990 to 2008, mobile source CH₄ emissions declined by 56 percent, to 2.0 Tg CO₂ Eq. (97 Gg), due largely to control technologies employed in on-road vehicles since the mid-1990s to reduce CO, NO_x, NMVOC, and CH₄ emissions. Mobile source emissions of N₂O decreased by 40 percent, to 26.1 Tg CO₂ Eq. (84 Gg). Earlier generation control technologies initially resulted in higher N₂O emissions, causing a 26 percent increase in N₂O emissions from mobile sources between 1990 and 1998. Improvements in later-generation emission control technologies have reduced N₂O output, resulting in a 53 percent decrease in mobile source N₂O emissions from 1998 to 2008 (Figure 3-13). Overall, CH₄ and N₂O emissions were predominantly from gasoline-fueled passenger cars and light-duty trucks.

Table 3-13: CH₄ Emissions from Mobile Combustion (Tg CO₂ Eq.)

Fuel/Vehicle Type^a	1990	1995	2000	2005	2006	2007	2008
Gasoline On-Road	4.2	3.8	2.8	1.9	1.7	1.6	1.4
Passenger Cars	2.6	2.1	1.6	1.1	1.0	0.9	0.8
Light-Duty Trucks	1.4	1.4	1.1	0.7	0.6	0.6	0.6
Medium- and Heavy-Duty Trucks and Buses	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Motorcycles	+	+	+	+	+	+	+
Diesel On-Road	+	+	+	+	+	+	+
Passenger Cars	+	+	+	+	+	+	+
Light-Duty Trucks	+	+	+	+	+	+	+
Medium- and Heavy-Duty Trucks and Buses	+	+	+	+	+	+	+
Alternative Fuel On-Road	+	+	+	+	0.1	0.1	0.1
Non-Road	0.4	0.5	0.5	0.6	0.6	0.6	0.5
Ships and Other Boats	+	+	+	+	+	+	+
Rail	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Aircraft	0.2	0.1	0.2	0.2	0.1	0.1	0.1
Agricultural Equipment ^b	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Construction/Mining Equipment ^c	+	0.1	0.1	0.1	0.1	0.1	0.1
Other ^d	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	4.7	4.3	3.4	2.5	2.3	2.2	2.0

+ Less than 0.05 Tg CO₂ Eq.

^a See Annex 3.2 for definitions of on-road vehicle types.

^b Includes equipment, such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.

^c Includes equipment, such as cranes, dumpers, and excavators, as well as fuel consumption from trucks that are used off-road in construction.

^d "Other" includes snowmobiles and other recreational equipment, logging equipment, lawn and garden equipment, railroad equipment, airport equipment, commercial equipment, and industrial equipment, as well as fuel consumption from trucks that are used off-road for commercial/industrial purposes.

Note: Totals may not sum due to independent rounding.

¹⁵ See Annex 3.2 for a complete time series of emission estimates for 1990 through 2008.

Table 3-14: N₂O Emissions from Mobile Combustion (Tg CO₂ Eq.)

Fuel/Vehicle Type ^a	1990	1995	2000	2005	2006	2007	2008
Gasoline On-Road	40.1	49.8	48.4	32.1	29.0	25.5	21.8
Passenger Cars	25.4	26.9	25.2	17.7	15.7	13.7	11.7
Light-Duty Trucks	14.1	22.1	22.4	13.6	12.5	11.1	9.5
Medium- and Heavy-Duty Trucks and Buses	0.6	0.7	0.9	0.8	0.7	0.7	0.6
Motorcycles	+	+	+	+	+	+	+
Diesel On-Road	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Passenger Cars	+	+	+	+	+	+	+
Light-Duty Trucks	+	+	+	+	+	+	+
Medium- and Heavy-Duty Trucks and Buses	0.2	0.2	0.3	0.3	0.3	0.3	0.3
Alternative Fuel On-Road	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Non-Road	3.6	3.9	4.3	4.3	4.2	4.3	3.8
Ships and Boats	0.6	0.8	0.9	0.6	0.7	0.8	0.5
Rail	0.3	0.3	0.3	0.4	0.4	0.4	0.3
Aircraft	1.7	1.7	1.9	1.9	1.6	1.6	1.5
Agricultural Equipment ^b	0.2	0.3	0.3	0.4	0.4	0.4	0.4
Construction/Mining Equipment ^c	0.3	0.4	0.4	0.5	0.5	0.5	0.5
Other ^d	0.4	0.5	0.5	0.6	0.6	0.6	0.6
Total	43.9	54.0	53.2	36.9	33.6	30.3	26.1

+ Less than 0.05 Tg CO₂ Eq.

^a See Annex 3.2 for definitions of on-road vehicle types.

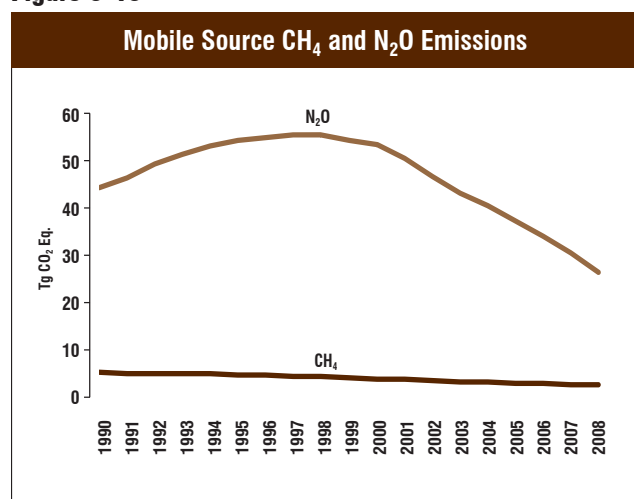
^b Includes equipment, such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.

^c Includes equipment, such as cranes, dumpers, and excavators, as well as fuel consumption from trucks that are used off-road in construction.

^d "Other" includes snowmobiles and other recreational equipment, logging equipment, lawn and garden equipment, railroad equipment, airport equipment, commercial equipment, and industrial equipment, as well as fuel consumption from trucks that are used off-road for commercial/industrial purposes.

Note: Totals may not sum due to independent rounding.

Figure 3-13



CO₂ from Fossil Fuel Combustion

Methodology

The methodology used by the United States for estimating CO₂ emissions from fossil fuel combustion is conceptually similar to the approach recommended by the IPCC for countries that intend to develop detailed, sectoral-based emission estimates (IPCC 2006). A detailed description of the U.S. methodology is presented in Annex 2.1, and is characterized by the following steps:

1. *Determine total fuel consumption by fuel type and sector.* Total fossil fuel consumption for each year is estimated by aggregating consumption data by end-use sector (e.g., commercial, industrial, etc.), primary fuel type (e.g., coal, petroleum, gas), and secondary fuel category (e.g., motor gasoline, distillate fuel oil, etc.). Fuel consumption data for the United States were obtained directly from the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE), primarily from the Monthly Energy Review and

published supplemental tables on petroleum product detail (EIA 2009b). The EIA does not include territories in its national energy statistics, so fuel consumption data for territories were collected separately from Grillot (2009).¹⁶

For consistency of reporting, the IPCC has recommended that countries report energy data using the International Energy Agency (IEA) reporting convention and/or IEA data. Data in the IEA format are presented “top down”—that is, energy consumption for fuel types and categories are estimated from energy production data (accounting for imports, exports, stock changes, and losses). The resulting quantities are referred to as “apparent consumption.” The data collected in the United States by EIA on an annual basis and used in this inventory are predominantly from mid-stream or conversion energy consumers such as refiners and electric power generators. These annual surveys are supplemented with end-use energy consumption surveys, such as the Manufacturing Energy Consumption Survey, that are conducted on a periodic basis (every 4 years). These consumption data sets help inform the annual surveys to arrive at the national total and sectoral breakdowns for that total.¹⁷

It is also important to note that U.S. fossil fuel energy statistics are generally presented using gross calorific values (GCV) (i.e., higher heating values). Fuel consumption activity data presented here have not been adjusted to correspond to international standards, which are to report energy statistics in terms of net calorific values (NCV) (i.e., lower heating values).¹⁸

2. *Subtract uses accounted for in the Industrial Processes chapter.* Portions of the fuel consumption data for seven fuel categories—coking coal, distillate fuel, industrial

other coal, petroleum coke, natural gas, residual fuel oil, and other oil—were reallocated to the industrial processes chapter, as they were consumed during non-energy related industrial activity. To make these adjustments, additional data were collected from AISI (2004 through 2009), Coffeyville (2009), Corathers (2009), U.S. Census Bureau (2009), EIA (2009g), EIA (2001), Smith, G. (2007), USGS (2009a), USGS (1995, 1998, 2000 through 2002, 2009), USGS (1991 through 2009), USGS (2009b), USGS (1991 through 2008), and USGS (1994 through 2009).¹⁹

3. *Adjust for biofuels, conversion of fossil fuels, and exports of CO₂.* Fossil fuel consumption estimates are adjusted downward to exclude (1) fuels with biogenic origins; (2) fuels created from other fossil fuels; and (3) exports of CO₂. Fuels with biogenic origins are assumed to result in no net CO₂ emissions, and must be subtracted from fuel consumption estimates, which includes ethanol added to motor gasoline. Synthetic natural gas is created from industrial coal, and is currently included in EIA statistics for both coal and natural gas. Therefore, synthetic natural gas is subtracted from energy consumption statistics.²⁰ Since October 2000, the Dakota Gasification Plant has been exporting CO₂ to Canada by pipeline. Since this CO₂ is not emitted to the atmosphere in the United States, energy used to produce this CO₂ is subtracted from energy consumption statistics. To make these adjustments, additional data for ethanol were collected from EIA (2009b) and data for synthetic natural gas were collected from EIA (2009e), and data for CO₂ exports were collected from the Dakota Gasification Company (2006), Fitzpatrick (2002), Erickson (2003), and EIA (2007b).
4. *Adjust Sectoral Allocation of Distillate Fuel Oil and Motor Gasoline.* EPA had conducted a separate bottom-up analysis of transportation fuel consumption based on the Federal Highway Administration’s (FHWA) VMT that indicated that the amount of distillate and motor gasoline consumption allocated

¹⁶ 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 and contributed emissions of 43 Tg CO₂ Eq. in 2008.

¹⁷ See IPCC Reference Approach for estimating CO₂ emissions from fossil fuel combustion in Annex 4 for a comparison of U.S. estimates using top-down and bottom-up approaches.

¹⁸ A crude convention to convert between gross and net calorific values is to multiply the heat content of solid and liquid fossil fuels by 0.95 and gaseous fuels by 0.9 to account for the water content of the fuels. Biomass-based fuels in U.S. energy statistics, however, are generally presented using net calorific values.

¹⁹ See sections on Iron and Steel Production and Metallurgical Coke Production, Ammonia Production and Urea Consumption, Petrochemical Production, Titanium Dioxide Production, Ferroalloy Production, Aluminum Production, and Silicon Carbide Production and Consumption in the Industrial Processes chapter.

²⁰ These adjustments are explained in greater detail in Annex 2.1.

to the transportation sector in the EIA statistics should be adjusted. Therefore, for these estimates, the transportation sector's distillate fuel and motor gasoline consumption was adjusted upward to match the value obtained from the bottom-up analysis based on VMT. As the total distillate and motor gasoline consumption estimate from EIA are considered to be accurate at the national level, the distillate consumption totals for the residential, commercial, and industrial sectors were adjusted downward proportionately. The data sources used in the bottom-up analysis of transportation fuel consumption include AAR (2008 through 2009), Benson (2002 through 2004), DOE (1993 through 2009), EIA (2009a), EIA (1991 through 2009), EPA (2009), and FHWA (1996 through 2009).

5. *Adjust for fuels consumed for non-energy uses.* U.S. aggregate energy statistics include consumption of fossil fuels for non-energy purposes. These are fossil fuels that are manufactured into plastics, asphalt, lubricants, or other products. Depending on the end-use, this can result in storage of some or all of the C contained in the fuel for a period of time. As the emission pathways of C used for non-energy purposes are vastly different than fuel combustion (since the C in these fuels ends up in products instead of being combusted), these emissions are estimated separately in the Carbon Emitted and Stored in Products from Non-Energy Uses of Fossil Fuels section in this chapter. Therefore, the amount of fuels used for non-energy purposes was subtracted from total fuel consumption. Data on non-fuel consumption was provided by EIA (2009b).
6. *Subtract consumption of international bunker fuels.* According to the UNFCCC reporting guidelines emissions from international transport activities, or bunker fuels, should not be included in national totals. U.S. energy consumption statistics include these bunker fuels (e.g., distillate fuel oil, residual fuel oil, and jet fuel) as part of consumption by the transportation end-use sector, however, so emissions from international transport activities were calculated separately following the same procedures used for emissions from consumption of all fossil fuels (i.e., estimation of consumption, and determination of C content). The Office of the Under Secretary of Defense (Installations and Environment) and the Defense

Energy Support Center (Defense Logistics Agency) of the U.S. Department of Defense (DoD) (DESC 2009) supplied data on military jet fuel and marine fuel use. Commercial jet fuel use was obtained from FAA (2006 and 2008); residual and distillate fuel use for civilian marine bunkers was obtained from DOC (1991 through 2009) for 1990 through 2001, 2007 and 2008, and DHS (2008) for 2003 through 2006. Consumption of these fuels was subtracted from the corresponding fuels in the transportation end-use sector. Estimates of international bunker fuel emissions for the United States are discussed in detail later in the International Bunker Fuels section of this chapter.

7. *Determine the total C content of fuels consumed.* Total C was estimated by multiplying the amount of fuel consumed by the amount of C in each fuel. This total C estimate defines the maximum amount of C that could potentially be released to the atmosphere if all of the C in each fuel was converted to CO₂. The C content coefficients used by the United States were obtained from EIA's *Emissions of Greenhouse Gases in the United States 2007* (EIA 2009c), and an EPA analysis of C content coefficients used in the mandatory reporting rule (EPA 2010). A discussion of the methodology used to develop the C content coefficients are presented in Annexes 2.1 and 2.2.
8. *Estimate CO₂ Emissions.* Total CO₂ emissions are the product of the adjusted energy consumption (from the previous methodology steps 1 through 6), the C content of the fuels consumed, and the fraction of C that is oxidized. The fraction oxidized was assumed to be 100 percent for petroleum, coal, and natural gas based on guidance in IPCC (2006) (see Annex 2.1).
9. *Allocate transportation emissions by vehicle type.* This report provides a more detailed accounting of emissions from transportation because it is such a large consumer of fossil fuels in the United States. For fuel types other than jet fuel, fuel consumption data by vehicle type and transportation mode were used to allocate emissions by fuel type calculated for the transportation end-use sector.
 - For on-road vehicles, annual estimates of combined motor gasoline and diesel fuel consumption by vehicle category were obtained from FHWA (1996 through 2009); for each vehicle category, the percent

Box 3-2: Carbon Intensity of U.S. Energy Consumption

Fossil fuels are the dominant source of energy in the United States, and CO₂ is emitted as a product from their combustion. Useful energy, however, is generated in the United States from many other sources that do not emit CO₂ in the energy conversion process, such as renewable (i.e., hydropower, biofuels, geothermal, solar, and wind) and nuclear sources.

Energy-related CO₂ emissions can be reduced by not only lowering total energy consumption (e.g., through conservation measures) but also by lowering the C intensity of the energy sources employed (e.g., fuel switching from coal to natural gas). The amount of C emitted from the combustion of fossil fuels is dependent upon the C content of the fuel and the fraction of that C that is oxidized. Fossil fuels vary in their average C content, ranging from about 53 Tg CO₂ Eq./QBtu for natural gas to upwards of 95 Tg CO₂ Eq./QBtu for coal and petroleum coke. In general, the C content per unit of energy of fossil fuels is the highest for coal products, followed by petroleum, and then natural gas. Other sources of energy, however, may be directly or indirectly C neutral (i.e., zero Tg CO₂ Eq./Btu). Energy generated from nuclear and many renewable sources do not result in direct emissions of CO₂. Biofuels such as wood and ethanol are also considered to be C neutral; although these fuels do emit CO₂, in the long run the CO₂ emitted from biomass consumption does not increase atmospheric CO₂ concentrations if the biogenic C emitted is offset by the growth of new biomass. The overall C intensity of the U.S. economy is thus dependent upon the quantity and combination of fuels and other energy sources employed to meet demand.

Table 3-15 provides a time series of the C intensity for each sector of the U.S. economy. The time series incorporates only the energy consumed from the direct combustion of fossil fuels in each sector. For example, the C intensity for the residential sector does not include the energy from or emissions related to the consumption of electricity for lighting or wood for heat. Looking only at this direct consumption of fossil fuels, the residential sector exhibited the lowest C intensity, which is related to the large percentage of its energy derived from natural gas for heating. The C intensity of the commercial sector has predominantly declined since 1990 as commercial businesses shift away from petroleum to natural gas. The industrial sector was more dependent on petroleum and coal than either the residential or commercial sectors, and thus had higher C intensities over this period. The C intensity of the transportation sector was closely related to the C content of petroleum products (e.g., motor gasoline and jet fuel, both around 70 Tg CO₂ Eq./EJ), which were the primary sources of energy. Lastly, the electricity generation sector had the highest C intensity due to its heavy reliance on coal for generating electricity.

Table 3-15: Carbon Intensity from Direct Fossil Fuel Combustion by Sector (Tg CO₂ Eq./QBtu)

Sector	1990	1995	2000	2005	2006	2007	2008
Residential ^a	57.4	56.6	56.7	56.6	56.5	56.3	56.0
Commercial ^a	59.2	57.7	57.1	57.5	57.2	57.0	56.7
Industrial ^a	64.2	63.0	62.7	64.2	64.5	64.1	63.6
Transportation ^a	71.1	71.0	71.3	71.4	71.6	71.9	71.6
Electricity Generation ^b	87.3	86.5	86.2	85.8	85.4	84.7	84.9
U.S. Territories ^c	73.0	73.1	72.5	73.6	73.7	73.8	73.7
All Sectors^e	73.0	72.4	73.0	73.5	73.5	73.3	73.1

^a Does not include electricity or renewable energy consumption.

^b Does not include electricity produced using nuclear or renewable energy.

^c Does not include nuclear or renewable energy consumption.

Note: Excludes non-energy fuel use emissions and consumption.

In contrast to Table 3-15, Table 3-16 presents C intensity values that incorporate energy consumed from all sources (i.e., fossil fuels, renewables, and nuclear). In addition, the emissions related to the generation of electricity have been attributed to both electricity generation and the end-use sectors in which that electricity was eventually consumed. This table, therefore, provides a more complete picture of the actual C intensity of each end-use sector per unit of energy consumed. The transportation end-use sector in Table 3-16 emerges as the most C intensive when all sources of energy are included, due to its almost complete reliance on petroleum products and relatively minor amount of biomass-based fuels used, such as ethanol. The “other end-use sectors” (i.e., residential, commercial, and industrial) use significant quantities of biofuels such as wood, thereby lowering the overall C intensity. The C intensity of the electricity generation sector differs greatly from the scenario in Table 3-15, where only the energy consumed from the direct combustion of fossil fuels was included. This difference is due almost entirely to the inclusion of electricity generation from nuclear and hydropower sources, which do not emit CO₂.

Box 3-2: Carbon Intensity of U.S. Energy Consumption (continued)

Table 3-16: Carbon Intensity from All Energy Consumption by Sector (Tg CO₂ Eq./Qbtu)

Sector	1990	1995	2000	2005	2006	2007	2008
Transportation ^a	70.9	70.6	70.9	70.5	70.3	70.2	69.2
Other End-Use Sectors ^{a, b}	57.8	56.6	58.0	58.5	57.8	57.8	57.2
Electricity Generation ^c	59.4	58.2	60.3	60.5	59.4	59.7	59.1
All Sectors^d	61.4	60.4	61.6	62.0	61.5	61.4	60.6

^a Includes electricity (from fossil fuel, nuclear, and renewable sources) and direct renewable energy consumption.

^b Other End-Use Sectors includes the residential, commercial, and industrial sectors.

^c Includes electricity generation from nuclear and renewable sources.

^d Includes nuclear and renewable energy consumption.

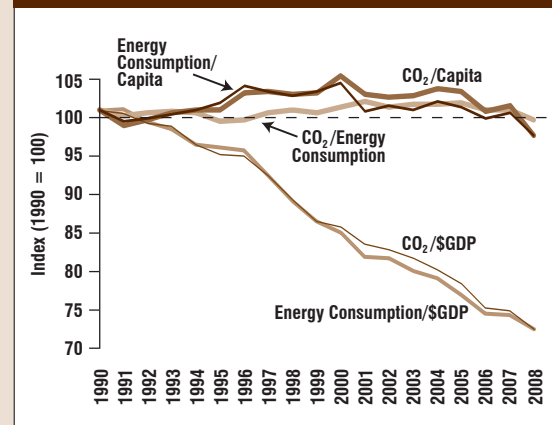
Note: Excludes non-energy fuel use emissions and consumption.

By comparing the values in Table 3-15 and Table 3-16, a few observations can be made. The use of renewable and nuclear energy sources has resulted in a significantly lower C intensity of the U.S. economy. Over the nineteen-year period of 1990 through 2008, however, the C intensity of U.S. energy consumption has been fairly constant, as the proportion of renewable and nuclear energy technologies have not changed significantly. Per capita energy consumption has fluctuated, but is now roughly equivalent to levels in 1990 (see Figure 3-14). Due to a general shift from a manufacturing-based economy to a service-based economy, as well as overall increases in efficiency, energy consumption and energy-related CO₂ emissions per dollar of gross domestic product (GDP) have both declined since 1990 (BEA 2009).

Carbon intensity estimates were developed using nuclear and renewable energy data from EIA (2009a), EPA (2010), and fossil fuel consumption data as discussed above and presented in Annex 2.1.

Figure 3-14

U.S. Energy Consumption and Energy-Related CO₂ Emissions Per Capita and Per Dollar GDP



gasoline, diesel, and other (e.g., CNG, LPG) fuel consumption are estimated using data from DOE (1993 through 2009).

- For non-road vehicles, activity data were obtained from AAR (2008 through 2009), APTA (2007 through 2009), BEA (1991 through 2009), Benson (2002 through 2004), DOE (1993 through 2008), DESC (2009), DOC (1991 through 2009), DOT (1991 through 2009), EIA (2009a), EIA (2009d), EIA (2007a), EIA (2002), EIA (1991 through 2009), EPA (2009), FAA (2008), and Gaffney (2007).
- For jet fuel used by aircraft, CO₂ emissions were calculated directly based on reported consumption of fuel as reported by EIA, and allocated to commercial aircraft using

flight-specific fuel consumption data from the Federal Aviation Administration's (FAA) Aviation Environmental Design Tool (AEDT) (FAA 2010).²¹ Allocation to domestic general aviation was made using FAA Aerospace Forecast data, and allocation

²¹ Data for inventory years 2000 through 2005 were developed using the FAA's System for assessing Aviation's Global Emissions (SAGE) model. That tool has been subsequently replaced by the Aviation Environmental Design Tool (AEDT), which calculates noise in addition to aircraft fuel burn and emissions for all commercial flights globally in a given year. Data for inventory years 2006-2008 were developed using AEDT. The AEDT model dynamically models aircraft performance in space and time to produce fuel burn, emissions and noise. Full flight gate-to-gate analyses are possible for study sizes ranging from a single flight at an airport to scenarios at the regional, national, and global levels. AEDT is currently used by the U.S. government to consider the interdependencies between aircraft-related fuel burn, noise and emissions.

to domestic military uses was made using DoD data (see Annex 3.7).

Heat contents and densities were obtained from EIA (2009a) and USAF (1998).²²

Uncertainty and Time-Series Consistency

For estimates of CO₂ from fossil fuel combustion, the amount of CO₂ emitted is directly related to the amount of fuel consumed, the fraction of the fuel that is oxidized, and the carbon content of the fuel. Therefore, a careful accounting of fossil fuel consumption by fuel type, average carbon contents of fossil fuels consumed, and production of fossil fuel-based products with long-term carbon storage should yield an accurate estimate of CO₂ emissions.

Nevertheless, there are uncertainties in the consumption data, carbon content of fuels and products, and carbon oxidation efficiencies. For example, given the same primary fuel type (e.g., coal, petroleum, or natural gas), the amount of carbon contained in the fuel per unit of useful energy can vary. For the United States, however, the impact of these uncertainties on overall CO₂ emission estimates is believed to be relatively small. See, for example, Marland and Pippin (1990).

Although statistics of total fossil fuel and other energy consumption are relatively accurate, the allocation of this consumption to individual end-use sectors (i.e., residential, commercial, industrial, and transportation) is less certain. For example, for some fuels the sectoral allocations are based on price rates (i.e., tariffs), but a commercial establishment may be able to negotiate an industrial rate or a small industrial establishment may end up paying an industrial rate, leading to a misallocation of emissions. Also, the deregulation of the natural gas industry and the more recent deregulation of the electric power industry have likely led to some minor problems in collecting accurate energy statistics as firms in these industries have undergone significant restructuring.

To calculate the total CO₂ emission estimate from energy-related fossil fuel combustion, the amount of fuel used

in these non-energy production processes were subtracted from the total fossil fuel consumption for 2008. The amount of CO₂ emissions resulting from non-energy related fossil fuel use has been calculated separately and reported in the Carbon Emitted from Non-Energy Uses of Fossil Fuels section of this report. These factors all contribute to the uncertainty in the CO₂ estimates. Detailed discussions on the uncertainties associated with C emitted from Non-Energy Uses of Fossil Fuels can be found within that section of this chapter.

Various sources of uncertainty surround the estimation of emissions from international bunker fuels, which are subtracted from the U.S. totals (see the detailed discussions on these uncertainties provided in the International Bunker Fuels section of this chapter). Another source of uncertainty is fuel consumption by U.S. territories. The United States does not collect energy statistics for its territories at the same level of detail as for the fifty states and the District of Columbia. Therefore, estimating both emissions and bunker fuel consumption by these territories is difficult.

Uncertainties in the emission estimates presented above also result from the data used to allocate CO₂ emissions from the transportation end-use sector to individual vehicle types and transport modes. In many cases, bottom-up estimates of fuel consumption by vehicle type do not match aggregate fuel-type estimates from EIA. Further research is planned to improve the allocation into detailed transportation end-use sector emissions.

The uncertainty analysis was performed by primary fuel type for each end-use sector, using the IPCC-recommended Tier 2 uncertainty estimation methodology, Monte Carlo Simulation technique, with @RISK software. For this uncertainty estimation, the inventory estimation model for CO₂ from fossil fuel combustion was integrated with the relevant variables from the inventory estimation model for International Bunker Fuels, to realistically characterize the interaction (or endogenous correlation) between the variables of these two models. About 150 input variables were modeled for CO₂ from energy-related Fossil Fuel Combustion (including about 10 for non-energy fuel consumption and about 20 for International Bunker Fuels).

²² For a more detailed description of the data sources used for the analysis of the transportation end use sector see the Mobile Combustion (excluding CO₂) and International Bunker Fuels sections of the Energy chapter, Annex 3.2, and Annex 3.7.

In developing the uncertainty estimation model, uniform distributions were assumed for all activity-related input variables and emission factors, based on the SAIC/EIA (2001) report.²³ Triangular distributions were assigned for the oxidization factors (or combustion efficiencies). The uncertainty ranges were assigned to the input variables based on the data reported in SAIC/EIA (2001) and on conversations with various agency personnel.²⁴

The uncertainty ranges for the activity-related input variables were typically asymmetric around their inventory estimates; the uncertainty ranges for the emissions factors were symmetric. Bias (or systematic uncertainties) associated with these variables accounted for much of the uncertainties associated with these variables (SAIC/EIA 2001).²⁵ For purposes of this uncertainty analysis, each input variable was simulated 10,000 times through Monte Carlo Sampling.

The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 3-17. Fossil fuel combustion CO₂ emissions in 2008 were estimated to be between 5,481.0 and 5,875.0 Tg CO₂ Eq. at a 95 percent confidence level. This indicates a range of 1 percent below to 6 percent above the 2008 emission estimate of 5,572.8 Tg CO₂ Eq.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2008. Details on the emission trends through time are described in more detail in the Methodology section, above.

²³ SAIC/EIA (2001) characterizes the underlying probability density function for the input variables as a combination of uniform and normal distributions (the former to represent the bias component and the latter to represent the random component). However, for purposes of the current uncertainty analysis, it was determined that uniform distribution was more appropriate to characterize the probability density function underlying each of these variables.

²⁴ In the SAIC/EIA (2001) report, the quantitative uncertainty estimates were developed for each of the three major fossil fuels used within each end-use sector; the variations within the sub-fuel types within each end-use sector were not modeled. However, for purposes of assigning uncertainty estimates to the sub-fuel type categories within each end-use sector in the current uncertainty analysis, SAIC/EIA (2001)-reported uncertainty estimates were extrapolated.

²⁵ Although, in general, random uncertainties are the main focus of statistical uncertainty analysis, when the uncertainty estimates are elicited from experts, their estimates include both random and systematic uncertainties. Hence, both these types of uncertainties are represented in this uncertainty analysis.

QA/QC and Verification

A source-specific QA/QC plan for CO₂ from fossil fuel combustion was developed and implemented. This effort included a Tier 1 analysis, as well as portions of a Tier 2 analysis. The Tier 2 procedures that were implemented involved checks specifically focusing on the activity data and methodology used for estimating CO₂ emissions from fossil fuel combustion in the United States. Emission totals for the different sectors and fuels were compared and trends were investigated to determine whether any corrective actions were needed. Minor corrective actions were taken.

Recalculations Discussion

The Energy Information Administration (EIA 2009b) updated energy consumption statistics across the time series. These revisions primarily impacted the emission estimates for 2006 and 2007. In addition, carbon content coefficients were updated based on the EPA (2010) analysis. Overall, these changes resulted in an average annual increase of 23.7 Tg CO₂ Eq. (0.4 percent) in CO₂ emissions from fossil fuel combustion for the period 1990 through 2007.

Planned Improvements

An analysis is being undertaken to update the carbon content factors for coal, as presented in the annexes of this report. To reduce uncertainty of CO₂ from fossil fuel combustion estimates, efforts will be taken to work with EIA and other agencies to improve the quality of the U.S. territories data. This improvement is not all-inclusive, and is part of an ongoing analysis and efforts to continually improve the CO₂ from fossil fuel combustion estimates. In addition, further expert elicitation may be conducted to better quantify the total uncertainty associated with emissions from this source.

CH₄ and N₂O from Stationary Combustion

Methodology

Methane and N₂O emissions from stationary combustion were estimated by multiplying fossil fuel and wood consumption data by emission factors (by sector and fuel type). National coal, natural gas, fuel oil, and wood consumption data were grouped by sector: industrial,

Table 3-17: Tier 2 Quantitative Uncertainty Estimates for CO₂ Emissions from Energy-related Fossil Fuel Combustion by Fuel Type and Sector (Tg CO₂ Eq. and Percent)

Fuel/Sector	2008 Emission Estimate (Tg CO ₂ Eq.)	Uncertainty Range Relative to Emission Estimate ^a			
		(Tg CO ₂ Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Coal^b	2,076.6	1,985.5	2,249.6	-4%	+8%
Residential	0.7	0.7	0.8	-5%	+16%
Commercial	6.4	6.1	7.4	-4%	+17%
Industrial	102.9	99.2	120.2	-4%	+17%
Transportation	NE	NE	NE	NA	NA
Electricity Generation	1,962.6	1,864.6	2,128.1	-5%	+8%
U.S. Territories	4.1	3.6	4.8	-12%	+19%
Natural Gas^b	1,227.0	1,236.8	1,306.2	+1%	+6%
Residential	264.7	257.5	283.5	-3%	+7%
Commercial	169.7	165.1	181.8	-3%	+7%
Industrial	393.6	402.9	444.0	+2%	+13%
Transportation	35.8	34.9	38.4	-3%	+7%
Electricity Generation	361.6	351.6	380.4	-3%	+5%
U.S. Territories	1.6	1.4	1.8	-13%	+17%
Petroleum^b	2,268.8	2,157.1	2,425.3	-5%	+7%
Residential	77.3	73.2	81.3	-5%	+5%
Commercial	43.4	41.3	45.2	-5%	+4%
Industrial	322.9	276.5	382.1	-14%	+18%
Transportation	1,749.4	1,651.5	1,879.6	-6%	+7%
Electricity Generation	38.9	37.2	41.7	-4%	+7%
U.S. Territories	36.9	34.1	41.0	-8%	+11%
Total (excluding Geothermal)^b	5,572.4	5,480.6	5,874.6	-2%	+5%
Geothermal	0.4	NE	NE	NE	NE
Total (including Geothermal)^{b,c}	5,572.8	5,481.0	5,875.0	-1%	+6%

NA (Not Applicable).
NE (Not Estimated).
^a Range of emission estimates predicted by Monte Carlo Simulation for a 95 percent confidence interval.
^b The low and high estimates for total emissions were calculated separately through simulations and, hence, the low and high emission estimates for the sub-source categories do not sum to total emissions.
^c Geothermal emissions added for reporting purposes, but an uncertainty analysis was not performed for CO₂ emissions from geothermal production.

commercial, residential, electricity generation, and U.S. territories. For the CH₄ and N₂O estimates, fuel consumption data for coal, natural gas, and fuel oil for the United States were obtained from EIA's *Monthly Energy Review* and unpublished supplemental tables on petroleum product detail (EIA 2009a). Wood consumption data for the United States was obtained from EIA's *Annual Energy Review* (EIA 2009b). Because the United States does not include territories in its national energy statistics, fuel consumption data for

territories were provided separately by Grillot (2009).²⁶ Fuel consumption for the industrial sector was adjusted to subtract out construction and agricultural use, which is reported under mobile sources.²⁷ Construction and agricultural fuel use was obtained from EPA (2006). Estimates for wood biomass consumption for fuel combustion do not include

²⁶ U.S. territories data also include combustion from mobile activities because data to allocate territories' energy use were unavailable. For this reason, CH₄ and N₂O emissions from combustion by U.S. territories are only included in the stationary combustion totals.

²⁷ Though emissions from construction and farm use occur due to both stationary and mobile sources, detailed data was not available to determine the magnitude from each. Currently, these emissions are assumed to be predominantly from mobile sources.

wood wastes, liquors, municipal solid waste, tires, etc. that are reported as biomass by EIA.

Emission factors for the four end-use sectors were provided by the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). U.S. territories' emission factors were estimated using the U.S. emission factors for the primary sector in which each fuel was combusted.

More detailed information on the methodology for calculating emissions from stationary combustion, including emission factors and activity data, is provided in Annex 3.1.

Uncertainty and Time-Series Consistency

Methane emission estimates from stationary sources exhibit high uncertainty, primarily due to difficulties in calculating emissions from wood combustion (i.e., fireplaces and wood stoves). The estimates of CH₄ and N₂O emissions presented are based on broad indicators of emissions (i.e., fuel use multiplied by an aggregate emission factor for different sectors), rather than specific emission processes (i.e., by combustion technology and type of emission control).

An uncertainty analysis was performed by primary fuel type for each end-use sector, using the IPCC-recommended Tier 2 uncertainty estimation methodology, Monte Carlo Simulation technique, with @RISK software.

The uncertainty estimation model for this source category was developed by integrating the CH₄ and N₂O stationary source inventory estimation models with the model for CO₂ from fossil fuel combustion to realistically characterize the interaction (or endogenous correlation) between the variables of these three models. About 90 input variables were simulated for the uncertainty analysis of this source category (about 55 from the CO₂ emissions from fossil fuel combustion inventory estimation model and about 35 from the stationary source inventory models).

In developing the uncertainty estimation model, uniform distribution was assumed for all activity-related input variables and N₂O emission factors, based on the SAIC/

EIA (2001) report.²⁸ For these variables, the uncertainty ranges were assigned to the input variables based on the data reported in SAIC/EIA (2001).²⁹ However, the CH₄ emission factors differ from those used by EIA. Since these factors were obtained from IPCC/UNEP/OECD/IEA (1997), uncertainty ranges were assigned based on IPCC default uncertainty estimates (IPCC 2000).

The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 3-18. Stationary combustion CH₄ emissions in 2008 (including biomass) were estimated to be between 4.3 and 15.6 Tg CO₂ Eq. at a 95 percent confidence level. This indicates a range of 36 percent below to 133 percent above the 2008 emission estimate of 6.7 Tg CO₂ Eq. Stationary combustion N₂O emissions in 2008 (including biomass) were estimated to be between 10.8 and 41.1 Tg CO₂ Eq. at a 95 percent confidence level. This indicates a range of 24 percent below to 189 percent above the 2008 emissions estimate of 14.2 Tg CO₂ Eq.

The uncertainties associated with the emission estimates of CH₄ and N₂O are greater than those associated with estimates of CO₂ from fossil fuel combustion, which mainly rely on the carbon content of the fuel combusted. Uncertainties in both CH₄ and N₂O estimates are due to the fact that emissions are estimated based on emission factors representing only a limited subset of combustion conditions. For the indirect greenhouse gases, uncertainties are partly due to assumptions concerning combustion technology types, age of equipment, emission factors used, and activity data projections.

²⁸ SAIC/EIA (2001) characterizes the underlying probability density function for the input variables as a combination of uniform and normal distributions (the former distribution to represent the bias component and the latter to represent the random component). However, for purposes of the current uncertainty analysis, it was determined that uniform distribution was more appropriate to characterize the probability density function underlying each of these variables.

²⁹ In the SAIC/EIA (2001) report, the quantitative uncertainty estimates were developed for each of the three major fossil fuels used within each end-use sector; the variations within the sub-fuel types within each end-use sector were not modeled. However, for purposes of assigning uncertainty estimates to the sub-fuel type categories within each end-use sector in the current uncertainty analysis, SAIC/EIA (2001)-reported uncertainty estimates were extrapolated.

Table 3-18: Tier 2 Quantitative Uncertainty Estimates for CH₄ and N₂O Emissions from Energy-Related Stationary Combustion, Including Biomass (Tg CO₂ Eq. and Percent)

Source	Gas	2008 Emission Estimate (Tg CO ₂ Eq.)	Uncertainty Range Relative to Emission Estimate ^a			
			(Tg CO ₂ Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Stationary Combustion	CH ₄	6.7	4.3	15.6	-36%	+133%
Stationary Combustion	N ₂ O	14.2	10.8	41.1	-24%	+189%

^a Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2008. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

A source-specific QA/QC plan for stationary combustion was developed and implemented. This effort included a Tier 1 analysis, as well as portions of a Tier 2 analysis. The Tier 2 procedures that were implemented involved checks specifically focusing on the activity data and emission factor sources and methodology used for estimating CH₄, N₂O, and the indirect greenhouse gases from stationary combustion in the United States. Emission totals for the different sectors and fuels were compared and trends were investigated.

Recalculations Discussion

Historical CH₄ and N₂O emissions from stationary sources (excluding CO₂) were revised due to a couple of changes. Slight changes to emission estimates for sectors are due to revised data from EIA (2009a). This revision is explained in greater detail in the section on CO₂ Emissions from Fossil Fuel Combustion within this sector. Wood consumption data from EIA (2009b) were revised for the residential, industrial, and electric power sectors. The combination of the methodological and historical data changes resulted in an average annual increase of less than 0.1 Tg CO₂ Eq. (0.1 percent) in CH₄ emissions from stationary combustion and an average annual decrease of less than 0.1 Tg CO₂ Eq. (0.2 percent) in N₂O emissions from stationary combustion for the period 1990 through 2007. Details on the emission trends through time are described in more detail in the Methodology section, above.

Planned Improvements

Several items are being evaluated to improve the CH₄ and N₂O emission estimates from stationary combustion and to reduce uncertainty. Efforts will be taken to work with EIA and other agencies to improve the quality of the U.S. territories data. Because these data are not broken out by stationary and mobile uses, further research will be aimed at trying to allocate consumption appropriately. In addition, the uncertainty of biomass emissions will be further investigated since it was expected that the exclusion of biomass from the uncertainty estimates would reduce the uncertainty; and in actuality the exclusion of biomass increases the uncertainty. These improvements are not all-inclusive, but are part of an ongoing analysis and efforts to continually improve these stationary estimates.

CH₄ and N₂O from Mobile Combustion

Methodology

Estimates of CH₄ and N₂O emissions from mobile combustion were calculated by multiplying emission factors by measures of activity for each fuel and vehicle type (e.g., light-duty gasoline trucks). Activity data included VMT for on-road vehicles and fuel consumption for non-road mobile sources. The activity data and emission factors used are described in the subsections that follow. A complete discussion of the methodology used to estimate CH₄ and N₂O emissions from mobile combustion and the emission factors used in the calculations is provided in Annex 3.2.

On-Road Vehicles

Estimates of CH₄ and N₂O emissions from gasoline and diesel on-road vehicles are based on VMT and emission factors by vehicle type, fuel type, model year, and emission control technology. Emission estimates for alternative fuel

vehicles (AFVs)³⁰ are based on VMT and emission factors by vehicle and fuel type.

Emission factors for gasoline and diesel on-road vehicles utilizing Tier 2 and low emission vehicle (LEV) technologies were developed by ICF (2006b); all other gasoline and diesel on-road vehicle emissions factors were developed by ICF (2004). These factors were derived from EPA, California Air Resources Board (CARB) and Environment Canada laboratory test results of different vehicle and control technology types. The EPA, CARB and Environment Canada tests were designed following the Federal Test Procedure (FTP), which covers three separate driving segments, since vehicles emit varying amounts of GHGs depending on the driving segment. These driving segments are: (1) a transient driving cycle that includes cold start and running emissions; (2) a cycle that represents running emissions only; and (3) a transient driving cycle that includes hot start and running emissions. For each test run, a bag was affixed to the tailpipe of the vehicle and the exhaust was collected; the content of this bag was then analyzed to determine quantities of gases present. The emissions characteristics of segment 2 were used to define running emissions, and subtracted from the total FTP emissions to determine start emissions. These were then recombined based upon the ratio of start to running emissions for each vehicle class from MOBILE6.2, an EPA emission factor model that predicts gram per mile emissions of CO₂, CO, HC, NO_x, and PM from vehicles under various conditions, to approximate average driving characteristics.³¹

Emission factors for AFVs were developed by ICF (2006a) after examining Argonne National Laboratory's GREET 1.7-Transportation Fuel Cycle Model (ANL 2006) and Lipman and Delucchi (2002). These sources describe AFV emission factors in terms of ratios to conventional vehicle emission factors. Ratios of AFV to conventional vehicle emissions factors were then applied to estimated Tier 1 emissions factors from light-duty gasoline vehicles to estimate light-duty AFVs. Emissions factors for heavy-duty AFVs were developed in relation to gasoline heavy-duty

vehicles. A complete discussion of the data source and methodology used to determine emission factors from AFVs is provided in Annex 3.2.

Annual VMT data for 1990 through 2008 were obtained from the Federal Highway Administration's (FHWA) Highway Performance Monitoring System database as reported in Highway Statistics (FHWA 1996 through 2009). VMT estimates were then allocated from FHWA's vehicle categories to fuel-specific vehicle categories using the calculated shares of vehicle fuel use for each vehicle category by fuel type reported in DOE (1993 through 2009) and information on total motor vehicle fuel consumption by fuel type from FHWA (1996 through 2009). VMT for AFVs were taken from Browning (2003). The age distributions of the U.S. vehicle fleet were obtained from EPA (2007c, 2000), and the average annual age-specific vehicle mileage accumulation of U.S. vehicles were obtained from EPA (2000).

Control technology and standards data for on-road vehicles were obtained from EPA's Office of Transportation and Air Quality (EPA 2007a, 2007b, 2000, 1998, and 1997) and Browning (2005). These technologies and standards are defined in Annex 3.2, and were compiled from EPA (1993, 1994a, 1994b, 1998, 1999a) and IPCC/UNEP/OECD/IEA (1997).

Non-Road Vehicles

To estimate emissions from non-road vehicles, fuel consumption data were employed as a measure of activity, and multiplied by fuel-specific emission factors (in grams of N₂O and CH₄ per kilogram of fuel consumed).³² Activity data were obtained from AAR (2008 through 2009), APTA (2007 through 2009), APTA (2006), BEA (1991 through 2005), Benson (2002 through 2004), DHS (2008), DOC (1991 through 2008), DOE (1993 through 2009), DESC (2008), DOT (1991 through 2009), EIA (2008a, 2007a, 2007b, 2002), EIA (2007 through 2009), EIA (1991 through 2009), EPA (2009), Esser (2003 through 2004), FAA (2010, 2009, and 2006), Gaffney (2007), and Whorton (2006 through 2009). Emission factors for non-road modes were taken from IPCC/UNEP/OECD/IEA (1997) and Browning (2009).

³⁰ Alternative fuel and advanced technology vehicles are those that can operate using a motor fuel other than gasoline or diesel. This includes electric or other bi-fuel or dual-fuel vehicles that may be partially powered by gasoline or diesel.

³¹ Additional information regarding the model can be found online at <http://www.epa.gov/OMS/m6.htm>.

³² The consumption of international bunker fuels is not included in these activity data, but is estimated separately under the International Bunker Fuels source category.

Uncertainty and Time-Series Consistency

A quantitative uncertainty analysis was conducted for the on-road portion of the mobile source sector using the IPCC-recommended Tier 2 uncertainty estimation methodology, Monte Carlo simulation technique, using @RISK software. The uncertainty analysis was performed on 2008 estimates of CH₄ and N₂O emissions, incorporating probability distribution functions associated with the major input variables. For the purposes of this analysis, the uncertainty was modeled for the following two major sets of input variables: (1) VMT data, by vehicle and fuel type, and (2) emission factor data, by vehicle, fuel, and control technology type.

Uncertainty analyses were not conducted for NO_x, CO, or NMVOC emissions. Emission factors for these gases have been extensively researched since emissions of these gases from motor vehicles are regulated in the United States, and the uncertainty in these emission estimates is believed to be relatively low. However, a much higher level of uncertainty is associated with CH₄ and N₂O emission factors, because emissions of these gases are not regulated in the United States (and, therefore, there are not adequate emission test data), and because, unlike CO₂ emissions, the emission pathways of CH₄ and N₂O are highly complex.

The results of the Tier 2 quantitative uncertainty analysis for the mobile source CH₄ and N₂O emissions from on-road vehicles are summarized in Table 3-19. As noted above, an uncertainty analysis was not performed for CH₄ and N₂O emissions from non-road vehicles. Mobile combustion CH₄ emissions (from on-road vehicles) in 2008 were estimated to be between 1.4 and 1.7 Tg CO₂ Eq. at a 95 percent confidence level. This indicates a range of 10 percent below to 11 percent above the corresponding 2008 emission estimate of

1.5 Tg CO₂ Eq. Also at a 95 percent confidence level, mobile combustion N₂O emissions from on-road vehicles in 2008 were estimated to be between 18.3 and 26.3 Tg CO₂ Eq., indicating a range of 18 percent below to 18 percent above the corresponding 2008 emission estimate of 22.3 Tg CO₂ Eq.

This uncertainty analysis is a continuation of a multi-year process for developing quantitative uncertainty estimates for this source category using the IPCC Tier 2 approach to uncertainty analysis. As a result, as new information becomes available, uncertainty characterization of input variables may be improved and revised. For additional information regarding uncertainty in emission estimates for CH₄ and N₂O please refer to the Uncertainty Annex.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2008. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

A source-specific QA/QC plan for mobile combustion was developed and implemented. This plan is based on the IPCC-recommended QA/QC Plan. The specific plan used for mobile combustion was updated prior to collection and analysis of this current year of data. This effort included a Tier 1 analysis, as well as portions of a Tier 2 analysis. The Tier 2 procedures focused on the emission factor and activity data sources, as well as the methodology used for estimating emissions. These procedures included a qualitative assessment of the emissions estimates to determine whether they appear consistent with the most recent activity data and emission factors available. A comparison of historical emissions between the current Inventory and the previous Inventory was also conducted to ensure that the changes in

Table 3-19: Tier 2 Quantitative Uncertainty Estimates for CH₄ and N₂O Emissions from On-Road Sources (Tg CO₂ Eq. and Percent)

Source	Gas	2008 Emission Estimate (Tg CO ₂ Eq.)	Uncertainty Range Relative to Emission Estimate ^{a, b}			
			Lower Bound	Upper Bound	Lower Bound (%)	Upper Bound (%)
On-Road Sources	CH ₄	1.5	1.4	1.7	-10%	+11%
On-Road Sources	N ₂ O	22.3	18.3	26.3	-18%	+18%

^a 2008 emission estimates and the uncertainty ranges presented in this table correspond to on-road vehicles, comprising conventional and alternative fuel vehicles. Because the uncertainty associated with the emissions from non-road vehicles were not estimated, they were excluded in the estimates reported in this table.

^b Range of emission estimates predicted by Monte Carlo Simulation for a 95 percent confidence interval.

estimates were consistent with the changes in activity data and emission factors.

Recalculations Discussion

In order to ensure that these estimates are continuously improved, the calculation methodology is revised annually based on comments from internal and external reviewers. A number of adjustments were made to the methodologies used in calculating emissions in the current Inventory relative to the previous Inventory report.

Emission factors for CH₄ and N₂O from the consumption of residual fuel oil and distillate fuel by ships and boats have been updated across the time series (Browning 2009). CH₄ emission factors for residual and distillate fuel dropped 89 and 92 percent, respectively. N₂O emission factors for residual and distillate fuel increased 93 and 79 percent, respectively.

Commercial jet fuel emissions for the years 2006 through 2007 are now calculated directly from jet fuel consumption data from the FAA's AEDT (FAA 2010) database. Previously, commercial aircraft activity data for 2006 through 2007 was estimated by multiplying DOT (1991 through 2009) data by the percentage difference between 2005 (the most recent available SAGE data point) and the respective year.

As a result of these changes, estimates of CH₄ emissions were lower while N₂O emissions were slightly higher relative to the previous Inventory. CH₄ emissions for 2007 decreased the most, 3 percent (0.1 Tg CO₂ Eq.). Nitrous oxide emissions for 2000 increased 0.7 percent (0.4 Tg CO₂ Eq.), the greatest increase of any year relative to the previous Inventory.

Planned Improvements

While the data used for this report represent the most accurate information available, five areas have been identified that could potentially be improved in the short-term given available resources.

1. Develop updated emissions factors for diesel vehicles, motorcycle, and biodiesel vehicles. Previous emission factors were based upon extrapolations from other vehicle classes and new test data from Environment Canada may allow for better estimation of emission factors for these vehicles.
2. Develop new emission factors for non-road equipment. The current inventory estimates for non-CO₂ emissions

from non-road sources are based on emission factors from IPCC guidelines published in 1996. Recent data on non-road sources from Environment Canada and the California Air Resources Board will be investigated in order to assess the feasibility of developing new N₂O and CH₄ emissions factors for non-road equipment.

3. Examine the feasibility of estimating aircraft N₂O and CH₄ emissions by the number of takeoffs and landings, instead of total fuel consumption. Various studies have indicated that aircraft N₂O and CH₄ emissions are more dependent on aircraft takeoffs and landings than on total aircraft fuel consumption; however, aircraft emissions are currently estimated from fuel consumption data. FAA's SAGE and AEDT databases contain detailed data on takeoffs and landings for each calendar year starting in 2000, and could potentially be used to conduct a Tier II analysis of aircraft emissions. This methodology will require a detailed analysis of the number of takeoffs and landings by aircraft type on domestic trips, the development of procedures to develop comparable estimates for years prior to 2000, and the dynamic interaction of ambient air with aircraft exhausts is developed. The feasibility of this approach will be explored.
4. Develop improved estimates of domestic waterborne fuel consumption. The inventory estimates for residual and distillate fuel used by ships and boats is based in part on data on bunker fuel use from the U.S. Department of Commerce. The Department of Homeland Security (DHS) maintains an electronic reporting system that automatically registers monthly sales of bunker fuel at ports, which may provide a more accurate and comprehensive estimate of residual and distillate bunker fuel use by reducing the amount of non-reporting. This system has been used to collect data since 2002, and these data could be incorporated into the development of inventory figures. The DHS figures will need to be reconciled with figures from the current sources of data and a methodology will need to be developed to produce updated estimates for prior years.
5. Continue to examine the use of EPA's MOVES model in the development of the inventory estimates, including use for uncertainty analysis. Although the Inventory uses some of the underlying data from MOVES, such as vehicle age distributions by model year, MOVES is not

used directly in calculating mobile source emissions. As MOVES goes through additional testing and refinement, the use of MOVES will be further explored.

3.2. Carbon Emitted from Non-Energy Uses of Fossil Fuels (IPCC Source Category 1A)

In addition to being combusted for energy, fossil fuels are also consumed for non-energy uses (NEU) in the United States. The fuels used for these purposes are diverse, including natural gas, liquefied petroleum gases (LPG), asphalt (a viscous liquid mixture of heavy crude oil distillates), petroleum coke (manufactured from heavy oil), and coal coke (manufactured from coking coal). The non-energy applications are equally diverse, and include feedstocks for the manufacture of plastics, rubber, synthetic fibers and other materials; reducing agents for the production of various metals and inorganic products; and non-energy products such as lubricants, waxes, and asphalt (IPCC 2006).

Carbon dioxide emissions arise from non-energy uses via several pathways. Emissions may occur during the manufacture of a product, as is the case in producing plastics or rubber from fuel-derived feedstocks. Additionally, emissions may occur during the product’s lifetime, such as during solvent use. Overall, throughout the time series and across all uses, about 61 percent of the total C consumed for non-energy purposes was stored in products, and not released to the atmosphere; the remaining 39 percent was emitted.

There are several areas in which non-energy uses of fossil fuels are closely related to other parts of the inventory. For example, some of the NEU products release CO₂ at the end of their commercial life when they are combusted after disposal; these emissions are reported separately within the Energy chapter in the Incineration of Waste source category.

In addition, there is some overlap between fossil fuels consumed for non-energy uses and the fossil-derived CO₂ emissions accounted for in the Industrial Processes chapter, especially for fuels used as reducing agents. To avoid double-counting, the “raw” non-energy fuel consumption data reported by EIA are modified to account for these overlaps. There are also net exports of petrochemicals that are not completely accounted for in the EIA data, and the inventory calculations also make adjustments to address the effect of net exports on the mass of C in non-energy applications.

As shown in Table 3-20, fossil fuel emissions in 2008 from the non-energy uses of fossil fuels were 134.2 Tg CO₂ Eq., which constituted approximately 2 percent of overall fossil fuel emissions. In 2008, the consumption of fuels for non-energy uses (after the adjustments described above) was 4,921.9 TBtu, an increase of 10 percent since 1990 (see Table 3-21). About 57.3 Tg of the C (210.3 Tg CO₂ Eq.) in these fuels was stored, while the remaining 36.6 Tg C (134.2 Tg CO₂ Eq.) was emitted.

Methodology

The first step in estimating C stored in products was to determine the aggregate quantity of fossil fuels consumed for non-energy uses. The C content of these feedstock fuels is equivalent to potential emissions, or the product of consumption and the fuel-specific C content values. Both the non-energy fuel consumption and C content data were supplied by the EIA (2009a) (see Annex 2.1). Consumption of natural gas, LPG, pentanes plus, naphthas, other oils, and special naphtha were adjusted to account for net exports of these products that are not reflected in the raw data from EIA. Consumption values for industrial coking coal, petroleum coke, other oils, and natural gas in Table 3-21 and Table 3-22 have been adjusted to subtract non-energy uses that are included in the source categories of the Industrial Processes

Table 3-20: CO₂ Emissions from Non-Energy Use Fossil Fuel Consumption (Tg CO₂ Eq.)

Type	1990	1995	2000	2005	2006	2007	2008
Potential Emissions	313.5	354.8	389.4	379.3	383.6	374.7	344.5
C Stored	193.9	211.8	243.3	242.8	242.2	239.4	210.3
Emissions as a % of Potential	38%	40%	38%	36%	37%	36%	39%
Emissions	119.6	142.9	146.1	136.5	141.4	135.3	134.2

chapter.³³ Consumption values were also adjusted to subtract net exports of intermediary chemicals.

For the remaining non-energy uses, the quantity of C stored was estimated by multiplying the potential emissions by a storage factor. For several fuel types—petrochemical feedstocks (including natural gas for non-fertilizer uses, LPG, pentanes plus, naphthas, other oils, still gas, special naphtha, and industrial other coal), asphalt and road oil, lubricants, and waxes—U.S. data on C stocks and flows were used to develop C storage factors, calculated as the ratio of (a) the C stored by the fuel’s non-energy products to (b) the total C content of the fuel consumed. A lifecycle approach was

used in the development of these factors in order to account for losses in the production process and during use. Because losses associated with municipal solid waste management are handled separately in this sector under the Incineration of Waste source category, the storage factors do not account for losses at the disposal end of the life cycle. For industrial coking coal and distillate fuel oil, storage factors were taken from IPCC/UNEP/OECD/IEA (1997), which in turn draws from Marland and Rotty (1984). For the remaining fuel types (petroleum coke, miscellaneous products, and other petroleum), IPCC does not provide guidance on storage factors, and assumptions were made based on the potential fate of C in the respective NEU products.

Table 3-21: Adjusted Consumption of Fossil Fuels for Non-Energy Uses (TBtu)

Sector/Fuel Type	1990	1995	2000	2005	2006	2007	2008
Industry	4,206.3	4,831.7	5,259.0	5,154.1	5,178.1	5,083.6	4,672.2
Industrial Coking Coal	+	75.0	82.2	53.3	73.8	30.2	50.1
Industrial Other Coal	8.2	11.3	12.4	11.9	12.4	12.4	12.4
Natural Gas to Chemical Plants, Other Uses	275.4	335.9	421.5	396.3	405.7	402.9	383.1
Asphalt & Road Oil	1,170.2	1,178.2	1,275.7	1,323.2	1,261.2	1,197.0	1,012.0
LPG	1,119.1	1,506.6	1,606.8	1,443.8	1,488.4	1,482.6	1,409.2
Lubricants	186.3	177.8	189.9	160.2	156.1	161.2	149.6
Pentanes Plus	77.5	289.7	229.3	146.3	105.5	132.6	114.8
Naphtha (<401 ° F)	325.9	355.6	593.7	679.5	618.0	542.5	467.2
Other Oil (>401 ° F)	661.4	602.5	527.0	514.7	573.3	669.0	599.0
Still Gas	21.3	40.1	12.6	67.7	57.2	44.2	47.3
Petroleum Coke	82.1	45.6	49.7	136.2	177.9	160.7	165.6
Special Naphtha	100.7	67.7	94.4	60.9	68.9	75.4	83.2
Distillate Fuel Oil	7.0	8.0	11.7	16.0	17.5	17.5	17.5
Waxes	33.3	40.6	33.1	31.4	26.1	21.9	19.1
Miscellaneous Products	137.8	97.1	119.2	112.8	136.0	133.5	142.0
Transportation	176.0	167.9	179.4	151.3	147.4	152.2	141.3
Lubricants	176.0	167.9	179.4	151.3	147.4	152.2	141.3
U.S. Territories	86.7	90.8	165.5	121.9	134.5	128.6	108.4
Lubricants	0.7	2.0	16.4	4.6	7.3	7.1	6.1
Other Petroleum (Misc. Prod.)	86.0	88.8	149.1	117.3	127.2	121.5	102.3
Total	4,469.0	5,090.5	5,603.8	5,427.3	5,460.0	5,364.4	4,921.9

+ Does not exceed 0.05 TBtu.

Note: To avoid double-counting, coal coke, petroleum coke, natural gas consumption, and other oils are adjusted for industrial process consumption reported in the Industrial Processes sector. Natural gas, LPG, Pentanes Plus, Naphthas, Special Naphtha, and Other Oils are adjusted to account for exports of chemical intermediates derived from these fuels. For residual oil (not shown in the table), all non-energy use is assumed to be consumed in C black production, which is also reported in the Industrial Processes chapter.

Note: Totals may not sum due to independent rounding.

³³ These source categories include Iron and Steel Production, Lead Production, Zinc Production, Ammonia Manufacture, Carbon Black Manufacture (included in Petrochemical Production), Titanium Dioxide Production, Ferroalloy Production, Silicon Carbide Production, and Aluminum Production.

Table 3-22: 2008 Adjusted Non-Energy Use Fossil Fuel Consumption, Storage, and Emissions

Sector/Fuel Type	Adjusted Non-Energy Use ^a (TBtu)	Carbon Content Coefficient (Tg C/QBtu)	Potential Carbon (Tg C)	Storage Factor	Carbon Stored (Tg C)	Carbon Emissions (Tg C)	Carbon Emissions (Tg CO ₂ Eq.)
Industry	4,672.2	-	88.9	-	56.9	32.1	117.5
Industrial Coking Coal	50.1	31.00	1.6	0.10	0.2	1.4	5.1
Industrial Other Coal	12.4	25.82	0.3	0.61	0.2	0.1	0.5
Natural Gas to Chemical Plants	383.1	14.47	5.5	0.61	3.4	2.2	7.9
Asphalt & Road Oil	1,012.0	20.55	20.8	1.00	20.8	+	+
LPG	1,409.2	17.06	24.0	0.61	14.7	9.3	34.2
Lubricants	149.6	20.20	3.0	0.09	0.3	2.7	10.1
Pentanes Plus	114.8	19.10	2.2	0.61	1.3	0.9	3.1
Naphtha (<401° F)	467.2	18.55	8.7	0.61	5.3	3.4	12.3
Other Oil (>401° F)	599.0	20.17	12.1	0.61	7.4	4.7	17.2
Still Gas	47.3	17.51	0.8	0.61	0.5	0.3	1.2
Petroleum Coke	165.6	27.85	4.6	0.30	1.4	3.2	11.8
Special Naphtha	83.2	19.74	1.6	0.61	1.0	0.6	2.3
Distillate Fuel Oil	17.5	20.17	0.4	0.50	0.2	0.2	0.6
Waxes	19.1	19.80	0.4	0.58	0.2	0.2	0.6
Miscellaneous Products	142.0	20.31	2.9	0.00	0.0	2.9	10.6
Transportation	141.3	-	2.9	-	0.3	2.6	9.5
Lubricants	141.3	20.20	2.9	0.09	0.3	2.6	9.5
U.S. Territories	108.4	-	2.2	-	0.2	2.0	7.2
Lubricants	6.1	20.20	0.1	0.09	0.0	0.1	0.4
Other Petroleum (Misc. Prod.)	102.3	20.00	2.0	0.10	0.2	1.8	6.8
Total	4,921.9	-	93.9	-	57.3	36.6	134.2

+ Does not exceed 0.05 Tg.
- Not applicable.
^a To avoid double counting, net exports have been deducted.
Note: Totals may not sum due to independent rounding.

Lastly, emissions were estimated by subtracting the C stored from the potential emissions (see Table 3-20). More detail on the methodology for calculating storage and emissions from each of these sources is provided in Annex 2.3.

Where storage factors were calculated specifically for the United States, data were obtained on (1) products such as asphalt, plastics, synthetic rubber, synthetic fibers, cleansers (soaps and detergents), pesticides, food additives, antifreeze and deicers (glycols), and silicones; and (2) industrial releases including volatile organic compound, solvent, and non-combustion CO emissions, Toxics Release Inventory (TRI) releases, hazardous waste incineration, and energy recovery. Data were taken from a variety of industry sources, government reports, and expert communications. Sources include EPA reports and databases such as compilations of air emission factors (EPA 2001), *National Emissions*

Inventory (NEI) *Air Pollutant Emissions Trends Data* (EPA 2008), *Toxics Release Inventory, 1998* (2000b), *Biennial Reporting System* (EPA 2004, 2007a), and pesticide sales and use estimates (EPA 1998, 1999, 2002, 2004); the EIA *Manufacturer's Energy Consumption Survey* (MECS) (EIA 1994, 1997, 2001, 2005, 2009b); the National Petrochemical & Refiners Association (NPRA 2002); the U.S. Census Bureau (1999, 2004); the American Plastics Council (APC 2007; Bank of Canada (2006); Financial Planning Association (2006); INEGI (2006); the United States International Trade Commission (2008); Gosselin, Smith, and Hodge (1984); the Rubber Manufacturers' Association (RMA 2009a,b); the International Institute of Synthetic Rubber Products (IISRP 2000, 2003); the Fiber Economics Bureau (FEB 2009); and the American Chemistry Council (ACC 2009). Specific data sources are listed in full detail in Annex 2.3.

Uncertainty and Time-Series Consistency

An uncertainty analysis was conducted to quantify the uncertainty surrounding the estimates of emissions and storage factors from non-energy uses. This analysis, performed using @RISK software and the IPCC-recommended Tier 2 methodology (Monte Carlo Simulation technique), provides for the specification of probability density functions for key variables within a computational structure that mirrors the calculation of the inventory estimate. The results presented below provide the 95 percent confidence interval, the range of values within which emissions are likely to fall, for this source category.

As noted above, the non-energy use analysis is based on U.S.-specific storage factors for (1) feedstock materials (natural gas, LPG, pentanes plus, naphthas, other oils, still gas, special naphthas, and other industrial coal); (2) asphalt; (3) lubricants; and (4) waxes. For the remaining fuel types (the “other” category), the storage factors were taken directly from the IPCC *Guidelines for National Greenhouse Gas Inventories*, where available, and otherwise assumptions

were made based on the potential fate of carbon in the respective NEU products. To characterize uncertainty, five separate analyses were conducted, corresponding to each of the five categories. In all cases, statistical analyses or expert judgments of uncertainty were not available directly from the information sources for all the activity variables; thus, uncertainty estimates were determined using assumptions based on source category knowledge.

The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 3-23 (emissions) and Table 3-24 (storage factors). Carbon emitted from non-energy uses of fossil fuels in 2008 was estimated to be between 106.9 and 145.4 Tg CO₂ Eq. at a 95 percent confidence level. This indicates a range of 20 percent below to 8 percent above the 2008 emission estimate of 134.2 Tg CO₂ Eq. The uncertainty in the emission estimates is a function of uncertainty in both the quantity of fuel used for non-energy purposes and the storage factor.

In Table 3-24, feedstocks and asphalt contribute least to overall storage factor uncertainty on a percentage basis.

Table 3-23: Tier 2 Quantitative Uncertainty Estimates for CO₂ Emissions from Non-Energy Uses of Fossil Fuels (Tg CO₂ Eq. and Percent)

Source	Gas	2008 Emission Estimate (Tg CO ₂ Eq.)	Uncertainty Range Relative to Emission Estimate ^a			
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Feedstocks	CO ₂	78.7	63.7	95.5	-19%	+21%
Asphalt	CO ₂	0.00	0.2	0.8	NA	NA
Lubricants	CO ₂	20.0	16.6	23.3	-17%	+16%
Waxes	CO ₂	0.6	0.4	0.9	-28%	+54%
Other	CO ₂	34.9	15.1	35.6	-57%	+2%
Total	CO₂	134.2	106.9	145.4	-20%	+8%

^a Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval. NA (Not Applicable).

Table 3-24: Tier 2 Quantitative Uncertainty Estimates for Storage Factors of Non-Energy Uses of Fossil Fuels (Percent)

Source	Gas	2008 Storage Factor (%)	Uncertainty Range Relative to Emission Estimate ^a			
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Feedstocks	CO ₂	61%	59%	63%	-4%	+3%
Asphalt	CO ₂	100%	99%	100%	-1%	+0%
Lubricants	CO ₂	9%	4%	17%	-61%	+88%
Waxes	CO ₂	58%	49%	71%	-16%	+22%
Other	CO ₂	17%	18%	63%	+6%	+279%

^a Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval, as a percentage of the inventory value (also expressed in percent terms).

Although the feedstocks category—the largest use category in terms of total carbon flows—appears to have tight confidence limits, this is to some extent an artifact of the way the uncertainty analysis was structured. As discussed in Annex 2.3, the storage factor for feedstocks is based on an analysis of six fates that result in long-term storage (e.g., plastics production), and eleven that result in emissions (e.g., volatile organic compound emissions). Rather than modeling the total uncertainty around all of these fate processes, the current analysis addresses only the storage fates, and assumes that all C that is not stored is emitted. As the production statistics that drive the storage values are relatively well-characterized, this approach yields a result that is probably biased toward understating uncertainty.

As is the case with the other uncertainty analyses discussed throughout this document, the uncertainty results above address only those factors that can be readily quantified. More details on the uncertainty analysis are provided in Annex 2.3.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2008. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

A source-specific QA/QC plan for non-energy uses of fossil fuels was developed and implemented. This effort included a Tier 1 analysis, as well as portions of a Tier 2 analysis for non-energy uses involving petrochemical feedstocks and for imports and exports. The Tier 2 procedures that were implemented involved checks specifically focusing on the activity data and methodology for estimating the fate of C (in terms of storage and emissions) across the various end-uses of fossil C. Emission and storage totals for the different subcategories were compared, and trends across the time series were analyzed to determine whether any corrective actions were needed. Corrective actions were taken to rectify minor errors and to improve the transparency of the calculations, facilitating future QA/QC.

For petrochemical import and export data, special attention was paid to NAICS numbers and titles to verify that none had changed or been removed. Import and export totals were compared for 2007 as well as their trends across the time series.

Recalculations Discussion

The Rubber Manufacturers Association's *Scrap Tire Markets in the United States: 9th Biennial Edition* (RMA 2009) began reporting the amount of scrap tires in each end use market in thousands of tons (as opposed to millions of tires as they had done previously). RMA also updated their assumed weight for passenger and commercial scrap tires to 22.5 pounds and 110 pounds, respectively. As a result, the percentage of rubber abraded during tire use for these two categories was reduced from 20 percent for all tires to 10 and 8 percent for passenger and commercial tires, respectively. These changes resulted in an average 73 percent reduction in carbon black emissions and an average 68 percent reduction in synthetic rubber carbon emissions per year across the time series.

Additionally, the EIA Manufacturer's Energy Consumption Survey (MECS) for 2006 was released in the past year. MECS is only released once every four years and contributes to approximately 26 percent (as a time-weighted average) of the C accounted for in feedstocks. Updating the energy recovery emissions with this new data resulted in an average annual increase of 4 percent in emissions from feedstocks for 2003 through 2007.

Planned Improvements

There are several improvements planned for the future:

- Improving the uncertainty analysis. Most of the input parameter distributions are based on professional judgment rather than rigorous statistical characterizations of uncertainty.
- Better characterizing flows of fossil C. Additional "fates" may be researched, including the fossil C load in organic chemical wastewaters, plasticizers, adhesives, films, paints, and coatings. There is also a need to further clarify the treatment of fuel additives and backflows (especially methyl tert-butyl ether, MTBE).

Finally, although U.S.-specific storage factors have been developed for feedstocks, asphalt, lubricants, and waxes, default values from IPCC are still used for two of the non-energy fuel types (industrial coking coal and distillate oil), and broad assumptions are being used for miscellaneous products and other petroleum. Over the long term, there are plans to improve these storage factors by conducting analyses of C fate similar to those described in Annex 2.3.

3.3. Incineration of Waste (IPCC Source Category 1A1a)

Incineration is used to manage about 7 to 19 percent of the solid wastes generated in the United States, depending on the source of the estimate and the scope of materials included in the definition of solid waste (EPA 2000, Goldstein and Matdes 2001, Kaufman et al. 2004, Simmons et al. 2006, ArSova et al. 2008). In the context of this section, waste includes all municipal solid waste (MSW) as well as tires. In the United States, almost all incineration of MSW occurs at waste-to-energy facilities where useful energy is recovered, and thus emissions from waste incineration are accounted for in the Energy chapter. Similarly, tires are combusted for energy recovery in industrial and utility boilers. Incineration of waste results in conversion of the organic inputs to CO₂. According to IPCC guidelines, when the CO₂ emitted is of fossil origin, it is counted as a net anthropogenic emission of CO₂ to the atmosphere. Thus, the emissions from waste incineration are calculated by estimating the quantity of waste combusted and the fraction of the waste that is C derived from fossil sources.

Most of the organic materials in municipal solid wastes are of biogenic origin (e.g., paper, yard trimmings), and have their net C flows accounted for under the Land Use, Land-Use Change, and Forestry chapter. However, some components—plastics, synthetic rubber, synthetic fibers, and carbon black—are of fossil origin. Plastics in the U.S. waste stream are primarily in the form of containers, packaging, and durable goods. Rubber is found in durable goods, such as carpets, and in non-durable goods, such as clothing and footwear. Fibers in municipal solid wastes are predominantly from clothing and home furnishings. As noted above, tires (which contain rubber and carbon black) are also considered a “non-hazardous” waste and are included in the waste incineration estimate, though waste disposal practices for tires differ from municipal solid waste (viz., most incineration occurs outside of MSW combustion facilities).

Approximately 26 million metric tons of waste was incinerated in the United States in 2008 (EPA 2008). Carbon dioxide emissions from incineration of waste rose 63 percent since 1990, to an estimated 13.1 Tg CO₂ Eq. (13,128 Gg) in 2008, as the volume of tires and other fossil C-containing materials in waste increased (see Table 3-25 and Table 3-26). Waste incineration is also a source of N₂O and CH₄ emissions

(De Soete 1993; IPCC 2006). Nitrous oxide emissions from the incineration of waste were estimated to be 0.4 Tg CO₂ Eq. (1 Gg N₂O) in 2008, and have not changed significantly since 1990. Methane emissions from the incineration of waste were estimated to be less than 0.05 Tg CO₂ Eq. (less than 0.5 Gg CH₄) in 2008, and have not changed significantly since 1990.

Methodology

Emissions of CO₂ from the incineration of waste include CO₂ generated by the incineration of plastics, synthetic fibers, and synthetic rubber, as well as the incineration of synthetic rubber and carbon black in tires. These emissions were estimated by multiplying the amount of each material incinerated by the C content of the material and the fraction oxidized (98 percent). Plastics incinerated in municipal solid wastes were categorized into seven plastic resin types, each material having a discrete C content. Similarly, synthetic rubber is categorized into three product types, and synthetic fibers were categorized into four product types, each having a discrete C content. Scrap tires contain several types of synthetic rubber, as well as carbon black. Each type of synthetic rubber has a discrete C content, and carbon black is 100 percent C. Emissions of CO₂ were calculated based on the amount of scrap tires used for fuel and the synthetic rubber and carbon black content of tires.

More detail on the methodology for calculating emissions from each of these waste incineration sources is provided in Annex 3.6.

For each of the methods used to calculate CO₂ emissions from the incineration of waste, data on the quantity of product combusted and the C content of the product are needed. For plastics, synthetic rubber, and synthetic fibers, the amount of specific materials discarded as municipal solid waste (i.e., the quantity generated minus the quantity recycled) was taken from *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures* (EPA 1999 through 2003, 2005 through 2009) and detailed unpublished backup data for some years not shown in the reports (Schneider 2007). The proportion of total waste discarded that is incinerated was derived from data in *BioCycle's "State of Garbage in America"* (ArSova et al. 2008). For synthetic rubber and carbon black in scrap tires, information was obtained from *U.S. Scrap Tire Markets in the United States 2007 Edition* (RMA 2009a). For 2008, synthetic rubber mass

Table 3-25: CO₂ and N₂O Emissions from the Incineration of Waste (Tg CO₂ Eq.)

Gas/Waste Product	1990	1995	2000	2005	2006	2007	2008
CO₂	8.0	11.5	11.3	12.6	12.7	13.3	13.1
Plastics	5.6	6.3	6.1	6.9	6.7	7.0	6.7
Synthetic Rubber in Tires	0.3	1.4	1.5	1.6	1.7	1.8	1.8
Carbon Black in Tires	0.4	1.7	1.8	2.0	2.1	2.3	2.3
Synthetic Rubber in MSW	0.9	1.0	0.8	0.9	0.9	1.0	1.0
Synthetic Fibers	0.8	1.1	1.0	1.2	1.2	1.2	1.3
N₂O	0.5	0.5	0.4	0.4	0.4	0.4	0.4
CH₄	+	+	+	+	+	+	+
Total	8.5	11.9	11.7	13.0	13.1	13.7	13.5

+ Does not exceed 0.05 Tg CO₂ Eq.

Table 3-26: CO₂ and N₂O Emissions from the Incineration of Waste (Gg)

Gas/Waste Product	1990	1995	2000	2005	2006	2007	2008
CO₂	8,049	11,461	11,270	12,616	12,684	13,289	13,128
Plastics	5,588	6,323	6,104	6,919	6,722	6,966	6,739
Synthetic Rubber in Tires	308	1,356	1,454	1,599	1,712	1,823	1,823
Carbon Black in Tires	385	1,696	1,818	1,958	2,113	2,268	2,268
Synthetic Rubber in MSW	932	973	847	946	928	1,021	1,031
Synthetic Fibers	838	1,115	1,046	1,194	1,208	1,212	1,268
N₂O	2	1	1	1	1	1	1
CH₄	+	+	+	+	+	+	+

+ Does not exceed 0.05 Tg CO₂ Eq.

in tires is assumed to be equal to that in 2007 due to a lack of more recently available data.

Average C contents for the “Other” plastics category, synthetic rubber in municipal solid wastes, and synthetic fibers were calculated from 1998 production statistics, which divide their respective markets by chemical compound. Information about scrap tire composition was taken from the Rubber Manufacturers’ Association internet site (RMA 2009b).

The assumption that 98 percent of organic C is oxidized (which applies to all waste incineration categories for CO₂ emissions) was reported in EPA’s life cycle analysis of greenhouse gas emissions and sinks from management of solid waste (EPA 2006).

Incineration of waste also results in emissions of N₂O and CH₄. These emissions were calculated as a function of the total estimated mass of waste incinerated and an emission factor. As noted above, N₂O and CH₄ emissions are a function of total waste incinerated in each year; for 1990 through 2006, these data were derived from the information published in *BioCycle* (ArSova et al. 2008). Data on total

waste incinerated was not available for 2007 and 2008, so this value was assumed to equal the most recent value available (2006). Table 3-27 provides data on municipal solid waste generation and percentage combusted for the total waste stream. According to Covanta Energy (Bahor 2009) and confirmed by additional research based on ISWA (ERC 2009), all municipal solid waste combustors in the United States are continuously fed stoker units. The emission factors of N₂O and CH₄ emissions per quantity of municipal solid waste combusted are default emission factors for this technology type and were taken from the IPCC 2006 Guidelines (IPCC 2006).

Uncertainty and Time-Series Consistency

A Tier 2 Monte Carlo analysis was performed to determine the level of uncertainty surrounding the estimates of CO₂ emissions and N₂O emissions from the incineration of waste (given the very low emissions for CH₄, no uncertainty estimate was derived). IPCC Tier 2 analysis allows the specification of probability density functions for key variables within a computational structure that mirrors

Table 3-27: Municipal Solid Waste Generation (Metric Tons) and Percent Combusted

Year	Waste Generated	Waste Discarded	Waste Incinerated	Incinerated (% of Discards)
1990	266,365,714	235,733,657	30,632,057	13.0
1995	296,390,405	216,364,996	29,639,040	13.7
2000	371,071,109	252,328,354	25,974,978	10.3
2005	363,274,720	259,559,787	29,973,520	10.0
2006	374,686,965	267,526,493	25,853,401	9.7
2007	374,686,965 ^a	267,526,493 ^a	25,853,401 ^a	9.7 ^c
2008	374,686,965 ^a	267,526,493 ^a	25,853,401 ^a	9.7 ^c

^a Assumed equal to 2006 value.
Source: Arsova et al. (2008).

the calculation of the inventory estimate. Uncertainty estimates and distributions for waste generation variables (i.e., plastics, synthetic rubber, and textiles generation) were obtained through a conversation with one of the authors of the *Municipal Solid Waste in the United States* reports. Statistical analyses or expert judgments of uncertainty were not available directly from the information sources for the other variables; thus, uncertainty estimates for these variables were determined using assumptions based on source category knowledge and the known uncertainty estimates for the waste generation variables.

The uncertainties in the waste incineration emission estimates arise from both the assumptions applied to the data and from the quality of the data. Key factors include MSW incineration rate; fraction oxidized; missing data on waste composition; average C content of waste components; assumptions on the synthetic/biogenic C ratio; and combustion conditions affecting N₂O emissions. The highest levels of uncertainty surround the variables that are based on assumptions (e.g., percent of clothing and footwear composed of synthetic rubber); the lowest levels of uncertainty surround variables that were determined by

quantitative measurements (e.g., combustion efficiency, C content of C black).

The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 3-28. Waste incineration CO₂ emissions in 2008 were estimated to be between 10.8 and 14.4 Tg CO₂ Eq. at a 95 percent confidence level. This indicates a range of 18 percent below to 10 percent above the 2008 emission estimate of 13.1 Tg CO₂ Eq. Also at a 95 percent confidence level, waste incineration N₂O emissions in 2008 were estimated to be between 0.1 and 1.3 Tg CO₂ Eq. This indicates a range of 66 percent below to 212 percent above the 2008 emission estimate of 0.4 Tg CO₂ Eq.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2008. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification

A source-specific QA/QC plan was implemented for incineration of waste. This effort included a Tier 1 analysis, as well as portions of a Tier 2 analysis. The Tier 2 procedures

Table 3-28: Tier 2 Quantitative Uncertainty Estimates for CO₂ and N₂O from the Incineration of Waste (Tg CO₂ Eq. and Percent)

Source	Gas	2008 Emission Estimate (Tg CO ₂ Eq.)	Uncertainty Range Relative to Emission Estimate ^a			
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Incineration of Waste	CO ₂	13.1	10.8	14.4	-18%	+10%
Incineration of Waste	N ₂ O	0.4	0.1	1.3	-66%	+212%

^a Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

that were implemented involved checks specifically focusing on the activity data and specifically focused on the emission factor and activity data sources and methodology used for estimating emissions from incineration of waste. Trends across the time series were analyzed to determine whether any corrective actions were needed. Actions were taken to streamline the activity data throughout the incineration of waste calculations.

Recalculations Discussion

Rather than basing the estimate of the percentage discards combusted on data from *MSW Facts and Figures*, as had been done in previous years, the percent of discards combusted was updated with *BioCycle*'s time series estimate. This percentage was used along with discard values for plastics, synthetic rubber, and synthetic fibers from EPA's *MSW Facts and Figures* (the same data source as in previous years) to estimate CO₂ emissions. The change in the source for percentage combusted was made because using *BioCycle* data for discards is in line with other estimates in the Inventory; *BioCycle* data are used to estimate CH₄ emissions from landfills and N₂O emissions from waste incineration. This change decreases CO₂ emissions annually on average by 32 percent across the time series for materials other than tires (the estimate for tires is not affected by this change)

The Rubber Manufacturers Association changed their reporting for the scrap tire market for 2007 (RMA 2009a). Previously, the scrap tire market was profiled by end use in millions of tires, assuming light duty scrap tires weighed 20 pounds and commercial scrap tires weighed 100 pounds. RMA (2009a) estimates the scrap tire market by end use in thousands of tons assuming that light duty scrap tires weigh 22.5 pounds and commercial scrap tires weigh 110 pounds (RMA 2009b). Assuming that average scrap tire weights and composition could change over time, previous Scrap Tire Reports were analyzed to establish a time series for the following factors for both light duty and commercial tires that would affect CO₂ emissions from scrap tire incineration:

- Scrap tire weight
- Tire composition: percent synthetic rubber
- Tire composition: percent carbon black
- Market composition: percent light duty tires disposed

Where this data was not available in the time series the missing values were linearly interpolated between bracketing years' data or, for the ends of time series, set equal to the closest year with reported data. This updated methodology resulted in an average annual increase in CO₂ emissions of 52 percent.

An emissions estimate for CH₄ was also added according to the 2006 IPCC Guidelines (IPCC 2006). Assuming that all municipal solid waste combustors in the United States use continuously fed stoker technology (Bahor 2009, ERC 2009), a default emissions factor from IPCC (2006) of 0.2 kg CH₄/Gg waste was applied to *BioCycle* estimates for the amount of waste combusted for all years in the Inventory.

Planned Improvements

Additional data sources for calculating the N₂O and CH₄ emission factors for U.S. incineration of waste may be investigated.

3.4. Coal Mining (IPCC Source Category 1B1a)

Three types of coal mining related activities release CH₄ to the atmosphere: underground mining, surface mining, and post-mining (i.e., coal-handling) activities. Underground coal mines contribute the largest share of CH₄ emissions. In 2008, 137 gassy underground coal mines in the United States employ ventilation systems to ensure that CH₄ levels remain within safe concentrations. These systems can exhaust significant amounts of CH₄ to the atmosphere in low concentrations. Additionally, 24 U.S. coal mines supplement ventilation systems with degasification systems. Degasification systems are wells drilled from the surface or boreholes drilled inside the mine that remove large volumes of CH₄ before, during, or after mining. In 2008, 13 coal mines collected CH₄ from degasification systems and utilized this gas, thus reducing emissions to the atmosphere. Of these mines, 12 coal mines sold CH₄ to the natural gas pipeline and one coal mine used CH₄ from its degasification system to heat mine ventilation air on site. In addition, one of the coal mines that sold gas to pipelines also used CH₄ to fuel a thermal coal dryer. Surface coal mines also release CH₄ as the overburden is removed and the coal is exposed, but the level of emissions is much lower than from underground mines.

Finally, some of the CH₄ retained in the coal after mining is released during processing, storage, and transport of the coal.

Total CH₄ emissions in 2008 were estimated to be 67.6 Tg CO₂ Eq. (3,221 Gg), a decline of 20 percent since 1990 (see Table 3-29 and Table 3-30). Of this amount, underground mines accounted for 67 percent, surface mines accounted for 21 percent, and post-mining emissions accounted for 12 percent. The decline in CH₄ emissions from underground mines from 1996 to 2002 was the result of the reduction of overall coal production, the mining of less gassy coal, and an increase in CH₄ recovered and used. Since that time, underground coal production and the associated methane emissions have remained fairly level, while surface coal production and its associated emissions have generally increased.

Methodology

The methodology for estimating CH₄ emissions from coal mining consists of two parts. The first part involves estimating CH₄ emissions from underground mines. Because

of the availability of ventilation system measurements, underground mine emissions can be estimated on a mine-by-mine basis and then summed to determine total emissions. The second step involves estimating emissions from surface mines and post-mining activities by multiplying basin-specific coal production by basin-specific emission factors.

Underground mines. Total CH₄ emitted from underground mines was estimated as the sum of CH₄ liberated from ventilation systems and CH₄ liberated by means of degasification systems, minus CH₄ recovered and used. The Mine Safety and Health Administration (MSHA) samples CH₄ emissions from ventilation systems for all mines with detectable³⁴ CH₄ concentrations. These mine-by-mine measurements are used to estimate CH₄ emissions from ventilation systems.

Some of the higher-emitting underground mines also use degasification systems (e.g., wells or boreholes) that remove CH₄ before, during, or after mining. This CH₄ can then be collected for use or vented to the atmosphere. Various approaches were employed to estimate the quantity of CH₄

Table 3-29: CH₄ Emissions from Coal Mining (Tg CO₂ Eq.)

Activity	1990	1995	2000	2005	2006	2007	2008
Underground Mining	62.3	46.7	39.5	35.0	35.7	35.9	44.9
Liberated	67.9	59.0	54.4	50.2	54.3	51.0	59.7
Recovered & Used	(5.6)	(12.2)	(14.9)	(15.1)	(18.6)	(15.1)	(14.8)
Surface Mining	12.0	11.5	12.3	13.3	14.0	13.8	14.3
Post-Mining (Underground)	7.7	6.9	6.7	6.4	6.3	6.1	6.1
Post-Mining (Surface)	2.0	1.9	2.0	2.2	2.3	2.2	2.3
Total	84.1	67.1	60.5	56.9	58.3	58.1	67.6

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.

Table 3-30: CH₄ Emissions from Coal Mining (Gg)

Activity	1990	1995	2000	2005	2006	2007	2008
Underground Mining	2,968	2,226	1,882	1,668	1,701	1,710	2,138
Liberated	3,234	2,808	2,592	2,389	2,587	2,427	2,844
Recovered & Used	(266)	(583)	(710)	(721)	(886)	(717)	(707)
Surface Mining	574	548	586	633	668	659	681
Post-Mining (Underground)	368	330	318	306	299	290	292
Post-Mining (Surface)	93	89	95	103	109	107	111
Total	4,003	3,193	2,881	2,710	2,776	2,765	3,221

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.

³⁴ MSHA records coal mine CH₄ readings with concentrations of greater than 50 ppm (parts per million) CH₄. Readings below this threshold are considered non-detectable.

collected by each of the twenty mines using these systems, depending on available data. For example, some mines report to EPA the amount of CH₄ liberated from their degasification systems. For mines that sell recovered CH₄ to a pipeline, pipeline sales data published by state petroleum and natural gas agencies were used to estimate degasification emissions. For those mines for which no other data are available, default recovery efficiency values were developed, depending on the type of degasification system employed.

Finally, the amount of CH₄ recovered by degasification systems and then used (i.e., not vented) was estimated. In 2008, 12 active coal mines sold recovered CH₄ into the local gas pipeline networks and one coal mine used recovered CH₄ on site for heating. Emissions avoided for these projects were estimated using gas sales data reported by various state agencies. For most mines with recovery systems, companies and state agencies provided individual well production information, which was used to assign gas sales to a particular year. For the few remaining mines, coal mine operators supplied information regarding the number of years in advance of mining that gas recovery occurs.

Surface Mines and Post-Mining Emissions. Surface mining and post-mining CH₄ emissions were estimated by multiplying basin-specific coal production, obtained from the Energy Information Administration's Annual Coal Report (see Table 3-31) (EIA 2008), by basin-specific emission factors. Surface mining emission factors were developed by assuming that surface mines emit two times as much CH₄ as the average in situ CH₄ content of the coal. Revised data on in situ CH₄ content and emissions factors are taken from EPA (2005), EPA (1996), and AAPG (1984). This calculation

accounts for CH₄ released from the strata surrounding the coal seam. For post-mining emissions, the emission factor was assumed to be 32.5 percent of the average in situ CH₄ content of coals mined in the basin.

Uncertainty and Time-Series Consistency

A quantitative uncertainty analysis was conducted for the coal mining source category using the IPCC-recommended Tier 2 uncertainty estimation methodology. Because emission estimates from underground ventilation systems were based on actual measurement data, uncertainty is relatively low. A degree of imprecision was introduced because the measurements used were not continuous but rather an average of quarterly instantaneous readings. Additionally, the measurement equipment used can be expected to have resulted in an average of 10 percent overestimation of annual CH₄ emissions (Mutmansky and Wang 2000). Estimates of CH₄ recovered by degasification systems are relatively certain because many coal mine operators provided information on individual well gas sales and mined through dates. Many of the recovery estimates use data on wells within 100 feet of a mined area. Uncertainty also exists concerning the radius of influence of each well. The number of wells counted, and thus the avoided emissions, may vary if the drainage area is found to be larger or smaller than currently estimated.

Compared to underground mines, there is considerably more uncertainty associated with surface mining and post-mining emissions because of the difficulty in developing accurate emission factors from field measurements. However, since underground emissions comprise the majority of total coal mining emissions, the uncertainty associated with underground emissions is the primary factor that determines overall uncertainty. The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 3-32. Coal mining CH₄ emissions in 2008 were estimated to be between 57.7 and 82.6 Tg CO₂ Eq. at a 95 percent confidence level. This indicates a range of 15 percent increase below to 22 percent above the 2008 emission estimate of 67.6 Tg CO₂ Eq.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2008. Details on the emission trends through time are described in more detail in the Methodology section, above.

Table 3-31: Coal Production (Thousand Metric Tons)

Year	Underground	Surface	Total
1990	384,250	546,818	931,068
1995	359,477	577,638	937,115
2000	338,173	635,592	973,765
2005	334,404	691,460	1,025,864
2006	325,703	728,459	1,054,162
2007	319,145	720,035	1,039,179
2008	323,938	737,845	1,061,782

Table 3-32: Tier 2 Quantitative Uncertainty Estimates for CH₄ Emissions from Coal Mining (Tg CO₂ Eq. and Percent)

Source	Gas	2008 Emission Estimate (Tg CO ₂ Eq.)	Uncertainty Range Relative to Emission Estimate ^a			
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Coal Mining	CH ₄	67.6	57.7	82.6	-15%	+22%

^a Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Recalculations Discussion

In the previous Inventory, calculations of emissions avoided at the two active Jim Walters Resources (JWR) coal mines in Alabama were performed using the previous method. This was done in order to take a better documented approach and to track the four coal mines individually rather than as a group. Emissions avoided calculations for any pre-drainage wells at JWR coal mines are based on publicly-available data records from the Alabama State Oil & Gas Board. Emission reductions are calculated for pre-drainage wells that are located inside the mine plan boundaries and are declared “shut-in” by the O&G Board. The total production for a well is claimed in the year that the well was shut-in and mined through.

3.5. Abandoned Underground Coal Mines (IPCC Source Category 1B1a)

Underground coal mines contribute the largest share of CH₄ emissions, with active underground mines the leading source of underground emissions. However, mines also continue to release CH₄ after closure. As mines mature and coal seams are mined through, mines are closed and abandoned. Many are sealed and some flood through intrusion of groundwater or surface water into the void. Shafts or portals are generally filled with gravel and capped with a concrete seal, while vent pipes and boreholes are plugged in a manner similar to oil and gas wells. Some abandoned mines are vented to the atmosphere to prevent the buildup of CH₄ that may find its way to surface structures through overburden fractures. As work stops within the mines, the CH₄ liberation decreases but it does not stop completely. Following an initial decline, abandoned mines can liberate CH₄ at a near-steady rate over an extended period of time, or, if flooded, produce gas for only a few years. The gas can migrate to the surface through the conduits described above, particularly if they have not been sealed adequately. In

addition, diffuse emissions can occur when CH₄ migrates to the surface through cracks and fissures in the strata overlying the coal mine. The following factors influence abandoned mine emissions:

- Time since abandonment;
- Gas content and adsorption characteristics of coal;
- CH₄ flow capacity of the mine;
- Mine flooding;
- Presence of vent holes; and
- Mine seals.

Gross abandoned mine CH₄ emissions ranged from 6.0 to 9.1 Tg CO₂ Eq. from 1990 through 2008, varying, in general, by less than 1 to approximately 19 percent from year to year. Fluctuations were due mainly to the number of mines closed during a given year as well as the magnitude of the emissions from those mines when active. Gross abandoned mine emissions peaked in 1996 (9.1 Tg CO₂ Eq.) due to the large number of mine closures from 1994 to 1996 (70 gassy mines closed during the three-year period). In spite of this rapid rise, abandoned mine emissions have been generally on the decline since 1996. There were fewer than fifteen gassy mine closures during each of the years from 1998 through 2008, with only five closures in 2008. By 2008, gross abandoned mine emissions increased to 9.0 Tg CO₂ Eq. (see Table 3-33 and Table 3-34). Gross emissions are reduced by CH₄ recovered and used at 31 mines, resulting in net emissions in 2008 of 5.9 Tg CO₂ Eq.

Methodology

Estimating CH₄ emissions from an abandoned coal mine requires predicting the emissions of a mine from the time of abandonment through the inventory year of interest. The flow of CH₄ from the coal to the mine void is primarily dependent on the mine’s emissions when active and the extent to which the mine is flooded or sealed. The CH₄ emission rate before

Table 3-33: CH₄ Emissions from Abandoned Underground Coal Mines (Tg CO₂ Eq.)

Activity	1990	1995	2000	2005	2006	2007	2008
Abandoned Underground Mines	6.0	8.9	8.9	7.0	7.6	8.9	9.0
Recovered & Used	0.0	0.7	1.5	1.4	2.1	3.3	3.1
Total	6.0	8.2	7.4	5.6	5.5	5.7	5.9

Note: Totals may not sum due to independent rounding.

Table 3-34: CH₄ Emissions from Abandoned Underground Coal Mines (Gg)

Activity	1990	1995	2000	2005	2006	2007	2008
Abandoned Underground Mines	288	424	422	334	364	425	429
Recovered & Used	0	32	72	68	100	156	148
Total	288	392	350	266	264	269	281

Note: Totals may not sum due to independent rounding.

abandonment reflects the gas content of the coal, rate of coal mining, and the flow capacity of the mine in much the same way as the initial rate of a water-free conventional gas well reflects the gas content of the producing formation and the flow capacity of the well. A well or a mine which produces gas from a coal seam and the surrounding strata will produce less gas through time as the reservoir of gas is depleted. Depletion of a reservoir will follow a predictable pattern depending on the interplay of a variety of natural physical conditions imposed on the reservoir. The depletion of a reservoir is commonly modeled by mathematical equations and mapped as a type curve. Type curves which are referred to as decline curves have been developed for abandoned coal mines. Existing data on abandoned mine emissions through time, although sparse, appear to fit the hyperbolic type of decline curve used in forecasting production from natural gas wells.

In order to estimate CH₄ emissions over time for a given mine, it is necessary to apply a decline function, initiated upon abandonment, to that mine. In the analysis, mines were grouped by coal basin with the assumption that they will generally have the same initial pressures, permeability and isotherm. As CH₄ leaves the system, the reservoir pressure, Pr, declines as described by the isotherm. The emission rate declines because the mine pressure (Pw) is essentially constant at atmospheric pressure, for a vented mine, and the PI term is essentially constant at the pressures of interest (atmospheric to 30 psia). A rate-time equation can be generated that can be used to predict future emissions.

This decline through time is hyperbolic in nature and can be empirically expressed as:

$$q = q_i (1 + bD_i t)^{-1/b}$$

where,

- q = Gas rate at time t in thousand cubic feet per day (mcf/d)
- q_i = Initial gas rate at time zero (t₀) in mcf/d
- b = The hyperbolic exponent, dimensionless
- D_i = Initial decline rate, 1/yr
- t = Elapsed time from t₀ (years)

This equation is applied to mines of various initial emission rates that have similar initial pressures, permeability and adsorption isotherms (EPA 2003).

The decline curves created to model the gas emission rate of coal mines must account for factors that decrease the rate of emission after mining activities cease, such as sealing and flooding. Based on field measurement data, it was assumed that most U.S. mines prone to flooding will become completely flooded within eight years and therefore no longer have any measurable CH₄ emissions. Based on this assumption, an average decline rate for flooding mines was established by fitting a decline curve to emissions from field measurements. An exponential equation was developed from emissions data measured at eight abandoned mines known to be filling with water located in two of the five basins. Using a least squares, curve-fitting algorithm, emissions data were matched to the exponential equation shown below. There

was not enough data to establish basin-specific equations as was done with the vented, non-flooding mines (EPA 2003).

$$q = q_i e^{(-Dt)}$$

where,

- q = Gas flow rate at time t in mcf/d
- q_i = Initial gas flow rate at time zero (t₀) in mcf/d
- D = Decline rate, 1/yr
- t = Elapsed time from t₀ (years)

Seals have an inhibiting effect on the rate of flow of CH₄ into the atmosphere compared to the rate that would be emitted if the mine had an open vent. The total volume emitted will be the same, but will occur over a longer period. The methodology, therefore, treats the emissions prediction from a sealed mine similar to emissions from a vented mine, but uses a lower initial rate depending on the degree of sealing. The computational fluid dynamics simulator was again used with the conceptual abandoned mine model to predict the decline curve for inhibited flow. The percent sealed is defined as 100 × (1 – (initial emissions from sealed mine / emission rate at abandonment prior to sealing)). Significant differences are seen between 50 percent, 80 percent and 95 percent closure. These decline curves were therefore used as the high, middle, and low values for emissions from sealed mines (EPA 2003).

For active coal mines, those mines producing over 100 mcf/d account for 98 percent of all CH₄ emissions. This same relationship is assumed for abandoned mines. It was determined that 457 abandoned mines closing after 1972 produced emissions greater than 100 mcf/d when active. Further, the status of 271 of the 457 mines (or 60 percent) is known to be either: (1) vented to the atmosphere; (2) sealed to some degree (either earthen or concrete seals); or, (3) flooded (enough to inhibit CH₄ flow to the atmosphere). The remaining 40 percent of the mines were placed in one of the three categories by applying a probability distribution analysis based on the known status of other mines located in the same coal basin (EPA 2003).

Inputs to the decline equation require the average emission rate and the date of abandonment. Generally this data is available for mines abandoned after 1972; however, such data are largely unknown for mines closed before 1972. Information that is readily available such as coal production by state and county are helpful, but do not provide enough

data to directly employ the methodology used to calculate emissions from mines abandoned after 1971. It is assumed that pre-1972 mines are governed by the same physical, geologic, and hydrologic constraints that apply to post-1972 mines; thus, their emissions may be characterized by the same decline curves.

During the 1970s, 78 percent of CH₄ emissions from coal mining came from seventeen counties in seven states. In addition, mine closure dates were obtained for two states, Colorado and Illinois, for the hundred year period extending from 1900 through 1999. The data were used to establish a frequency of mine closure histogram (by decade) and applied to the other five states with gassy mine closures. As a result, basin-specific decline curve equations were applied to 145 gassy coal mines estimated to have closed between 1920 and 1971 in the United States, representing 78 percent of the emissions. State-specific, initial emission rates were used based on average coal mine CH₄ emissions rates during the 1970s (EPA 2003).

Abandoned mines emission estimates are based on all closed mines known to have active mine CH₄ ventilation emission rates greater than 100 mcf/d at the time of abandonment; a list by region is shown in Table 3-35. For example, for 1990 the analysis included 145 mines closed before 1972 and 258 mines closed between 1972 and 1990. Initial emission rates based on MSHA reports, time of abandonment, and basin-specific decline curves influenced by a number of factors were used to calculate annual emissions for each mine in the database. Coal mine degasification data are not available for years prior to 1990, thus the initial emission rates used reflect ventilation emissions only for pre-1990 closures. Methane degasification amounts were added to the quantity of CH₄ ventilated for the total CH₄ liberation rate for seventeen mines that closed between 1992 and 2008. Since the sample of gassy mines (with active mine emissions greater than 100 mcf/d) is assumed to account for 78 percent of the pre-1971 and 98 percent of the post-1971 abandoned mine emissions, the modeled results were multiplied by 1.22 and 1.02 to account for all U.S. abandoned mine emissions.

From 1993 through 2008, emission totals were downwardly adjusted to reflect abandoned mine CH₄ emissions avoided from those mines. The inventory totals were not adjusted for abandoned mine reductions in 1990 through 1992, because no data was reported for abandoned coal mining CH₄ recovery projects during that time.

Table 3-35: Number of gassy abandoned mines occurring in U.S. basins grouped by class according to post-abandonment state

Basin	Sealed	Vented	Flooded	Total Known	Unknown	Total Mines
Central Appalachia	25	25	48	98	119	217
Illinois	30	3	14	47	25	72
Northern Appalachia	42	22	16	80	33	113
Warrior Basin	0	0	15	15	0	15
Western Basins	26	3	2	31	9	40
Total	123	53	95	271	186	457

Uncertainty and Time-Series Consistency

A quantitative uncertainty analysis was conducted to estimate the uncertainty surrounding the estimates of emissions from abandoned underground coal mines. The uncertainty analysis described below provides for the specification of probability density functions for key variables within a computational structure that mirrors the calculation of the inventory estimate. The results provide the range within which, with 95 percent certainty, emissions from this source category are likely to fall.

As discussed above, the parameters for which values must be estimated for each mine in order to predict its decline curve are: (1) the coal’s adsorption isotherm; (2) CH₄ flow capacity as expressed by permeability; and (3) pressure at abandonment. Because these parameters are not available for each mine, a methodological approach to estimating emissions was used that generates a probability distribution of potential outcomes based on the most likely value and the probable range of values for each parameter. The range of values is not meant to capture the extreme values, but values that represent the highest and lowest quartile of the cumulative probability density function of each parameter. Once the low, mid, and high values are selected, they are applied to a probability density function.

The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 3-36. Abandoned coal mines CH₄ emissions in 2008 were estimated to be between 4.8 and 7.5 Tg CO₂ Eq. at a 95 percent confidence level. This indicates a range of 19 percent below to 27 percent above the 2008 emission estimate of 5.9 Tg CO₂ Eq. One of the reasons for the relatively narrow range is that mine-specific data is used in the methodology. The largest degree of uncertainty is associated with the unknown status mines (which account for 40 percent of the mines), with a ±53 percent uncertainty.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2008. Details on the emission trends through time are described in more detail in the Methodology section, above.

3.6. Natural Gas Systems (IPCC Source Category 1B2b)

The U.S. natural gas system encompasses hundreds of thousands of wells, hundreds of processing facilities, and over a million miles of transmission and distribution pipelines. Overall, natural gas systems emitted 96.4 Tg CO₂ Eq. (4,591 Gg) of CH₄ in 2008, a 26 percent decrease over 1990 emissions (see Table 3-37 and Table 3-38), and 30.0 Tg CO₂ Eq. (29,973 Gg) of non-combustion CO₂ in 2008, a 20 percent decrease over 1990 emissions (see Table 3-39 and Table 3-40). Improvements in management practices and technology, along with the replacement of older equipment, have helped to stabilize emissions. Methane emissions decreased since 2007 despite an increase in production and production wells due to a decrease in emissions from offshore platforms and an increase in Natural Gas STAR production sector emissions reductions.

Methane and non-combustion CO₂ emissions from natural gas systems are generally process related, with normal operations, routine maintenance, and system upsets being the primary contributors. Emissions from normal operations include: natural gas engines and turbine uncombusted exhaust, bleed and discharge emissions from pneumatic devices, and fugitive emissions from system components. Routine maintenance emissions originate from pipelines, equipment, and wells during repair and maintenance activities. Pressure surge relief systems and accidents can lead to system upset emissions. Below is a characterization

Table 3-36: Tier 2 Quantitative Uncertainty Estimates for CH₄ Emissions from Abandoned Underground Coal Mines (Tg CO₂ Eq. and Percent)

Source	Gas	2008 Emission Estimate (Tg CO ₂ Eq.)	Uncertainty Range Relative to Emission Estimate ^a			
			(Tg CO ₂ Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Abandoned Underground Coal Mines	CH ₄	5.9	4.8	7.5	-19%	+27%

^a Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

of the four major stages of the natural gas system. Each of the stages is described and the different factors affecting CH₄ and non-combustion CO₂ emissions are discussed.

Field Production. In this initial stage, wells are used to withdraw raw gas from underground formations. Emissions arise from the wells themselves, gathering pipelines, and well-site gas treatment facilities such as dehydrators and separators. Fugitive emissions and emissions from pneumatic devices account for the majority of CH₄ emissions. Flaring emissions account for the majority of the non-combustion CO₂ emissions. Emissions from field production accounted for approximately 15 percent of CH₄ emissions and about 28 percent of non-combustion CO₂ emissions from natural gas systems in 2008.

Processing. In this stage, natural gas liquids and various other constituents from the raw gas are removed, resulting in “pipeline quality” gas, which is injected into the transmission system. Fugitive CH₄ emissions from compressors, including compressor seals, are the primary emission source from this stage. The majority of non-combustion CO₂ emissions come from acid gas removal units, which are designed to remove CO₂ from natural gas. Processing plants account for about 13 percent of CH₄ emissions and approximately 71 percent of non-combustion CO₂ emissions from natural gas systems.

Transmission and Storage. Natural gas transmission involves high pressure, large diameter pipelines that transport gas long distances from field production and processing areas to distribution systems or large volume customers such as power plants or chemical plants. Compressor station facilities, which contain large reciprocating and turbine compressors, are used to move the gas throughout the United States transmission system. Fugitive CH₄ emissions from these compressor stations and from metering and regulating stations account for the majority of the emissions from this stage. Pneumatic devices and engine uncombusted exhaust are also sources of CH₄ emissions from transmission facilities.

Natural gas is also injected and stored in underground formations, or liquefied and stored in above ground tanks, during periods of low demand (e.g., summer), and withdrawn, processed, and distributed during periods of high demand (e.g., winter). Compressors and dehydrators are the primary contributors to emissions from these storage facilities. Methane emissions from the transmission and storage sector account for approximately 41 percent of emissions from natural gas systems, while CO₂ emissions from transmission and storage account for less than 1 percent of the non-combustion CO₂ emissions from natural gas systems.

Distribution. Distribution pipelines take the high-pressure gas from the transmission system at “city gate” stations, reduce the pressure and distribute the gas through primarily underground mains and service lines to individual end users. There were over 1,188,000 miles of distribution mains in 2008, an increase from just over 944,000 miles in 1990 (OPS 2008b). Distribution system emissions, which account for approximately 31 percent of CH₄ emissions from natural gas systems and less than 1 percent of non-combustion CO₂ emissions, result mainly from fugitive emissions from gate stations and pipelines. An increased use of plastic piping, which has lower emissions than other pipe materials, has reduced emissions from this stage. Distribution system CH₄ emissions in 2008 were 10.5 percent lower than 1990 levels.

Methodology

The primary basis for estimates of CH₄ and non-combustion-related CO₂ emissions from the U.S. natural gas industry is a detailed study by the Gas Research Institute and EPA (EPA/GRI 1996). The EPA/GRI study developed over 80 CH₄ emission and activity factors to characterize emissions from the various components within the operating stages of the U.S. natural gas system. The same activity factors were used to estimate both CH₄ and non-combustion CO₂ emissions. However, the CH₄ emission factors were

Table 3-37: CH₄ Emissions from Natural Gas Systems (Tg CO₂ Eq.)^a

Stage	1990	1995	2000	2005	2006	2007	2008
Field Production	34.2	38.7	40.3	23.9	25.0	18.4	14.1
Processing	15.0	15.1	14.6	11.4	11.6	12.0	13.0
Transmission and Storage	46.9	46.4	44.4	39.0	38.2	39.6	39.4
Distribution	33.4	32.4	31.4	29.3	28.3	29.4	29.9
Total	129.5	132.6	130.7	103.6	103.1	99.5	96.4

^aIncluding CH₄ emission reductions achieved by the Natural Gas STAR program and NESHAP regulations.
Note: Totals may not sum due to independent rounding.

Table 3-38: CH₄ Emissions from Natural Gas Systems (Gg) ^a

Stage	1990	1995	2000	2005	2006	2007	2008
Field Production	1,629	1,842	1,918	1,139	1,189	877	674
Processing	714	718	693	545	552	573	617
Transmission and Storage	2,235	2,211	2,115	1,855	1,820	1,886	1,877
Distribution	1,591	1,543	1,497	1,395	1,346	1,402	1,424
Total	6,169	6,313	6,223	4,935	4,907	4,738	4,591

^aIncluding CH₄ emission reductions achieved by the Natural Gas STAR program and NESHAP regulations.
Note: Totals may not sum due to independent rounding.

Table 3-39: Non-combustion CO₂ Emissions from Natural Gas Systems (Tg CO₂ Eq.)

Stage	1990	1995	2000	2005	2006	2007	2008
Field Production	9.5	17.5	6.0	7.6	8.2	9.5	8.5
Processing	27.8	24.6	23.3	21.7	21.2	21.2	21.4
Transmission and Storage	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Distribution	+	+	+	+	+	+	+
Total	37.3	42.2	29.4	29.5	29.5	30.8	30.0

+ Emissions are less than 0.05 Tg CO₂ Eq.
Note: Totals may not sum due to independent rounding.

Table 3-40: Non-combustion CO₂ Emissions from Natural Gas Systems (Gg)

Stage	1990	1995	2000	2005	2006	2007	2008
Field Production	9,461	17,523	5,956	7,633	8,221	9,525	8,495
Processing	27,752	24,621	23,333	21,736	21,204	21,188	21,375
Transmission and Storage	59	61	61	61	60	61	61
Distribution	46	45	44	41	40	41	42
Total	37,317	42,249	29,394	29,472	29,526	30,816	29,973

Note: Totals may not sum due to independent rounding.

adjusted for CO₂ content when estimating fugitive and vented non-combustion CO₂ emissions. The EPA/GRI study was based on a combination of process engineering studies and measurements at representative gas facilities. From this analysis, a 1992 emission estimate was developed using the emission and activity factors, except where direct activity

data was available (e.g., offshore platform counts, processing plant counts, transmission pipeline miles, and distribution pipelines). For other years, a set of industry activity factor drivers was developed that can be used to update activity factors. These drivers include statistics on gas production, number of wells, system throughput, miles of various kinds

of pipe, and other statistics that characterize the changes in the U.S. natural gas system infrastructure and operations. See Annex 3.4 for more detailed information on the methodology and data used to calculate CH₄ and non-combustion CO₂ emissions from natural gas systems.

Activity factor data were taken from the following sources: American Gas Association (AGA 1991–1998); Minerals and Management Service (MMS 2009a-d); Monthly Energy Review (EIA 2009f); Natural Gas Liquids Reserves Report (EIA 2005); Natural Gas Monthly (EIA 2009b,c,e); the Natural Gas STAR Program annual emissions savings (EPA 2009); Oil and Gas Journal (OGJ 1997–2009); Office of Pipeline Safety (OPS 2009a-b); Federal Energy Regulatory Commission (FERC 2009) and other Energy Information Administration publications (EIA 2001, 2004, 2009a,d); World Oil Magazine (2009a-b). Data for estimating emissions from hydrocarbon production tanks were incorporated (EPA 1999). Coalbed CH₄ well activity factors were taken from the Wyoming Oil and Gas Conservation Commission (Wyoming 2009) and the Alabama State Oil and Gas Board (Alabama 2009). Other state well data was taken from: American Association of Petroleum Geologists (AAPG 2004); Brookhaven College (Brookhaven 2004); Kansas Geological Survey (Kansas 2009); Montana Board of Oil and Gas Conservation (Montana 2009); Oklahoma Geological Survey (Oklahoma 2009); Morgan Stanley (Morgan Stanley 2005); Rocky Mountain Production Report (Lippman 2003); New Mexico Oil Conservation Division (New Mexico 2009, 2005); Texas Railroad Commission (Texas 2009a-d); Utah Division of Oil, Gas and Mining (Utah 2009). Emission factors were taken from EPA/GRI (1996). GTI's Unconventional Natural Gas and Gas Composition Databases (GTI 2001) were used to adapt the CH₄ emission factors into non-combustion related CO₂ emission factors. Additional information about CO₂ content in transmission quality natural gas was obtained via the internet from numerous U.S. transmission companies to help further develop the non-combustion CO₂ emission factors.

Uncertainty and Time-Series Consistency

A quantitative uncertainty analysis was conducted to determine the level of uncertainty surrounding estimates of emissions from natural gas systems. Performed using @RISK software and the IPCC-recommended Tier 2

methodology (Monte Carlo Simulation technique), this analysis provides for the specification of probability density functions for key variables within a computational structure that mirrors the calculation of the inventory estimate. The @RISK model utilizes 1992 (base year) emissions to quantify the uncertainty associated with the emissions estimates. The top ten emission sources for the year 2008 are the same as 2007. The overall emissions change for the base year between the 2007 and 2008 inventories are minimal (0.002 percent) and as a result the change in associated uncertainty for the natural gas systems is going to be negligible. Due to the negligible change, the uncertainty associated with emissions estimates for 2008 is assumed to be the same as in the 2007 iteration.

The results presented provide with 95 percent certainty the range within which emissions from this source category are likely to fall for the year 2008. The heterogeneous nature of the natural gas industry makes it difficult to sample facilities that are completely representative of the entire industry. Because of this, scaling up from model facilities introduces a degree of uncertainty. Additionally, highly variable emission rates were measured among many system components, making the calculated average emission rates uncertain. The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 3-41. Natural gas systems CH₄ emissions in 2008 were estimated to be between 73.4 and 138.3 Tg CO₂ Eq. at a 95 percent confidence level. Natural gas systems non-energy CO₂ emissions in 2008 were estimated to be between 22.8 and 43.0 Tg CO₂ Eq. at 95 percent confidence level.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2008. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification Discussion

A number of potential data sources were investigated to improve selected emission factors in the natural gas industry. First, alternative data sources to improve transmission segment compressor station equipment activity factors and the emission factor for condensate tank flashing emissions were investigated. Neither datasets provided data adequate to update the current inventory factors.

Table 3-41: Tier 2 Quantitative Uncertainty Estimates for CH₄ and Non-energy CO₂ Emissions from Natural Gas Systems (Tg CO₂ Eq. and Percent)

Source	Gas	2008 Emission Estimate (Tg CO ₂ Eq.)	Uncertainty Range Relative to Emission Estimate ^a			
			(Tg CO ₂ Eq.)		(%)	
			Lower Bound ^c	Upper Bound ^c	Lower Bound ^c	Upper Bound ^c
Natural Gas Systems	CH ₄	96.4	73.4	138.3	-24%	+43%
Natural Gas Systems ^b	CO ₂	30.0	22.8	43.0	-24%	+43%

^a Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
^b An uncertainty analysis for the non-energy CO₂ emissions was not performed. The relative uncertainty estimated (expressed as a percent) from the CH₄ uncertainty analysis was applied to the point estimate of non-energy CO₂ emissions.
^c All reported values are rounded after calculation. As a result, lower and upper bounds may not be duplicable from other rounded values as shown in table.

The Federal Energy Regulatory Commission (FERC) Form 2 collects data from operators of compressor stations on interstate natural gas transmission pipelines. This data provides the number of interstate compressor stations as well as installed compression capacity. A U.S.EIA representative aggregated data from each submission and also contacted several compressor stations on intrastate pipelines to gather similar data to that which is available through FERC Form 2 for interstate stations. The U.S. reviewed this data for inclusion in the Inventory; however, this data set is not complete, missing the majority of intrastate compressor station data. Therefore, the current activity data source was not changed.

Recalculations Discussion

Most recalculations are the result of updating the previous Inventory activity data with revised values, with only one exception. Changes in CO₂ emissions from Natural Gas Systems are mostly the result of updating the previous Inventory activity data with revised values. In addition, the data source for the number of liquefied natural gas (LNG) import terminals was changed to Federal Energy Regulatory Commission reported data (FERC 2009) to provide a more accurate and current emissions estimate from LNG import terminals. Overall, these changes resulted in an average annual increase of 3.0 Tg CO₂ Eq. (9 percent) in CO₂ emissions from Natural Gas Systems for the period 1990 through 2007.

Planned Improvements

Emission reductions reported to Natural Gas STAR are deducted from the total sector emissions each year in the natural gas systems inventory model to estimate emissions. Originally, these reductions countered only a small portion

of the total sector emissions; however, it has increased rapidly in recent years. Natural Gas STAR Partners may use their own site-specific emission factors and therefore do not necessarily apply the average emission factors assumed in the national Inventory when estimating their emission reductions. As a result, the Natural Gas STAR reported reductions, in some cases, are exceeding the emission estimated for those particular sources. A study will be initiated to identify sources that have the most discrepancy due to the Inventory emissions being exceeded by reported Natural Gas STAR reductions. Natural gas well venting due to unconventional well completions and workovers, as well as conventional gas well blowdowns to unload liquids have already been identified as sources for which Natural Gas STAR reported reductions are significantly larger than the estimated inventory emissions. Improvements to the emission factors and/or the way in which reductions are accounted for from the sources identified in the study will be investigated.

Separately, a larger study is currently underway to update selected emission factors used in the national Inventory. Most of the activity factors and emission factors in the natural gas model are from the EPA/GRI (1996) study. The current study seeks to review selected emission factors in the natural gas industry, and as appropriate, conduct measurement-based studies to develop updated emission factors to better reflect current national circumstances. Results from these studies are expected in the next few years, and will be incorporated into the Inventory, pending a peer review.

A study prepared for the Texas Environmental Research Consortium measured emissions rates from several oil and condensate tanks in Texas (TERC 2009). This data was plotted and compared to other estimation methods, such as the Vasquez-Beggs correlation and the current inventory emission factor. Because of the limited dataset and

unexpected jumps in data points which can be attributed to non-flashing emission affects, the United States decided that further investigation would be necessary before updating the inventory emission factor. A similar study for TCEQ was recently released for public comment and the United States will review the results of this additional study for the next inventory update cycle.

3.7. Petroleum Systems (IPCC Source Category 1B2a)

Methane emissions from petroleum systems are primarily associated with crude oil production, transportation, and refining operations. During each of these activities, CH₄ emissions are released to the atmosphere as fugitive emissions, vented emissions, emissions from operational upsets, and emissions from fuel combustion. Fugitive and vented CO₂ emissions from petroleum systems are primarily associated with crude oil production and refining operations but are negligible in transportation operations. Combusted CO₂ emissions from fuels are already accounted for in the Fossil Fuels Combustion source category, and hence have not been taken into account in the Petroleum Systems source category. Total CH₄ and CO₂ emissions from petroleum systems in 2008 were 29.1 Tg CO₂ Eq. (1,384 Gg CH₄) and 0.5 Tg CO₂ (453 Gg), respectively. Since 1990, CH₄ emissions have declined by 14 percent, due to industry efforts to reduce emissions and a decline in domestic oil production (see Table 3-42 and Table 3-43). Carbon dioxide emissions have also declined by 19 percent since 1990 due to similar reasons (see Table 3-44 and Table 3-45).

Production Field Operations. Production field operations account for almost 98 percent of total CH₄ emissions from petroleum systems. Vented CH₄ from field operations account for 90.9 percent of the emissions from the production sector, unburned CH₄ combustion emissions account for 5.3 percent, fugitive emissions are 3.6 percent, and process upset emissions are slightly over two-tenths of a percent. The most dominant sources of emissions, in order of magnitude, are shallow water offshore oil platforms, natural-gas-powered pneumatic devices (low bleed and high bleed), field storage tanks, gas engines, chemical injection pumps and deep water offshore platforms. These seven sources alone emit about 95 percent of the production field operations emissions. Offshore platform emissions are a combination

of fugitive, vented, and unburned fuel combustion emissions from all equipment housed on oil platforms producing oil and associated gas. Emissions from high and low-bleed pneumatics occur when pressurized gas that is used for control devices is bled to the atmosphere as they cycle open and closed to modulate the system. Emissions from storage tanks occur when the CH₄ entrained in crude oil under pressure volatilizes once the crude oil is put into storage tanks at atmospheric pressure. Emissions from gas engines are due to unburned CH₄ that vents with the exhaust. Emissions from chemical injection pumps are due to the 25 percent that use associated gas to drive pneumatic pumps. The remaining five percent of the emissions are distributed among 26 additional activities within the four categories: vented, fugitive, combustion and process upset emissions. For more detailed, source-level data on CH₄ emissions in production field operations, refer to Annex 3.5.

Vented CO₂ associated with natural gas emissions from field operations account for almost 99 percent of the total CO₂ emissions from this source category, while fugitive and process upsets together account for about 1 percent of the emissions. The most dominant sources of vented emissions are field storage tanks, pneumatic devices (high bleed and low bleed), shallow water offshore oil platforms, and chemical injection pumps. These five sources together account for 98.4 percent of the non-combustion CO₂ emissions from this source category, while the remaining 0.6 percent of the emissions is distributed among 24 additional activities within the three categories: vented, fugitive and process upsets.

Crude Oil Transportation. Crude oil transportation activities account for less than one half of one percent of total CH₄ emissions from the oil industry. Venting from tanks and marine vessel loading operations accounts for 61 percent of CH₄ emissions from crude oil transportation. Fugitive emissions, almost entirely from floating roof tanks, account for 19 percent. The remaining 20 percent is distributed among six additional sources within these two categories. Emissions from pump engine drivers and heaters were not estimated due to lack of data.

Crude Oil Refining. Crude oil refining processes and systems account for slightly less than two percent of total CH₄ emissions from the oil industry because most of the CH₄ in crude oil is removed or escapes before the crude oil is delivered to the refineries. There is an insignificant amount of CH₄ in all refined products. Within refineries, vented

Table 3-42: CH₄ Emissions from Petroleum Systems (Tg CO₂ Eq.)

Stage	1990	1995	2000	2005	2006	2007	2008
Production Field Operations	33.2	31.3	29.5	27.5	27.5	28.1	28.4
Pneumatic Device Venting	10.3	9.7	9.0	8.3	8.3	8.4	8.7
Tank Venting	3.8	3.4	3.2	2.8	2.8	2.9	2.8
Combustion & Process Upsets	1.9	1.7	1.6	1.5	1.5	1.5	1.6
Misc. Venting & Fugitives	16.8	16.0	15.3	14.5	14.5	15.0	14.8
Wellhead Fugitives	0.5	0.5	0.5	0.4	0.4	0.4	0.5
Crude Oil Transportation	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Refining	0.5	0.5	0.6	0.6	0.6	0.6	0.5
Total	33.9	32.0	30.2	28.2	28.2	28.8	29.1

Note: Totals may not sum due to independent rounding.

Table 3-43: CH₄ Emissions from Petroleum Systems (Gg)

Stage	1990	1995	2000	2005	2006	2007	2008
Production Field Operations	1,581	1,492	1,406	1,312	1,311	1,340	1,354
Pneumatic Device Venting	489	463	428	397	396	398	415
Tank Venting	179	161	153	134	134	137	135
Combustion & Process Upsets	88	82	76	71	71	72	75
Misc. Venting & Fugitives	799	762	726	690	693	714	707
Wellhead Fugitives	26	25	22	19	17	20	23
Crude Oil Transportation	7	6	5	5	5	5	5
Refining	25	26	28	28	28	27	25
Total	1,613	1,524	1,439	1,344	1,344	1,372	1,384

Note: Totals may not sum due to independent rounding.

Table 3-44: CO₂ Emissions from Petroleum Systems (Tg CO₂ Eq.)

Stage	1990	1995	2000	2005	2006	2007	2008
Production Field Operations	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Pneumatic Device Venting	+	+	+	+	+	+	+
Tank Venting	0.3	0.3	0.3	0.2	0.2	0.3	0.2
Misc. Venting & Fugitives	+	+	+	+	+	+	+
Wellhead Fugitives	+	+	+	+	+	+	+
Crude Refining	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total	0.6	0.5	0.5	0.5	0.5	0.5	0.5

+ Does not exceed 0.05 Tg CO₂ Eq.

Table 3-45: CO₂ Emissions from Petroleum Systems (Gg)

Stage	1990	1995	2000	2005	2006	2007	2008
Production Field Operations	376	341	323	285	285	292	288
Pneumatic Device Venting	27	26	24	22	22	22	23
Tank Venting	328	296	281	246	246	252	247
Misc. Venting & Fugitives	18	18	17	16	16	16	16
Wellhead Fugitives	1	1	1	1	1	1	1
Crude Refining	180	187	211	205	203	182	165
Total	555	528	534	490	488	474	453

Note: Totals may not sum due to independent rounding.

emissions account for about 86 percent of the emissions, while both fugitive and combustion emissions account for approximately seven percent each. Refinery system blowdowns for maintenance and the process of asphalt blowing—with air, to harden the asphalt—are the primary venting contributors. Most of the fugitive CH₄ emissions from refineries are from leaks in the fuel gas system. Refinery combustion emissions include small amounts of unburned CH₄ in process heater stack emissions and unburned CH₄ in engine exhausts and flares.

Asphalt blowing from crude oil refining accounts for 36 percent of the total non-combustion CO₂ emissions in petroleum systems.

Methodology

The methodology for estimating CH₄ emissions from petroleum systems is a bottom-up approach, based on comprehensive studies of CH₄ emissions from U.S. petroleum systems (EPA 1996, EPA 1999). These studies combined emission estimates from 64 activities occurring in petroleum systems from the oil wellhead through crude oil refining, including 33 activities for crude oil production field operations, 11 for crude oil transportation activities, and 20 for refining operations. Annex 3.5 provides greater detail on the emission estimates for these 64 activities. The estimates of CH₄ emissions from petroleum systems do not include emissions downstream of oil refineries because these emissions are very small compared to CH₄ emissions upstream of oil refineries.

The methodology for estimating CH₄ emissions from the 64 oil industry activities employs emission factors initially developed by EPA (1999). Activity factors for the years 1990 through 2008 were collected from a wide variety of statistical resources. Emissions are estimated for each activity by multiplying emission factors (e.g., emission rate per equipment item or per activity) by their corresponding activity factor (e.g., equipment count or frequency of activity). EPA (1999) provides emission factors for all activities except those related to offshore oil production and field storage tanks. For offshore oil production, two emission factors were calculated using data collected over a one-year period for all federal offshore platforms (EPA 2005, MMS 2004). One emission factor is for oil platforms in shallow water, and one emission factor is for oil platforms in deep water. Emission factors are held constant for the period

1990 through 2008. The number of platforms in shallow water and the number of platforms in deep water are used as activity factors and are taken from Minerals Management Service statistics (MMS 2009a-c). For oil storage tanks, the emissions factor was calculated from API TankCalc data as the total emissions per barrel of crude charge (EPA 1999).

For some years, complete activity factor data were not available. In such cases, one of three approaches was employed. Where appropriate, the activity factor was calculated from related statistics using ratios developed for EPA (1996). For example, EPA (1996) found that the number of heater treaters (a source of CH₄ emissions) is related to both number of producing wells and annual production. To estimate the activity factor for heater treaters, reported statistics for wells and production were used, along with the ratios developed for EPA (1996). In other cases, the activity factor was held constant from 1990 through 2008 based on EPA (1999). Lastly, the previous year's data were used when data for the current year were unavailable. The CH₄ and CO₂ sources in the production sector share common activity factors. See Annex 3.5 for additional detail.

Among the more important references used to obtain activity factors are the Energy Information Administration annual and monthly reports (EIA 1990 through 2008, 1990 through 2009, 1995 through 2009a-b), Methane Emissions from the Natural Gas Industry by the Gas Research Institute and EPA (EPA/GRI 1996a-d), Estimates of Methane Emissions from the U.S. Oil Industry (EPA 1999), consensus of industry peer review panels, MMS reports (MMS 2005, 2009a-c), analysis of MMS data (EPA 2005, MMS 2004), the Oil & Gas Journal (OGJ 2009a,b), the Interstate Oil and Gas Compact Commission (IOGCC 2008), and the United States Army Corps of Engineers (1995-2008).

The methodology for estimating CO₂ emissions from petroleum systems combines vented, fugitive and process upset emissions sources from 29 activities for crude oil production field operations and one activity from petroleum refining. Emissions are estimated for each activity by multiplying emission factors by their corresponding activity factors. The emission factors for CO₂ are estimated by multiplying the CH₄ emission factors by a conversion factor, which is the ratio of CO₂ content and methane content in produced associated gas. The only exceptions to this methodology are the emission factors for crude oil storage tanks, which are obtained from API TankCalc simulation

runs, and the emission factor for asphalt blowing, which was derived using the methodology and sample data from API (2004).

Uncertainty and Time-Series Consistency

This section describes the analysis conducted to quantify uncertainty associated with the estimates of emissions from petroleum systems. Performed using @RISK software and the IPCC-recommended Tier 2 methodology (Monte Carlo Simulation technique), the method employed provides for the specification of probability density functions for key variables within a computational structure that mirrors the calculation of the inventory estimate. The results provide the range within which, with 95 percent certainty, emissions from this source category are likely to fall.

The detailed, bottom-up inventory analysis used to evaluate U.S. petroleum systems reduces the uncertainty related to the CH₄ emission estimates in comparison to a top-down approach. However, some uncertainty still remains. Emission factors and activity factors are based on a combination of measurements, equipment design data, engineering calculations and studies, surveys of selected facilities and statistical reporting. Statistical uncertainties arise from natural variation in measurements, equipment types, operational variability and survey and statistical methodologies. Published activity factors are not available every year for all 64 activities analyzed for petroleum systems; therefore, some are estimated. Because of the dominance of the seven major sources, which account for 92.9 percent of the total methane emissions, the uncertainty surrounding these seven sources has been estimated most rigorously, and serves as the basis for determining the overall uncertainty of petroleum systems emission estimates.

The results of the Tier 2 quantitative uncertainty analysis are summarized in Table 3-46. Because the top emission sources have not changed from 2006 and revised base-year data has by less than 0.03 percent, the relative uncertainty ranges computed for 2006 and published in the previous Inventory were taken as valid and applied to the 2008 inventory emission estimates. Petroleum systems CH₄ emissions in 2008 were estimated to be between 20.9 and 71.0 Tg CO₂ Eq., while CO₂ emissions were estimated to be between 0.3 and 1.1 Tg CO₂ Eq. at a 95 percent confidence level. This indicates a range of 28 percent below to 144 percent above the 2008 emission estimates of 29.1 and 0.5 Tg CO₂ Eq. for CH₄ and CO₂, respectively.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2008. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification Discussion

The United States investigated potential inventory improvements to the crude oil storage tank flashing emission factor and the potential inclusion of non-energy CO₂ emission sources from maintenance (such as welding and cutting), incineration of waste materials and byproducts from thermal oxidizers, decoking processes for tubing in thermal crackers and heater or boiler tubes, delayed and flexi-coking, and catalyst regeneration for refinery units.

The U.S. EIA collects information in form EIA-810 on all refinery fuel usage; however, the report does not distinguish for which activities the fuel was consumed. Therefore, estimates for fuels consumed for petroleum refining, for sources such as maintenance, are included in

Table 3-46: Tier 2 Quantitative Uncertainty Estimates for CH₄ and CO₂ Emissions from Petroleum Systems (Tg CO₂ Eq. and Percent)

Source	Gas	2008 Emission Estimate (Tg CO ₂ Eq.)	Uncertainty Range Relative to Emission Estimate ^a			
			(Tg CO ₂ Eq.)		(%)	
			Lower Bound ^b	Upper Bound ^b	Lower Bound ^b	Upper Bound ^b
Petroleum Systems	CH ₄	29.1	20.9	71.0	-28%	+144%
Petroleum Systems	CO ₂	0.5	0.3	1.1	-28%	+144%

^a Range of 2006 relative uncertainty predicted by Monte Carlo Stochastic Simulation, based on 1995 base year activity factors, for a 95 percent confidence interval.

^b All reported values are rounded after calculation. As a result, lower and upper bounds may not be duplicable from other rounded values as shown in table.

the industrial sector of the Fossil Fuel Combustion chapter; with the available data it was not possible to report this source separately or move the fuel consumed by refineries to the Petroleum Systems source category. Similarly, other sources such as incineration of waste and byproducts, and coke burn, are accounted for the Fossil Fuel Combustion source category or other source categories.

Recalculations Discussion

Most revisions were due to updating previous years' data with revised data from existing data sources. Well completion venting, well drilling, and offshore platform activity factors were updated from existing data sources from 1990 onward.

Activity factors for average stripper well production were revised from 1993 onward with a new data source, IOGCC (2008). Previously, the entire time series was assumed to be constant with average stripper well production of 2.2 barrels of oil per day. IOGCC (2008) provides improved estimated data for each year starting in 1993; 1990 through 1992 are still assumed to be an average of 2.2 barrels of oil per day. Updating the activity factor for average stripper well production resulted in an increase of emissions of 1.3 Gg from 2007 levels.

Non-combusted CO₂ emissions from asphalt blowing were included for the first time in this inventory. The activity factor for asphalt blowing are the same as those already used CH₄ emission calculations. However, a new CO₂ emissions factor for asphalt blowing was derived from API (2004). Carbon dioxide emissions from asphalt blowing resulted in an increase in total CO₂ emissions from petroleum systems of 0.18 Tg CO₂ Eq. in 2007, or 38 percent of total emissions from petroleum systems.

The total effect of the recalculations was to increase emissions by 2 Gg of CH₄ and 166 Gg of CO₂ in 2007.

Planned Improvements

As noted above, nearly all emission factors used in the development of the petroleum systems estimates were taken from EPA (1995, 1996, 1999), with the remaining emission factors taken from EPA default values (EPA 2005) and a consensus of industry peer review panels. These emission factors will be reviewed as part of future inventory work. Results of this review and analysis will be incorporated into future inventories, as appropriate.

Data available in a recently released TCEQ study (as discussed in the QA/QC and Verification section) will be reviewed and considered as a potential update to the emission factor from crude oil storage tank flashing emissions.

A study prepared for the Texas Environmental Research Consortium measured emissions rates from several oil and condensate tanks in Texas (TERC 2009). This data was plotted and compared to other estimation methods, such as the Vasquez-Beggs correlation and the current inventory emission factor. Because of the limited dataset and unexpected jumps in data points that can be attributed to non-flashing emission affects, the further investigation is necessary before updating the inventory emission factor. A similar study for Texas Council on Environmental Quality has recently been released for public comment. The results of this additional study will be reviewed for the next inventory update cycle.

3.8. Energy Sources of Indirect Greenhouse Gas Emissions

In addition to the main greenhouse gases addressed above, many energy-related activities generate emissions of indirect greenhouse gases. Total emissions of nitrogen oxides (NO_x), carbon monoxide (CO), and non-CH₄ volatile organic compounds (NMVOCs) from energy-related activities from 1990 to 2008 are reported in Table 3-49.

Methodology

These emission estimates were obtained from preliminary data (EPA 2009), and disaggregated based on EPA (2003), which, in its final iteration, will be published on the National Emission Inventory (NEI) Air Pollutant Emission Trends web site. Emissions were calculated either for individual categories or for many categories combined, using basic activity data (e.g., the amount of raw material processed) as an indicator of emissions. National activity data were collected for individual categories from various agencies. Depending on the category, these basic activity data may include data on production, fuel deliveries, raw material processed, etc.

Activity data were used in conjunction with emission factors, which together relate the quantity of emissions to the activity. Emission factors are generally available from the

Box 3-3: Carbon Dioxide Transport, Injection, and Geological Storage

Carbon dioxide is produced, captured, transported, and used for Enhanced Oil Recovery (EOR) as well as commercial and non-EOR industrial applications. This CO₂ is produced from both naturally-occurring CO₂ reservoirs and from industrial sources such as natural gas processing plants and ammonia plants. In the current Inventory, emissions from naturally-produced CO₂ are estimated based on the application.

In the current Inventory, the CO₂ that is used in non-EOR industrial and commercial applications (e.g., food processing, chemical production) is assumed to be emitted to the atmosphere during its industrial use. These emissions are discussed in the Carbon Dioxide Consumption section. The naturally-occurring CO₂ used in EOR operations is assumed to be fully sequestered. Additionally, all anthropogenic CO₂ emitted from natural gas processing and ammonia plants is assumed to be emitted to the atmosphere, regardless of whether the CO₂ is captured or not. These emissions are currently included in the Natural Gas Systems and the Ammonia Production sections of the Inventory, respectively.

IPCC (2006) includes, for the first time, methodological guidance to estimate emissions from the capture, transport, injection, and geological storage of CO₂. The methodology is based on the principle that the carbon capture and storage system should be handled in a complete and consistent manner across the entire Energy sector. The approach accounts for CO₂ captured at natural and industrial sites as well as emissions from capture, transport, and use. For storage specifically, a Tier 3 methodology is outlined for estimating and reporting emissions based on site-specific evaluations. However, IPCC (2006) notes that if a national regulatory process exists, emissions information available through that process may support development of CO₂ emissions estimates for geologic storage.

In October 2007, the U.S. EPA announced plans to develop regulations for geologic sequestration of CO₂ under the EPA Underground Injection Control Program. Given that the regulatory process is in its early phases, and site-specific emissions estimates are not yet available, emissions estimates from CO₂ capture, transport, injection and geologic storage are not yet included in national totals. Preliminary estimates indicate that the amount of CO₂ captured from industrial and natural sites, as well as fugitive emissions from pipelines is 44.2 Tg CO₂ (44,175 Gg CO₂) (see Table 3-47 and Table 3-48). Site-specific monitoring and reporting data for CO₂ injection sites (i.e., EOR operations) were not readily available; therefore, these estimates assume all CO₂ is emitted.

Table 3-47: Potential Emissions from CO₂ Capture and Transport (Tg CO₂ Eq.)

Stage	1990	1995	2000	2005	2006	2007	2008
Acid Gas Removal Plants	4.8	3.7	2.3	5.8	6.2	6.1	6.7
Naturally Occurring CO ₂	20.8	22.5	23.2	28.3	30.2	33.1	36.1
Ammonia Production Plants	0.0	0.7	0.7	0.7	0.7	0.7	1.4
Pipelines Transporting CO ₂	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	25.6	26.9	26.1	34.7	37.1	39.9	44.2

Table 3-48: Potential Emissions from CO₂ Capture and Transport (Gg)

Stage	1990	1995	2000	2005	2006	2007	2008
Acid Gas Removal Plants	4,832	3,672	2,264	5,798	6,224	6,088	6,726
Naturally Occurring CO ₂	20,811	22,547	23,208	28,267	30,224	33,086	36,096
Ammonia Production Plants	0	676	676	676	676	676	1,353
Pipelines Transporting CO ₂	8	8	8	7	8	9	9
Total	25,643	26,896	26,149	34,742	37,124	39,851	44,175

EPA's *Compilation of Air Pollutant Emission Factors*, AP-42 (EPA 1997). The EPA currently derives the overall emission control efficiency of a source category from a variety of information sources, including published reports, the *1985 National Acid Precipitation and Assessment Program Emissions Inventory*, and other EPA databases.

Uncertainty and Time-Series Consistency

Uncertainties in these estimates are partly due to the accuracy of the emission factors used and accurate estimates of activity data. A quantitative uncertainty analysis was not performed.

Table 3-49: NO_x, CO, and NMVOC Emissions from Energy-Related Activities (Gg)

Gas/Source	1990	1995	2000	2005	2006	2007	2008
NO_x	21,106	20,586	18,477	15,319	14,473	13,829	13,012
Mobile Combustion	10,862	10,536	10,199	9,012	8,488	7,965	7,441
Stationary Combustion	10,023	9,862	8,053	5,858	5,545	5,432	5,148
Oil and Gas Activities	139	100	111	321	319	318	318
Incineration of Waste	82	88	114	129	121	114	106
<i>International Bunker Fuels^a</i>	<i>2,020</i>	<i>1,566</i>	<i>1,344</i>	<i>1,705</i>	<i>1,796</i>	<i>1,789</i>	<i>1,923</i>
CO	125,640	104,402	89,714	69,062	65,399	61,739	58,078
Mobile Combustion	119,360	97,630	83,559	62,692	58,972	55,253	51,533
Stationary Combustion	5,000	5,383	4,340	4,649	4,695	4,744	4,792
Incineration of Waste	978	1,073	1,670	1,403	1,412	1,421	1,430
Oil and Gas Activities	302	316	146	318	319	320	322
<i>International Bunker Fuels^a</i>	<i>130</i>	<i>124</i>	<i>128</i>	<i>133</i>	<i>162</i>	<i>159</i>	<i>167</i>
NMVOCs	12,620	10,538	8,952	7,798	7,702	7,604	7,507
Mobile Combustion	10,932	8,745	7,229	6,330	6,037	5,742	5,447
Stationary 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
<i>International Bunker Fuels^a</i>	<i>61</i>	<i>50</i>	<i>45</i>	<i>54</i>	<i>59</i>	<i>58</i>	<i>62</i>

^a These values are presented for informational purposes only and are not included or are already accounted for in totals.
Note: Totals may not sum due to independent rounding.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2008. Details on the emission trends through time are described in more detail in the Methodology section, above.

3.9. International Bunker Fuels (IPCC Source Category 1: Memo Items)

Emissions resulting from the combustion of fuels used for international transport activities, termed international bunker fuels under the UNFCCC, are currently not included in national emission totals, but are reported separately based upon location of fuel sales. The decision to report emissions from international bunker fuels separately, instead of allocating them to a particular country, was made by the Intergovernmental Negotiating Committee in establishing the Framework Convention on Climate Change.³⁵ These decisions are reflected in the Revised 1996 IPCC Guidelines,

³⁵ See report of the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change on the work of its ninth session, held at Geneva from 7 to 18 February 1994 (A/AC.237/55, annex I, para. 1c).

as well as the 2006 IPCC GLs, in which countries are requested to report emissions from ships or aircraft that depart from their ports with fuel purchased within national boundaries and are engaged in international transport separately from national totals (IPCC/UNEP/OECD/IEA 1997).³⁶

Greenhouse gases emitted from the combustion of international bunker fuels, like other fossil fuels, include CO₂, CH₄ and N₂O. Two transport modes are addressed under the IPCC definition of international bunker fuels: aviation and marine.³⁷ Emissions from ground transport activities—even when crossing international borders are allocated to the country where the fuel was loaded into the vehicle and, therefore, are not counted as bunker fuel emissions.

³⁶ Note that the definition of international bunker fuels used by the UNFCCC differs from that used by the International Civil Aviation Organization.

³⁷ Most emission related international aviation and marine regulations are under the rubric of the International Civil Aviation Organization (ICAO) or the International Maritime Organization (IMO), which develop international codes, recommendations, and conventions, such as the International Convention of the Prevention of Pollution from Ships (MARPOL).

The IPCC Guidelines distinguish between different modes of air traffic. Civil aviation comprises aircraft used for the commercial transport of passengers and freight, military aviation comprises aircraft under the control of national armed forces, and general aviation applies to recreational and small corporate aircraft. The IPCC Guidelines further define international bunker fuel use from civil aviation as the fuel combusted for civil (e.g., commercial) aviation purposes by aircraft arriving or departing on international flight segments. However, as mentioned above, and in keeping with the IPCC Guidelines, only the fuel purchased in the United States and used by aircraft taking-off (i.e., departing) from the United States are reported here. The standard fuel used for civil aviation is kerosene-type jet fuel, while the typical fuel used for general aviation is aviation gasoline.³⁸

Emissions of CO₂ from aircraft are essentially a function of fuel use. Methane and N₂O emissions also depend upon engine characteristics, flight conditions, and flight phase (i.e., take-off, climb, cruise, descent, and landing). Methane is the product of incomplete combustion and occurs mainly during the landing and take-off phases. In jet engines, N₂O is primarily produced by the oxidation of atmospheric nitrogen, and the majority of emissions occur during the cruise phase. International marine bunkers comprise emissions from fuels burned by ocean-going ships of all flags that are engaged in international transport. Ocean-going ships are generally classified as cargo and passenger carrying, military (i.e., Navy), fishing, and miscellaneous support ships (e.g., tugboats). For the purpose of estimating greenhouse gas emissions, international bunker fuels are solely related to cargo and passenger carrying vessels, which is the largest of the four categories, and military vessels. Two main types of fuels are used on sea-going vessels: distillate diesel fuel and residual fuel oil. Carbon dioxide is the primary greenhouse gas emitted from marine shipping.

Overall, aggregate greenhouse gas emissions in 2008 from the combustion of international bunker fuels from both aviation and marine activities were 136.6 Tg CO₂ Eq., or twenty-one percent above emissions in 1990 (see Table 3-50 and Table 3-51). Emissions from both international flights and international shipping voyages departing from the United States have increased by 66 percent and decreased by

11 percent, respectively, since 1990. The majority of these emissions were in the form of CO₂; however, small amounts of CH₄ and N₂O were also emitted.

Methodology

Emissions of CO₂ were estimated by applying C content and fraction oxidized factors to fuel consumption activity data. This approach is analogous to that described under CO₂ from Fossil Fuel Combustion. C content and fraction oxidized factors for jet fuel, distillate fuel oil, and residual fuel oil were taken directly from EIA and are presented in Annex 2.1, Annex 2.2, and Annex 3.7 of this Inventory. Density conversions were taken from Chevron (2000), ASTM (1989), and USAF (1998). Heat content for distillate fuel oil and residual fuel oil were taken from EIA (2009) and USAF (1998), and heat content for jet fuel was taken from EIA (2009). A complete description of the methodology and a listing of the various factors employed can be found in Annex 2.1. See Annex 3.7 for a specific discussion on the methodology used for estimating emissions from international bunker fuel use by the U.S. military.

Emission estimates for CH₄ and N₂O were calculated by multiplying emission factors by measures of fuel consumption by fuel type and mode. Emission factors used in the calculations of CH₄ and N₂O emissions were obtained from the Revised 1996 IPCC Guidelines (IPCC/UNEP/OECD/IEA 1997). For aircraft emissions, the following values, in units of grams of pollutant per kilogram of fuel consumed (g/kg), were employed: 0.09 for CH₄ and 0.1 for N₂O. For marine vessels consuming either distillate diesel or residual fuel oil the following values (g/MJ), were employed: 0.32 for CH₄ and 0.08 for N₂O. Activity data for aviation included solely jet fuel consumption statistics, while the marine mode included both distillate diesel and residual fuel oil.

Activity data on aircraft fuel consumption for inventory years 2000 through 2005 were developed using the FAA's System for Assessing Aviation's Global Emissions (SAGE) model (FAA 2006). That tool has been subsequently replaced by the Aviation Environmental Design Tool (AEDT), which calculates noise in addition to aircraft fuel burn and emissions for flights globally in a given year (FAA 2010). Data for inventory years 2006 through 2008 were developed using AEDT.

³⁸ Naphtha-type jet fuel was used in the past by the military in turbojet and turboprop aircraft engines.

Table 3-50: CO₂, CH₄, and N₂O Emissions from International Bunker Fuels (Tg CO₂ Eq.)

Gas/Mode	1990	1995	2000	2005	2006	2007	2008
CO₂	111.8	99.8	98.5	110.5	129.1	127.1	135.2
Aviation	46.4	51.2	58.8	57.5	75.3	73.2	77.0
Marine	65.4	48.6	39.7	53.0	53.8	53.9	58.2
CH₄	0.2	0.1	0.1	0.1	0.2	0.2	0.2
Aviation	+	+	+	+	+	+	+
Marine	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N₂O	1.1	0.9	0.9	1.0	1.2	1.2	1.2
Aviation	0.5	0.6	0.6	0.6	0.8	0.8	0.8
Marine	0.5	0.4	0.3	0.4	0.4	0.4	0.5
Total	113.0	100.9	99.5	111.7	130.5	128.4	136.6

+ Does not exceed 0.05 Tg CO₂ Eq.
Note: Totals may not sum due to independent rounding. Includes aircraft cruise altitude emissions.

Table 3-51: CO₂, CH₄, and N₂O Emissions from International Bunker Fuels (Gg)

Gas/Mode	1990	1995	2000	2005	2006	2007	2008
CO₂	111,828	99,817	98,482	110,505	129,104	127,054	135,226
Aviation	46,399	51,228	58,785	57,492	75,272	73,198	77,029
Marine	65,429	48,589	39,697	53,014	53,832	53,856	58,196
CH₄	8	6	6	7	8	7	8
Aviation	2	2	2	2	2	2	2
Marine	7	5	4	5	5	5	6
N₂O	3	3	3	3	4	4	4
Aviation	2	2	2	2	2	2	3
Marine	2	1	1	1	1	1	1

Note: Totals may not sum due to independent rounding. Includes aircraft cruise altitude emissions.

International aviation bunker fuel consumption from 1990-2008 was calculated by assigning the difference between the sum of domestic activity data (in Tbtu) from SAGE and the AEDT, and the reported EIA transportation jet fuel consumption to the international bunker fuel category for jet fuel from EIA (2009). Data on U.S. Department of Defense (DoD) aviation bunker fuels and total jet fuel consumed by the U.S. military was supplied by the Office of the Under Secretary of Defense (Installations and Environment), DoD. Estimates of the percentage of each Service's total operations that were international operations were developed by DoD. Military aviation bunkers included international operations, operations conducted from naval vessels at sea, and operations conducted from U.S. installations principally over international water in direct support of military operations at sea. Military aviation bunker fuel emissions were estimated using military fuel and operations data synthesized from unpublished data by the Defense Energy Support Center, under DoD's Defense

Logistics Agency (DESC 2009). Together, the data allow the quantity of fuel used in military international operations to be estimated. Densities for each jet fuel type were obtained from a report from the U.S. Air Force (USAF 1998). Final jet fuel consumption estimates are presented in Table 3-52. See Annex 3.7 for additional discussion of military data.

Activity data on distillate diesel and residual fuel oil consumption by cargo or passenger carrying marine vessels departing from U.S. ports were taken from unpublished data collected by the Foreign Trade Division of the U.S. Department of Commerce's Bureau of the Census (DOC 1991 through 2009) for 1990 through 2001, 2007, and 2008, and the Department of Homeland Security's Bunker Report for 2003 through 2006 (DHS 2008). Fuel consumption data for 2002 was interpolated due to inconsistencies in reported fuel consumption data. Activity data on distillate diesel consumption by military vessels departing from U.S. ports were provided by DESC (2009). The total amount of

Table 3-52: Aviation Jet Fuel Consumption for International Transport (Million Gallons)

Nationality	1990	1995	2000	2005	2006	2007	2008
U.S. and Foreign Carriers	4,934	5,465	6,157	6,022	7,884	7,667	8,068
U.S. Military	862	581	480	462	400	410	386
Total	5,796	6,046	6,638	6,484	8,284	8,078	8,455

Note: Totals may not sum due to independent rounding.

Table 3-53: Marine Fuel Consumption for International Transport (Million Gallons)

Fuel Type	1990	1995	2000	2005	2006	2007	2008
Residual Fuel Oil	4,781	3,495	2,967	3,881	4,004	4,059	4,373
Distillate Diesel Fuel & Other	617	573	290	444	446	358	445
U.S. Military Naval Fuels	522	334	329	471	414	444	437
Total	5,920	4,402	3,586	4,796	4,864	4,861	5,254

Note: Totals may not sum due to independent rounding.

fuel provided to naval vessels was reduced by 13 percent to account for fuel used while the vessels were not-underway (i.e., in port). Data on the percentage of steaming hours underway versus not-underway were provided by the U.S. Navy. These fuel consumption estimates are presented in Table 3-53.

Uncertainty and Time-Series Consistency

Emission estimates related to the consumption of international bunker fuels are subject to the same uncertainties as those from domestic aviation and marine mobile combustion emissions; however, additional uncertainties result from the difficulty in collecting accurate fuel consumption activity data for international transport activities separate from domestic transport activities.³⁹ For example, smaller aircraft on shorter routes often carry sufficient fuel to complete several flight segments without refueling in order to minimize time spent at the airport gate or take advantage of lower fuel prices at particular airports. This practice, called tankering, when done on international flights, complicates the use of fuel sales data for estimating bunker fuel emissions. Tankering is less common with the type of large, long-range aircraft that make many international flights from the United States, however. Similar practices occur in the marine shipping industry where fuel costs represent a significant portion of overall operating costs and fuel prices

vary from port to port, leading to some tankering from ports with low fuel costs.

Uncertainties exist with regard to the total fuel used by military aircraft and ships, and in the activity data on military operations and training that were used to estimate percentages of total fuel use reported as bunker fuel emissions. Total aircraft and ship fuel use estimates were developed from DoD records, which document fuel sold to the Navy and Air Force from the Defense Logistics Agency. These data may slightly over or under estimate actual total fuel use in aircraft and ships because each Service may have procured fuel from, and/or may have sold to, traded with, and/or given fuel to other ships, aircraft, governments, or other entities. There are uncertainties in aircraft operations and training activity data. Estimates for the quantity of fuel actually used in Navy and Air Force flying activities reported as bunker fuel emissions had to be estimated based on a combination of available data and expert judgment. Estimates of marine bunker fuel emissions were based on Navy vessel steaming hour data, which reports fuel used while underway and fuel used while not underway. This approach does not capture some voyages that would be classified as domestic for a commercial vessel. Conversely, emissions from fuel used while not underway preceding an international voyage are reported as domestic rather than international as would be done for a commercial vessel. There is uncertainty associated with ground fuel estimates for 1997 through 2001. Small fuel quantities may have been used in vehicles or equipment other than that which was assumed for each fuel type.

³⁹ See uncertainty discussions under Carbon Dioxide Emissions from Fossil Fuel Combustion.

There are also uncertainties in fuel end-uses by fuel-type, emissions factors, fuel densities, diesel fuel sulfur content, aircraft and vessel engine characteristics and fuel efficiencies, and the methodology used to back-calculate the data set to 1990 using the original set from 1995. The data were adjusted for trends in fuel use based on a closely correlating, but not matching, data set. All assumptions used to develop the estimate were based on process knowledge, Department and military Service data, and expert judgments. The magnitude of the potential errors related to the various uncertainties has not been calculated, but is believed to be small. The uncertainties associated with future military bunker fuel emission estimates could be reduced through additional data collection.

Although aggregate fuel consumption data have been used to estimate emissions from aviation, the recommended method for estimating emissions of gases other than CO₂ in the Revised 1996 IPCC Guidelines is to use data by specific aircraft type (IPCC/UNEP/OECD/IEA 1997). The IPCC also recommends that cruise altitude emissions be estimated separately using fuel consumption data, while landing and take-off (LTO) cycle data be used to estimate near-ground level emissions of gases other than CO₂.⁴⁰

There is also concern as to the reliability of the existing DOC (1991 through 2009) data on marine vessel fuel consumption reported at U.S. customs stations due to the significant degree of inter-annual variation.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2008. Details on the emission trends through time are described in more detail in the Methodology section, above.

⁴⁰ U.S. aviation emission estimates for CO, NO_x, and NMVOCs are reported by EPA's National Emission Inventory (NEI) Air Pollutant Emission Trends web site, and reported under the Mobile Combustion section. It should be noted that these estimates are based solely upon LTO cycles and consequently only capture near ground-level emissions, which are more relevant for air quality evaluations. These estimates also include both domestic and international flights. Therefore, estimates reported under the Mobile Combustion section overestimate IPCC-defined domestic CO, NO_x, and NMVOC emissions by including landing and take-off (LTO) cycles by aircraft on international flights, but underestimate because they do not include emissions from aircraft on domestic flight segments at cruising altitudes. The estimates in Mobile Combustion are also likely to include emissions from ocean-going vessels departing from U.S. ports on international voyages.

QA/QC and Verification

A source-specific QA/QC plan for international bunker fuels was developed and implemented. This effort included a Tier 1 analysis, as well as portions of a Tier 2 analysis. The Tier 2 procedures that were implemented involved checks specifically focusing on the activity data and emission factor sources and methodology used for estimating CO₂, CH₄, and N₂O from international bunker fuels in the United States. Emission totals for the different sectors and fuels were compared and trends were investigated. No corrective actions were necessary.

Recalculations Discussion

Slight changes to emission estimates are due to revisions made to historical activity data for aviation jet fuel consumption using the FAA's AEDT. These historical data changes resulted in changes to the emission estimates for 1990 through 2007 relative to the previous Inventory, which averaged to an annual increase in emissions from international bunker fuels of 0.9 Tg CO₂ Eq. (0.9 percent) in CO₂ emissions, an annual increase of less than 0.1 Tg CO₂ Eq. (0.9 percent) in CH₄ emissions, and an annual increase of less than 0.1 Tg CO₂ Eq. (2 percent) in N₂O emissions.

3.10. Wood Biomass and Ethanol Consumption (IPCC Source Category 1A)

The combustion of biomass fuels such as wood, charcoal, and wood waste and biomass-based fuels such as ethanol from corn and woody crops generates CO₂. However, in the long run the CO₂ emitted from biomass consumption does not increase atmospheric CO₂ concentrations, assuming that the biogenic C emitted is offset by the uptake of CO₂ that results from the growth of new biomass. As a result, CO₂ emissions from biomass combustion have been estimated separately from fossil fuel-based emissions and are not included in the U.S. totals. Net C fluxes from changes in biogenic C reservoirs in wooded or crop lands are accounted for in the Land Use, Land-Use Change, and Forestry chapter.

In 2008, total CO₂ emissions from the burning of woody biomass in the industrial, residential, commercial, and electricity generation sectors were approximately 198.4 Tg CO₂ Eq. (198,417 Gg) (see Table 3-54 and Table 3-55). As the largest consumer of woody biomass, the industrial sector

Table 3-54: CO₂ Emissions from Wood Consumption by End-Use Sector (Tg CO₂ Eq.)

End-Use Sector	1990	1995	2000	2005	2006	2007	2008
Industrial	135.3	155.1	153.6	136.3	142.2	136.8	121.8
Residential	59.8	53.6	43.3	44.3	40.2	44.3	50.5
Commercial	6.8	7.5	7.4	7.2	6.7	7.2	7.5
Electricity Generation	13.3	12.9	13.9	19.1	18.7	19.2	18.6
Total	215.2	229.1	218.1	206.9	207.9	207.4	198.4

Note: Totals may not sum due to independent rounding.

Table 3-55: CO₂ Emissions from Wood Consumption by End-Use Sector (Gg)

End-Use Sector	1990	1995	2000	2005	2006	2007	2008
Industrial	135,348	155,075	153,559	136,269	142,226	136,767	121,821
Residential	59,808	53,621	43,309	44,340	40,215	44,340	50,527
Commercial	6,779	7,463	7,370	7,182	6,675	7,159	7,453
Electricity Generation	13,252	12,932	13,851	19,074	18,748	19,175	18,615
Total	215,186	229,091	218,088	206,865	207,864	207,441	198,417

Note: Totals may not sum due to independent rounding.

was responsible for 61 percent of the CO₂ emissions from this source. Emissions from this sector decreased from 2007 to 2008 due to a corresponding decrease in wood consumption. The residential sector was the second largest emitter, constituting 25 percent of the total, while the commercial and electricity generation sectors accounted for the remainder.

Biomass-derived fuel consumption in the United States consisted primarily of ethanol use in the transportation sector. Ethanol is primarily produced from corn grown in the Midwest, and was used mostly in the Midwest and South. Pure ethanol can be combusted, or it can be mixed with gasoline as a supplement or octane-enhancing agent. The most common mixture is a 90 percent gasoline, 10 percent ethanol blend known as gasohol. Ethanol and ethanol blends are often used to fuel public transport vehicles such as buses, or centrally fueled fleet vehicles. These fuels burn cleaner than gasoline (i.e., lower in NO_x and hydrocarbon emissions), and have been employed in urban areas with poor air quality. However, because ethanol is a hydrocarbon fuel, its combustion emits CO₂.

In 2008, the United States consumed an estimated 809 trillion Btu of ethanol, and as a result, produced approximately 53.3 Tg CO₂ Eq. (53,346 Gg) (see Table 3-56 and Table 3-57) of CO₂ emissions. Ethanol production and consumption has grown steadily every year since 1990, with the exception of 1996 due to short corn supplies and high prices in that year.

Methodology

Woody biomass emissions were estimated by applying two EIA gross heat contents (Lindstrom 2006) to U.S. consumption data (EIA 2009) (see Table 3-58), provided in energy units for the industrial, residential, commercial, and electric generation sectors. One heat content (16.953114 MMBtu/MT wood and wood waste) was applied to the industrial sector's consumption, while the other heat content (15.432359 MMBtu/MT wood and wood waste) was applied to the consumption data for the other sectors. An EIA emission factor of 0.434 MT C/MT wood (Lindstrom 2006) was then applied to the resulting quantities of woody biomass to obtain CO₂ emission estimates. It was assumed that the woody biomass contains black liquor and other wood wastes, has a moisture content of 12 percent, and is converted into CO₂ with 100 percent efficiency. The emissions from ethanol consumption were calculated by applying an EIA emission factor of 17.99 Tg C/QBtu (Lindstrom 2006) to U.S. ethanol consumption estimates that were provided in energy units (EIA 2009) (see Table 3-59).

Uncertainty and Time-Series Consistency

It is assumed that the combustion efficiency for woody biomass is 100 percent, which is believed to be an overestimate of the efficiency of wood combustion processes in the United States. Decreasing the combustion efficiency would decrease emission estimates. Additionally, the heat

Table 3-56: CO₂ Emissions from Ethanol Consumption (Tg CO₂ Eq.)

End-Use Sector	1990	1995	2000	2005	2006	2007	2008
Transportation	4.1	7.6	9.1	22.0	29.7	37.5	52.2
Industrial	0.1	0.1	0.1	0.5	0.7	0.7	0.9
Commercial	+	+	+	0.1	0.1	0.1	0.2
Total	4.2	7.7	9.2	22.6	30.5	38.3	53.3

+ Does not exceed 0.05 Tg CO₂ Eq.

Table 3-57: CO₂ Emissions from Ethanol Consumption (Gg)

End-Use Sector	1990	1995	2000	2005	2006	2007	2008
Transportation	4,066	7,570	9,077	22,034	29,725	37,470	52,238
Industrial	55	104	85	460	651	662	923
Commercial	33	9	25	59	84	132	184
Total	4,155	7,683	9,188	22,554	30,459	38,264	53,346

content applied to the consumption of woody biomass in the residential, commercial, and electric power sectors is unlikely to be a completely accurate representation of the heat content for all the different types of woody biomass consumed within these sectors. Emission estimates from ethanol production are more certain than estimates from woody biomass consumption due to better activity data collection methods and uniform combustion techniques.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2008. Details on the emission trends through time are described in more detail in the Methodology section, above.

Recalculations Discussion

Wood consumption values were revised for 2005 through 2007 based on updated information from EIA's Annual Energy Review (EIA 2009). EIA (2009) also reported minor changes in wood consumption for all sectors in 2007. This adjustment of historical data for wood biomass consumption resulted in an average annual decrease in emissions from wood biomass consumption of 0.3Tg CO₂ Eq. (about 0.2 percent) from 1990 through 2007. Slight adjustments were made to ethanol consumption based on updated information from EIA (2009), which slightly decreased estimates for ethanol consumed. As a result of these adjustments, average annual emissions from ethanol consumption decreased by less than 0.1 Tg CO₂ Eq. (less than 0.1 percent) relative to the previous Inventory.

Table 3-58: Woody Biomass Consumption by Sector (Trillion Btu)

End-Use Sector	1990	1995	2000	2005	2006	2007	2008
Industrial	1,442	1,652	1,636	1,452	1,515	1,457	1,298
Residential	580	520	420	430	390	430	490
Commercial	66	72	71	70	65	69	72
Electricity Generation	129	125	134	185	182	186	181
Total	2,216	2,370	2,262	2,136	2,152	2,142	2,041

Table 3-59: Ethanol Consumption by Sector (Trillion Btu)

End-Use Sector	1990	1995	2000	2005	2006	2007	2008
Transportation	61.7	114.8	137.6	334.1	450.7	568.2	792.1
Industrial	0.8	1.6	1.3	7.0	9.9	10.0	14.0
Commercial	0.5	0.1	0.4	0.9	1.3	2.0	2.8
Total	63.0	116.5	139.3	342.0	461.9	580.2	808.9