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INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990 – 2010

APRIL 15, 2012

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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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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.

Table of Contents

List of Tables, Figures, and Boxes

Tables

Figures

Boxes

Executive Summary

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

In 1992, the United States signed and ratified the UNFCCC. As stated in Article 2 of the UNFCCC, "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."[2]

Parties to the Convention, by ratifying, "shall develop, periodically update, publish and make available…national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies…"[3] The United States views this 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 2010. 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 Intergovernmental Panel on Climate Change (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. emission inventory has continued 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 IPCC methodologies were expanded, resulting in a more comprehensive and detailed estimate of emissions.

[BEGIN BOX]

Box ES- 1: Methodological approach for estimating and reporting U.S. emissions and sinks

In following the UNFCCC requirement under Article 4.1 to develop and submit national greenhouse gas emissions inventories, the emissions and sinks presented in this report are organized by source and sink categories and calculated using internationally-accepted methods provided by the IPCC.[5] Additionally, the calculated emissions and sinks in a given year for the United States are presented in a common manner in line with the UNFCCC reporting guidelines for the reporting of inventories under this international agreement.[6] The use of consistent methods to calculate emissions and sinks by all nations providing their inventories to the UNFCCC ensures that

[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/2006/sbsta/eng/09.pdf>.

[5] See < http://www.ipcc-nggip.iges.or.jp/public/index.html>.

[6] See < http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/5270.php>.

these reports are comparable. In this regard, U.S. emissions and sinks reported in this inventory report are comparable to emissions and sinks reported by other countries. Emissions and sinks provided in this inventory do not preclude alternative examinations, but rather this inventory report presents emissions and sinks in a common format consistent with how countries are to report inventories under the UNFCCC. The report itself follows this standardized format, and provides an explanation of the IPCC methods used to calculate emissions and sinks, and the manner in which those calculations are conducted.

On October 30, 2009, the U.S. Environmental Protection Agency (EPA) published a rule for the mandatory reporting of greenhouse gases (GHG) from large GHG emissions sources in the United States. Implementation of 40 CFR Part 98 is referred to as the Greenhouse Gas Reporting Program (GHGRP). 40 CFR part 98 applies to direct greenhouse gas emitters, fossil fuel suppliers, industrial gas suppliers, and facilities that inject CO_2 underground for sequestration or other reasons. Reporting is at the facility level, except for certain suppliers of fossil fuels and industrial greenhouse gases. For calendar year 2010, the first year in which data were reported, facilities in 29 categories provided in 40 CFR part 98 were required to report their 2010 emissions by the September 30, 2011 reporting deadline.[7] The GHGRP dataset and the data presented in this inventory report are complementary and, as indicated in the respective planned improvements sections in this report's chapters, EPA is analyzing how to use facility-level GHGRP data to improve the national estimates presented in this inventory.

[END BOX]

ES.1. Background Information

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as bromofluorocarbons (i.e., halons). As stratospheric ozone depleting substances, CFCs, HCFCs, and halons are covered under the Montreal Protocol on Substances that Deplete the Ozone Layer. The UNFCCC defers to this earlier international treaty. Consequently, Parties to the UNFCCC are not required to include these gases in their national greenhouse gas emission inventories.[8] Some other fluorine-containing halogenated substances—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—do not deplete stratospheric ozone but are potent greenhouse gases. These latter substances are addressed by the UNFCCC and accounted for in national greenhouse gas emission inventories.

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

Although the direct greenhouse gases CO_2, CH_4, and N_2O occur naturally in the atmosphere, human activities have changed their atmospheric concentrations. From the pre-industrial era (i.e., ending about 1750) to 2010, concentrations of these greenhouse gases have increased globally by 39, 158, and 19 percent, respectively (IPCC 2007 and NOAA/ESLR 2009).

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

[7] See <http://www.epa.gov/climatechange/emissions/ghgrulemaking.html> and <http://ghgdata.epa.gov/ghgp/main.do>.

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

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 balance of the earth (e.g., affect cloud formation or albedo).[9] The IPCC developed the Global Warming Potential (GWP) concept to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to another gas.

The GWP of a greenhouse gas is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kilogram (kg) of a trace substance relative to that of 1 kg of a reference gas (IPCC 2001). Direct radiative effects occur when the gas itself is a greenhouse gas. The reference gas used is CO_2, and therefore GWP-weighted emissions are measured in teragrams (or million metric tons) of CO_2 equivalent (Tg CO_2 Eq.).[10,11] All gases in this Executive Summary are presented in units of Tg CO_2 Eq.

The UNFCCC reporting guidelines for national inventories were updated in 2006,[12] 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 2010 are consistent with estimates developed prior to the publication of the IPCC Third Assessment Report (TAR) (IPCC 2001) and the IPCC Fourth Assessment Report (AR4) (IPCC 2007). Therefore, to comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using SAR GWP values. All estimates are provided throughout the report in both CO_2 equivalents and unweighted units. A comparison of emission values using the SAR GWPs versus the TAR and AR4 GWPs can be found in Chapter 1 and, in more detail, in Annex 6.1 of this report. The GWP values used in this report are listed below in Table ES-1.

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

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

Source: IPCC (1996)
* The CH_4 GWP includes the direct effects and those indirect effects due

[9] 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.

[10] Carbon comprises 12/44^{ths} of carbon dioxide by weight.

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

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

to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

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

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

In 2010, total U.S. greenhouse gas emissions were 6,821.8 Tg or million metric tons CO_2 Eq. Total U.S. emissions have increased by 10.5 percent from 1990 to 2010, and emissions increased from 2009 to 2010 by 3.2 percent (213.5 Tg CO_2 Eq.). The increase from 2009 to 2010 was primarily due to an increase in economic output resulting in an increase in energy consumption across all sectors, and much warmer summer conditions resulting in an increase in electricity demand for air conditioning that was generated primarily by combusting coal and natural gas. Since 1990, U.S. emissions have increased at an average annual rate of 0.5 percent.

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 2010.

Figure ES-1: U.S. Greenhouse Gas Emissions by Gas

Figure ES-2: Annual Percent Change in U.S. Greenhouse Gas Emissions

Figure ES-3: Cumulative Change in Annual U.S. Greenhouse Gas Emissions Relative to 1990

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

Gas/Source	1990	2005	2006	2007	2008	2009	2010
CO_2	**5,100.5**	**6,107.6**	**6,019.0**	**6,118.6**	**5,924.3**	**5,500.5**	**5,706.4**
Fossil Fuel Combustion	4,738.3	5,746.5	5,653.0	5,757.8	5,571.5	5,206.2	5,387.8
Electricity Generation	1,820.8	2,402.1	2,346.4	2,412.8	2,360.9	2,146.4	2,258.4
Transportation	1,485.9	1,896.6	1,878.1	1,893.9	1,789.8	1,727.9	1,745.5
Industrial	846.4	816.4	848.1	844.4	806.5	726.6	777.8
Residential	338.3	357.9	321.5	341.6	349.3	339.0	340.2
Commercial	219.0	223.5	208.6	218.9	225.1	224.6	224.2
U.S. Territories	27.9	50.0	50.3	46.1	39.8	41.7	41.6
Non-Energy Use of Fuels	119.6	144.1	143.8	134.9	138.6	123.7	125.1
Iron and Steel Production & Metallurgical Coke Production	99.6	66.0	68.9	71.1	66.1	42.1	54.3
Natural Gas Systems	37.6	29.9	30.8	31.0	32.8	32.2	32.3
Cement Production	33.3	45.2	45.8	44.5	40.5	29.0	30.5
Lime Production	11.5	14.4	15.1	14.6	14.3	11.2	13.2
Incineration of Waste	8.0	12.5	12.5	12.7	11.9	11.7	12.1
Limestone and Dolomite Use	5.1	6.8	8.0	7.7	6.3	7.6	10.0
Ammonia Production	13.0	9.2	8.8	9.1	7.9	7.9	8.7
Cropland Remaining Cropland	7.1	7.9	7.9	8.2	8.6	7.2	8.0
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	3.5	4.9	4.1	3.4	4.4
Soda Ash Production and Consumption	4.1	4.2	4.2	4.1	4.1	3.6	3.7
Petrochemical Production	3.3	4.2	3.8	3.9	3.4	2.7	3.3

Aluminum Production	6.8	4.1	3.8	4.3	4.5	3.0	3.0
Carbon Dioxide Consumption	1.4	1.3	1.7	1.9	1.8	1.8	2.2
Titanium Dioxide Production	1.2	1.8	1.8	1.9	1.8	1.6	1.9
Ferroalloy Production	2.2	1.4	1.5	1.6	1.6	1.5	1.7
Zinc Production	0.6	1.0	1.0	1.0	1.2	0.9	1.2
Phosphoric Acid Production	1.5	1.4	1.2	1.2	1.2	1.0	1.0
Wetlands Remaining Wetlands	1.0	1.1	0.9	1.0	1.0	1.1	1.0
Lead Production	0.5	0.6	0.6	0.6	0.5	0.5	0.5
Petroleum Systems	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Silicon Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.1	0.2
Land Use, Land-Use Change, and Forestry (Sink)[a]	*(881.8)*	*(1,085.9)*	*(1,110.4)*	*(1,108.2)*	*(1,087.5)*	*(1,062.6)*	*(1,074.7)*
Wood Biomass and Ethanol Consumption[b]	*218.6*	*228.6*	*233.7*	*241.1*	*252.1*	*244.1*	*266.1*
International Bunker Fuels[c]	*111.8*	*109.8*	*128.4*	*127.6*	*133.7*	*122.3*	*127.8*
CH_4	**668.3**	**625.8**	**664.6**	**656.2**	**667.9**	**672.2**	**666.5**
Natural Gas Systems	189.6	190.5	217.7	205.3	212.7	220.9	215.4
Enteric Fermentation	133.8	139.0	141.4	143.8	143.4	142.6	141.3
Landfills	147.7	112.7	111.7	111.7	113.1	111.2	107.8
Coal Mining	84.1	56.8	58.1	57.8	66.9	70.1	72.6
Manure Management	31.7	47.9	48.4	52.7	51.8	50.7	52.0
Petroleum Systems	35.2	29.2	29.2	29.8	30.0	30.7	31.0
Wastewater Treatment	15.9	16.5	16.7	16.6	16.6	16.5	16.3
Rice Cultivation	7.1	6.8	5.9	6.2	7.2	7.3	8.6
Stationary Combustion	7.5	6.6	6.2	6.5	6.6	6.3	6.3
Abandoned Underground Coal Mines	6.0	5.5	5.5	5.3	5.3	5.1	5.0
Forest Land Remaining Forest Land	2.5	8.1	17.9	14.6	8.8	5.8	4.8
Mobile Combustion	4.7	2.5	2.4	2.2	2.1	2.0	1.9
Composting	0.3	1.6	1.6	1.7	1.7	1.6	1.6
Petrochemical Production	0.9	1.1	1.0	1.0	0.9	0.8	0.9
Iron and Steel Production & Metallurgical Coke Production	1.0	0.7	0.7	0.7	0.6	0.4	0.5
Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Ferroalloy Production	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[c]	0.2	*0.1*	*0.2*	*0.2*	*0.2*	*0.1*	*0.2*
N_2O	**316.2**	**331.9**	**336.8**	**334.9**	**317.1**	**304.0**	**306.2**
Agricultural Soil Management	200.0	213.1	211.1	211.1	212.9	207.3	207.8
Stationary Combustion	12.3	20.6	20.8	21.2	21.1	20.7	22.6
Mobile Combustion	43.9	37.0	33.7	29.0	25.2	22.5	20.6
Manure Management	14.8	17.6	18.4	18.5	18.3	18.2	18.3
Nitric Acid Production	17.6	16.4	16.1	19.2	16.4	14.5	16.7
Wastewater Treatment	3.5	4.7	4.8	4.8	4.9	5.0	5.0
N_2O from Product Uses	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Forest Land Remaining Forest Land	2.1	7.0	15.0	12.2	7.5	5.1	4.3
Adipic Acid Production	15.8	7.4	8.9	10.7	2.6	2.8	2.8
Composting	0.4	1.7	1.8	1.8	1.9	1.8	1.7
Settlements Remaining Settlements	1.0	1.5	1.5	1.6	1.5	1.4	1.4
Incineration of Waste	0.5	0.4	0.4	0.4	0.4	0.4	0.4
Field Burning of Agricultural Residues	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wetlands Remaining Wetlands	+	+	+	+	+	+	+
International Bunker Fuels[c]	*1.1*	*1.0*	*1.2*	*1.2*	*1.2*	*1.1*	*1.2*
HFCs	**36.9**	**115.0**	**116.0**	**120.0**	**117.5**	**112.1**	**123.0**
Substitution of Ozone Depleting	0.3	99.0	101.9	102.7	103.6	106.3	114.6

Substances							
HCFC-22 Production	36.4	15.8	13.8	17.0	13.6	5.4	8.1
Semiconductor Manufacture	0.2	0.2	0.3	0.3	0.3	0.3	0.3
PFCs	**20.6**	**6.2**	**6.0**	**7.5**	**6.6**	**5.6**	**5.6**
Semiconductor Manufacture	2.2	3.2	3.5	3.7	4.0	4.0	4.1
Aluminum Production	18.4	3.0	2.5	3.8	2.7	1.6	1.6
SF_6	**32.6**	**17.8**	**16.8**	**15.6**	**15.0**	**13.9**	**14.0**
Electrical Transmission and Distribution	26.7	13.9	13.0	12.2	12.2	11.8	11.8
Magnesium Production and Processing	5.4	2.9	2.9	2.6	1.9	1.1	1.3
Semiconductor Manufacture	0.5	1.0	1.0	0.8	0.9	1.0	0.9
Total	**6,175.2**	**7,204.2**	**7,159.3**	**7,252.8**	**7,048.3**	**6,608.3**	**6,821.8**
Net Emission (Sources and Sinks)	**5,293.4**	**6,118.3**	**6,048.9**	**6,144.5**	**5,960.9**	**5,545.7**	**5,747.1**

+ Does not exceed 0.05 Tg CO_2 Eq.

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

[b] Emissions from Wood Biomass and Ethanol Consumption are not included specifically in summing energy sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for Land Use, Land-Use Change, and Forestry.

[c] Emissions from International Bunker Fuels are not included in totals.

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

Note: Totals may not sum due to independent rounding.

Figure ES-4 illustrates the relative contribution of the direct greenhouse gases to total U.S. emissions in 2010. The primary greenhouse gas emitted by human activities in the United States was CO_2, representing approximately 83.6 percent of total greenhouse gas emissions. The largest source of CO_2, and of overall greenhouse gas emissions, was fossil fuel combustion. CH_4 emissions, which have decreased by 0.3 percent since 1990, resulted primarily from natural gas systems, enteric fermentation associated with domestic livestock, and decomposition of wastes in landfills. Agricultural soil management, mobile source fuel combustion and stationary fuel combustion were the major sources of N_2O emissions. Ozone depleting substance substitute emissions and emissions of HFC-23 during the production of HCFC-22 were the primary contributors to aggregate HFC emissions. PFC emissions resulted from semiconductor manufacturing and as a by-product of primary aluminum production, while electrical transmission and distribution systems accounted for most SF_6 emissions.

Figure ES-4: 2010 Greenhouse Gas Emissions by Gas (percentages based on Tg CO_2 Eq.)

Overall, from 1990 to 2010, total emissions of CO_2 increased by 605.9 Tg CO_2 Eq. (11.9 percent), while total emissions of CH_4 and N_2O decreased by 1.7 Tg CO_2 Eq. (0.3 percent), and 10.0 Tg CO_2 Eq. (3.2 percent), respectively. During the same period, aggregate weighted emissions of HFCs, PFCs, and SF_6 rose by 52.5 Tg CO_2 Eq. (58.2 percent). From 1990 to 2010, HFCs increased by 86.1 Tg CO_2 Eq. (233.1 percent), PFCs decreased by 15.0 Tg CO_2 Eq. (72.7 percent), and SF_6 decreased by 18.6 Tg CO_2 Eq. (57.0 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, and SF_6 are significant because many of these gases have extremely high global warming potentials and, in the cases of PFCs and SF_6, long atmospheric lifetimes. Conversely, U.S. greenhouse gas emissions were partly offset by carbon sequestration in forests, trees in urban areas, agricultural soils, and landfilled yard trimmings and food scraps, which, in aggregate, offset 15.8 percent of total emissions in 2010. The following sections describe each gas's contribution to total U.S. greenhouse gas emissions in more detail.

Carbon Dioxide Emissions

The global carbon cycle is made up of large carbon flows and reservoirs. Billions of tons of carbon in the form of CO_2 are absorbed by oceans and living biomass (i.e., sinks) and are emitted to the atmosphere annually through natural processes (i.e., sources). When in equilibrium, carbon fluxes among these various reservoirs are roughly balanced. Since the Industrial Revolution (i.e., about 1750), global atmospheric concentrations of CO_2 have risen about 39 percent (IPCC 2007 and NOAA/ESLR 2009), principally due to the combustion of fossil fuels. Within the

United States, fossil fuel combustion accounted for 94.4 percent of CO_2 emissions in 2010. Globally, approximately 30,313 Tg of CO_2 were added to the atmosphere through the combustion of fossil fuels in 2009, of which the United States accounted for about 18 percent.[13] Changes in land use and forestry practices can also emit CO_2 (e.g., through conversion of forest land to agricultural or urban use) or can act as a sink for CO_2 (e.g., through net additions to forest biomass). In addition to fossil-fuel combustion, several other sources emit significant quantities of CO_2. These sources include, but are not limited to non-energy use of fuels, iron and steel production and cement production (Figure ES-5).

Figure ES-5: 2010 Sources of CO_2 Emissions

As the largest source of U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion has accounted for approximately 78 percent of GWP-weighted emissions since 1990, growing slowly from 77 percent of total GWP-weighted emissions in 1990 to 79 percent in 2010. Emissions of CO_2 from fossil fuel combustion increased at an average annual rate of 0.7 percent from 1990 to 2010. The fundamental factors influencing this trend include (1) a generally growing domestic economy over the last 21 years, and (2) an overall growth in emissions from electricity generation and transportation activities. Between 1990 and 2010, CO_2 emissions from fossil fuel combustion increased from 4,738.3 Tg CO_2 Eq. to 5,387.8 Tg CO_2 Eq.—a 13.7 percent total increase over the twenty-one-year period. From 2009 to 2010, these emissions increased by 181.6 Tg CO_2 Eq. (3.5 percent).

Historically, changes in emissions from fossil fuel combustion have been the dominant factor affecting U.S. emission trends. Changes in CO_2 emissions from fossil fuel combustion are influenced by many long-term and short-term factors, including population and economic growth, energy price fluctuations, technological changes, and seasonal temperatures. In the short term, the overall consumption of fossil fuels in the United States fluctuates primarily 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. In the long 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 behavioral choices (e.g., walking, bicycling, or telecommuting to work instead of driving).

Figure ES-6: 2010 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type

Figure ES-7: 2010 End-Use Sector Emissions of CO_2, CH_4, and N_2O from Fossil Fuel Combustion

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

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

[13] Global CO_2 emissions from fossil fuel combustion were taken from Energy Information Administration *International Energy Statistics 2010* < http://tonto.eia.doe.gov/cfapps/ipdbproject/IEDIndex3.cfm> EIA (2010a).

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

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

End-Use Sector	1990	2005	2006	2007	2008	2009	2010
Transportation	**1,489.0**	**1,901.3**	**1,882.6**	**1,899.0**	**1,794.5**	**1,732.4**	**1,750.0**
Combustion	1,485.9	1,896.6	1,878.1	1,893.9	1,789.8	1,727.9	1,745.5
Electricity	3.0	4.7	4.5	5.1	4.7	4.5	4.5
Industrial	**1,533.1**	**1,553.3**	**1,560.2**	**1,559.8**	**1,503.8**	**1,328.6**	**1,415.4**
Combustion	846.4	816.4	848.1	844.4	806.5	726.6	777.8
Electricity	686.8	737.0	712.0	715.4	697.3	602.0	637.6
Residential	**931.4**	**1,214.7**	**1,152.4**	**1,205.2**	**1,192.2**	**1,125.5**	**1,183.7**
Combustion	338.3	357.9	321.5	341.6	349.3	339.0	340.2
Electricity	593.0	856.7	830.8	863.5	842.9	786.5	843.5
Commercial	**757.0**	**1,027.2**	**1,007.6**	**1,047.7**	**1,041.1**	**978.0**	**997.1**
Combustion	219.0	223.5	208.6	218.9	225.1	224.6	224.2
Electricity	538.0	803.7	799.0	828.8	816.0	753.5	772.9
U.S. Territories[a]	**27.9**	**50.0**	**50.3**	**46.1**	**39.8**	**41.7**	**41.6**
Total	**4,738.3**	**5,746.5**	**5,653.0**	**5,757.8**	**5,571.5**	**5,206.2**	**5,387.8**
Electricity Generation	**1,820.8**	**2,402.1**	**2,346.4**	**2,412.8**	**2,360.9**	**2,146.4**	**2,258.4**

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.

Transportation End-Use Sector. Transportation activities (excluding international bunker fuels) accounted for 32 percent of CO_2 emissions from fossil fuel combustion in 2010.[14] Virtually all of the energy consumed in this end-use sector came from petroleum products. Nearly 65 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. From 1990 to 2010, transportation emissions rose by 18 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 34 percent from 1990 to 2010, as a result of a confluence of factors including population growth, economic growth, urban sprawl, and low fuel prices over much of this period.

Industrial End-Use Sector. Industrial CO_2 emissions, resulting both directly from the combustion of fossil fuels and indirectly from the generation of electricity that is consumed by industry, accounted for 26 percent of CO_2 from fossil fuel combustion in 2010. Approximately 55 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. In contrast to the other end-use sectors, emissions from industry have steadily declined since 1990. This decline is 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.

Residential and Commercial End-Use Sectors. The residential and commercial end-use sectors accounted for 22 and 19 percent, respectively, of CO_2 emissions from fossil fuel combustion in 2010. Both sectors relied heavily on electricity for meeting energy demands, with 71 and 78 percent, respectively, of their emissions attributable to electricity consumption for lighting, heating, cooling, and operating appliances. The remaining emissions were due to the consumption of natural gas and petroleum for heating and cooking. Emissions from these end-use sectors have increased 29 percent since 1990, due to increasing electricity consumption for lighting, heating, air conditioning, and operating appliances.

[14] If emissions from international bunker fuels are included, the transportation end-use sector accounted for 34.0 percent of U.S. emissions from fossil fuel combustion in 2010.

Electricity Generation. The United States relies on electricity to meet a significant portion of its energy demands. Electricity generators consumed 36 percent of U.S. energy from fossil fuels and emitted 42 percent of the CO_2 from fossil fuel combustion in 2010. The type of fuel combusted by electricity generators has a significant effect on their emissions. For example, some electricity is generated with low CO_2 emitting energy technologies, particularly non-fossil options such as nuclear, hydroelectric, or geothermal energy. However, electricity generators rely on coal for over half of their total energy requirements and accounted for 94 percent of all coal consumed for energy in the United States in 2010. Consequently, changes in electricity demand have a significant impact on coal consumption and associated CO_2 emissions.

Other significant CO_2 trends included the following:

- CO_2 emissions from non-energy use of fossil fuels have increased 5.5 Tg CO_2 Eq. (4.6 percent) from 1990 through 2010. Emissions from non-energy uses of fossil fuels were 125.1 Tg CO_2 Eq. in 2010, which constituted 2.2 percent of total national CO_2 emissions, approximately the same proportion as in 1990.
- CO_2 emissions from iron and steel production and metallurgical coke production increased by 12.2 Tg CO_2 Eq. (28.9 percent) from 2009 to 2010, upsetting a trend of decreasing emissions. Despite this, from 1990 through 2010 emissions declined by 45.5 percent (45.3 Tg CO_2 Eq.). This decline is due to the restructuring of the industry, technological improvements, and increased scrap utilization.
- In 2010, CO_2 emissions from cement production increased by 1.5 Tg CO_2 Eq. (5.1 percent) from 2009. After decreasing in 1991 by two percent from 1990 levels, cement production emissions grew every year through 2006; emissions decreased in the three years prior to 2010. Overall, from 1990 to 2010, emissions from cement production have decreased by 8.3 percent, a decrease of 2.8 Tg CO_2 Eq.
- Net CO_2 uptake from Land Use, Land-Use Change, and Forestry increased by 192.8 Tg CO_2 Eq. (21.9 percent) from 1990 through 2010. 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

Methane (CH_4) is more than 20 times as effective as CO_2 at trapping heat in the atmosphere (IPCC 1996). Over the last two hundred and fifty years, the concentration of CH_4 in the atmosphere increased by 158 percent (IPCC 2007). Anthropogenic sources of CH_4 include natural gas and petroleum systems, agricultural activities, landfills, coal mining, wastewater treatment, stationary and mobile combustion, and certain industrial processes (see Figure ES-8).

Figure ES-8: 2010 Sources of CH_4 Emissions

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

- Natural gas systems were the largest anthropogenic source category of CH_4 emissions in the United States in 2010 with 215.4 Tg CO_2 Eq. of CH_4 emitted into the atmosphere. Those emissions have increased by 25.8 Tg CO_2 Eq. (13.6 percent) since 1990.
- Enteric fermentation is the second largest anthropogenic source of CH_4 emissions in the United States. In 2010, enteric fermentation CH_4 emissions were 141.3 Tg CO_2 Eq. (21.2 percent of total CH_4 emissions), which represents an increase of 7.5 Tg CO_2 Eq. (5.6 percent) since 1990.
- Landfills are the third largest anthropogenic source of CH_4 emissions in the United States, accounting for 16.2 percent of total CH_4 emissions (107.8 Tg CO_2 Eq.) in 2010. From 1990 to 2010, CH_4 emissions from landfills decreased by 39.8 Tg CO_2 Eq. (27.0 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,[15] which has more than offset the additional CH_4 emissions resulting from an increase in the amount of municipal solid waste landfilled.

- In 2010, CH_4 emissions from coal mining were 72.6 Tg CO_2 Eq., a 2.5 Tg CO_2 Eq. (3.5 percent) increase over 2009 emission levels. The overall decline of 11.5 Tg CO_2 Eq. (13.6 percent) from 1990 results from the mining of less gassy coal from underground mines and the increased use of CH_4 collected from degasification systems.
- Methane emissions from manure management increased by 64.0 percent since 1990, from 31.7 Tg CO_2 Eq. in 1990 to 52.0 Tg CO_2 Eq. in 2010. The majority of this increase was from swine and dairy cow manure, since the general trend in manure management is one of increasing use of liquid systems, which tends to produce greater CH_4 emissions. The increase in liquid systems is the combined result of a shift to larger facilities, and to facilities in the West and Southwest, all of which tend to use liquid systems. Also, new regulations limiting the application of manure nutrients have shifted manure management practices at smaller dairies from daily spread to manure managed and stored on site.

Nitrous Oxide Emissions

N_2O is produced by biological processes that occur in soil and water and by a variety of anthropogenic activities in the agricultural, energy-related, industrial, and waste management fields. While total N_2O emissions are much lower than CO_2 emissions, N_2O is approximately 300 times more powerful than CO_2 at trapping heat in the atmosphere (IPCC 1996). Since 1750, the global atmospheric concentration of N_2O has risen by approximately 19 percent (IPCC 2007). The main anthropogenic activities producing N_2O in the United States are agricultural soil management, fuel combustion in motor vehicles, stationary fuel combustion, manure management and nitric acid production (see Figure ES-9).

Figure ES-9: 2010 Sources of N_2O Emissions

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

- In 2010, N_2O emissions from mobile combustion were 20.6 Tg CO_2 Eq. (approximately 6.7 percent of U.S. N_2O emissions). From 1990 to 2010, N_2O emissions from mobile combustion decreased by 53.1 percent. However, from 1990 to 1998 emissions increased by 25.6 percent, due to control technologies that reduced NO_x emissions while increasing N_2O emissions. Since 1998, newer control technologies have led to an overall decline in N_2O from this source.
- N_2O emissions from adipic acid production were 2.8 Tg CO_2 Eq. in 2010, and have decreased significantly in recent years due to the widespread installation of pollution control measures. Emissions from adipic acid production have decreased by 82.2 percent since 1990 and by 84.0 percent since a peak in 1995.
- N_2O emissions from stationary combustion increased 10.3 Tg CO_2 Eq. (84.4 percent) from 1990 through 2010. N_2O emissions from this source increased primarily as a result of an increase in the number of coal fluidized bed boilers in the electric power sector.
- Agricultural soils accounted for approximately 67.9 percent of N_2O emissions in the United States in 2010. Estimated emissions from this source in 2010 were 207.8 Tg CO_2 Eq. Annual N_2O emissions from agricultural soils fluctuated between 1990 and 2010, although overall emissions were 3.9 percent higher in 2010 than in 1990.

HFC, PFC, and SF_6 Emissions

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

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

stratospheric ozone layer, and are therefore acceptable alternatives under the Montreal Protocol.

These compounds, however, along with SF_6, are potent greenhouse gases. In addition to having high global warming potentials, SF_6 and PFCs have extremely long atmospheric lifetimes, resulting in their essentially irreversible accumulation in the atmosphere once emitted. Sulfur hexafluoride is the most potent greenhouse gas the IPCC has evaluated (IPCC 1996).

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

Figure ES-10: 2010 Sources of HFCs, PFCs, and SF_6 Emissions

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

- Emissions resulting from the substitution of ozone depleting substances (ODS) (e.g., CFCs) have been consistently increasing, from small amounts in 1990 to 114.6 Tg CO_2 Eq. in 2010. Emissions from ODS substitutes are both the largest and the fastest growing source of HFC, PFC, and SF_6 emissions. These emissions have been increasing as phase-out of ODS required under the Montreal Protocol came 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 77.8 percent (28.3 Tg CO_2 Eq.) from 1990 through 2010, 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 of thermal oxidation at some plants to reduce HFC-23 emissions.
- SF_6 emissions from electric power transmission and distribution systems decreased by 55.7 percent (14.9 Tg CO_2 Eq.) from 1990 to 2010, primarily because of higher purchase prices for SF_6 and efforts by industry to reduce emissions.
- PFC emissions from aluminum production decreased by 91.5 percent (16.9 Tg CO_2 Eq.) from 1990 to 2010, due to both industry emission reduction efforts and declines in 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 twenty-one-year period of 1990 to 2010, total emissions in the Energy and Agriculture sectors grew by 645.8 Tg CO_2 Eq. (12.2 percent), and 40.6 Tg CO_2 Eq. (10.5 percent), respectively. Emissions slightly decreased in the Industrial Processes sector by 10.5 Tg CO_2 Eq. (3.4 percent) , while emissions from the Waste and Solvent and Other Product Use sectors decreased by 35.2 Tg CO_2 Eq. (21.0 percent) and less than 0.1 Tg CO_2 Eq. (0.4 percent), respectively. Over the same period, estimates of net C sequestration in the Land Use, Land-Use Change, and Forestry (LULUCF) sector (magnitude of emissions plus CO_2 flux from all LULUCF source categories) increased by 187.0 Tg CO_2 Eq. (21.5 percent).

Figure ES-11: U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector

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

Chapter/IPCC Sector	1990		2005	2006	2007	2008	2009	2010
Energy	5,287.7		6,282.4	6,214.4	6,294.3	6,125.4	5,752.7	5,933.5
Industrial Processes	313.9		330.1	335.5	347.3	319.1	268.2	303.4

Solvent and Other Product Use	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Agriculture	387.8	424.6	425.4	432.6	433.8	426.4	428.4
Land-Use Change and Forestry	13.8	25.6	43.2	37.6	27.4	20.6	19.6
Waste	167.7	137.2	136.5	136.7	138.2	136.0	132.5
Total Emissions	**6,175.2**	**7,204.2**	**7,159.3**	**7,252.8**	**7,048.3**	**6,608.3**	**6,821.8**
Land-Use Change and Forestry (Sinks)	(881.8)	(1,085.9)	(1,110.4)	(1,108.2)	(1,087.5)	(1,062.6)	(1,074.7)
Net Emissions (Emissions and Sinks)	**5,293.4**	**6,118.3**	**6,048.9**	**6,144.5**	**5,960.9**	**5,545.7**	**5,747.1**

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

Energy

The Energy chapter contains emissions of all greenhouse gases resulting from stationary and mobile energy activities including fuel combustion and fugitive fuel emissions. Energy-related activities, primarily fossil fuel combustion, accounted for the vast majority of U.S. CO_2 emissions for the period of 1990 through 2010. In 2010, approximately 85 percent of the energy consumed in the United States (on a Btu basis) was produced through the combustion of fossil fuels. The remaining 15 percent came from other energy sources such as hydropower, biomass, nuclear, wind, and solar energy (see Figure ES-12). Energy-related activities are also responsible for CH_4 and N_2O emissions (50 percent and 14 percent of total U.S. emissions of each gas, respectively). Overall, emission sources in the Energy chapter account for a combined 87.0 percent of total U.S. greenhouse gas emissions in 2010.

Figure ES-12: 2010 U.S. Energy Consumption by Energy Source

Industrial Processes

The Industrial Processes chapter contains by-product or fugitive emissions of greenhouse gases from industrial processes not directly related to energy activities such as fossil fuel combustion. For example, industrial processes can chemically transform raw materials, which often release waste gases such as CO_2, CH_4, and N_2O. These processes include iron and steel production and metallurgical coke production, cement production, ammonia production and urea consumption, lime production, limestone and dolomite use (e.g., flux stone, flue gas desulfurization, and glass manufacturing), soda ash production and consumption, titanium dioxide production, phosphoric acid production, ferroalloy production, CO_2 consumption, silicon carbide production and consumption, aluminum production, petrochemical production, nitric acid production, adipic acid production, lead production, and zinc production. Additionally, emissions from industrial processes release HFCs, PFCs, and SF_6. Overall, emission sources in the Industrial Process chapter account for 4.4 percent of U.S. greenhouse gas emissions in 2010.

Solvent and Other Product Use

The Solvent and Other Product Use chapter contains greenhouse gas emissions that are produced as a by-product of various solvent and other product uses. In the United States, emissions from N_2O from product uses, the only source of greenhouse gas emissions from this sector, accounted for about 0.1 percent of total U.S. anthropogenic greenhouse gas emissions on a carbon equivalent basis in 2010.

Agriculture

The Agricultural chapter contains anthropogenic emissions from agricultural activities (except fuel combustion, which is addressed in the Energy chapter, and agricultural CO_2 fluxes, which are addressed in the Land Use, Land-Use Change, and Forestry Chapter). Agricultural activities contribute directly to emissions of greenhouse gases through a variety of processes, including the following source categories: enteric fermentation in domestic livestock, livestock manure management, rice cultivation, agricultural soil management, and field burning of agricultural residues. CH_4 and N_2O were the primary greenhouse gases emitted by agricultural activities. CH_4 emissions from enteric fermentation and manure management represented 21.2 percent and 7.8 percent of total CH_4 emissions from

anthropogenic activities, respectively, in 2010. Agricultural soil management activities such as fertilizer application and other cropping practices were the largest source of U.S. N_2O emissions in 2010, accounting for 67.9 percent. In 2010, emission sources accounted for in the Agricultural chapters were responsible for 6.3 percent of total U.S. greenhouse gas emissions.

Land Use, Land-Use Change, and Forestry

The Land Use, Land-Use Change, and Forestry chapter contains emissions of CH_4 and N_2O, and emissions and removals of CO_2 from forest management, other land-use activities, and land-use change. Forest management practices, tree planting in urban areas, the management of agricultural soils, and the landfilling of yard trimmings and food scraps resulted in a net uptake (sequestration) of C in the United States. Forests (including vegetation, soils, and harvested wood) accounted for 86 percent of total 2010 net CO_2 flux, urban trees accounted for 9 percent, mineral and organic soil carbon stock changes accounted for 4 percent, and landfilled yard trimmings and food scraps accounted for 1 percent of the total net flux in 2010. 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 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 2010 resulted in a net C sequestration of 1,074.7 Tg CO_2 Eq. (Table ES-5). This represents an offset of 18.8 percent of total U.S. CO_2 emissions, or 15.8 percent of total greenhouse gas emissions in 2010. Between 1990 and 2010, total land use, land-use change, and forestry net C flux resulted in a 21.9 percent increase in CO_2 sequestration, primarily due to an increase in the rate of net C accumulation in forest C stocks, particularly in aboveground and belowground tree biomass, and harvested wood pools. Annual C accumulation in landfilled yard trimmings and food scraps slowed over this period, while the rate of annual C accumulation increased in urban trees.

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

Sink Category	1990	2005	2006	2007	2008	2009	2010
Forest Land Remaining Forest Land	(701.4)	(940.9)	(963.5)	(959.2)	(938.3)	(910.6)	(921.8)
Cropland Remaining Cropland	(29.4)	(18.3)	(19.1)	(19.7)	(18.1)	(17.4)	(15.6)
Land Converted to Cropland	2.2	5.9	5.9	5.9	5.9	5.9	5.9
Grassland Remaining Grassland	(52.2)	(8.9)	(8.8)	(8.6)	(8.5)	(8.3)	(8.3)
Land Converted to Grassland	(19.8)	(24.4)	(24.2)	(24.0)	(23.8)	(23.6)	(23.6)
Settlements Remaining Settlements	(57.1)	(87.8)	(89.8)	(91.9)	(93.9)	(95.9)	(98.0)
Other (Landfilled Yard Trimmings and Food Scraps)	(24.2)	(11.6)	(11.0)	(10.9)	(10.9)	(12.7)	(13.3)
Total	**(881.8)**	**(1,085.9)**	**(1,110.4)**	**(1,108.2)**	**(1,087.5)**	**(1,062.6)**	**(1,074.7)**

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

Emissions from Land Use, Land-Use Change, and Forestry are shown in Table ES-6. Liming of agricultural soils and urea fertilization in 2010 resulted in CO_2 emissions of 3.9 Tg CO_2 Eq. (3,906 Gg) and 4.1 Tg CO_2 Eq. (4,143 Gg), respectively. Lands undergoing peat extraction (i.e., *Peatlands Remaining Peatlands*) resulted in CO_2 emissions of 1.0 Tg CO_2 Eq. (983 Gg), and N_2O emissions of less than 0.05 Tg CO_2 Eq. The application of synthetic fertilizers to forest soils in 2010 resulted in direct N_2O emissions of 0.4 Tg CO_2 Eq. (1 Gg). Direct N_2O emissions from fertilizer application to forest soils have increased by 455 percent since 1990, but still account for a relatively small portion of overall emissions. Additionally, direct N_2O emissions from fertilizer application to settlement soils in 2010 accounted for 1.4 Tg CO_2 Eq. (5 Gg). This represents an increase of 43 percent since 1990. Forest fires in 2010 resulted in CH_4 emissions of 4.8 Tg CO_2 Eq. (231 Gg), and in N_2O emissions of 4.0 Tg CO_2 Eq. (14 Gg).

Table ES-6: Emissions from Land Use, Land-Use Change, and Forestry (Tg or million metric tons CO_2 Eq.)

Source Category	1990	2005	2006	2007	2008	2009	2010
CO_2	**8.1**	**8.9**	**8.8**	**9.2**	**9.6**	**8.3**	**9.0**
Cropland Remaining Cropland: Liming of Agricultural Soils	4.7	4.3	4.2	4.5	5.0	3.7	3.9
Cropland Remaining Cropland: Urea Fertilization	2.4	3.5	3.7	3.8	3.6	3.6	4.1
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	1.0	1.1	0.9	1.0	1.0	1.1	1.0
CH_4	**2.5**	**8.1**	**17.9**	**14.6**	**8.8**	**5.8**	**4.8**
Forest Land Remaining Forest Land: Forest Fires	2.5	8.1	17.9	14.6	8.8	5.8	4.8
N_2O	**3.1**	**8.5**	**16.5**	**13.8**	**9.0**	**6.5**	**5.7**
Forest Land Remaining Forest Land: Forest Fires	2.1	6.6	14.6	11.9	7.2	4.7	4.0
Forest Land Remaining Forest Land: Forest Soils	0.1	0.4	0.4	0.4	0.4	0.4	0.4
Settlements Remaining Settlements: Settlement Soils	1.0	1.5	1.5	1.6	1.5	1.4	1.4
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
Total	**13.8**	**25.6**	**43.2**	**37.6**	**27.4**	**20.6**	**19.6**

+ Less than 0.05 Tg CO_2 Eq.

Note: Totals may not sum due to independent rounding.

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 81.4 percent of this chapter's emissions, and 16.2 percent of total U.S. CH_4 emissions.[16] Additionally, wastewater treatment accounts for 16.1 percent of Waste emissions, 2.5 percent of U.S. CH_4 emissions, and 1.6 percent of U.S. N_2O emissions. Emissions of CH_4 and N_2O from composting are also accounted for in this chapter; generating emissions of 1.6 Tg CO_2 Eq. and 1.7 Tg CO_2 Eq., respectively. Overall, emission sources accounted for in the Waste chapter generated 1.9 percent of total U.S. greenhouse gas emissions in 2010.

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 2010.

Figure ES-13: Emissions Allocated to Economic Sectors

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

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

Implied Sectors	1990	2005	2006	2007	2008	2009	2010
Electric Power Industry	1,866.2	2,448.8	2,393.0	2,459.1	2,405.8	2,191.4	2,306.5
Transportation	1,545.2	2,017.5	1,994.5	2,002.4	1,889.8	1,819.3	1,834.0
Industry	1,564.8	1,438.1	1,499.8	1,489.6	1,448.5	1,317.2	1,394.2
Agriculture	431.9	496.0	516.7	517.6	505.8	492.8	494.8
Commercial	388.0	374.3	359.9	372.2	381.8	382.0	381.7
Residential	345.4	371.3	336.1	358.4	368.4	360.0	365.2
U.S. Territories	33.7	58.2	59.3	53.5	48.4	45.5	45.5
Total Emissions	**6,175.2**	**7,204.2**	**7,159.3**	**7,252.8**	**7,048.3**	**6,608.3**	**6,821.8**
Land Use, Land-Use Change, and Forestry (Sinks)	(881.8)	(1,085.9)	(1,110.4)	(1,108.2)	(1,087.5)	(1,062.6)	(1,074.7)
Net Emissions (Sources and Sinks)	**5,293.4**	**6,118.3**	**6,048.9**	**6,144.5**	**5,960.9**	**5,545.7**	**5,747.1**

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

Using this categorization, emissions from electricity generation accounted for the largest portion (34 percent) of U.S. greenhouse gas emissions in 2010. Transportation activities, in aggregate, accounted for the second largest portion (27 percent), while emissions from industry accounted for the third largest portion (20 percent) of U.S. greenhouse gas emissions in 2010. In contrast to electricity generation and transportation, emissions from industry have in general declined over the past decade. The long-term decline in these emissions has been due to structural changes in the U.S. economy (i.e., shifts from a manufacturing-based to a service-based economy), fuel switching, and energy efficiency improvements. The remaining 19 percent of U.S. greenhouse gas emissions were contributed by, in order of importance, the agriculture, commercial, and residential sectors, plus emissions from U.S. territories. Activities related to agriculture accounted for 7 percent of U.S. emissions; unlike other economic sectors, agricultural sector emissions were dominated by N_2O emissions from agricultural soil management and CH_4 emissions from enteric fermentation. The commercial and residential sectors accounted for 6 and 5 percent, respectively, of emissions and U.S. territories accounted for 1 percent of emissions; emissions from these sectors primarily consisted of CO_2 emissions from fossil fuel combustion.

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

Electricity is ultimately consumed in the economic sectors described above. Table ES-8 presents greenhouse gas emissions from economic sectors with emissions related to electricity generation distributed into end-use categories (i.e., emissions from electricity generation are allocated to the economic sectors in which the electricity is consumed). To distribute electricity emissions among end-use sectors, emissions from the source categories assigned to electricity generation were allocated to the residential, commercial, industry, transportation, and agriculture economic sectors according to retail sales of electricity.[17] These source categories include CO_2 from fossil fuel combustion and the use of limestone and dolomite for flue gas desulfurization, CO_2 and N_2O from incineration of waste, CH_4 and N_2O from stationary sources, and SF_6 from electrical transmission and distribution systems.

When emissions from electricity are distributed among these sectors, industrial activities account for the largest share of U.S. greenhouse gas emissions (30 percent) in 2010. Transportation is the second largest contributor to total U.S. emissions (27 percent). The residential and commercial sectors contributed the next largest shares of total U.S. greenhouse gas emissions in 2010. Emissions from these sectors increase substantially when emissions from electricity are included, due to their relatively large share of electricity consumption (e.g., lighting, appliances, etc.). In all sectors except agriculture, CO_2 accounts for more than 80 percent of greenhouse gas emissions, primarily from the combustion of fossil fuels. Figure ES-14 shows the trend in these emissions by sector from 1990 to 2010.

Table ES-8: U.S Greenhouse Gas Emissions by Economic Sector with Electricity-Related Emissions Distributed

[17] 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.

(Tg or million metric tons CO_2 Eq.)

Implied Sectors	1990	2005	2006	2007	2008	2009	2010
Industry	2,237.7	2,159.9	2,198.5	2,185.9	2,131.5	1,905.8	2,019.0
Transportation	1,548.3	2,022.3	1,999.1	2,007.6	1,894.6	1,823.9	1,838.6
Residential	953.2	1,244.6	1,183.4	1,238.5	1,227.3	1,162.9	1,226.6
Commercial	939.4	1,193.6	1,174.8	1,216.9	1,213.3	1,151.3	1,171.0
Agriculture	462.9	525.5	544.2	550.5	533.3	518.9	521.1
U.S. Territories	33.7	58.2	59.3	53.5	48.4	45.5	45.5
Total Emissions	**6,175.2**	**7,204.2**	**7,159.3**	**7,252.8**	**7,048.3**	**6,608.3**	**6,821.8**
Land Use, Land-Use Change, and Forestry (Sinks)	(881.8)	(1,085.9)	(1,110.4)	(1,108.2)	(1,087.5)	(1,062.6)	(1,074.7)
Net Emissions (Sources and Sinks)	**5,293.4**	**6,118.3**	**6,048.9**	**6,144.5**	**5,960.9**	**5,545.7**	**5,747.1**

See Table 2-14 for more detailed data.

Figure ES-14: Emissions with Electricity Distributed to Economic Sectors

[BEGIN BOX]

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 2010; (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 0.5 percent since 1990. This rate is slightly slower than that for total energy and for fossil fuel consumption, and much slower than that for electricity consumption, overall gross domestic product and national population (see Figure ES-15).

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

Variable	1990	2005	2006	2007	2008	2009	2010	Growth Rate[a]
GDP[b]	100	157	161	165	164	158	163	2.5%
Electricity Consumption[c]	100	134	135	137	136	131	137	1.6%
Fossil Fuel Consumption[c]	100	119	117	119	116	109	113	0.6%
Energy Consumption[c]	100	119	118	121	119	113	117	0.8%
Population[d]	100	118	120	121	122	123	123	1.1%
Greenhouse Gas Emissions[e]	100	117	116	117	114	107	110	0.5%

[a] Average annual growth rate
[b] Gross Domestic Product in chained 2005 dollars (BEA 2010)
[c] Energy content-weighted values (EIA 2010b)
[d] U.S. Census Bureau (2010)
[e] GWP-weighted values

Figure ES-15: U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product
Source: BEA (2010), U.S. Census Bureau (2010), and emission estimates in this report.

[END BOX]

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

The reporting requirements of the UNFCCC[18] request that information be provided on indirect greenhouse gases, which include CO, NO_x, NMVOCs, and SO_2. These gases do not have a direct global warming effect, but indirectly affect terrestrial radiation absorption by influencing the formation and destruction of tropospheric and stratospheric ozone, or, in the case of SO_2, by affecting the absorptive characteristics of the atmosphere. Additionally, some of these gases may react with other chemical compounds in the atmosphere to form compounds that are greenhouse gases.

Since 1970, the United States has published estimates of annual emissions of CO, NO_x, NMVOCs, and SO_2 (EPA 2010, EPA 2009),[19] 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.

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

Gas/Activity	1990	2005	2006	2007	2008	2009	2010
NO_x	**21,705**	**15,899**	**15,039**	**14,380**	**13,545**	**11,467**	**11,467**
Mobile Fossil Fuel Combustion	10,862	9,012	8,488	7,965	7,441	6,206	6,206
Stationary Fossil Fuel Combustion	10,023	5,858	5,545	5,432	5,148	4,159	4,159
Industrial Processes	591	569	553	537	520	568	568
Oil and Gas Activities	139	321	319	318	318	393	393
Incineration of Waste	82	129	121	114	106	128	128
Agricultural Burning	8	6	7	8	8	8	8
Solvent Use	1	3	4	4	4	3	3
Waste	+	2	2	2	2	2	2
CO	**129,976**	**70,791**	**67,227**	**63,613**	**59,993**	**51,431**	**51,431**
Mobile Fossil Fuel Combustion	119,360	62,692	58,972	55,253	51,533	43,355	43,355
Stationary Fossil Fuel Combustion	5,000	4,649	4,695	4,744	4,792	4,543	4,543
Industrial Processes	4,125	1,555	1,597	1,640	1,682	1,549	1,549
Incineration of Waste	978	1,403	1,412	1,421	1,430	1,403	1,403
Agricultural Burning	268	184	233	237	270	247	247
Oil and Gas Activities	302	318	319	320	322	345	345
Waste	1	7	7	7	7	7	7
Solvent Use	5	2	2	2	2	2	2
NMVOCs	**20,930**	**13,761**	**13,594**	**13,423**	**13,254**	**9,313**	**9,313**
Mobile Fossil Fuel Combustion	10,932	6,330	6,037	5,742	5,447	4,151	4,151
Solvent Use	5,216	3,851	3,846	3,839	3,834	2,583	2,583
Industrial Processes	2,422	1,997	1,933	1,869	1,804	1,322	1,322
Stationary Fossil Fuel Combustion	912	716	918	1,120	1,321	424	424
Oil and Gas Activities	554	510	510	509	509	599	599
Incineration of Waste	222	241	238	234	230	159	159
Waste	673	114	113	111	109	76	76
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA
SO_2	**20,935**	**13,466**	**12,388**	**11,799**	**10,368**	**8,599**	**8,599**
Stationary Fossil Fuel Combustion	18,407	11,541	10,612	10,172	8,891	7,167	7,167
Industrial Processes	1,307	831	818	807	795	798	798
Mobile Fossil Fuel Combustion	793	889	750	611	472	455	455
Oil and Gas Activities	390	181	182	184	187	154	154

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

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

Incineration of Waste	38	24	24	24	23	24	24
Waste	+	1	1	1	1	1	1
Solvent Use	+	+	+	+	+	+	+
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA

Source: (EPA 2010, EPA 2009) except for estimates from field burning of agricultural residues.
NA (Not Available)
Note: Totals may not sum due to independent rounding.
+ Does not exceed 0.5 Gg.

Key Categories

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) 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 are sources or sinks that have the greatest contribution to the absolute overall level of national emissions in any of the years covered by the time series. In addition, when an entire time series of emission estimates is prepared, a thorough investigation of key categories must also account for the influence of trends of individual source and sink categories. Finally, a qualitative evaluation of key categories should be performed, in order to capture any key categories that were not identified in either of the quantitative analyses.

Figure ES-16 presents 2010 emission estimates for the key categories as defined by a level analysis (i.e., the contribution of each source or sink category to the total inventory level). The UNFCCC reporting guidelines request that key category analyses be reported at an appropriate level of disaggregation, which may lead to source and sink category names which differ from those used elsewhere in the inventory report. For more information regarding key categories, see section 1.5 and Annex 1.

Figure ES-16: 2010 Key Categories

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 CO_2 emissions from energy-related activities and cement processing, are considered to have low uncertainties. For some other categories of emissions, however, a lack of data or an incomplete understanding of how emissions are generated increases the uncertainty associated with the estimates presented. Acquiring a better understanding of the uncertainty associated with inventory estimates is an important step in helping to prioritize future work and improve the overall quality of the Inventory. 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

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

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.

[BEGIN BOX]

Box ES- 3: 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 2006 IPCC Guidelines (IPCC 2006), which states, “Both methodological changes and refinements over time are an essential part of improving inventory quality. It is good practice to change or refine methods” when: available data have changed; the previously used method is not consistent with the IPCC guidelines for that category; a category has become key; the previously used method is insufficient to reflect mitigation activities in a transparent manner; the capacity for inventory preparation has increased; new inventory methods become available; and for correction of errors.” 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 2010) has been recalculated to reflect the change, per the 2006 IPCC Guidelines (IPCC 2006). 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.

[END BOX]

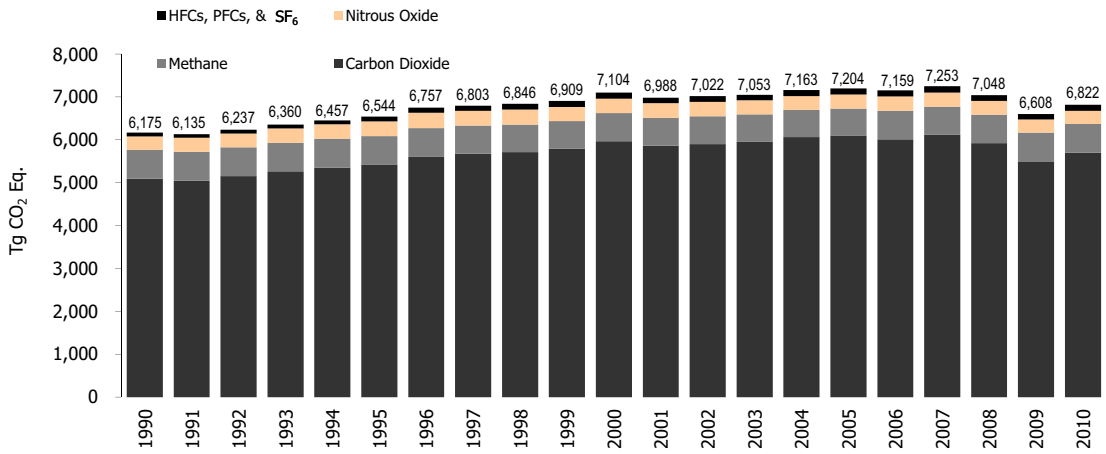


Figure ES-1: U.S. Greenhouse Gas Emissions by Gas

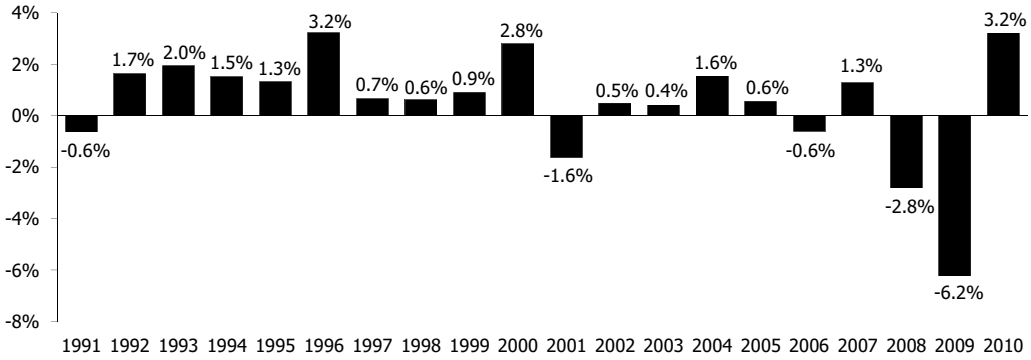


Figure ES-2: Annual Percent Change in U.S. Greenhouse Gas Emissions

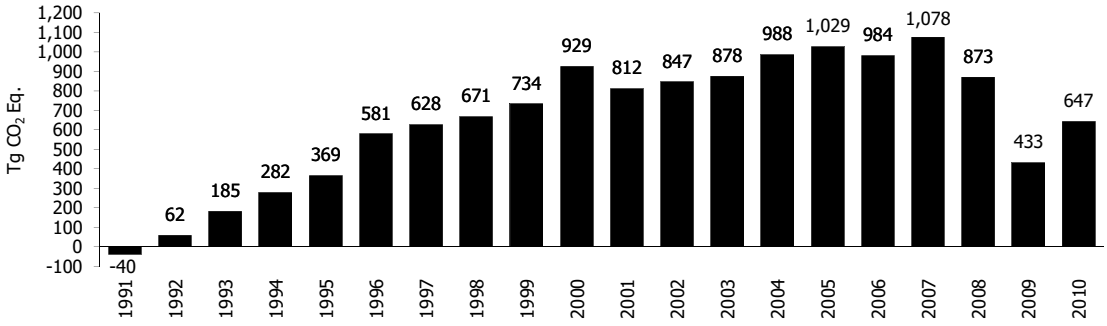


Figure ES-3: Cumulative Change in Annual U.S. Greenhouse Gas Emissions Relative to 1990

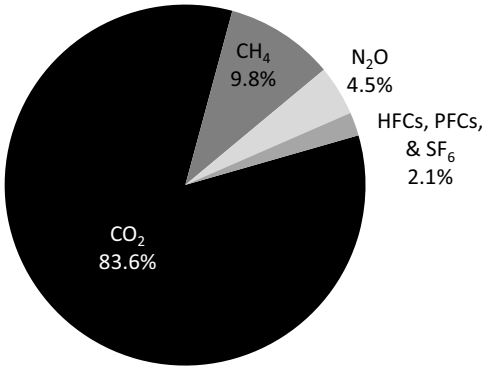


Figure ES-4: 2010 Greenhouse Gas Emissions by Gas (percents based on Tg CO_2 Eq.)

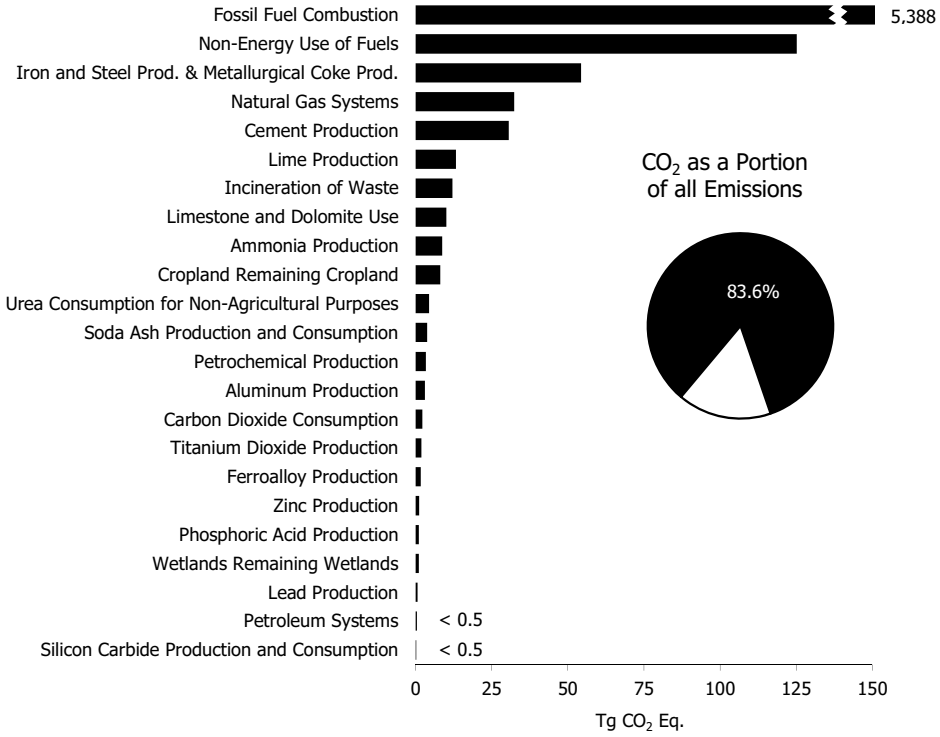


Figure ES-5: 2010 Sources of CO_2 Emissions

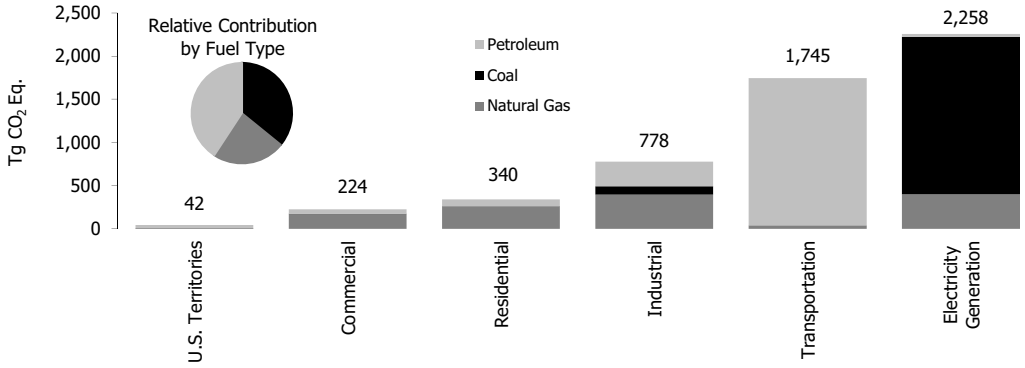


Figure ES-6: 2010 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type
Note: Electricity generation also includes emissions of less than 0.5 Tg CO_2 Eq. from geothermal-based electricity generation.

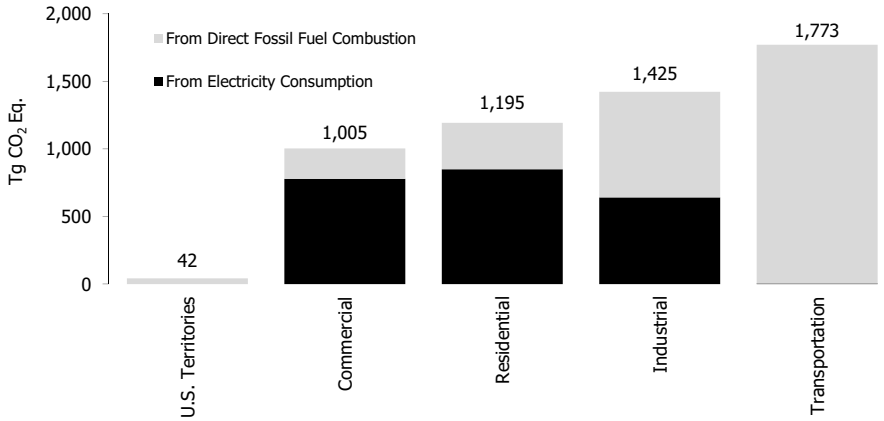


Figure ES-7: 2010 End-Use Sector Emissions of CO_2, CH_4, and N_2O from Fossil Fuel Combustion

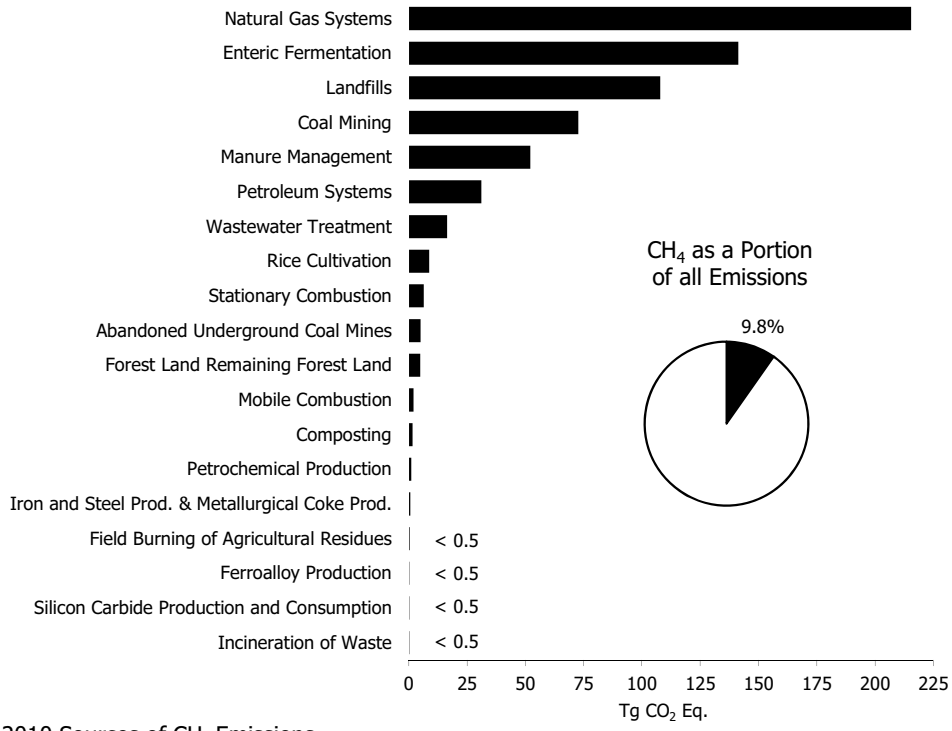


Figure ES-8: 2010 Sources of CH_4 Emissions

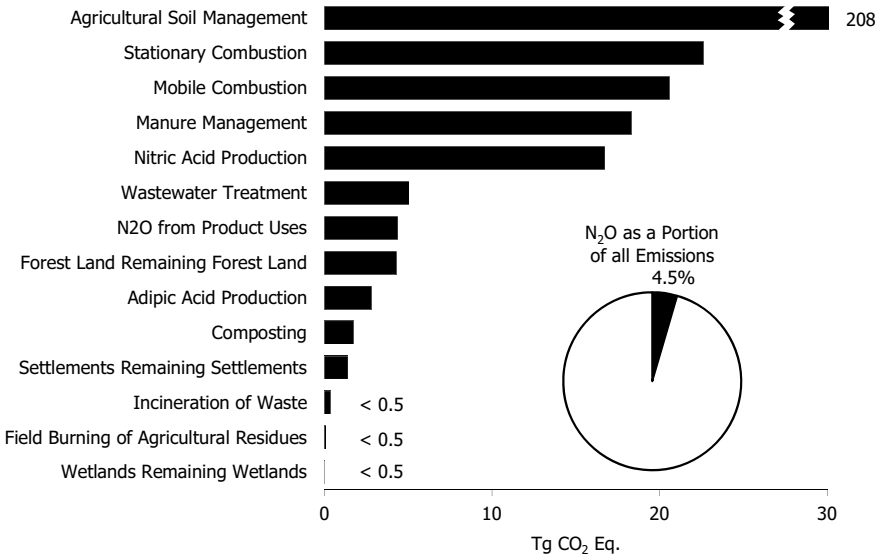


Figure ES-9: 2010 Sources of N_2O Emissions

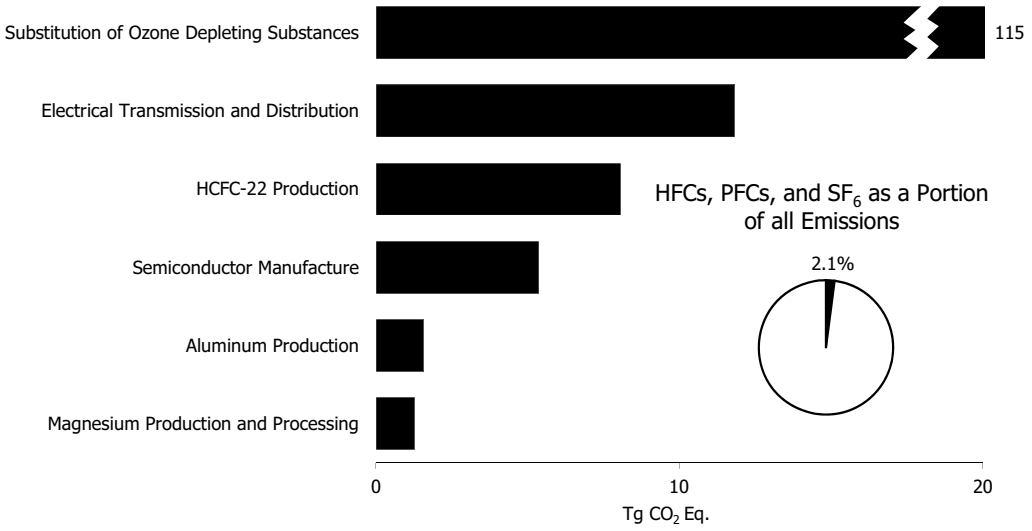
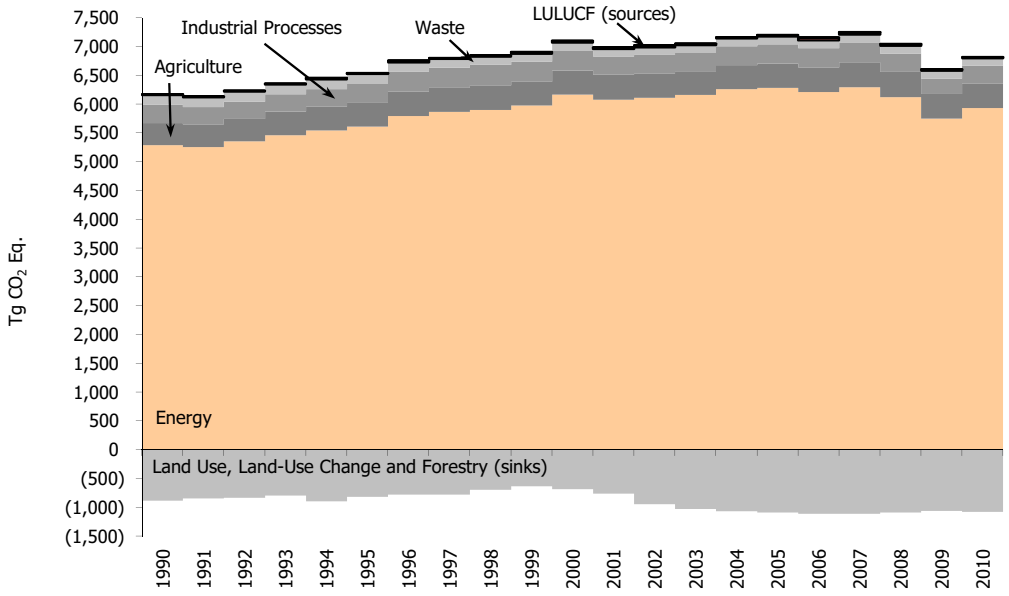


Figure ES-10: 2010 Sources of HFCs, PFCs, and SF_6 Emissions



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

Figure ES-11: U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector

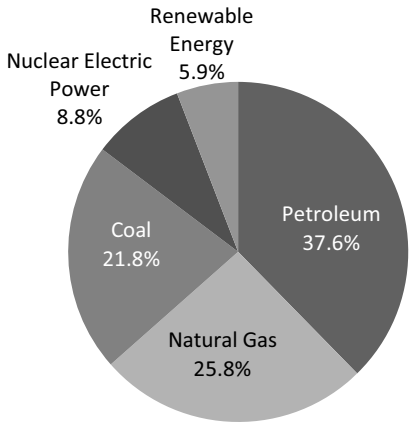


Figure ES-12: 2010 U.S. Energy Consumption by Energy Source

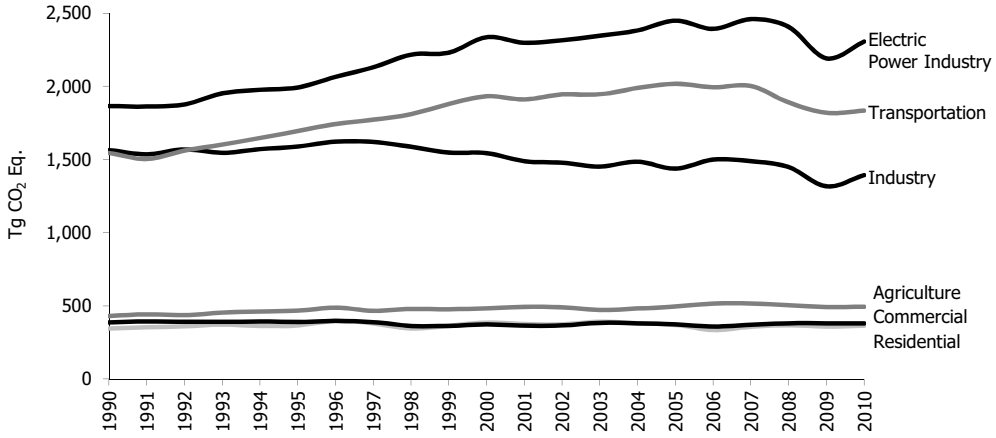


Figure ES-13: Emissions Allocated to Economic Sectors
Note: Does not include U.S. Territories.

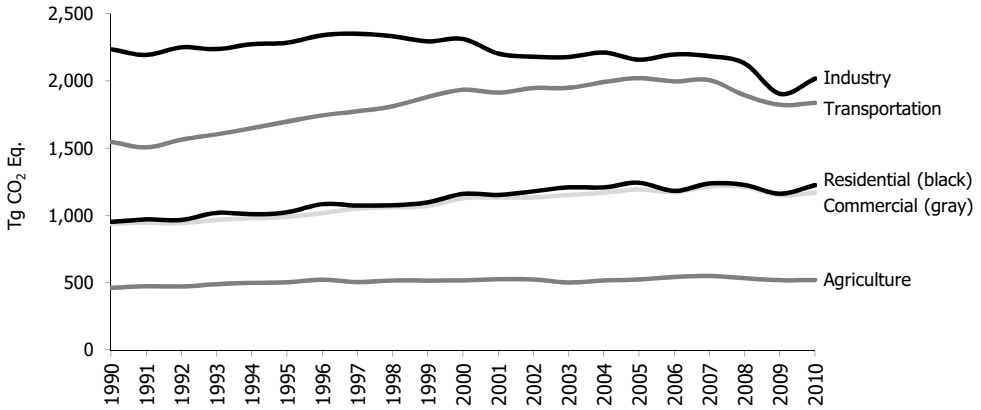


Figure ES-14: Emissions with Electricity Distributed to Economic Sectors
Note: Does not include U.S. Territories.

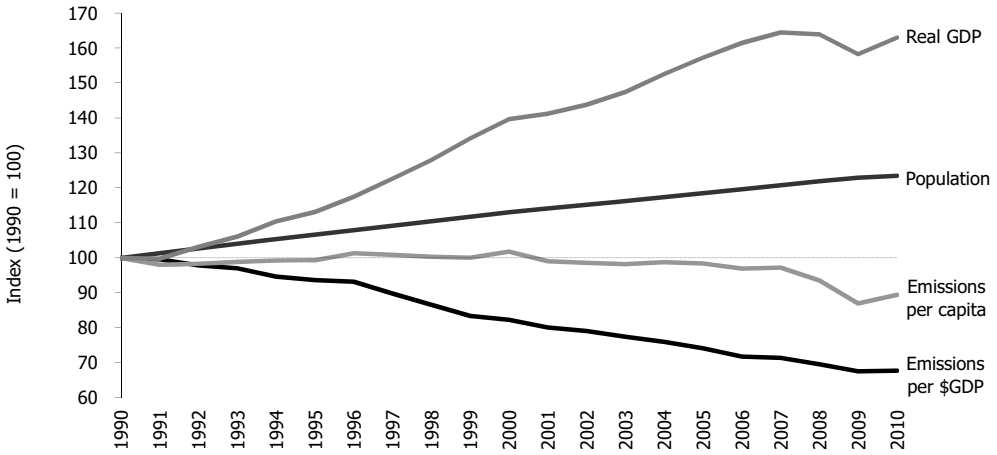


Figure ES-15: U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product

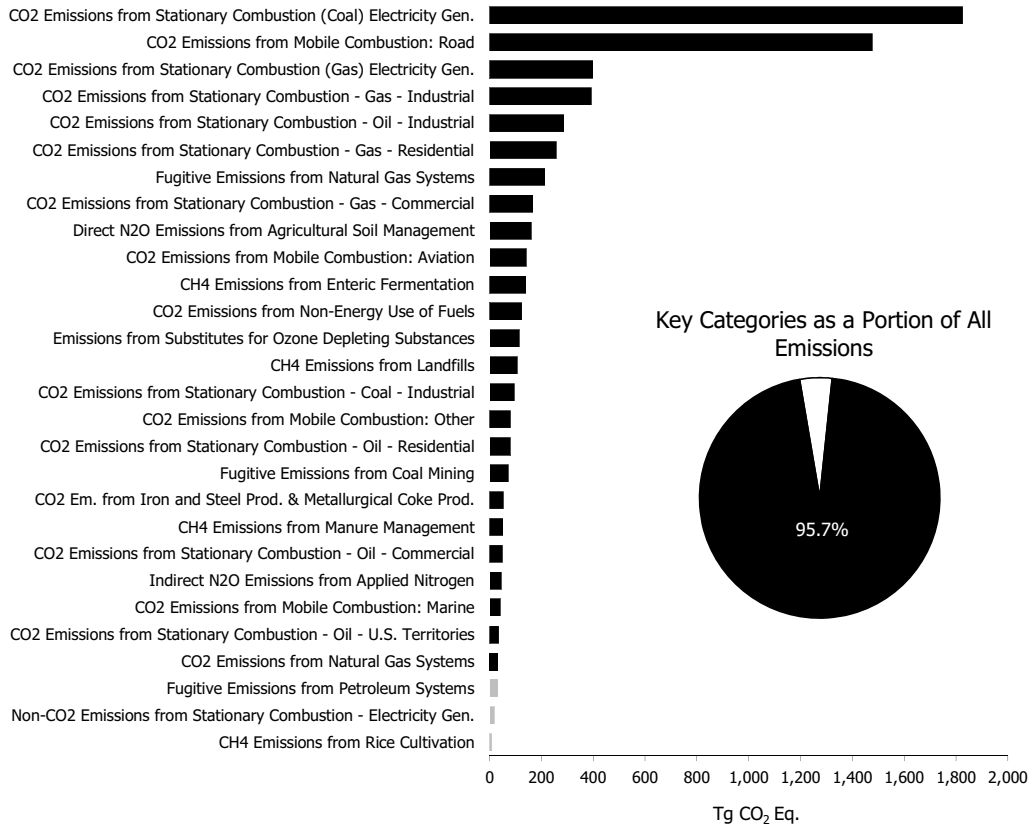


Figure ES-16: 2010 Key Categories

Notes: For a complete discussion of the key category analysis, see Annex 1.
Black bars indicate a Tier 1 level assessment key category.
Gray bars indicate a Tier 2 level assessment key category.

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 2010. 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.[21] 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."[22,23]

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…"[24] 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 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 includes 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 inventory provides a national estimate of sources and sinks for the United States, including all states and U.S. territories.[25] The structure of this report is consistent with the current

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

[22] 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).

[23] 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)

[24] 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>.

[25] U.S. Territories include American Samoa, Guam, Puerto Rico, U.S. Virgin Islands, Wake Island, and other U.S. Pacific Islands.

UNFCCC Guidelines on Annual Inventories (UNFCCC 2006).

[BEGIN BOX]

Box 1-1: Methodological approach for estimating and reporting U.S. emissions and sinks

In following the UNFCCC requirement under Article 4.1 to develop and submit national greenhouse gas emissions inventories, the emissions and sinks presented in this report are organized by source and sink categories and calculated using internationally-accepted methods provided by the IPCC.[26] Additionally, the calculated emissions and sinks in a given year for the U.S. are presented in a common manner in line with the UNFCCC reporting guidelines for the reporting of inventories under this international agreement.[27] The use of consistent methods to calculate emissions and sinks by all nations providing their inventories to the UNFCCC ensures that these reports are comparable. In this regard, U.S. emissions and sinks reported in this inventory report are comparable to emissions and sinks reported by other countries. Emissions and sinks provided in this inventory do not preclude alternative examinations, but rather this inventory report presents emissions and sinks in a common format consistent with how countries are to report inventories under the UNFCCC. The report itself follows this standardized format, and provides an explanation of the IPCC methods used to calculate emissions and sinks, and the manner in which those calculations are conducted.

On October 30, 2009, the U.S. Environmental Protection Agency (EPA) published a rule for the mandatory reporting of greenhouse gases (GHG) from large GHG emissions sources in the United States. Implementation of 40 CFR Part 98 is referred to as the Greenhouse Gas Reporting Program (GHGRP). 40 CFR part 98 applies to direct greenhouse gas emitters, fossil fuel suppliers, industrial gas suppliers, and facilities that inject CO_2 underground for sequestration or other reasons. Reporting is at the facility level, except for certain suppliers of fossil fuels and industrial greenhouse gases. For calendar year 2010, the first year in which data were reported, facilities in 29 categories provided in 40 CFR part 98 were required to report their 2010 emissions by the September 30, 2011 reporting deadline.[28] The GHGRP dataset and the data presented in this inventory report are complementary and, as indicated in the respective planned improvements sections in this report's chapters, EPA is analyzing how to use facility-level GHGRP data to improve the national estimates presented in this inventory.

[END BOX]

1.1. Background Information

Science

For over the past 200 years, the burning of fossil fuels such as coal and oil, deforestation, and other sources have caused the concentrations of heat-trapping "greenhouse gases" to increase significantly in our atmosphere. These gases absorb some of the energy being radiated from the surface of the earth and trap it in the atmosphere, essentially acting like a blanket that makes the earth's surface warmer than it would be otherwise.

Greenhouse gases are necessary to life as we know it, because without them the planet's surface would be about 60 ºF cooler than present. But, as the concentrations of these gases continue to increase in the atmosphere, the Earth's temperature is climbing above past levels. According to NOAA and NASA data, the Earth's average surface temperature has increased by about 1.2 to 1.4 ºF since 1900. The ten warmest years on record (since 1850) have all occurred in the past 13 years (EPA 2009). Most of the warming in recent decades is very likely the result of human activities. Other aspects of the climate are also changing such as rainfall patterns, snow and ice cover, and sea level.

[26] See <http://www.ipcc-nggip.iges.or.jp/public/index.html>.

[27] See <http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/5270.php>

[28] See <http://www.epa.gov/climatechange/emissions/ghgrulemaking.html> and <http://ghgdata.epa.gov/ghgp/main.do>.

If greenhouse gases continue to increase, climate models predict that the average temperature at the Earth's surface could increase from 2.0 to 11.5 ºF above 1990 levels by the end of this century (IPCC 2007). Scientists are certain that human activities are changing the composition of the atmosphere, and that increasing the concentration of greenhouse gases will change the planet's climate. But they are not sure by how much it will change, at what rate it will change, or what the exact effects will be.[29]

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 (CO_2), 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.[30] 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).

> *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, CO_2, methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as bromofluorocarbons (i.e., halons). As stratospheric ozone depleting substances, CFCs, HCFCs, and halons are covered under the Montreal Protocol on Substances that Deplete the Ozone Layer. The UNFCCC defers to this earlier international treaty. Consequently, Parties to the UNFCCC are not required to include these gases in national greenhouse gas inventories.[31] Some other fluorine-containing halogenated substances—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—do not deplete stratospheric ozone but are potent greenhouse gases. These latter substances are addressed by the UNFCCC and accounted for in national greenhouse gas 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 (NO_2), sulfur dioxide (SO_2), and tropospheric (ground level) ozone O_3. 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).

CO_2, CH_4, and N_2O 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,

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[29] For more information see <http://www.epa.gov/climatechange/science>

[30] For more on the science of climate change, see NRC (2001).

[31] Emissions estimates of CFCs, HCFCs, halons and other ozone-depleting substances are included in this document for informational purposes.

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.

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_2O	SF_6	CF_4
Pre-industrial atmospheric concentration	280 ppm	0.700 ppm	0.270 ppm	0 ppt	40 ppt
Atmospheric concentration	390 ppm	1.750-1.871 ppm[a]	0.322-0.323 ppm[a]	6.8-7.4 ppt	74 ppt
Rate of concentration change	1.4 ppm/yr	0.005 ppm/yr[b]	0.26%/yr	Linear[c]	Linear[c]
Atmospheric lifetime (years)	50-200[d]	12[e]	114[e]	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 CO_2 is from NOAA/ESRL (2009).

[a] 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).

[b] The growth rate for atmospheric CH_4 has been decreasing from 1.4 ppb/yr in 1984 to less than 0 ppb/yr in 2001, 2004, and 2005.

[c] IPCC (2007) identifies the rate of concentration change for SF_6 and CF_4 as linear.

[d] No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes.

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

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 (H_2O). 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 affects 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 (CO_2). 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 CO_2. Atmospheric CO_2 is part of this global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. CO_2 concentrations in the atmosphere increased from approximately 280 parts per million by volume (ppmv) in pre-industrial times to 390 ppmv in 2010, a 39.2 percent increase (IPCC 2007 and NOAA/ESRL 2009).[32,33] The IPCC definitively states that "the present atmospheric CO_2 increase is caused by anthropogenic emissions of CO_2" (IPCC 2001). The predominant source of anthropogenic CO_2 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 CO_2. In its Fourth Assessment Report, the IPCC stated "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 CO_2 is the most important (IPCC 2007).

Methane (CH_4). CH_4 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 CH_4, as does the decomposition of municipal solid wastes. CH_4 is also emitted during the production and distribution of natural gas and petroleum, and is released as a by-product of coal

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

[33] 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).

mining and incomplete fossil fuel combustion. Atmospheric concentrations of CH_4 have increased by about 158 percent since 1750, from a pre-industrial value of about 700 ppb to 1,750-1,871 ppb in 2010,[34] although the rate of increase has been declining. The IPCC has estimated that slightly more than half of the current CH_4 flux to the atmosphere is anthropogenic, from human activities such as agriculture, fossil fuel use, and waste disposal (IPCC 2007).

CH_4 is removed from the atmosphere through a reaction with the hydroxyl radical (OH) and is ultimately converted to CO_2. Minor removal processes also include reaction with chlorine in the marine boundary layer, a soil sink, and stratospheric reactions. Increasing emissions of CH_4 reduce the concentration of OH, a feedback that may increase the atmospheric lifetime of CH_4 (IPCC 2001).

Nitrous Oxide (N_2O). Anthropogenic sources of N_2O 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 N_2O has increased by 19 percent since 1750, from a pre-industrial value of about 270 ppb to 322-323 ppb in 2010,[35] a concentration that has not been exceeded during the last thousand years. N_2O 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,[36] where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,[37] 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 IPCC's fourth assessment, "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 CO_2 and CH_4. 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 chloroform, and carbon tetrachloride) and bromine (halons, methyl bromide, and hydrobromofluorocarbons [HFCs]) 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

[34] 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 2010).

[35] 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 2010).

[36] 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.

[37] 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.

importation of HCFCs by non-Article 5[38] countries 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 SF_6 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 SF_6 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 SF_6 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 CH_4 and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g., the hydroxyl radical, OH) that would otherwise assist in destroying CH_4 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 CO_2. Carbon monoxide concentrations are both short-lived in the atmosphere and spatially variable.

Nitrogen Oxides (NO_x). The primary climate change effects of nitrogen oxides (i.e., NO and NO_2) are indirect and result from their role in promoting the formation of ozone in the troposphere and, to a lesser degree, lower stratosphere, where they have positive radiative forcing effects.[39] Additionally, NO_x emissions from aircraft are also likely to decrease CH_4 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 N_2O. Concentrations of NO_x are both relatively short-lived in the atmosphere and spatially variable.

Nonmethane Volatile Organic Compounds (NMVOCs). Non-CH_4 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 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

[38] 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.

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

aerosols, sulfates, and volcanic aerosols, and anthropogenically manufactured aerosols such as industrial dust and carbonaceous[40] aerosols (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.[41] 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 CO_2, and therefore GWP-weighted emissions are measured in teragrams of CO_2 equivalent (Tg CO_2 Eq.)[42] The relationship between gigagrams (Gg) of a gas and Tg CO_2 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 CO_2 Eq. = Teragrams of CO_2 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 CO_2 equivalent terms at summary inventory level, using GWP values provided by the IPCC in its Second Assessment Report... based on the effects of greenhouse gases over a*

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

[41] 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).

[42] Carbon comprises 12/44^{ths} of carbon dioxide by weight.

100-year time horizon.[43]

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) 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., SO_2 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 gases that are short-lived and spatially inhomogeneous in the atmosphere.

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_2O	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_2F_6	10,000	9,200
C_4F_{10}	2,600	7,000
C_6F_{14}	3,200	7,400
SF_6	3,200	23,900

Source: (IPCC 1996)
[a] 100-year time horizon
[b] The GWP of CH_4 includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

[BEGIN BOX]

Box 1-2: 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 CO_2 radiative forcing and an improved CO_2 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.

[43] 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)

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_2O	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_2F_6	9,200	11,900	12,200	2,700	3,000
C_4F_10	7,000	8,600	8,860	1,600	1,860
C6F14	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 CH_4 includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

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 inventories[44] 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 2010 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.

[END BOX]

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

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

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 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.

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Box 1-3: IPCC Reference Approach

The UNFCCC reporting guidelines require countries to complete a "top-down" reference approach for estimating CO_2 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.

[END BOX]

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."[45] 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

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

calculations, was also performed twice to include or exclude LULUCF categories.

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 2010. 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.

Table 1-4: Key Categories for the United States (1990-2010)

		Tier 1				Tier 2					
IPCC Source Categories	**Gas**	**Level Without LULUCF**	**Trend Without LULUCF**	**Level With LULUCF**	**Trend With LULUCF**	**Level Without LULUCF**	**Trend Without LULUCF**	**Level With LULUCF**	**Trend With LULUCF**	**Qual [a]**	**2010 Emissions (Tg CO_2 Eq.)**
Energy											
CO_2 Emissions from Stationary Combustion - Coal - Electricity	CO_2	•	•	•	•	•	•	•	•		1,827.3
CO_2 Emissions from Mobile Combustion: Road	CO_2	•	•	•	•	•	•	•	•		1,478.9
CO_2 Emissions from Stationary Combustion - Gas - Electricity Generation	CO_2	•	•	•	•	•	•	•	•		399.4
CO_2 Emissions from Stationary Combustion - Gas - Industrial	CO_2	•	•	•	•	•	•	•	•		394.2
CO_2 Emissions from Stationary Combustion - Oil - Industrial	CO_2	•	•	•	•	•	•	•	•		287.4
CO_2 Emissions from Stationary Combustion - Gas - Residential	CO_2	•		•	•	•		•			258.8
CO_2 Emissions from Stationary Combustion - Gas - Commercial	CO_2	•	•	•	•	•		•			167.7
CO_2 Emissions from Mobile Combustion: Aviation	CO_2	•	•	•	•	•	•	•	•		142.4
CO_2 Emissions from Non-Energy Use of Fuels	CO_2	•	•	•	•	•	•	•			125.1
CO_2 Emissions from Stationary Combustion - Coal - Industrial	CO_2	•	•	•	•	•	•	•	•		96.2
CO_2 Emissions from Mobile Combustion: Other	CO_2	•		•							81.5
CO_2 Emissions from Stationary Combustion - Oil - Residential	CO_2	•	•	•	•						80.7
CO_2 Emissions from Stationary Combustion - Oil - Commercial	CO_2	•	•	•	•						51.1

IPCC Source Categories	Gas	Tier 1				Tier 2				Qual [a]	2010 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 Mobile Combustion: Marine	CO_2	•	•	•	•						42.6
CO_2 Emissions from Stationary Combustion - Oil - U.S. Territories	CO_2	•	•	•	•						36.7
CO_2 Emissions from Natural Gas Systems	CO_2	•	•	•	•	•	•	•	•		32.3
CO_2 Emissions from Stationary Combustion - Oil - Electricity Generation	CO_2	•	•	•	•		•		•		31.3
CO_2 Emissions from Stationary Combustion - Coal - Commercial	CO_2		•		•						5.5
Fugitive Emissions from Natural Gas Systems	CH_4	•	•	•		•	•	•			215.4
Fugitive Emissions from Coal Mining	CH_4	•	•	•	•	•	•	•	•		72.6
Fugitive Emissions from Petroleum Systems	CH_4	•	•	•	•	•	•	•	•		31.0
Non-CO_2 Emissions from Stationary Combustion - Residential	CH_4					•	•	•	•		3.5
Non-CO_2 Emissions from Stationary Combustion - Electricity Generation	N_2O		•		•	•	•	•	•		18.5
Non-CO_2 Emissions from Stationary Combustion - Industrial	N_2O						•				2.8
International Bunker Fuels[b]	Several									•	129.2
Industrial Processes											
CO_2 Emissions from Iron and Steel Production & Metallurgical Coke Production	CO_2	•	•	•	•	•	•	•	•		54.3
CO_2 Emissions from Cement Production	CO_2	•	•	•	•						30.5
CO_2 Emissions from Aluminum Production	CO_2						•		•		3.0
N_2O Emissions from Adipic Acid Production	N_2O		•		•						2.8
Emissions from Substitutes for Ozone Depleting Substances	HiGWP	•	•	•	•	•	•	•	•		114.6
SF_6 Emissions from Electrical Transmission and Distribution	HiGWP		•		•		•		•		11.8

IPCC Source Categories	Gas	Tier 1				Tier 2				Qual [a]	2010 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		
HFC-23 Emissions from HCFC-22 Production	HiGWP	•	•	•	•		•		•		8.1
PFC Emissions from Aluminum Production	HiGWP		•		•	•	•	•	•		1.6
Agriculture											
CH_4 Emissions from Enteric Fermentation	CH_4	•	•	•	•	•		•			141.3
CH_4 Emissions from Manure Management	CH_4	•	•	•	•	•	•	•	•		52.0
CH_4 Emissions from Rice Cultivation	CH_4					•		•			8.6
Direct N_2O Emissions from Agricultural Soil Management	N_2O	•	•	•	•	•	•	•	•		162.3
Indirect N_2O Emissions from Applied Nitrogen	N_2O	•		•		•	•	•	•		45.5
Waste											
CH_4 Emissions from Landfills	CH_4	•	•	•	•	•	•	•	•		107.8
Land Use, Land Use Change, and Forestry											
CO_2 Emissions from Changes in Forest Carbon Stocks	CO_2			•	•			•	•		(921.8)
CO_2 Emissions from Urban Trees	CO_2			•	•			•	•		(98.0)
CO_2 Emissions from Cropland Remaining Cropland	CO_2			•	•			•	•		(15.6)
CO_2 Emissions from Landfilled Yard Trimmings and Food Scraps	CO_2				•			•	•		(13.3)
CO_2 Emissions from Grassland Remaining Grassland	CO_2			•	•			•	•		(8.3)
CH_4 Emissions from Forest Fires	CH_4								•		4.8
N_2O Emissions from Forest Fires	N_2O								•		4.0
Key Categories Subtotal Without LULUCF											**6,644.0**
Total Emissions Without LULUCF											**6,802.2**
Percent of Total Without LULUCF											**97.7%**
Key Categories Subtotal With LULUCF											**5,595.7**
Total Emissions With LULUCF											**5,747.1**
Percent of Total With LULUCF											**97.4%**

[a]Qualitative criteria.
[b]Emissions 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 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 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.

Figure 1-1: U.S. QA/QC Plan Summary

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 CO_2 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 CH_4 and N_2O 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 SF_6 from electrical transmission and distribution is limited due to a lack of activity data regarding national SF_6 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.

Table 1-5: Estimated Overall Inventory Quantitative Uncertainty (Tg CO_2 Eq. and Percent)

Gas	2010 Emission Estimate[a] (Tg CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[b] (Tg CO_2 Eq.)		Uncertainty Range Relative to Emission Estimate[b] (%)		Mean[c] (Tg CO_2 Eq.)	Standard Deviation[c] (Tg CO_2 Eq.)
		Lower Bound[d]	Upper Bound[d]	Lower Bound	Upper Bound		
CO_2	5,706.0	5,570	5,958	-2%	4%	5,763	101
CH_4[e]	666.5	578	751	-13%	13%	658	43
N_2O[e]	306.2	265	431	-14%	41%	339	43
PFC, HFC & SF_6[e]	140.3	138	156	-1%	11%	147	4
Total	**6,819.1**	**6,682**	**7,137**	**-2%**	**5%**	**6,906**	**117**
Net Emissions (Sources and Sinks)	**5,744.4**	**5,575**	**6,094**	**-3%**	**6%**	**5,830**	**133**

Notes:

[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 2.8 Tg CO_2 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 upper bound 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 CH_4, N_2O and high GWP gases used in the inventory emission calculations for 2010.

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.

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 2010. 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 not included, 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 2006 UNFCCC Guidelines on Reporting and Review (UNFCCC 2006), 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.

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_2O from product uses.
Agriculture	Anthropogenic emissions from agricultural activities except fuel combustion, which is addressed under Energy.
Land Use, Land-Use	Emissions and removals of CO_2, CH_4, and N_2O

Change, and Forestry	from forest management, other land-use activities, and land-use change.
Waste	Emissions from waste management activities.

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

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 and 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.

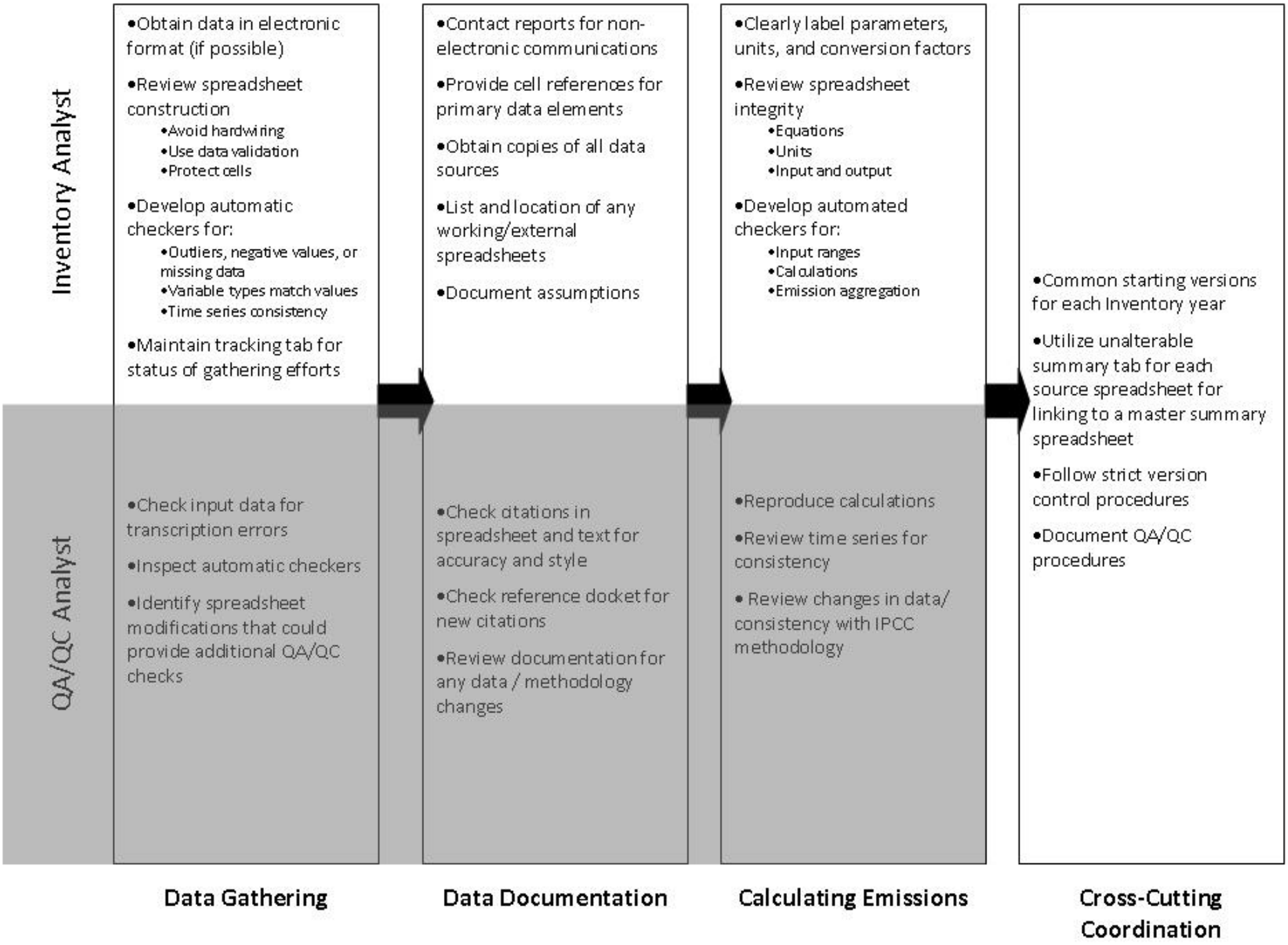
Planned Improvements: A discussion on any source-specific planned improvements, if applicable.

Special attention is given to CO_2 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 1-7: List of Annexes

ANNEX 1 Key Category Analysis
ANNEX 2 Methodology and Data for Estimating CO_2 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_2O, and Indirect Greenhouse Gases from Stationary Combustion
3.2. Methodology for Estimating Emissions of CH_4, N_2O, 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_2O 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_2O Emissions from Manure Management
3.11. Methodology for Estimating N2O 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 Cropland and Grassland
3.14. Methodology for Estimating CH_4 Emissions from Landfills
ANNEX 4 IPCC Reference Approach for Estimating CO_2 Emissions from Fossil Fuel Combustion
ANNEX 5 Assessment of the Sources and Sinks of Greenhouse Gas Emissions Not Included
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

Figure 1-1: U.S. QA/QC Plan Summary



2. Trends in Greenhouse Gas Emissions

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

In 2010, total U.S. greenhouse gas emissions were 6,821.8 Tg or million metric tons CO_2 Eq. Total U.S. emissions have increased by 10.5 percent from 1990 to 2010, and emissions increased from 2009 to 2010 by 3.2 percent (213.5 Tg CO_2 Eq.). The increase from 2009 to 2010 was primarily due to an increase in economic output resulting in an increase in energy consumption across all sectors, and, much warmer summer conditions resulting in an increase in electricity demand for air conditioning that was generated primarily by combusting coal and natural gas. Since 1990, U.S. emissions have increased at an average annual rate of 0.5 percent.

Figure 2-1: U.S. Greenhouse Gas Emissions by Gas

Figure 2-2: Annual Percent Change in U.S. Greenhouse Gas Emissions

Figure 2-3: Cumulative Change in Annual U.S. Greenhouse Gas Emissions Relative to 1990

As the largest contributor to U.S. greenhouse gas emissions, carbon dioxide (CO_2) from fossil fuel combustion has accounted for approximately 78 percent of global warming potential (GWP) weighted emissions since 1990, from 77 percent of total GWP-weighted emissions in 1990 to 79 percent in 2010. Emissions from this source category grew by 13.7 percent (649.5 Tg CO_2 Eq.) from 1990 to 2010 and were responsible for most of the increase in national emissions during this period. From 2009 to 2010, these emissions increased by 3.5 percent (181.6 Tg CO_2 Eq.). Historically, changes in emissions from fossil fuel combustion have been the dominant factor affecting U.S. emission trends.

Changes in CO_2 emissions from fossil fuel combustion are influenced by many long-term and short-term factors, including population and economic growth, energy price fluctuations, technological changes, and seasonal temperatures. On an annual basis, the overall consumption of fossil fuels in the United States fluctuates primarily 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 behavioral choices (e.g., walking, bicycling, or telecommuting to work instead of driving).

Energy-related CO_2 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 CO_2 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 2006.

From 2006 to 2007, emissions from fuel combustion grew at a rate slightly higher than the average growth rate since 1990. There were a number of factors contributing to this increase. More energy-intensive 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 14.4 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 more energy-intensive weather conditions, electricity prices remained relatively stable compared to 2006, and natural gas prices decreased slightly. Emissions from the industrial sector decreased compared to 2006 as a result of a decrease in industrial production and 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 1.4 percent, 2.5 percent, and 28.8 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 5.5 percent decrease 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 energy[46] consumption for electricity generation increased by 16.6 percent from 2007 to 2008, driven by a significant increase in solar and wind energy consumption (of 17.0 percent and 60.2 percent, respectively). This increase in renewable energy generation contributed to a decrease in the carbon intensity of electricity generation.

From 2008 to 2009, CO_2 from fossil fuel combustion emissions experienced a decrease of 6.6 percent, the greatest decrease of any year over the course of the twenty one-year period. Various factors contributed to this decrease in emissions. The continued economic downturn resulted in a 3.5 percent decrease in GDP, and a decrease in energy consumption across all sectors. The economic downturn also impacted total industrial production and manufacturing output, which decreased by 11.2 and 13.5 percent, respectively. In 2009, the price of coal used to generate electricity increased, while the price of natural gas used to generate electricity decreased significantly. As a result, natural gas was used for a greater share of electricity generation in 2009 than 2008, and coal was used for a smaller share. The fuel switching from coal to natural gas and additional electricity generation from other energy sources in 2009, which included a 7.3 percent increase in hydropower generation from the previous year, resulted in a decrease in carbon intensity, and in turn, a decrease in emissions from electricity generation. From 2008 to 2009, industrial sector emissions decreased significantly as a result of a decrease in output from energy-intensive industries of 23.6 percent in nonmetallic mineral and 30.3 percent in primary metal industries. The residential and commercial sectors only experienced minor decreases in emissions as summer and winter weather conditions were less energy-intensive from 2008 to 2009, and the price of electricity only increased slightly. Heating degree days decreased slightly and cooling degree days decreased by 3.8 percent from 2008 to 2009.

From 2009 to 2010, CO_2 emissions from fossil fuel combustion increased by 3.5 percent, which represents the largest annual increase in CO_2 emissions from fossil fuel combustion for the twenty one-year period.[47] This increase is primarily due to an increase in economic output 2009 to 2010, where total industrial production and manufacturing output increased by 5.3 and 5.8 percent, respectively (FRB 2011). Carbon dioxide emissions from fossil fuel combustion in the industrial sector increased by 7.0 percent, including increased emissions from the combustion of fuel oil, natural gas and coal. Overall, coal consumption increased by 5.4 percent, the largest increase in coal consumption for the twenty one-year period. In 2010, weather conditions remained fairly constant in the winter and were much hotter in the summer compared to 2009, as heating degree days decreased slightly (0.7 percent) and cooling degree days increased by 19 percent to their highest levels in the twenty one-year period. As a result of the more energy-intensive summer weather conditions, electricity sales to the residential and commercial end-use sectors in 2010 increased approximately 6.3 percent and 1.7 percent, respectively.

[46] Renewable energy, as defined in EIA's energy statistics, includes the following energy sources: hydroelectric power, geothermal energy, biofuels, solar energy, and wind energy.

[47] This increase also represents the largest absolute and percentage increase since 1988 (EIA 2011a).

Overall, from 1990 to 2010, total emissions of CO_2 increased by 605.9 Tg CO_2 Eq. (11.9 percent), while total emissions of CH_4 and N_2O decreased by 1.7 Tg CO_2 Eq. (0.3 percent), and 10.0 Tg CO_2 Eq. (3.2 percent), respectively. During the same period, aggregate weighted emissions of HFCs, PFCs, and SF_6 rose by 52.5 Tg CO_2 Eq. (58.2 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, and SF_6 are significant because many of them have extremely high GWPs and, in the cases of PFCs and SF_6, 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. These were estimated to offset 15.8 percent of total emissions in 2010.

Table 2-1 summarizes emissions and sinks from all U.S. anthropogenic sources in weighted units of Tg CO_2 Eq., while unweighted gas emissions and sinks in gigagrams (Gg) are provided in Table 2-2.

Table 2-1: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Tg CO_2 Eq.)

Gas/Source	1990	2005	2006	2007	2008	2009	2010
CO_2	**5,100.5**	**6,107.6**	**6,019.0**	**6,118.6**	**5,924.3**	**5,500.5**	**5,706.4**
Fossil Fuel Combustion	4,738.3	5,746.5	5,653.0	5,757.8	5,571.5	5,206.2	5,387.8
Electricity Generation	1,820.8	2,402.1	2,346.4	2,412.8	2,360.9	2,146.4	2,258.4
Transportation	1,485.9	1,896.6	1,878.1	1,893.9	1,789.8	1,727.9	1,745.5
Industrial	846.4	816.4	848.1	844.4	806.5	726.6	777.8
Residential	338.3	357.9	321.5	341.6	349.3	339.0	340.2
Commercial	219.0	223.5	208.6	218.9	225.1	224.6	224.2
U.S. Territories	27.9	50.0	50.3	46.1	39.8	41.7	41.6
Non-Energy Use of Fuels	119.6	144.1	143.8	134.9	138.6	123.7	125.1
Iron and Steel Production & Metallurgical Coke Production	99.6	66.0	68.9	71.1	66.1	42.1	54.3
Natural Gas Systems	37.6	29.9	30.8	31.0	32.8	32.2	32.3
Cement Production	33.3	45.2	45.8	44.5	40.5	29.0	30.5
Lime Production	11.5	14.4	15.1	14.6	14.3	11.2	13.2
Incineration of Waste	8.0	12.5	12.5	12.7	11.9	11.7	12.1
Limestone and Dolomite Use	5.1	6.8	8.0	7.7	6.3	7.6	10.0
Ammonia Production	13.0	9.2	8.8	9.1	7.9	7.9	8.7
Cropland Remaining Cropland	7.1	7.9	7.9	8.2	8.6	7.2	8.0
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	3.5	4.9	4.1	3.4	4.4
Soda Ash Production and Consumption	4.1	4.2	4.2	4.1	4.1	3.6	3.7
Petrochemical Production	3.3	4.2	3.8	3.9	3.4	2.7	3.3
Aluminum Production	6.8	4.1	3.8	4.3	4.5	3.0	3.0
Carbon Dioxide Consumption	1.4	1.3	1.7	1.9	1.8	1.8	2.2
Titanium Dioxide Production	1.2	1.8	1.8	1.9	1.8	1.6	1.9
Ferroalloy Production	2.2	1.4	1.5	1.6	1.6	1.5	1.7
Zinc Production	0.6	1.0	1.0	1.0	1.2	0.9	1.2
Phosphoric Acid Production	1.5	1.4	1.2	1.2	1.2	1.0	1.0
Wetlands Remaining Wetlands	1.0	1.1	0.9	1.0	1.0	1.1	1.0
Lead Production	0.5	0.6	0.6	0.6	0.5	0.5	0.5
Petroleum Systems	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Silicon Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.1	0.2
Land Use, Land-Use Change, and Forestry (Sink)[a]	*(881.8)*	*(1,085.9)*	*(1,110.4)*	*(1,108.2)*	*(1,087.5)*	*(1,062.6)*	*(1,074.7)*
Wood Biomass and Ethanol Consumption[b]	*218.6*	*228.6*	*233.7*	*241.1*	*252.1*	*244.1*	*266.1*
International Bunker Fuels[c]	*111.8*	*109.8*	*128.4*	*127.6*	*133.7*	*122.3*	*127.8*
CH_4	**668.3**	**625.8**	**664.6**	**656.2**	**667.9**	**672.2**	**666.5**
Natural Gas Systems	189.6	190.5	217.7	205.3	212.7	220.9	215.4
Enteric Fermentation	133.8	139.0	141.4	143.8	143.4	142.6	141.3
Landfills	147.7	112.7	111.7	111.7	113.1	111.2	107.8
Coal Mining	84.1	56.8	58.1	57.8	66.9	70.1	72.6

Manure Management	31.7	47.9	48.4	52.7	51.8	50.7	52.0
Petroleum Systems	35.2	29.2	29.2	29.8	30.0	30.7	31.0
Wastewater Treatment	15.9	16.5	16.7	16.6	16.6	16.5	16.3
Rice Cultivation	7.1	6.8	5.9	6.2	7.2	7.3	8.6
Stationary Combustion	7.5	6.6	6.2	6.5	6.6	6.3	6.3
Abandoned Underground Coal Mines	6.0	5.5	5.5	5.3	5.3	5.1	5.0
Forest Land Remaining Forest Land	2.5	8.1	17.9	14.6	8.8	5.8	4.8
Mobile Combustion	4.7	2.5	2.4	2.2	2.1	2.0	1.9
Composting	0.3	1.6	1.6	1.7	1.7	1.6	1.6
Petrochemical Production	0.9	1.1	1.0	1.0	0.9	0.8	0.9
Iron and Steel Production & Metallurgical Coke Production	1.0	0.7	0.7	0.7	0.6	0.4	0.5
Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Ferroalloy Production	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[c]	*0.2*	*0.1*	*0.2*	*0.2*	*0.2*	*0.1*	*0.2*
N_2O	**316.2**	**331.9**	**336.8**	**334.9**	**317.1**	**304.0**	**306.2**
Agricultural Soil Management	200.0	213.1	211.1	211.1	212.9	207.3	207.8
Stationary Combustion	12.3	20.6	20.8	21.2	21.1	20.7	22.6
Mobile Combustion	43.9	37.0	33.7	29.0	25.2	22.5	20.6
Manure Management	14.8	17.6	18.4	18.5	18.3	18.2	18.3
Nitric Acid Production	17.6	16.4	16.1	19.2	16.4	14.5	16.7
Wastewater Treatment	3.5	4.7	4.8	4.8	4.9	5.0	5.0
N_2O from Product Uses	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Forest Land Remaining Forest Land	2.1	7.0	15.0	12.2	7.5	5.1	4.3
Adipic Acid Production	15.8	7.4	8.9	10.7	2.6	2.8	2.8
Composting	0.4	1.7	1.8	1.8	1.9	1.8	1.7
Settlements Remaining Settlements	1.0	1.5	1.5	1.6	1.5	1.4	1.4
Incineration of Waste	0.5	0.4	0.4	0.4	0.4	0.4	0.4
Field Burning of Agricultural Residues	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wetlands Remaining Wetlands	+	+	+	+	+	+	+
International Bunker Fuels[c]	*1.1*	*1.0*	*1.2*	*1.2*	*1.2*	*1.1*	*1.2*
HFCs	**36.9**	**115.0**	**116.0**	**120.0**	**117.5**	**112.1**	**123.0**
Substitution of Ozone Depleting Substances	0.3	99.0	101.9	102.7	103.6	106.3	114.6
HCFC-22 Production	36.4	15.8	13.8	17.0	13.6	5.4	8.1
Semiconductor Manufacture	0.2	0.2	0.3	0.3	0.3	0.3	0.3
PFCs	**20.6**	**6.2**	**6.0**	**7.5**	**6.6**	**5.6**	**5.6**
Semiconductor Manufacture	2.2	3.2	3.5	3.7	4.0	4.0	4.1
Aluminum Production	18.4	3.0	2.5	3.8	2.7	1.6	1.6
SF_6	**32.6**	**17.8**	**16.8**	**15.6**	**15.0**	**13.9**	**14.0**
Electrical Transmission and Distribution	26.7	13.9	13.0	12.2	12.2	11.8	11.8
Magnesium Production and Processing	5.4	2.9	2.9	2.6	1.9	1.1	1.3
Semiconductor Manufacture	0.5	1.0	1.0	0.8	0.9	1.0	0.9
Total	**6,175.2**	**7,204.2**	**7,159.3**	**7,252.8**	**7,048.3**	**6,608.3**	**6,821.8**
Net Emissions (Sources and Sinks)	**5,293.4**	**6,118.3**	**6,048.9**	**6,144.5**	**5,960.9**	**5,545.7**	**5,747.1**

+ Does not exceed 0.05 Tg CO_2 Eq.

[a] The net CO_2 flux total includes both emissions and sequestration, and constitutes a sink in the United States. Sinks

are only included in net emissions total. Parentheses indicate negative values or sequestration.

[b] Emissions from Wood Biomass and Ethanol Consumption are not included specifically in summing energy sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for Land Use, Land-Use Change, and Forestry.

[c] Emissions from International Bunker Fuels are not included in totals.

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

Note: Totals may not sum due to independent rounding.

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

Gas/Source	1990	2005	2006	2007	2008	2009	2010
CO_2	**5,100,499**	**6,107,587**	**6,019,033**	**6,118,566**	**5,924,259**	**5,500,517**	**5,706,370**
Fossil Fuel Combustion	4,742,080	5,757,404	5,666,588	5,771,185	5,579,548	5,214,694	5,406,848
Electricity Generation	1,820,818	2,402,143	2,346,407	2,412,827	2,360,920	2,146,415	2,258,358
Transportation	1,485,939	1,896,604	1,878,114	1,893,889	1,789,846	1,727,909	1,745,466
Industrial	846,389	816,352	848,134	844,412	806,539	726,622	777,840
Residential	338,347	357,903	321,514	341,649	349,318	338,985	340,235
Commercial	218,963	223,511	208,580	218,875	225,069	224,586	224,243
U.S. Territories	27,882	49,968	50,284	46,123	39,845	41,650	41,649
Non-Energy Use of Fuels	119,627	144,098	143,761	134,863	138,624	123,712	125,130
Iron and Steel Production & Metallurgical Coke Production	99,593	66,000	68,854	71,138	66,092	42,113	54,276
Natural Gas Systems	37,574	30,140	30,118	31,047	32,811	32,165	32,297
Cement Production	33,278	45,197	45,792	44,538	40,531	29,018	30,509
Lime Production	11,533	14,379	15,100	14,595	14,330	11,225	13,151
Incineration of Waste	7,989	12,468	12,531	12,727	11,888	11,703	12,054
Limestone and Dolomite Use	5,127	6,768	8,035	7,702	6,276	7,649	10,017
Ammonia Production	13,047	9,196	8,781	9,074	7,883	7,855	8,678
Cropland Remaining Cropland	7,084	7,854	7,875	8,222	8,638	7,245	8,050
Urea Consumption for Non-Agricultural Purposes	3,784	3,653	3,519	4,944	4,065	3,415	4,365
Soda Ash Production and Consumption	4,141	4,228	4,162	4,140	4,099	3,554	3,735
Petrochemical Production	3,311	4,181	3,837	3,931	3,449	2,735	3,336
Aluminum Production	6,831	4,142	3,801	4,251	4,477	3,009	3,009
Carbon Dioxide Consumption	1,416	1,321	1,709	1,867	1,780	1,784	2,203
Titanium Dioxide Production	1,195	1,755	1,836	1,930	1,809	1,648	1,876
Ferroalloy Production	2,152	1,392	1,505	1,552	1,599	1,469	1,663
Zinc Production	632	1,030	1,030	1,025	1,159	943	1,168
Phosphoric Acid Production	1,529	1,386	1,167	1,166	1,187	1,018	1,017
Wetlands Remaining Wetlands	1,033	1,079	879	1,012	992	1,089	983
Lead Production	516	553	560	562	547	525	542
Petroleum Systems	394	305	306	310	297	325	337
Silicon Carbide Production and Consumption	375	219	207	196	175	145	181
Land Use, Land-Use Change, and Forestry	*(881,848)*	*(1,085,929)*	*(1,110,385)*	*(1,108,249)*	*(1,087,454)*	*(1,062,559)*	*(1,074,684)*
Wood Biomass and Ethanol Consumption[b]	*218,637*	*228,614*	*233,665*	*241,128*	*252,097*	*244,078*	*266,110*
International Bunker Fuels[c]	*111,828*	*109,765*	*128,413*	*127,643*	*133,730*	*122,338*	*127,841*
CH_4	**31,822**	**29,798**	**31,649**	**31,247**	**31,804**	**32,010**	**31,740**
Natural Gas Systems	9,029	9,071	10,369	9,774	10,127	10,519	10,259
Enteric Fermentation	6,373	6,618	6,731	6,850	6,829	6,788	6,728

Landfills	7,032	5,367	5,320	5,320	5,386	5,295	5,135
Coal Mining	4,003	2,705	2,768	2,754	3,186	3,340	3,458
Manure Management	1,511	2,280	2,303	2,508	2,465	2,416	2,478
Petroleum Systems	1,677	1,390	1,389	1,420	1,427	1,460	1,478
Wastewater Treatment	758	785	794	791	792	787	779
Rice Cultivation	339	326	282	295	343	349	410
Stationary Combustion	355	315	296	311	313	298	301
Abandoned Underground Coal Mines	288	264	261	254	253	244	237
Forest Land Remaining Forest Land	120	388	854	693	419	276	231
Mobile Combustion	223	121	114	107	99	93	91
Composting	15	75	75	79	80	75	75
Petrochemical Production	41	51	48	48	43	39	44
Iron and Steel Production & Metallurgical Coke	46	34	35	33	31	17	25
Field Burning of Agricultural Residues	10	8	11	11	11	11	11
Ferroalloy Production	1	+	+	+	+	+	+
Silicon Carbide Production and Consumption	1	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[c]	*8*	*7*	*8*	*8*	*8*	*7*	*8*
N_2O	**1,020**	**1,071**	**1,087**	**1,080**	**1,023**	**981**	**988**
Agricultural Soil Management	645	687	681	681	687	669	670
Stationary Combustion	40	66	67	68	68	67	73
Mobile Combustion	142	119	109	94	81	73	66
Manure Management	48	57	59	60	59	59	59
Nitric Acid Production	57	53	52	62	53	47	54
Wastewater Treatment	11	15	15	16	16	16	16
N_2O from Product Uses	14	14	14	14	14	14	14
Forest Land Remaining Forest Land	7	23	48	39	24	16	14
Adipic Acid Production	51	24	29	34	8	9	9
Composting	1	6	6	6	6	6	6
Settlements Remaining Settlements	3	5	5	5	5	4	5
Incineration of Waste	2	1	1	1	1	1	1
Field Burning of Agricultural Residues	+	+	+	+	+	+	+
Wetlands Remaining Wetlands	+	+	+	+	+	+	+
International Bunker Fuels[c]	*3*	*3*	*4*	*4*	*4*	*4*	*4*
HFCs	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Substitution of Ozone Depleting Substances	M	M	M	M	M	M	M
HCFC-22 Production	3	1	1	1	1	+	1
Semiconductor Manufacture	+	+	+	+	+	+	+
PFCs	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Semiconductor Manufacture	M	M	M	M	M	M	M
Aluminum Production	M	M	M	M	M	M	M
SF_6	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Electrical Transmission and Distribution	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 CO_2 flux total includes both emissions and sequestration, and constitutes a sink in the United States. Sinks are only included in net emissions total. Parentheses indicate negative values or sequestration.

[b] Emissions from Wood Biomass and Ethanol Consumption are not included specifically in summing energy sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for Land Use, Land-Use Change, and Forestry

[c] Emissions from International Bunker Fuels are not included in totals.

[d] 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 into a set of six sectors defined by the Intergovernmental Panel on Climate Change (IPCC). Over the twenty-one-year period of 1990 to 2010, total emissions in the Energy and Agriculture sectors grew by 645.8 Tg CO_2 Eq. (12.2 percent) and 40.6 Tg CO_2 Eq. (10.5 percent), respectively. Emissions decreased in the Industrial Process, Waste and Solvent and Other Product Use sectors by 10.5 Tg CO_2 Eq. (3.4 percent), 35.2 Tg CO_2 Eq. (21.0 percent) and less than 0.1 Tg CO_2 Eq. (0.4 percent), respectively. Over the same period, estimates of net C sequestration in the Land Use, Land-Use Change, and Forestry sector increased by 192.8 Tg CO_2 Eq. (21.9 percent).

Figure 2-4: U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector

Table 2-3: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (Tg CO_2 Eq.)

Chapter/IPCC Sector	1990	2005	2006	2007	2008	2009	2010
Energy	5,287.7	6,282.4	6,214.4	6,294.3	6,125.4	5,752.7	5,933.5
Industrial Processes	313.9	330.1	335.5	347.3	319.1	268.2	303.4
Solvent and Other Product Use	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Agriculture	387.8	424.6	425.4	432.6	433.8	426.4	428.4
Land Use, Land-Use Change, and Forestry (Emissions)	13.8	25.6	43.2	37.6	27.4	20.6	19.6
Waste	167.7	137.2	136.5	136.7	138.2	136.0	132.5
Total Emissions	**6,175.2**	**7,204.2**	**7,159.3**	**7,252.8**	**7,048.3**	**6,608.3**	**6,821.8**
Net CO_2 Flux from Land Use, Land-Use Change, and Forestry (Sinks)*	(881.8)	(1085.9)	(1110.4)	(1108.2)	(1087.5)	(1062.6)	(1074.7)
Net Emissions (Sources and Sinks)	**5,293.4**	**6,118.3**	**6,048.9**	**6,144.5**	**5,960.9**	**5,545.7**	**5,747.1**

* The net CO_2 flux total includes both emissions and sequestration, and constitutes a sink in the United States. Sinks are only included in net emissions total. Please refer to Table 2-9 for a breakout by source.

Note: Totals may not sum due to independent rounding.

Note: Parentheses indicate negative values or sequestration.

Energy

Energy-related activities, primarily fossil fuel combustion, accounted for the vast majority of U.S. CO_2 emissions for the period of 1990 through 2010. In 2010, approximately 85 percent of the energy consumed in the United States (on a Btu basis) was produced through the combustion of fossil fuels. The remaining 15 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 CO_2 as well as other greenhouse gas emissions from energy consumption is presented in the Energy chapter. Energy-related activities are also responsible for CH_4 and N_2O emissions (50 percent and 14 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.

Figure 2-5: 2010 Energy Chapter Greenhouse Gas Sources

Figure 2-6: 2010 U.S. Fossil Carbon Flows (Tg CO_2 Eq.)

Table 2-4: Emissions from Energy (Tg CO_2 Eq.)

Gas/Source	1990	2005	2006	2007	2008	2009	2010
CO_2	**4,903.9**	**5,933.3**	**5,840.4**	**5,936.7**	**5,755.2**	**5,374.1**	**5,557.6**
Fossil Fuel Combustion	4,738.3	5,746.5	5,653.0	5,757.8	5,571.5	5,206.2	5,387.8
Electricity Generation	1,820.8	2,402.1	2,346.4	2,412.8	2,360.9	2,146.4	2,258.4
Transportation	1,485.9	1,896.6	1,878.1	1,893.9	1,789.8	1,727.9	1,745.5
Industrial	846.4	816.4	848.1	844.4	806.5	726.6	777.8
Residential	338.3	357.9	321.5	341.6	349.3	339.0	340.2
Commercial	219.0	223.5	208.6	218.9	225.1	224.6	224.2
U.S. Territories	27.9	50.0	50.3	46.1	39.8	41.7	41.6
Non-Energy Use of Fuels	119.6	144.1	143.8	134.9	138.6	123.7	125.1
Natural Gas Systems	37.6	29.9	30.8	31.0	32.8	32.2	32.3
Incineration of Waste	8.0	12.5	12.5	12.7	11.9	11.7	12.1
Petroleum Systems	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Biomass - Wood[a]	*214.4*	*205.7*	*202.7*	*202.2*	*197.4*	*181.8*	*191.6*
International Bunker Fuels[b]	*111.8*	*109.8*	*128.4*	*127.6*	*133.7*	*122.3*	*127.8*
Biomass - Ethanol[a]	*4.2*	*22.9*	*31.0*	*38.9*	*54.7*	*62.3*	*74.5*
CH_4	**327.1**	**291.2**	**319.1**	**307.0**	**323.5**	**335.1**	**332.3**
Natural Gas Systems	189.6	190.5	217.7	205.3	212.7	220.9	215.4
Coal Mining	84.1	56.8	58.1	57.8	66.9	70.1	72.6
Petroleum Systems	35.2	29.2	29.2	29.8	30.0	30.7	31.0
Stationary Combustion	7.5	6.6	6.2	6.5	6.6	6.3	6.3
Abandoned Underground Coal	6.0	5.5	5.5	5.3	5.3	5.1	5.0
Mobile Combustion	4.7	2.5	2.4	2.2	2.1	2.0	1.9
Incineration of Waste	0.0	0.0	0.0	0.0	0.0	0.0	0.0
International Bunker Fuels[b]	*0.2*	*0.1*	*0.2*	*0.2*	*0.2*	*0.1*	*0.2*
N_2O	**56.7**	**58.0**	**54.8**	**50.6**	**46.7**	**43.6**	**43.6**
Stationary Combustion	12.3	20.6	20.8	21.2	21.1	20.7	22.6
Mobile Combustion	43.9	37.0	33.7	29.0	25.2	22.5	20.6
Incineration of Waste	0.5	0.4	0.4	0.4	0.4	0.4	0.4
International Bunker Fuels[b]	*1.1*	*1.0*	*1.2*	*1.2*	*1.2*	*1.1*	*1.2*
Total	**5,287.7**	**6,282.4**	**6,214.4**	**6,294.3**	**6,125.4**	**5,752.7**	**5,933.5**

+ Does not exceed 0.05 Tg CO_2 Eq.

[a] Emissions from Wood Biomass and Ethanol Consumption are not included specifically in summing energy sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for Land Use, Land-Use Change, and Forestry

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

Note: Totals may not sum due to independent rounding.

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 CO_2 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 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 CO_2 emissions from fossil fuel combustion by end-use sector.

Table 2-5: CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector (Tg CO_2 Eq.)

End-Use Sector	1990	2005	2006	2007	2008	2009	2010
Transportation	**1,489.0**	**1,901.3**	**1,882.6**	**1,899.0**	**1,794.5**	**1,732.4**	**1,750.0**
Combustion	1,485.9	1,896.6	1,878.1	1,893.9	1,789.8	1,727.9	1,745.5
Electricity	3.0	4.7	4.5	5.1	4.7	4.5	4.5
Industrial	**1,533.1**	**1,553.3**	**1,560.2**	**1,559.8**	**1,503.8**	**1,328.6**	**1,415.4**
Combustion	846.4	816.4	848.1	844.4	806.5	726.6	777.8
Electricity	686.8	737.0	712.0	715.4	697.3	602.0	637.6
Residential	**931.4**	**1,214.7**	**1,152.4**	**1,205.2**	**1,192.2**	**1,125.5**	**1,183.7**
Combustion	338.3	357.9	321.5	341.6	349.3	339.0	340.2
Electricity	593.0	856.7	830.8	863.5	842.9	786.5	843.5
Commercial	**757.0**	**1,027.2**	**1,007.6**	**1,047.7**	**1,041.1**	**978.0**	**997.1**
Combustion	219.0	223.5	208.6	218.9	225.1	224.6	224.2
Electricity	538.0	803.7	799.0	828.8	816.0	753.5	772.9
U.S. Territories	**27.9**	**50.0**	**50.3**	**46.1**	**39.8**	**41.7**	**41.6**
Total	**4,738.3**	**5,746.5**	**5,653.0**	**5,757.8**	**5,571.5**	**5,206.2**	**5,387.8**
Electricity Generation	**1,820.8**	**2,402.1**	**2,346.4**	**2,412.8**	**2,360.9**	**2,146.4**	**2,258.4**

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 2-7: 2010 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type

Figure 2-8: 2010 End-Use Sector Emissions from Fossil Fuel Combustion

The main driver of emissions in the Energy sector is CO_2 from fossil fuel combustion. Electricity generation is the largest emitter of CO_2, and electricity generators consumed 36 percent of U.S. energy from fossil fuels and emitted 42 percent of the CO_2 from fossil fuel combustion in 2010. Electricity generation emissions can also be allocated to the end-use sectors that are consuming that electricity, as presented in Table 2-5. The transportation end-use sector accounted for 1,750.0 Tg CO_2 Eq. in 2010, or approximately 32 percent of total CO_2 emissions from fossil fuel combustion. The industrial end-use sector accounted for 26 percent of CO_2 emissions from fossil fuel combustion. The residential and commercial end-use sectors accounted for 22 and 19 percent, respectively, of CO_2 emissions from fossil fuel combustion. Both of these end-use sectors were heavily reliant on electricity for meeting energy needs, with electricity consumption for lighting, heating, air conditioning, and operating appliances contributing 71 and 78 percent of emissions from the residential and commercial end-use sectors, respectively. Significant trends in emissions from energy source categories over the twenty one-year period from 1990 through 2010 included the following:

- Total CO_2 emissions from fossil fuel combustion increased from 4,738.3 Tg CO_2 Eq. to 5,387.8 Tg CO_2 Eq.—a 13.7 percent total increase over the twenty one-year period. From 2009 to 2010, these emissions increased by 181.6 Tg CO_2 Eq. (3.5 percent).
- CO_2 emissions from non-energy use of fossil fuels increased 5.5 Tg CO_2 Eq. (4.6 percent) from 1990 through 2010. Emissions from non-energy uses of fossil fuels were 125.1 Tg CO_2 Eq. in 2010, which constituted 2.2 percent of total national CO_2 emissions.
- CO_2 emissions from incineration of waste (12.1 Tg CO_2 Eq. in 2010) increased by 4.1 Tg CO_2 Eq. (50.9 percent) from 1990 through 2010, as the volume of plastics and other fossil carbon-containing materials in

municipal solid waste grew.

- N_2O emissions from stationary combustion increased 10.3 Tg CO_2 Eq. (84.4 percent) from 1990 through 2010. N_2O emissions from this source increased primarily as a result of an increase in the number of coal fluidized bed boilers in the electric power sector.
- CH_4 emissions from coal mining were 72.6 Tg CO_2 Eq. in 2010, a decline in emissions of 11.5 Tg CO_2 Eq. (13.6 percent) from 1990. This occurred as a result of the mining of less gassy coal from underground mines and the increased use of CH_4 collected from degasification systems.
- CH_4 emissions from natural gas systems were 215.4 Tg CO_2 Eq. in 2010; emissions have increased by 25.8Tg CO_2 Eq. (13.6 percent) since 1990.
- In 2010, N_2O emissions from mobile combustion were 20.6 Tg CO_2 Eq. (approximately 6.7 percent of U.S. N_2O emissions). From 1990 to 2010, N_2O emissions from mobile combustion decreased by 53.1 percent. However, from 1990 to 1998 emissions increased by 26 percent, due to control technologies that reduced NO_x emissions while increasing N_2O emissions. Since 1998, newer control technologies have led to a steady decline in N_2O from this source.

Industrial Processes

Greenhouse gas emissions are produced as the by-products of many non-energy-related industrial activities. For example, industrial processes can chemically transform raw materials, which often release waste gases such as CO_2, CH_4, and N_2O. These processes include iron and steel production and metallurgical coke production, cement production, ammonia production, urea consumption, lime production, limestone and dolomite use (e.g., flux stone, flue gas desulfurization, and glass manufacturing), soda ash production and consumption, titanium dioxide production, phosphoric acid production, ferroalloy production, CO_2 consumption, silicon carbide production and consumption, aluminum production, petrochemical production, nitric acid production, adipic acid production, lead production, and zinc production (see Figure 2-9). Industrial processes also release HFCs, PFCs and SF_6. In addition to their use as ODS substitutes, HFCs, PFCs, SF_6, 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.

Figure 2-9: 2010 Industrial Processes Chapter Greenhouse Gas Sources

Table 2-6: Emissions from Industrial Processes (Tg CO_2 Eq.)

Gas/Source	1990	2005	2006	2007	2008	2009	2010
CO_2	**188.5**	**165.4**	**169.9**	**172.6**	**159.5**	**118.1**	**139.7**
Iron and Steel Production & Metallurgical	99.6	66.0	68.9	71.1	66.1	42.1	54.3
Iron and Steel Production	*97.1*	*64.0*	*66.9*	*69.1*	*63.8*	*41.2*	*52.2*
Metallurgical Coke Production	*2.5*	*2.0*	*1.9*	*2.1*	*2.3*	*1.0*	*2.1*
Cement Production	33.3	45.2	45.8	44.5	40.5	29.0	30.5
Lime Production	11.5	14.4	15.1	14.6	14.3	11.2	13.2
Limestone and Dolomite Use	5.1	6.8	8.0	7.7	6.3	7.6	10.0
Ammonia Production	13.0	9.2	8.8	9.1	7.9	7.9	8.7
Urea Consumption for Non-Agriculture Purposes	3.8	3.7	3.5	4.9	4.1	3.4	4.4
Soda Ash Production and Consumption	4.1	4.2	4.2	4.1	4.1	3.6	3.7
Petrochemical Production	3.3	4.2	3.8	3.9	3.4	2.7	3.3
Aluminum Production	6.8	4.1	3.8	4.3	4.5	3.0	3.0
Carbon Dioxide Consumption	1.4	1.3	1.7	1.9	1.8	1.8	2.2
Titanium Dioxide Production	1.2	1.8	1.8	1.9	1.8	1.6	1.9
Ferroalloy Production	2.2	1.4	1.5	1.6	1.6	1.5	1.7

Zinc Production	0.6	1.0	1.0	1.0	1.2	0.9	1.2
Phosphoric Acid Production	1.5	1.4	1.2	1.2	1.2	1.0	1.0
Lead Production	0.5	0.6	0.6	0.6	0.5	0.5	0.5
Silicon Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.1	0.2
CH_4	**1.9**	**1.8**	**1.7**	**1.7**	**1.6**	**1.2**	**1.5**
Petrochemical Production	0.9	1.1	1.0	1.0	0.9	0.8	0.9
Iron and Steel Production & Metallurgical	1.0	0.7	0.7	0.7	0.6	0.4	0.5
Iron and Steel Production	1.0	0.7	0.7	0.7	0.6	0.4	0.5
Metallurgical Coke Production	+	+	+	+	+	+	+
Ferroalloy Production	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+
N_2O	**33.4**	**23.9**	**25.0**	**29.8**	**18.9**	**17.3**	**19.5**
Nitric Acid Production	17.6	16.4	16.1	19.2	16.4	14.5	16.7
Adipic Acid Production	15.8	7.4	8.9	10.7	2.6	2.8	2.8
HFCs	**36.9**	**115.0**	**116.0**	**120.0**	**117.5**	**112.1**	**123.0**
Substitution of Ozone Depleting Substances[a]	0.3	99.0	101.9	102.7	103.6	106.3	114.6
HCFC-22 Production	36.4	15.8	13.8	17.0	13.6	5.4	8.1
Semiconductor Manufacture	0.2	0.2	0.3	0.3	0.3	0.3	0.3
PFCs	**20.6**	**6.2**	**6.0**	**7.5**	**6.6**	**5.6**	**5.6**
Semiconductor Manufacture	2.2	3.2	3.5	3.7	4.0	4.0	4.1
Aluminum Production	18.4	3.0	2.5	3.8	2.7	1.6	1.6
SF_6	**32.6**	**17.8**	**16.8**	**15.6**	**15.0**	**13.9**	**14.0**
Electrical Transmission and Distribution	26.7	13.9	13.0	12.2	12.2	11.8	11.8
Magnesium Production and Processing	5.4	2.9	2.9	2.6	1.9	1.1	1.3
Semiconductor Manufacture	0.5	1.0	1.0	0.8	0.9	1.0	0.9
Total	**313.9**	**330.1**	**335.5**	**347.3**	**319.1**	**268.2**	**303.4**

+ Does not exceed 0.05 Tg CO_2 Eq.

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

Note: Totals may not sum due to independent rounding.

Overall, emissions from the Industrial Processes sector decreased by 3.4 percent from 1990 to 2010, as emission decreases from some sources have been offset by increases from other sources. Significant trends in emissions from industrial processes source categories over the twenty-one-year period from 1990 through 2010 included the following:

- Combined CO_2 and CH_4 emissions from iron and steel production and metallurgical coke production increased by 29 percent to 54.8 Tg CO_2 Eq. from 2009 to 2010, but have declined overall by 45.8 Tg CO_2 Eq. (45.5 percent) from 1990 through 2010, due to restructuring of the industry, technological improvements, and increased scrap steel utilization.
- CO_2 emissions from ammonia production (8.7 Tg CO_2 Eq. in 2010) decreased by 4.4 Tg CO_2 Eq. (33.5 percent) since 1990. This is due to a decrease in domestic ammonia production primarily attributed to market fluctuations. Urea consumption for non-agricultural purposes (4.4 Tg CO_2 Eq. in 2010) increased by 0.6 Tg CO_2 Eq. (15.3 percent) since 1990.
- N_2O emissions from adipic acid production were 2.8 Tg CO_2 Eq. in 2010, and have decreased significantly in recent years due to the widespread installation of pollution control measures. Emissions from adipic acid production have decreased by 82.2 percent since 1990 and by 84.0 percent since a peak in 1995.
- HFC emissions from ODS substitutes have been increasing from small amounts in 1990 to 114.6 Tg CO_2 Eq. in 2010. 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.
- PFC emissions from aluminum production decreased by about 91.5 percent (16.9 Tg CO_2 Eq.) from 1990 to 2010, due to both industry emission reduction efforts and lower domestic aluminum production.

Solvent and Other Product Use

Greenhouse gas emissions are produced as a by-product of various solvent and other product uses. In the United States, N_2O Emissions from Product Uses, the only source of greenhouse gas emissions from this sector, accounted for 4.4 Tg CO_2 Eq., or less than 0.1 percent of total U.S. greenhouse gas emissions in 2010 (see Table 2-7).

Table 2-7: N_2O Emissions from Solvent and Other Product Use (Tg CO_2 Eq.)

Gas/Source	1990	2005	2006	2007	2008	2009	2010
N_2O	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**
N_2O from Product Uses	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Total	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**	**4.4**

In 2010, N_2O emissions from product uses constituted 1.4 percent of U.S. N_2O emissions. From 1990 to 2010, emissions from this source category decreased by just under 0.4 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 2010, agricultural activities were responsible for emissions of 428.4 Tg CO_2 Eq., or 6.3 percent of total U.S. greenhouse gas emissions. CH_4 and N_2O were the primary greenhouse gases emitted by agricultural activities. CH_4 emissions from enteric fermentation and manure management represented about 21.2 percent and 7.8 percent of total CH_4 emissions from anthropogenic activities, respectively, in 2010. Agricultural soil management activities, such as fertilizer application and other cropping practices, were the largest source of U.S. N_2O emissions in 2010, accounting for 67.9 percent.

Figure 2-10: 2010 Agriculture Chapter Greenhouse Gas Sources

Table 2-8: Emissions from Agriculture (Tg CO_2 Eq.)

Gas/Source	1990	2005	2006	2007	2008	2009	2010
CH_4	**172.9**	**193.9**	**195.9**	**202.9**	**202.6**	**200.8**	**202.2**
Enteric Fermentation	133.8	139.0	141.4	143.8	143.4	142.6	141.3
Manure Management	31.7	47.9	48.4	52.7	51.8	50.7	52.0
Rice Cultivation	7.1	6.8	5.9	6.2	7.2	7.3	8.6
Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2	0.2	0.2	0.2
N_2O	**214.9**	**230.7**	**229.6**	**229.7**	**231.3**	**225.6**	**226.2**
Agricultural Soil Management	200.0	213.1	211.1	211.1	212.9	207.3	207.8
Manure Management	14.8	17.6	18.4	18.5	18.3	18.2	18.3
Field Burning of Agricultural Residues	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**387.8**	**424.6**	**425.4**	**432.6**	**433.8**	**426.4**	**428.4**

Note: Totals may not sum due to independent rounding.

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

- Agricultural soils produced approximately 67.9 percent of N_2O emissions in the United States in 2010. Estimated emissions from this source in 2010 were 207.8 Tg CO_2 Eq. Annual N_2O emissions from agricultural soils fluctuated between 1990 and 2010, although overall emissions were 3.9 percent higher in

2010 than in 1990. Nitrous oxide 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 second largest source of CH_4 emissions in the United States in 2010, at 141.3 Tg CO_2 Eq. Generally, emissions decreased from 1995 to 2003, though with a slight increase in 2002. This trend was mainly due to decreasing populations of both beef and dairy cattle and increased digestibility of feed for feedlot cattle. Emissions increased 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 for those years. Emissions decreased again in 2008, 2009, and 2010 as beef cattle populations decreased. During the timeframe of this analysis, populations of sheep have decreased 51 percent since 1990 while horse populations have increased over 87 percent, mostly since 1999. Goat and swine populations have increased 25 percent and 20 percent, respectively, during this timeframe.
- Overall, emissions from manure management increased 51.2 percent between 1990 and 2010. This encompassed an increase of 64.0 percent for CH_4, from 31.7 Tg CO_2 Eq. in 1990 to 52.0 Tg CO_2 Eq. in 2010; and an increase of 23.7 percent for N_2O, from 14.8 Tg CO_2 Eq. in 1990 to 18.3 Tg CO_2 Eq. in 2010. The majority of this increase was from swine and dairy cow manure, since the general trend in manure management is one of increasing use of liquid systems, which tends to produce greater CH_4 emissions.

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 16 percent of total U.S. greenhouse gas emissions in 2010. Forests (including vegetation, soils, and harvested wood) accounted for approximately 86 percent of total 2010 net CO_2 flux, urban trees accounted for 9 percent, mineral and organic soil carbon stock changes accounted for 4 percent, and landfilled yard trimmings and food scraps accounted for 1 percent of the total net flux in 2010. 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 and food scraps carbon in landfills.

Land use, land-use change, and forestry activities in 2010 resulted in a net C sequestration of 1,074.7 Tg CO_2 Eq. (293.1 Tg C) (Table 2-9). This represents an offset of approximately 19 percent of total U.S. CO_2 emissions, or 16 percent of total greenhouse gas emissions in 2010. Between 1990 and 2010, total land use, land-use change, and forestry net C flux resulted in a 21.9 percent increase in CO_2 sequestration.

Table 2-9: Net CO_2 Flux from Land Use, Land-Use Change, and Forestry (Tg CO_2 Eq.)

Sink Category	1990	2005	2006	2007	2008	2009	2010
Forest Land Remaining Forest Land	(701.4)	(940.9)	(963.5)	(959.2)	(938.3)	(910.6)	(921.8)
Cropland Remaining Cropland	(29.4)	(18.3)	(19.1)	(19.7)	(18.1)	(17.4)	(15.6)
Land Converted to Cropland	2.2	5.9	5.9	5.9	5.9	5.9	5.9
Grassland Remaining Grassland	(52.2)	(8.9)	(8.8)	(8.6)	(8.5)	(8.3)	(8.3)
Land Converted to Grassland	(19.8)	(24.4)	(24.2)	(24.0)	(23.8)	(23.6)	(23.6)
Settlements Remaining Settlements	(57.1)	(87.8)	(89.8)	(91.9)	(93.9)	(95.9)	(98.0)
Other (Landfilled Yard Trimmings and Food Scraps)	(24.2)	(11.6)	(11.0)	(10.9)	(10.9)	(12.7)	(13.3)
Total	**(881.8)**	**(1,085.9)**	**(1,110.4)**	**(1,108.2)**	**(1,087.5)**	**(1,062.6)**	**(1,074.7)**

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

Land use, land-use change, and forestry source categories also resulted in emissions of CO_2, CH_4, and N_2O that are not included in the net CO_2 flux estimates presented in Table 2-9. The application of crushed limestone and dolomite to managed land (i.e., soil liming) and urea fertilization resulted in CO_2 emissions of 8.0 Tg CO_2 Eq. in 2010, an increase of about 13.6 percent relative to 1990. Lands undergoing peat extraction resulted in CO_2 emissions of 1.0 Tg CO_2 Eq. (983 Gg), and N_2O emissions of less than 0.05 Tg CO_2 Eq. N_2O emissions from the application of synthetic fertilizers to forest soils have increased from 0.1 Tg CO_2 Eq. in 1990 to 0.4 Tg CO_2 Eq. in 2010. Settlement soils in 2010 resulted in direct N_2O emissions of 1.4 Tg CO_2 Eq., a 43 percent increase relative to 1990. Emissions from forest fires in 2010 resulted in CH_4 emissions of 4.8 Tg CO_2 Eq., and in N_2O emissions of 4.0 Tg CO_2 Eq. (Table 2-10).

Table 2-10: Emissions from Land Use, Land-Use Change, and Forestry (Tg CO_2 Eq.)

Source Category	1990	2005	2006	2007	2008	2009	2010
CO_2	**8.1**	**8.9**	**8.8**	**9.2**	**9.6**	**8.3**	**9.0**
Cropland Remaining Cropland:							
Liming of Agricultural Soils	4.7	4.3	4.2	4.5	5.0	3.7	3.9
Cropland Remaining Cropland: Urea							
Fertilization	2.4	3.5	3.7	3.8	3.6	3.6	4.1
Wetlands Remaining Wetlands:							
Peatlands Remaining Peatlands	1.0	1.1	0.9	1.0	1.0	1.1	1.0
CH_4	**2.5**	**8.1**	**17.9**	**14.6**	**8.8**	**5.8**	**4.8**
Forest Land Remaining Forest Land:							
Forest Fires	2.5	8.1	17.9	14.6	8.8	5.8	4.8
N_2O	**3.1**	**8.5**	**16.5**	**13.8**	**9.0**	**6.5**	**5.7**
Forest Land Remaining Forest Land:							
Forest Fires	2.1	6.6	14.6	11.9	7.2	4.7	4.0
Forest Land Remaining Forest Land:							
Forest Soils	0.1	0.4	0.4	0.4	0.4	0.4	0.4
Settlements Remaining Settlements:							
Settlement Soils	1.0	1.5	1.5	1.6	1.5	1.4	1.4
Wetlands Remaining Wetlands:							
Peatlands Remaining Peatlands	+	+	+	+	+	+	+
Total	**13.8**	**25.6**	**43.2**	**37.6**	**27.4**	**20.6**	**19.6**

+ Less than 0.05 Tg CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Other significant trends from 1990 to 2010 in emissions from land use, land-use change, and forestry source categories include:

- Net C sequestration by forest land has increased by approximately 31 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 20 years, although only at an average rate of 0.22 percent per year.
- Net sequestration of C by urban trees has increased by 71.8 percent over the period from 1990 to 2010. 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 44.9 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 2010, landfills were the third largest source of U.S. anthropogenic CH_4 emissions, accounting for 16.2 percent of total U.S. CH_4 emissions.[48] Additionally, wastewater treatment accounts for 2.5 percent of U.S. CH_4 emissions, and 1.6 percent of N_2O emissions. Emissions of CH_4 and N_2O from composting grew from 1990 to 2010, and resulted in emissions of 3.3 Tg CO_2 Eq. in 2010. A summary of greenhouse gas emissions from the Waste chapter is presented in Table 2-11.

Figure 2-11: 2010 Waste Chapter Greenhouse Gas Sources

Overall, in 2010, waste activities generated emissions of 132.5 Tg CO_2 Eq., or 1.9 percent of total U.S. greenhouse gas emissions.

Table 2-11: Emissions from Waste (Tg CO_2 Eq.)

Gas/Source	1990	2005	2006	2007	2008	2009	2010
CH_4	**163.9**	**130.8**	**130.0**	**130.0**	**131.4**	**129.3**	**125.8**
Landfills	147.7	112.7	111.7	111.7	113.1	111.2	107.8
Wastewater Treatment	15.9	16.5	16.7	16.6	16.6	16.5	16.3
Composting	0.3	1.6	1.6	1.7	1.7	1.6	1.6
N_2O	**3.8**	**6.4**	**6.5**	**6.7**	**6.8**	**6.7**	**6.8**
Wastewater Treatment	3.5	4.7	4.8	4.8	4.9	5.0	5.0
Composting	0.4	1.7	1.8	1.8	1.9	1.8	1.7
Total	**167.7**	**137.2**	**136.5**	**136.7**	**138.2**	**136.0**	**132.5**

Note: Totals may not sum due to independent rounding.

Some significant trends in U.S. emissions from waste source categories include the following:

- From 1990 to 2010, net CH_4 emissions from landfills decreased by 39.8 Tg CO_2 Eq. (27 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,[49] which has more than offset the additional CH_4 emissions resulting from an increase in the amount of municipal solid waste landfilled.
- Combined CH_4 and N_2O emissions from composting have generally increased since 1990, from 0.7 Tg CO_2 Eq. to 3.3 Tg CO_2 Eq. in 2010, which represents slightly less than a five-fold increase over the time series.
- From 1990 to 2010, CH_4 and N_2O emissions from wastewater treatment increased by 0.4 Tg CO_2 Eq. (2.7 percent) and 1.6 Tg CO_2 Eq. (46 percent), respectively.

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 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 (34 percent) of

[48] 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.

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

U.S. greenhouse gas emissions in 2010. Transportation activities, in aggregate, accounted for the second largest portion (27 percent). Emissions from industry accounted for about 20 percent of U.S. greenhouse gas emissions in 2010. 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 5.4 percent, and primarily consisted of CO_2 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 N_2O emissions from agricultural soil management and CH_4 emissions from enteric fermentation, rather than CO_2 from fossil fuel combustion. The commercial sector accounted for roughly 6 percent of emissions, while U.S. territories accounted for less than 1 percent.

CO_2 was also emitted and sequestered (in the form of C) 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 2010.

Figure 2-12: Emissions Allocated to Economic Sectors

Table 2-12: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (Tg CO_2 Eq. and Percent of Total in 2010)

Sector/Source	1990	2005	2006	2007	2008	2009	2010	Percent[a]
Electric Power Industry	**1,866.2**	**2,448.8**	**2,393.0**	**2,459.1**	**2,405.8**	**2,191.4**	**2,306.5**	**33.8%**
CO_2 from Fossil Fuel Combustion	1,820.8	2,402.1	2,346.4	2,412.8	2,360.9	2,146.4	2,258.4	33.1%
Stationary Combustion – N_2O and CH_4	7.7	16.5	16.7	17.2	17.3	17.2	18.9	0.3%
Incineration of Waste	8.5	12.9	12.9	13.1	12.3	12.1	12.4	0.2%
Electrical Transmission and Distribution	26.7	13.9	13.0	12.2	12.2	11.8	11.8	0.2%
Limestone and Dolomite Use	2.6	3.4	4.0	3.9	3.1	3.8	5.0	0.1%
Transportation	**1,545.2**	**2,017.5**	**1,994.5**	**2,002.4**	**1,889.8**	**1,819.3**	**1,834.0**	**26.9%**
CO_2 from Fossil Fuel Combustion	1,485.9	1,896.6	1,878.1	1,893.9	1,789.8	1,727.9	1,745.5	25.6%
Substitution of Ozone Depleting Substances	+	72.9	72.2	68.8	64.9	60.2	58.4	0.9%
Mobile Combustion	47.4	37.8	34.3	29.4	25.5	22.6	20.6	0.3%
Non-Energy Use of Fuels	11.8	10.2	9.9	10.2	9.5	8.5	9.5	0.1%
Industry	**1,564.8**	**1,438.1**	**1,499.8**	**1,489.6**	**1,448.5**	**1,317.2**	**1,394.2**	20.4%
CO_2 from Fossil Fuel Combustion	815.3	769.5	799.1	796.0	761.1	680.0	730.2	10.7%
Natural Gas Systems	227.2	228.6	229.6	236.6	240.8	252.6	247.3	3.6%
Non-Energy Use of Fuels	102.1	125.9	125.0	117.5	120.7	111.5	111.9	1.6%
Coal Mining	84.1	56.8	58.1	57.8	66.9	70.1	72.6	1.1%
Iron and Steel Production	100.5	66.7	69.6	71.8	66.7	42.5	54.8	0.8%
Petroleum Systems	35.6	29.5	29.5	30.1	30.3	31.0	31.4	0.5%
Cement Production	33.3	45.2	45.8	44.5	40.5	29.0	30.5	0.4%
Nitric Acid Production	17.6	16.4	16.1	19.2	16.4	14.5	16.7	0.2%
Substitution of Ozone Depleting Substances	+	6.4	7.1	7.8	8.5	10.9	13.5	0.2%
Lime Production	11.5	14.4	15.1	14.6	14.3	11.2	13.2	0.2%
Ammonia Production	13.0	9.2	8.8	9.1	7.9	7.9	8.7	0.1%
HCFC-22 Production	36.4	15.8	13.8	17.0	13.6	5.4	8.1	0.1%
Semiconductor Manufacture	2.9	4.4	4.7	4.8	5.1	5.3	5.4	0.1%
Limestone and Dolomite Use	2.6	3.4	4.0	3.9	3.1	3.8	5.0	0.1%
Abandoned Underground Coal Mines	6.0	5.5	5.5	5.3	5.3	5.1	5.0	0.1%
Aluminum Production	25.3	7.1	6.3	8.1	7.2	4.6	4.6	0.1%
N_2O from Product Uses	4.4	4.4	4.4	4.4	4.4	4.4	4.4	0.1%
Urea Consumption for Non-Agricultural	3.8	3.7	3.5	4.9	4.1	3.4	4.4	0.1%

Purposes								
Petrochemical Production	4.2	5.3	4.8	4.9	4.3	3.6	4.3	0.1%
Stationary Combustion	4.9	4.6	4.7	4.6	4.3	3.7	4.1	0.1%
Soda Ash Production and Consumption	4.1	4.2	4.2	4.1	4.1	3.6	3.7	0.1%
Adipic Acid Production	15.8	7.4	8.9	10.7	2.6	2.8	2.8	+
Carbon Dioxide Consumption	1.4	1.3	1.7	1.9	1.8	1.8	2.2	+
Titanium Dioxide Production	1.2	1.8	1.8	1.9	1.8	1.6	1.9	+
Ferroalloy Production	2.2	1.4	1.5	1.6	1.6	1.5	1.7	+
Mobile Combustion	0.9	1.3	1.3	1.3	1.3	1.3	1.4	+
Magnesium Production and Processing	5.4	2.9	2.9	2.6	1.9	1.1	1.3	+
Zinc Production	0.6	1.0	1.0	1.0	1.2	0.9	1.2	+
Phosphoric Acid Production	1.5	1.4	1.2	1.2	1.2	1.0	1.0	+
Lead Production	0.5	0.6	0.6	0.6	0.6	0.5	0.5	+
Silicon Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.2	0.2	+
Agriculture	**431.9**	**496.0**	**516.7**	**517.6**	**505.8**	**492.8**	**494.8**	**7.3%**
N_2O from Agricultural Soil Management	200.0	213.1	211.1	211.1	212.9	207.3	207.8	3.0%
Enteric Fermentation	133.8	139.0	141.4	143.8	143.4	142.6	141.3	2.1%
Manure Management	46.5	65.5	66.7	71.1	70.0	68.9	70.4	1.0%
CO_2 from Fossil Fuel Combustion	31.0	46.8	49.0	48.4	45.4	46.7	47.6	0.7%
CH_4 and N_2O from Forest Fires	4.6	14.8	32.6	26.4	16.0	10.5	8.8	0.1%
Rice Cultivation	7.1	6.8	5.9	6.2	7.2	7.3	8.6	0.1%
Liming of Agricultural Soils	4.7	4.3	4.2	4.5	5.0	3.7	3.9	0.1%
Urea Fertilization	2.4	3.5	3.7	3.8	3.6	3.6	4.1	0.1%
CO_2 and N_2O from Managed Peatlands	1.0	1.1	0.9	1.0	1.0	1.1	1.0	+
Mobile Combustion	0.3	0.5	0.5	0.5	0.5	0.5	0.5	+
N_2O from Forest Soils	0.1	0.4	0.4	0.4	0.4	0.4	0.4	+
Field Burning of Agricultural Residues	0.3	0.2	0.3	0.3	0.3	0.3	0.3	+
Stationary Combustion	+	+	+	+	+	+	+	+
Commercial	**388.0**	**374.3**	**359.9**	**372.2**	**381.8**	**382.0**	**381.7**	**5.6%**
CO_2 from Fossil Fuel Combustion	219.0	223.5	208.6	218.9	225.1	224.6	224.2	3.3%
Landfills	147.7	112.7	111.7	111.7	113.1	111.2	107.8	1.6%
Substitution of Ozone Depleting Substances	+	12.3	13.6	15.4	17.2	20.1	23.6	0.3%
Wastewater Treatment	15.9	16.5	16.7	16.6	16.6	16.5	16.3	0.2%
Human Sewage	3.5	4.7	4.8	4.8	4.9	5.0	5.0	0.1%
Composting	0.7	3.3	3.3	3.5	3.5	3.3	3.3	+
Stationary Combustion	1.3	1.3	1.2	1.3	1.3	1.3	1.3	+
Residential	**345.4**	**371.3**	**336.1**	**358.4**	**368.4**	**360.0**	**365.2**	**5.4%**
CO_2 from Fossil Fuel Combustion	338.3	357.9	321.5	341.6	349.3	339.0	340.2	5.0%
Substitution of Ozone Depleting Substances	0.3	7.3	8.9	10.7	12.9	15.1	19.1	0.3%
Stationary Combustion	5.7	4.6	4.1	4.5	4.7	4.5	4.4	0.1%
Settlement Soil Fertilization	1.0	1.5	1.5	1.6	1.5	1.4	1.4	+
U.S. Territories	**33.7**	**58.2**	**59.3**	**53.5**	**48.4**	**45.5**	**45.5**	**0.7%**
CO_2 from Fossil Fuel Combustion	27.9	50.0	50.3	46.1	39.8	41.7	41.6	0.6%
Non-Energy Use of Fuels	5.7	8.1	8.8	7.2	8.4	3.7	3.7	0.1%
Stationary Combustion	0.1	0.2	0.2	0.2	0.2	0.2	0.2	+
Total Emissions	**6,175.2**	**7,204.2**	**7,159.3**	**7,252.8**	**7,048.3**	**6,608.3**	**6,821.8**	**100.0%**
Sinks	**(881.8)**	**(1,085.9)**	**(1,110.4)**	**(1,108.2)**	**(1,087.5)**	**(1,062.6)**	**(1,074.7)**	**-15.8%**
CO_2 Flux from Forests[b]	(701.4)	(940.9)	(963.5)	(959.2)	(938.3)	(910.6)	(921.8)	-13.5%
Urban Trees	(57.1)	(87.8)	(89.8)	(91.9)	(93.9)	(95.9)	(98.0)	-1.4%
CO_2 Flux from Agricultural Soil Carbon Stocks	(99.2)	(45.6)	(46.1)	(46.3)	(44.4)	(43.4)	(41.6)	-0.6%
Landfilled Yard Trimmings and Food Scraps	(24.2)	(11.6)	(11.0)	(10.9)	(10.9)	(12.7)	(13.3)	-0.2%
Net Emissions	**5,293.4**	**6,118.3**	**6,048.9**	**6,144.5**	**5,960.9**	**5,545.7**	**5,747.1**	**84.2%**

Note: Includes all emissions of CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6. Parentheses indicate negative values or sequestration. Totals may not sum due to independent rounding.

ODS (Ozone Depleting Substances)

+ Does not exceed 0.05 Tg CO_2 Eq. or 0.05 percent.

[a] Percent of total emissions for year 2010.

[b] Includes the effects of net additions to stocks of carbon stored in harvested wood products.

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 34 percent of total U.S. greenhouse gas emissions in 2010. Emissions increased by 24 percent since 1990, as electricity demand grew and fossil fuels remained the dominant energy source for generation. Electricity generation-related emissions increased from 2009 to 2010 by 5.3 percent, primarily due to increased CO_2 emissions from fossil fuel combustion. The increase in electricity-related emissions was due to increased economic output and the resulting increase in electricity demand. Electricity-related emissions also increased due to an increase in the carbon intensity of fuels used to generate electricity. This was caused by fuel switching as the price of coal increased only slightly while the price of natural gas increased significantly. The fuel switching from coal to natural gas and the decrease in electricity generation from other energy sources in 2010, which included a 6 percent decline in hydropower generation from the previous year, resulted in an increase in carbon intensity, and in turn, an increase in emissions from electricity generation. 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 CO_2 Eq.)

Gas/Fuel Type or Source	1990	2005	2006	2007	2008	2009	2010
CO_2	**1,831.4**	**2,418.0**	**2,363.0**	**2,429.4**	**2,375.9**	**2,161.9**	**2,275.4**
Fossil Fuel Combustion	1,820.8	2,402.1	2,346.4	2,412.8	2,360.9	2,146.4	2,258.4
Coal	*1,547.6*	*1,983.8*	*1,953.7*	*1,987.3*	*1,959.4*	*1,740.9*	*1,827.3*
Natural Gas	*175.3*	*318.8*	*338.0*	*371.3*	*361.9*	*372.2*	*399.4*
Petroleum	*97.5*	*99.2*	*54.4*	*53.9*	*39.2*	*33.0*	*31.3*
Geothermal	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*
Incineration of Waste	8.0	12.5	12.5	12.7	11.9	11.7	12.1
Limestone and Dolomite Use	2.6	3.4	4.0	3.9	3.1	3.8	5.0
CH_4	**0.3**	**0.5**	**0.5**	**0.5**	**0.5**	**0.4**	**0.5**
Stationary Combustion*	0.3	0.5	0.5	0.5	0.5	0.4	0.5
Incineration of Waste	+	+	+	+	+	+	+
N_2O	**7.8**	**16.4**	**16.6**	**17.1**	**17.2**	**17.2**	**18.8**
Stationary Combustion*	7.4	16.0	16.2	16.7	16.8	16.8	18.5
Incineration of Waste	0.5	0.4	0.4	0.4	0.4	0.4	0.4
SF_6	**26.7**	**13.9**	**13.0**	**12.2**	**12.2**	**11.8**	**11.8**
Electrical Transmission and Distribution	26.7	13.9	13.0	12.2	12.2	11.8	11.8
Total	**1,866.2**	**2,448.8**	**2,393.0**	**2,459.1**	**2,405.8**	**2,191.4**	**2,306.5**

Note: Totals may not sum due to independent rounding.

* Includes only stationary combustion emissions related to the generation of electricity.

+ Does not exceed 0.05 Tg CO_2 Eq. or 0.05 percent.

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 each economic sector's share of retail sales of electricity consumption (EIA 2011 and Duffield 2006). These source categories include CO_2 from Fossil Fuel Combustion, CH_4 and N_2O from Stationary Combustion, Incineration of Waste, Limestone and Dolomite Use, and SF_6 from Electrical Transmission and Distribution Systems. Note that only 33 percent of the Limestone and Dolomite Use emissions

were associated with electricity generation and distributed as described; the remainder of Limestone and Dolomite Use emissions were attributed to the industrial processes economic end-use sector.[50]

When emissions from electricity are distributed among these sectors, industry activities account for the largest share of total U.S. greenhouse gas emissions (29.6 percent), followed closely by emissions from transportation (27.0 percent). Emissions from the residential and commercial sectors also increase substantially when emissions from electricity are included. In all sectors except agriculture, CO_2 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 2010.

Figure 2-13: Emissions with Electricity Distributed to Economic Sectors

Table 2-14: U.S. Greenhouse Gas Emissions by Economic Sector and Gas with Electricity-Related Emissions Distributed (Tg CO_2 Eq.) and Percent of Total in 2010

Sector/Gas	1990	2005	2006	2007	2008	2009	2010	Percent[a]
Industry	**2,237.7**	**2,159.9**	**2,198.5**	**2,185.9**	**2,131.5**	**1,905.8**	**2.019.0**	**29.6%**
Direct Emissions	1,564.8	1,438.1	1,499.8	1,489.6	1,448.5	1,317.2	1,394.2	20.4%
CO_2	1,141.3	1,087.6	1,121.1	1,113.5	1,071.3	938.2	1,009.5	14.8%
CH_4	318.5	285.5	314.0	301.6	318.0	329.4	327.1	4.8%
N_2O	41.8	32.5	33.7	38.4	27.4	25.4	27.9	0.4%
HFCs, PFCs, and SF_6	63.2	32.5	31.0	36.0	31.9	24.2	29.7	0.4%
Electricity-Related	672.9	721.8	698.7	696.3	683.0	588.6	624.9	9.2%
CO_2	660.3	712.7	689.9	687.9	674.5	580.6	616.4	9.0%
CH_4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	+
N_2O	2.8	4.8	4.9	4.8	4.9	4.6	5.1	0.1%
SF_6	9.6	4.1	3.8	3.4	3.5	3.2	3.2	+
Transportation	**1,548.3**	**2,022.3**	**1,999.1**	**2,007.6**	**1,894.6**	**1,823.9**	**1,838.6**	**27.0%**
Direct Emissions	1,545.2	2,017.5	1,994.5	2,002.4	1,889.8	1,819.3	1,834.0	26.9%
CO_2	1,497.8	1,906.8	1,888.0	1,904.1	1,799.4	1,736.5	1,755.0	25.7%
CH_4	4.5	2.2	2.1	1.9	1.8	1.6	1.6	+
N_2O	42.95	35.53	32.18	27.49	23.73	20.99	19.02	0.3%
HFCs[b]	+	72.9	72.2	68.8	64.9	60.2	58.4	0.9%
Electricity-Related	3.1	4.8	4.6	5.2	4.8	4.6	4.6	0.1%
CO_2	3.1	4.8	4.6	5.1	4.7	4.5	4.5	0.1%
CH_4	+	+	+	+	+	+	+	+
N_2O	+	+	+	+	+	+	+	+
SF_6	+	+	+	+	+	+	+	+
Commercial	**939.4**	**1,193.6**	**1,174.8**	**1,216.9**	**1,213.3**	**1,151.3**	**1,171.0**	**17.2%**
Direct Emissions	388.0	374.3	359.9	372.2	381.8	382.0	381.7	5.6%
CO_2	219.0	223.5	208.6	218.9	225.1	224.6	224.2	3.3%
CH_4	164.8	131.7	130.8	130.9	132.4	130.3	126.7	1.9%
N_2O	4.2	6.8	6.8	7.0	7.1	7.1	7.1	0.1%
HFCs	+	12.3	13.6	15.4	17.2	20.1	23.6	0.3%
Electricity-Related	551.4	819.3	814.9	844.7	831.6	769.2	789.3	11.6%
CO_2	541.1	809.0	804.7	834.5	821.2	758.9	778.7	11.4%

[50] 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.

CH_4	0.1	0.2	0.2	0.2	0.2	0.2	0.2	+
N_2O	2.3	5.5	5.7	5.9	5.9	6.0	6.4	0.1%
SF_6	7.9	4.7	4.4	4.2	4.2	4.2	4.0	0.1%
Residential	**953.2**	**1,244.6**	**1,183.4**	**1,238.5**	**1,227.3**	**1,162.9**	**1,226.6**	**18.0%**
Direct Emissions	345.4	371.3	336.1	358.4	368.4	360.0	365.2	5.4%
CO_2	338.3	357.9	321.5	341.6	349.3	339.0	340.2	5.0%
CH_4	4.6	3.6	3.3	3.6	3.7	3.6	3.5	0.1%
N_2O	2.1	2.4	2.4	2.5	2.4	2.3	2.3	+
HFCs	0.3	7.3	8.9	10.7	12.9	15.1	19.1	0.3%
Electricity-Related	607.8	873.4	847.4	880.1	858.9	803.0	861.4	12.6%
CO_2	596.5	862.4	836.7	869.4	848.3	792.2	849.8	12.5%
CH_4	0.1	0.2	0.2	0.2	0.2	0.2	0.2	+
N_2O	2.6	5.8	5.9	6.1	6.1	6.3	7.0	0.1%
SF_6	8.7	5.0	4.6	4.4	4.3	4.3	4.4	0.1%
Agriculture	**462.9**	**525.5**	**544.2**	**550.5**	**533.3**	**518.9**	**521.1**	**7.6%**
Direct Emissions	431.9	496.0	516.7	517.6	505.8	492.8	494.8	7.3%
CO_2	39.2	55.7	57.8	57.7	55.1	55.0	56.7	0.8%
CH_4	175.5	202.2	214.0	217.6	211.5	206.8	207.2	3.0%
N_2O	217.2	238.1	245.0	242.3	239.2	231.0	230.9	3.4%
Electricity-Related	31.0	29.5	27.5	32.9	27.5	26.0	26.3	0.4%
CO_2	30.4	29.1	27.1	32.5	27.2	25.7	25.9	0.4%
CH_4	+	+	+	+	+	+	+	+
N_2O	0.1	0.2	0.2	0.2	0.2	0.2	0.2	+
SF_6	0.4	0.2	0.1	0.2	0.1	0.1	0.1	+
U.S. Territories	**33.7**	**58.2**	**59.3**	**53.5**	**48.4**	**45.5**	**45.5**	**0.7%**
Total	**6,175.2**	**7,204.2**	**7,159.3**	**7,252.8**	**7,048.3**	**6,608.3**	**6,821.8**	**100%**

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.

+ Does not exceed 0.05 Tg CO_2 Eq. or 0.05 percent.

[a] Percent of total emissions for year 2010.

[b] Includes primarily HFC-134a.

Industry

The industrial end-use sector includes CO_2 emissions from fossil fuel combustion from all manufacturing facilities, in aggregate. This sector also includes emissions that are produced as a by-product of the non-energy-related industrial process activities. The variety of activities producing these non-energy-related emissions includes methane emissions from petroleum and natural gas systems, fugitive CH_4 emissions from coal mining, by-product CO_2 emissions from cement manufacture, and HFC, PFC, and SF_6 by-product emissions from semiconductor manufacture, to name a few. Since 1990, industrial sector emissions have declined. The decline has occurred both in direct emissions and indirect emissions associated with electricity use. However, the decline in direct emissions has been sharper. 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 2010. The largest sources of transportation greenhouse gases in 2010 were passenger cars (43 percent), light duty trucks, which include sport utility vehicles, pickup trucks, and minivans (19 percent), freight trucks (22 percent) and commercial aircraft (6 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. 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. 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. However, in 2010, fuel VMT grew by 0.3 percent, while average fuel economy decreased slightly. Among new vehicles sold annually, average fuel economy gradually declined from 1990 to 2004, reflecting substantial growth in sales of light-duty trucks—in particular, growth in the market share of sport utility vehicles—relative to passenger cars. Gasoline fuel consumption increased slightly, while consumption of diesel fuel continued to decrease, due in part to a decrease in commercial activity and freight trucking as a result of the economic recession.

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 2010, transportation emissions rose by 19 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 34 percent from 1990 to 2010, as a result of a confluence of factors including population growth, economic growth, urban sprawl, and low fuel prices over much of this period.

From 2008 to 2009, CO_2 emissions from the transportation end-use sector declined 4 percent. The decrease in emissions can largely be attributed to decreased economic activity in 2009 and an associated decline in the demand for transportation. 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 17 percent decrease in commercial aircraft emissions since 2007. From 2009 to 2010, CO_2 emissions from the transportation end-use sector increased by 1 percent as economic activity rebounded slightly in 2010.

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 CO_2 from fossil fuel combustion, which increased by 17 percent from 1990 to 2010. This rise in CO_2 emissions, combined with an increase in HFCs from close to zero emissions in 1990 to 58.4 Tg CO_2 Eq. in 2010, led to an increase in overall emissions from transportation activities of 19 percent.

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. 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. However, in 2010, fuel VMT grew by 0.3 percent, while average fuel economy decreased slightly. Among new vehicles sold annually, average fuel economy gradually declined from 1990 to 2004, reflecting substantial growth in sales of light-duty trucks—in particular, growth in the market share of sport utility vehicles—relative to passenger cars. Gasoline fuel consumption increased slightly, while consumption of diesel fuel continued to decrease, due in part to a decrease in commercial activity and freight trucking as a result of the economic recession.

Table 2-15: Transportation-Related Greenhouse Gas Emissions (Tg CO_2 Eq.)

Gas/Vehicle	1990	2005	2006	2007	2008	2009	2010
Passenger Cars	**657.4**	**709.6**	**682.9**	**847.4**	**807.0**	**798.7**	**787.9**
CO_2	629.3	662.3	639.1	804.4	769.3	766.0	757.5
CH_4	2.6	1.1	1.0	1.1	1.0	0.9	0.9
N_2O	25.4	17.8	15.7	17.3	14.7	12.4	10.9
HFCs	+	28.4	27.1	24.6	22.1	19.3	18.6
Light-Duty Trucks	**336.6**	**551.3**	**564.0**	**366.4**	**347.0**	**349.5**	**346.4**
CO_2	321.1	505.9	519.5	330.1	312.8	317.4	316.0
CH_4	1.4	0.7	0.7	0.3	0.3	0.3	0.3
N_2O	14.1	13.7	12.6	5.9	5.2	5.2	4.7
HFCs	+	31.0	31.2	30.1	28.6	26.6	25.4
Medium- and Heavy-Duty Trucks	**231.1**	**408.5**	**418.7**	**444.7**	**427.1**	**389.3**	**402.3**
CO_2	230.1	396.0	406.0	431.6	413.9	376.3	389.3
CH_4	0.2	0.2	0.2	0.2	0.2	0.2	0.2
N_2O	0.8	1.2	1.1	1.5	1.4	1.2	1.1
HFCs	+	11.1	11.4	11.5	11.6	11.6	11.6
Buses	**8.4**	**12.0**	**12.3**	**18.0**	**17.5**	**16.6**	**16.5**
CO_2	8.4	11.8	12.0	17.6	17.1	16.2	16.0
CH_4	+	+	+	+	+	+	+
N_2O	+	+	+	+	+	+	+
HFCs	+	0.2	0.3	0.3	0.4	0.4	0.4
Motorcycles	**1.8**	**1.7**	**1.9**	**4.3**	**4.5**	**4.3**	**3.8**
CO_2	1.7	1.6	1.9	4.3	4.4	4.2	3.7
CH_4	+	+	+	+	+	+	+
N_2O	+	+	+	+	+	+	+
Commercial Aircraft[a]	**136.8**	**162.8**	**138.5**	**139.5**	**123.4**	**112.5**	**115.2**
CO_2	135.4	161.2	137.1	138.1	122.2	111.4	114.0
CH_4	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N_2O	1.3	1.5	1.3	1.3	1.2	1.1	1.1
Other Aircraft[b]	**44.4**	**35.8**	**35.0**	**33.1**	**35.2**	**30.4**	**28.7**
CO_2	43.9	35.5	34.7	32.8	34.8	30.1	28.4
CH_4	0.1	0.1	0.1	0.1	0.1	+	+
N_2O	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Ships and Boats[c]	**45.1**	**45.2**	**48.4**	**55.2**	**37.1**	**34.0**	**43.3**
CO_2	44.5	44.5	47.7	54.4	36.6	33.5	42.6
CH_4	+	+	+	+	+	+	+
N_2O	0.6	0.6	0.7	0.8	0.5	0.5	0.6
HFCs	+	+	+	+	+	+	+
Rail	**39.0**	**53.0**	**55.1**	**54.4**	**50.7**	**43.4**	**46.3**
CO_2	38.5	50.3	52.4	51.6	47.9	40.7	43.5
CH_4	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N_2O	0.3	0.4	0.4	0.4	0.4	0.3	0.3
HFCs	+	2.2	2.2	2.2	2.3	2.3	2.3
Other Emissions from Electricity Generation[d]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipelines[e]	**36.0**	**32.2**	**32.3**	**34.2**	**35.6**	**36.6**	**38.8**
CO_2	36.0	32.2	32.3	34.2	35.6	36.6	38.8
Lubricants	**11.8**	10.2	9.9	10.2	9.5	8.5	9.5
CO_2	11.8	10.2	9.9	10.2	9.5	8.5	9.5
Total Transportation	**1,548.3**	**2,022.3**	**1,999.1**	**2,007.6**	**1,894.6**	**1,823.9**	**1,838.6**
International Bunker Fuels[f]	*113.0*	*110.9*	*129.8*	*129.0*	*135.1*	*123.6*	*129.2*

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

larger than 8500 lbs. HFC emissions primarily reflect HFC-134a.
+ Does not exceed 0.05 Tg CO_2 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] CO_2 estimates reflect natural gas used to power pipelines, but not electricity. While the operation of pipelines produces CH_4 and N_2O, 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.

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 and wastewater treatment emissions increasing 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 agriculture sector includes a variety of processes, including enteric fermentation in domestic livestock, livestock manure management, and agricultural soil management. In 2010, agricultural soil management was the largest source of N_2O emissions, and enteric fermentation was the second largest source of CH_4 emissions in the United States. This sector also includes small amounts of CO_2 emissions from fossil fuel combustion by motorized farm equipment like tractors. The agriculture sector relies less heavily on electricity than the other sectors.

[BEGIN BOX]

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, the Inventory expands upon the standard IPCC sectors common for UNFCCC reporting. Discussing greenhouse gas emissions relevant to U.S.-specific sectors improves communication of the report's findings.

In the Electricity Generation economic sector, CO_2 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 CH_4 and N_2O are also based on the EIA electric utility sector. Additional sources include CO_2, CH_4, and N_2O 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 SF_6 from Electrical Transmission and Distribution, and a portion of CO_2 from Limestone and Dolomite Use (from pollution control equipment installed in electricity generation plants).

In the Transportation economic sector, the CO_2 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 the CH_4 and N_2O from Mobile Combustion, based on the EIA transportation sector. Substitutes of Ozone Depleting Substitutes are apportioned based on their specific end-uses within the source category, with emissions from transportation refrigeration/air-conditioning systems to this economic sector. Finally, CO_2 emissions from Non-Energy Uses of Fossil Fuels identified as lubricants for transportation vehicles are included in the Transportation economic sector.

For the Industry economic sector, the CO_2 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 CH_4 and N_2O are also based on the EIA industrial sector, minus emissions apportioned to the Agriculture economic sector described below. Substitutes of Ozone Depleting Substitutes are apportioned based on their specific end-uses within the source category, with most emissions falling within the Industry economic sector (minus emissions from the other economic sectors). 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 from the actual process to make the material, not from fuels to power the plant) 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 CO_2 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 CO_2 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.

As agriculture equipment is included in EIA's industrial fuel consuming sector surveys, additional data is used to extract 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 CO_2 emissions from fossil fuel combustion, and CH_4 and N_2O emissions from stationary and mobile combustion (all data is removed from the Industrial economic sector, to avoid double-counting). The other emission sources included in this economic sector are intuitive for the agriculture sectors, such as N_2O emissions from Agricultural Soils, CH_4 from Enteric Fermentation (i.e., exhalation from the digestive tracts of domesticated animals), CH_4 and N_2O from Manure Management, CH_4 from Rice Cultivation, CO_2 emissions from Liming of Agricultural Soils and Urea Application, and CH_4 and N_2O from Forest Fires. N_2O emissions from the Application of Fertilizers to tree plantations (termed "forest land" by the IPCC) are also included in the Agriculture economic sector.

The Residential economic sector includes the CO_2 emissions from the combustion of fossil fuels reported for the EIA residential sector. Stationary combustion emissions of CH_4 and N_2O are also based on the EIA residential fuel consuming sector. Substitutes of Ozone Depleting Substitutes are apportioned based on their specific end-uses within the source category, with emissions from residential air-conditioning systems to this economic sector. N_2O emissions from the Application of Fertilizers to developed land (termed "settlements" by the IPCC) are also included in the Residential economic sector.

The Commercial economic sector includes the CO_2 emissions from the combustion of fossil fuels reported in the EIA commercial fuel consuming sector data. Stationary combustion emissions of CH_4 and N_2O are also based on the EIA commercial sector. Substitutes of Ozone Depleting Substitutes are apportioned based on their specific end-uses within the source category, with emissions from commercial refrigeration/air-conditioning systems to this economic

sector. Public works sources including direct CH_4 from Landfills and CH_4 and N_2O from Wastewater Treatment and Composting are included in this economic sector.

[END BOX]

[BEGIN BOX]

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 non-utilities combined—was the largest source of U.S. greenhouse gas emissions in 2010; (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 0.5 percent since 1990. This rate is slightly slower than that for total energy consumption and growth in national population since 1990 and much slower than that for electricity consumption and overall gross domestic product, respectively. Total U.S. greenhouse gas emissions are growing at a rate similar to that of fossil fuel consumption since 1990 (see Table 2-16).

Table 2-16: Recent Trends in Various U.S. Data (Index 1990 = 100)

Variable	1990		2005	2006	2007	2008	2009	2010	Growth
GDP[b]	100		157	161	165	164	158	163	2.5%
Electricity Consumption[c]	100		134	135	137	136	131	137	1.6%
Fossil Fuel Consumption[c]	100		119	117	119	116	109	113	0.6%
Energy Consumption[c]	100		119	118	121	119	113	117	0.8%
Population[d]	100		118	120	121	122	123	123	1.1%
Greenhouse Gas Emissions[e]	100		117	116	117	114	107	111	0.5%

[a] Average annual growth rate

[b] Gross Domestic Product in chained 2005 dollars (BEA 2011)

[c] Energy-content-weighted values (EIA 2011)

[d] U.S. Census Bureau (2011)

[e] GWP-weighted values

Figure 2-14: U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product
Source: BEA (2011), U.S. Census Bureau (2011), and emission estimates in this report.

[END BOX]

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

The reporting requirements of the UNFCCC[51] request that information be provided on indirect greenhouse gases, which include CO, NO_x, NMVOCs, and SO_2. These gases do not have a direct global warming effect, but indirectly

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

affect terrestrial radiation absorption by influencing the formation and destruction of tropospheric and stratospheric ozone, or, in the case of SO_2, by affecting the absorptive characteristics of the atmosphere. Additionally, some of these gases may react with other chemical compounds in the atmosphere to form compounds that are greenhouse gases. Carbon monoxide is produced when carbon-containing fuels are combusted incompletely. Nitrogen oxides (i.e., NO and NO_2) are created by lightning, fires, fossil fuel combustion, and in the stratosphere from N_2O. Non-CH_4 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, SO_2 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 CH_4 emissions—to form CO_2. Therefore, increased atmospheric concentrations of CO limit the number of hydroxyl molecules (OH) available to destroy CH_4.

Since 1970, the United States has published estimates of annual emissions of CO, NO_x, NMVOCs, and SO_2 (EPA 2010, EPA 2009),[52] 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.

Table 2-17: Emissions of NO_x, CO, NMVOCs, and SO_2 (Gg)

Gas/Activity	1990	2005	2006	2007	2008	2009	2010
NO_x	**21,707**	**15,900**	**15,039**	**14,380**	**13,547**	**11,468**	**11,468**
Mobile Fossil Fuel Combustion	10,862	9,012	8,488	7,965	7,441	6,206	6,206
Stationary Fossil Fuel Combustion	10,023	5,858	5,545	5,432	5,148	4,159	4,159
Industrial Processes	591	569	553	537	520	568	568
Oil and Gas Activities	139	321	319	318	318	393	393
Incineration of Waste	82	129	121	114	106	128	128
Agricultural Burning	8	6	7	8	8	8	8
Solvent Use	1	3	4	4	4	3	3
Waste	+	2	2	2	2	2	2
CO	**130,038**	**70,809**	**67,238**	**63,625**	**60,039**	**51,452**	**51,452**
Mobile Fossil Fuel Combustion	119,360	62,692	58,972	55,253	51,533	43,355	43,355
Stationary Fossil Fuel Combustion	5,000	4,649	4,695	4,744	4,792	4,543	4,543
Industrial Processes	4,125	1,555	1,597	1,640	1,682	1,549	1,549
Incineration of Waste	978	1,403	1,412	1,421	1,430	1,403	1,403
Agricultural Burning	268	184	233	237	270	247	247
Oil and Gas Activities	302	318	319	320	322	345	345
Waste	1	7	7	7	7	7	7
Solvent Use	5	2	2	2	2	2	2
NMVOCs	**20,930**	**13,761**	**13,594**	**13,423**	**13,254**	**9,313**	**9,313**
Mobile Fossil Fuel Combustion	10,932	6,330	6,037	5,742	5,447	4,151	4,151
Solvent Use	5,216	3,851	3,846	3,839	3,834	2,583	2,583
Industrial Processes	2,422	1,997	1,933	1,869	1,804	1,322	1,322
Stationary Fossil Fuel Combustion	912	716	918	1,120	1,321	424	424
Oil and Gas Activities	554	510	510	509	509	599	599
Incineration of Waste	222	241	238	234	230	159	159
Waste	673	114	113	111	109	76	76
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA

[52] NO_x and CO emission estimates from field burning of agricultural residues were estimated separately, and therefore not taken from EPA (2009) and EPA (2010).

SO_2	**20,935**	**13,466**	**12,388**	**11,799**	**10,368**	**8,599**	**8,599**
Stationary Fossil Fuel Combustion	18,407	11,541	10,612	10,172	8,891	7,167	7,167
Industrial Processes	1,307	831	818	807	795	798	798
Mobile Fossil Fuel Combustion	793	889	750	611	472	455	455
Oil and Gas Activities	390	181	182	184	187	154	154
Incineration of Waste	38	24	24	24	23	24	24
Waste	+	1	1	1	1	1	1
Solvent Use	+	+	+	+	+	+	+
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA

Source: (EPA 2010, EPA 2009) except for estimates from field burning of agricultural residues.

NA (Not Available)

Note: Totals may not sum due to independent rounding.

[BEGIN BOX]

Box 2-3: Sources and Effects of Sulfur Dioxide

Sulfur dioxide (SO_2) 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 SO_2 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 SO_2 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 SO_2 emissions in the Clean Air Act.

Electricity generation is the largest anthropogenic source of SO_2 emissions in the United States, accounting for 60 percent in 2010. 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.

[END BOX]

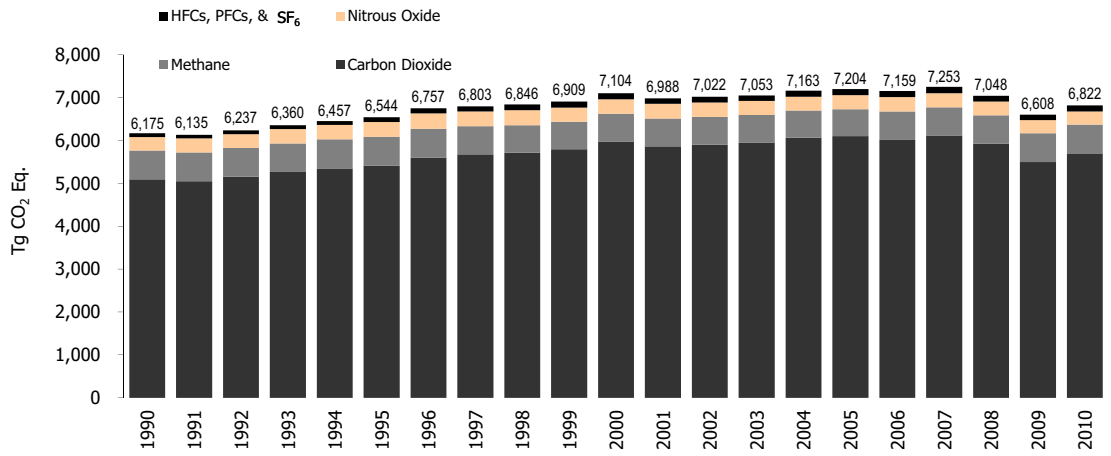


Figure 2-1: U.S. Greenhouse Gas Emissions by Gas

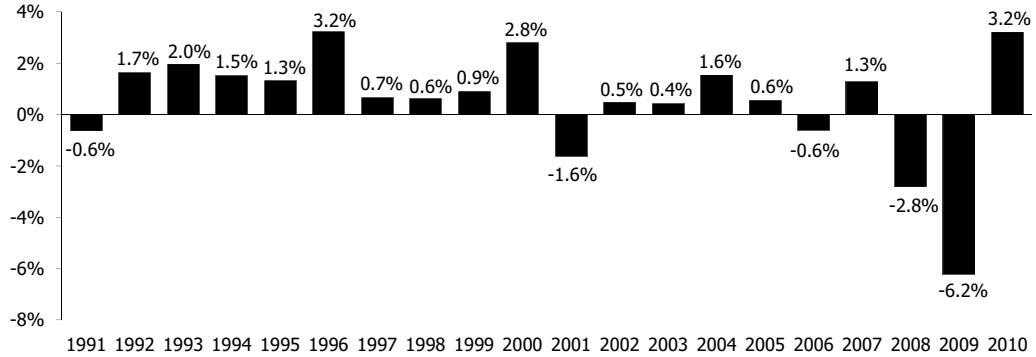


Figure 2-2: Annual Percent Change in U.S. Greenhouse Gas Emissions

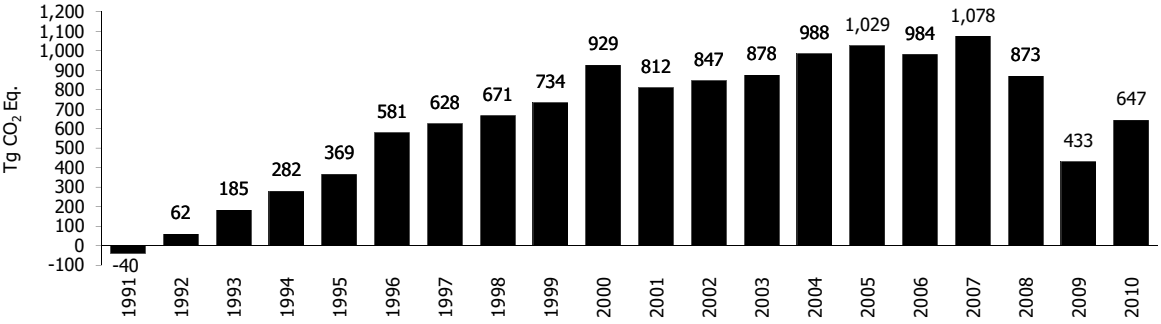
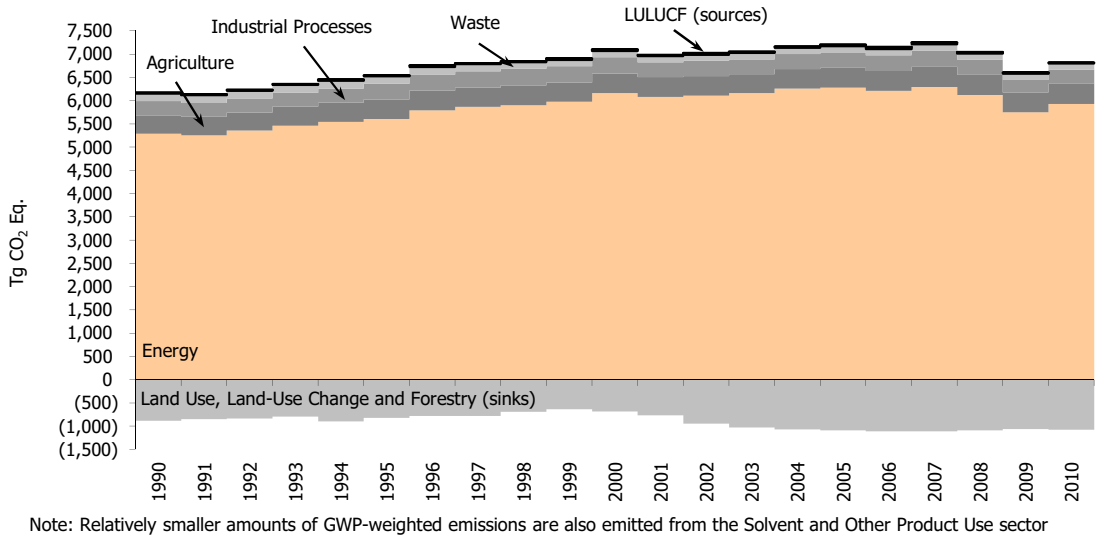


Figure 2-3: Cumulative Change in Annual U.S. Greenhouse Gas Emissions Relative to 1990



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

Figure 2-4: U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector

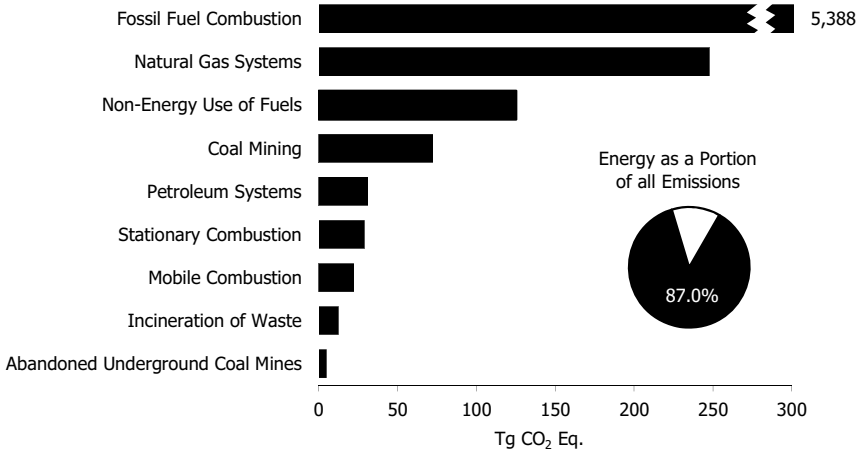


Figure 2-5: 2010 Energy Sector Greenhouse Gas Sources

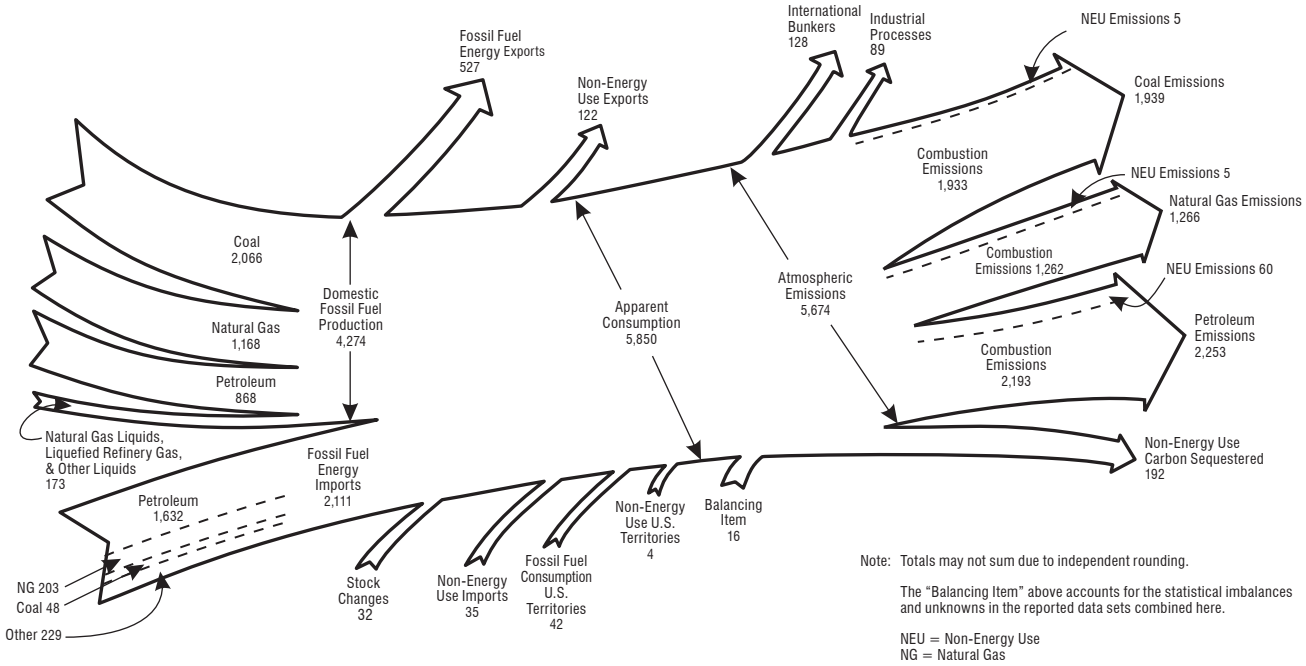


Figure 2-6 2010 U.S. Fossil Carbon Flows (Tg CO_2 Eq.)

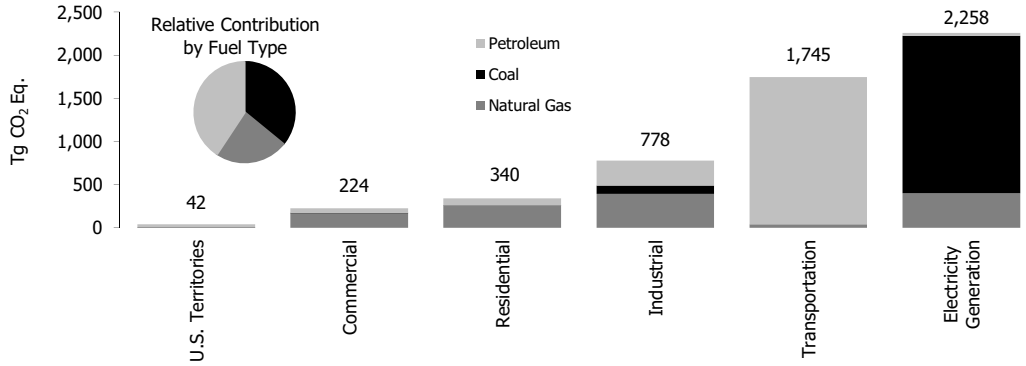


Figure 2-7: 2010 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type

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

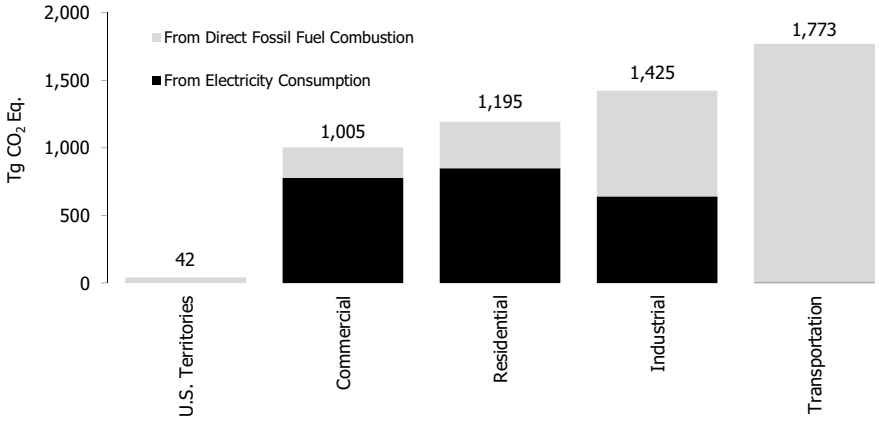


Figure 2-8: 2010 End-Use Sector Emissions from Fossil Fuel Combustion

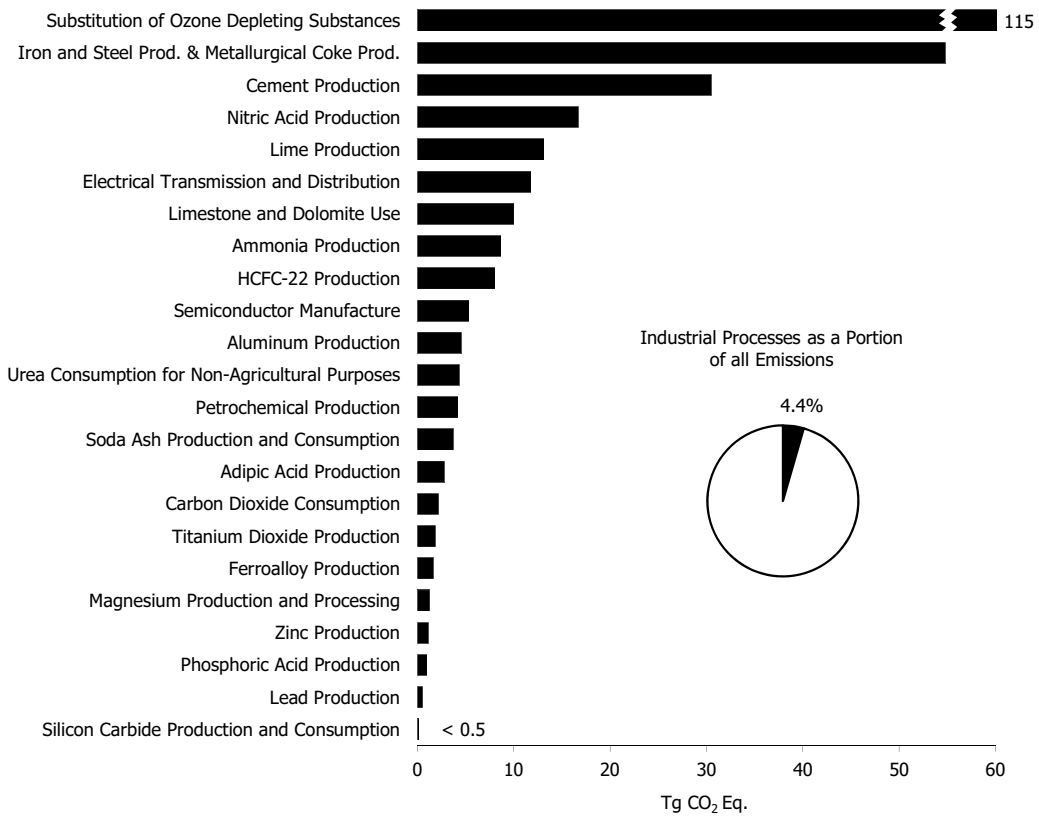


Figure 2-9: 2010 Industrial Processes Chapter Greenhouse Gas Sources

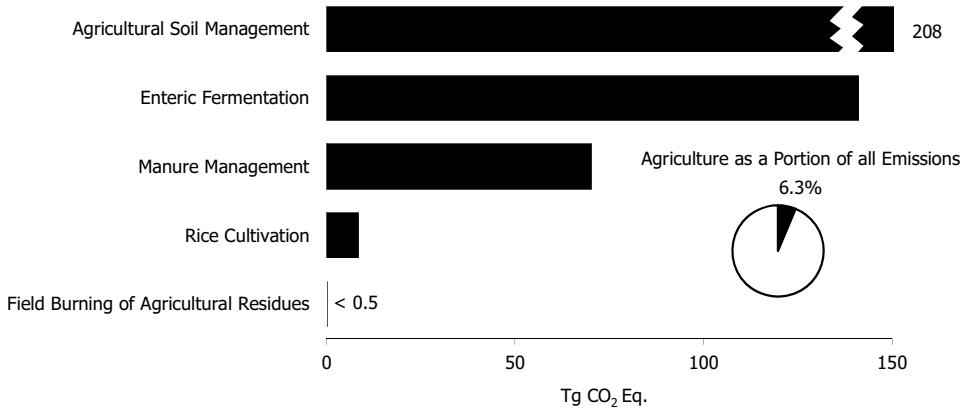


Figure 2-10: 2010 Agriculture Chapter Greenhouse Gas Sources

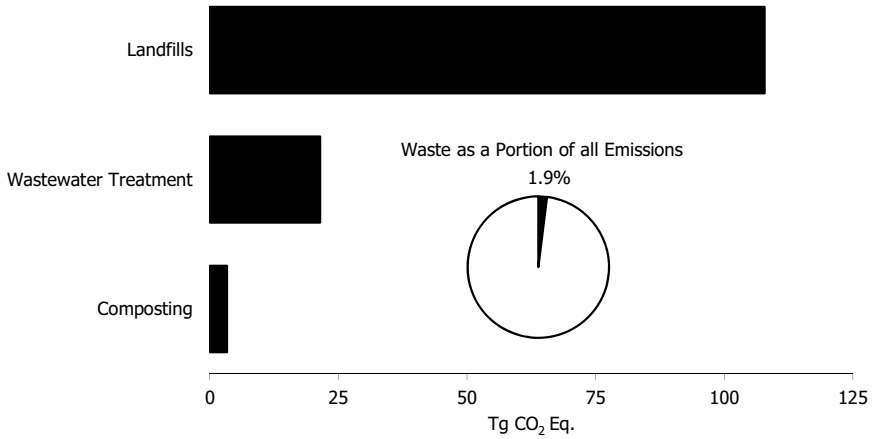


Figure 2-11: 2010 Waste Chapter Greenhouse Gas Sources

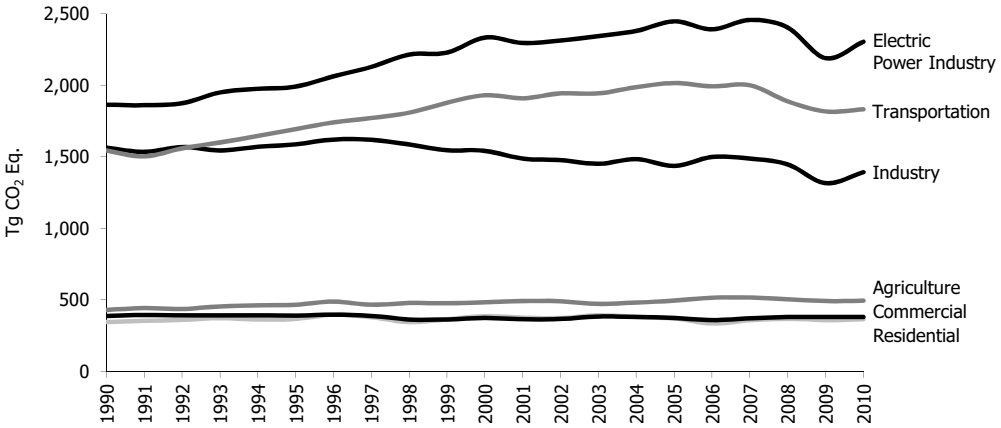


Figure 2-12: Emissions Allocated to Economic Sectors

Note: Does not include U.S. Territories.

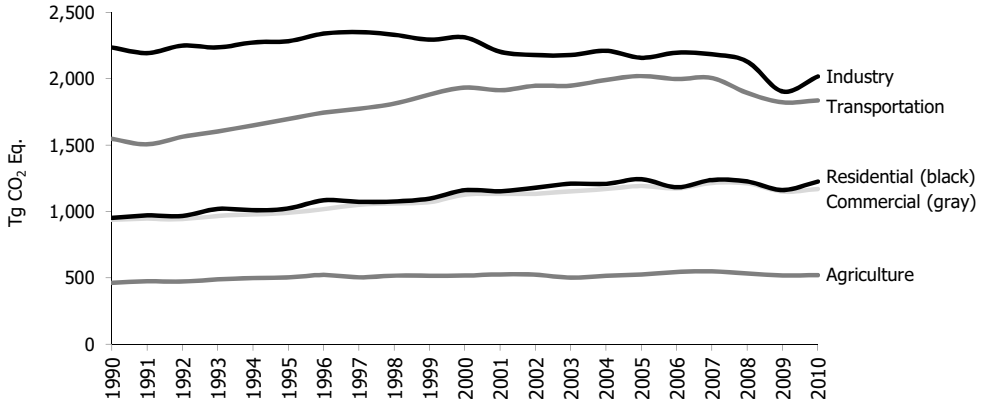


Figure 2-13: Emissions with Electricity Distributed to Economic Sectors

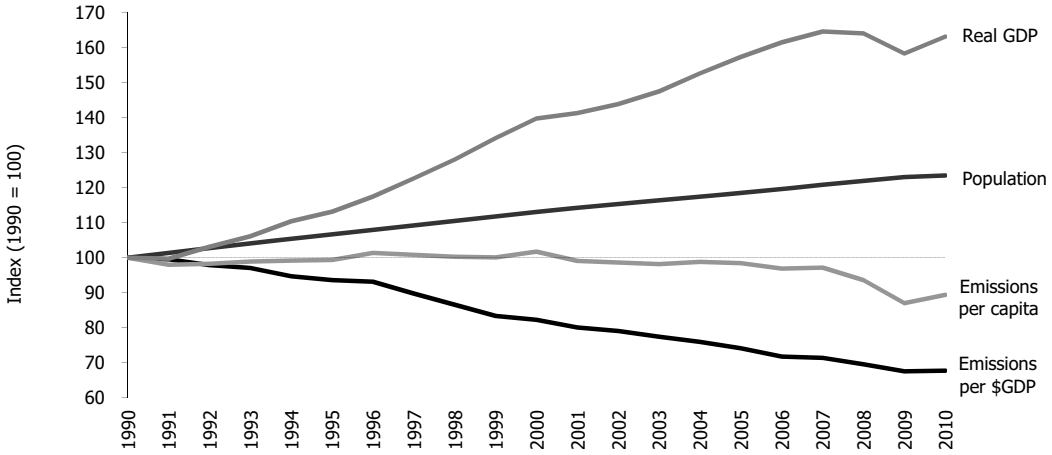


Figure 2-14: U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product

3. Energy

Energy-related activities were the primary sources of U.S. anthropogenic greenhouse gas emissions, accounting for 87.0 percent of total greenhouse gas emissions on a carbon dioxide (CO_2) equivalent basis[53] in 2010. This included 97, 50, and 14 percent of the nation's CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions, respectively. Energy-related CO_2 emissions alone constituted 81 percent of national emissions from all sources on a CO_2 equivalent basis, while the non-CO_2 emissions from energy-related activities represented a much smaller portion of total national emissions (5.5 percent collectively).

Emissions from fossil fuel combustion comprise the vast majority of energy-related emissions, with CO_2 being the primary gas emitted (see Figure 3-1). Globally, approximately 30,313 Tg of CO_2 were added to the atmosphere through the combustion of fossil fuels in 2009, of which the United States accounted for about 18 percent.[54] Due to their relative importance, fossil fuel combustion-related CO_2 emissions are considered separately, and in more detail than other energy-related emissions (see Figure 3-2). Fossil fuel combustion also emits CH_4 and N_2O. Stationary combustion of fossil fuels was the second largest source of N_2O emissions in the United States and mobile fossil fuel combustion was the third largest source.

Figure 3-1: 2010 Energy Chapter Greenhouse Gas Sources

Figure 3-2: 2010 U.S. Fossil Carbon Flows (Tg CO_2 Eq.)

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 CH_4 from natural gas systems, petroleum systems, and coal mining.

Table 3-1 summarizes emissions from the Energy sector in units of teragrams (or million metric tons) of CO_2 equivalents (Tg CO_2 Eq.), while unweighted gas emissions in gigagrams (Gg) are provided in Table 3-2. Overall, emissions due to energy-related activities were 5,933.5 Tg CO_2 Eq. in 2010, an increase of 12 percent since 1990.

Table 3-1: CO_2, CH_4, and N_2O Emissions from Energy (Tg CO_2 Eq.)

Gas/Source	1990	2005	2006	2007	2008	2009	2010
CO_2	**4,903.9**	**5,933.3**	**5,840.4**	**5,936.7**	**5,755.2**	**5,374.1**	**5,557.6**
Fossil Fuel Combustion	4,738.3	5,746.5	5,653.0	5,757.8	5,571.5	5,206.2	5,387.8
Electricity Generation	1,820.8	2,402.1	2,346.4	2,412.8	2,360.9	2,146.4	2,258.4
Transportation	1,485.9	1,896.6	1,878.1	1,893.9	1,789.8	1,727.9	1,745.5
Industrial	846.4	816.4	848.1	844.4	806.5	726.6	777.8
Residential	338.3	357.9	321.5	341.6	349.3	339.0	340.2
Commercial	219.0	223.5	208.6	218.9	225.1	224.6	224.2
U.S. Territories	27.9	50.0	50.3	46.1	39.8	41.7	41.6
Non-Energy Use of Fuels	119.6	144.1	143.8	134.9	138.6	123.7	125.1
Natural Gas Systems	37.6	29.9	30.8	31.0	32.8	32.2	32.3
Incineration of Waste	8.0	12.5	12.5	12.7	11.9	11.7	12.1
Petroleum Systems	0.4	0.3	0.3	0.3	0.3	0.3	0.3
*Biomass - Wood**	*214.4*	*205.7*	*202.7*	*202.2*	*197.4*	*181.8*	*191.6*
*International Bunker Fuels**	*111.8*	*109.8*	*128.4*	*127.6*	*133.7*	*122.3*	*127.8*
*Biomass – Ethanol**	*4.2*	*22.9*	*31.0*	*38.9*	*54.7*	*62.3*	*74.5*
CH_4	**327.1**	**291.2**	**319.1**	**307.0**	**323.5**	**335.1**	**332.3**
Natural Gas Systems	189.6	190.5	217.7	205.3	212.7	220.9	215.4

[53] Estimates are presented in units of teragrams of carbon dioxide equivalent (Tg CO_2 Eq.), which weight each gas by its global warming potential, or GWP, value. See section on global warming potentials in the Executive Summary.

[54] Global CO_2 emissions from fossil fuel combustion were taken from Energy Information Administration *International Energy Statistics 2010* < http://tonto.eia.doe.gov/cfapps/ipdbproject/IEDIndex3.cfm> EIA (2010).

Coal Mining	84.1	56.8	58.1	57.8	66.9	70.1	72.6
Petroleum Systems	35.2	29.2	29.2	29.8	30.0	30.7	31.0
Stationary Combustion	7.5	6.6	6.2	6.5	6.6	6.3	6.3
Abandoned Underground Coal Mines	6.0	5.5	5.5	5.3	5.3	5.1	5.0
Mobile Combustion	4.7	2.5	2.4	2.2	2.1	2.0	1.9
Incineration of Waste	+	+	+	+	+	+	+
*International Bunker Fuels**	*0.2*	*0.1*	*0.2*	*0.2*	*0.2*	*0.1*	*0.2*
N_2O	**56.7**	**58.0**	**54.8**	**50.6**	**46.7**	**43.6**	**43.6**
Mobile Combustion	43.9	37.0	33.7	29.0	25.2	22.5	20.6
Stationary Combustion	12.3	20.6	20.8	21.2	21.1	20.7	22.6
Incineration of Waste	0.5	0.4	0.4	0.4	0.4	0.4	0.4
*International Bunker Fuels**	*1.1*	*1.0*	*1.2*	*1.2*	*1.2*	*1.1*	*1.2*
Total	**5,287.7**	**6,282.4**	**6,214.4**	**6,294.3**	**6,125.4**	**5,752.7**	**5,933.5**

+ Does not exceed 0.05 Tg CO_2 Eq.

* These values are presented for informational purposes only, in line with IPCC methodological guidance and UNFCCC reporting obligations, and are not included in the specific energy sector contribution to the totals, and are already accounted for elsewhere.

Note: Totals may not sum due to independent rounding.

Table 3-2: CO_2, CH_4, and N_2O Emissions from Energy (Gg)

Gas/Source	1990	2005	2006	2007	2008	2009	2010
CO_2	**4,903,922**	**5,933,252**	**5,840,384**	**5,936,724**	**5,755,172**	**5,374,077**	**5,557,611**
Fossil Fuel Combustion	4,738,338	5,746,480	5,653,032	5,757,775	5,571,537	5,206,168	5,387,790
Non-Energy Use of Fuels	119,627	144,098	143,761	134,863	138,624	123,712	125,130
Natural Gas Systems	37,574	29,901	30,754	31,049	32,826	32,169	32,301
Incineration of Waste	7,989	12,468	12,531	12,727	11,888	11,703	12,054
Petroleum Systems	394	305	306	310	297	325	337
*Biomass -Wood**	*214,410*	*205,671*	*202,680*	*202,204*	*197,358*	*181,806*	*191,591*
*International Bunker Fuels**	*111,828*	*109,765*	*128,413*	*127,643*	*133,730*	*122,338*	*127,841*
*Biomass - Ethanol**	*4,227*	*22,943*	*30,985*	*38,924*	*54,739*	*62,272*	*74,519*
CH_4	**15,575**	**13,864**	**15,196**	**14,619**	**15,405**	**15,955**	**15,825**
Natural Gas Systems	9,029	9,071	10,369	9,774	10,127	10,519	10,259
Coal Mining	4,003	2,705	2,768	2,754	3,186	3,340	3,458
Petroleum Systems	1,677	1,390	1,389	1,420	1,427	1,460	1,478
Stationary Combustion	355	315	296	311	313	298	301
Abandoned Underground Coal Mines	288	264	261	254	253	244	237
Mobile Combustion	223	121	114	107	99	93	91
Incineration of Waste	+	+	+	+	+	+	+
*International Bunker Fuels**	*8*	*7*	*8*	*8*	*8*	*7*	*8*
N_2O	**183**	**187**	**177**	**163**	**151**	**141**	**141**
Mobile Combustion	142	119	109	94	81	73	66
Stationary Combustion	40	66	67	68	68	67	73
Incineration of Waste	2	1	1	1	1	1	1
*International Bunker Fuels**	*3*	*3*	4	4	4	4	4

+ Does not exceed 0.05 Tg CO_2 Eq.

* These values are presented for informational purposes only, in line with IPCC methodological guidance and UNFCCC reporting obligations, and are not included in the specific energy sector contribution to the totals, and are already accounted for elsewhere.

Note: Totals may not sum due to independent rounding.

[BEGIN BOX]

Box 3 1: Energy Data from the Greenhouse Gas Reporting Program

On October 30, 2009, the U.S. Environmental Protection Agency (EPA) published a rule for the mandatory reporting of greenhouse gases (GHG) from large GHG emissions sources in the United States. Implementation of 40 CFR Part 98 is referred to as the Greenhouse Gas Reporting Program (GHGRP). 40 CFR part 98 applies to direct greenhouse gas emitters, fossil fuel suppliers, industrial gas suppliers, and facilities that inject CO_2 underground for sequestration or other reasons. Reporting is at the facility level, except for certain suppliers of fossil fuels and industrial greenhouse gases. 40 CFR part 98 requires reporting by 41 industrial categories. In general, the threshold for reporting is 25,000 metric tons or more of CO_2 Eq. per year. For calendar year 2010, the first year in which data were reported, facilities in 29 categories provided in 40 CFR part 98 were required to report their 2010 emissions by the September 30, 2011 reporting deadline. Data reporting by affected facilities included the reporting of emissions from fuel combustion at that affected facility.

The GHGRP dataset and the data presented in this inventory report are complementary and, as indicated in the respective planned improvements sections for source categories in this chapter, EPA is analyzing how to use facility-level GHGRP data to improve the national estimates presented in this inventory. Most methodologies used in the GHGRP are consistent with IPCC, though for the GHGRP, facilities collect detailed information specific to their operations according to detailed measurement standards, which may differ with the more aggregated data collected for the inventory to estimate total, national U.S. emissions. It should be noted that the definitions and provisions for reporting fuel types in the GHGRP may differ from those used in the inventory in meeting the UNFCCC reporting guidelines. In line with the UNFCCC reporting guidelines, the inventory report is a comprehensive accounting of all emissions from fuel types identified in the IPCC guidelines and provides a separate reporting of emissions from biomass. Further information on the reporting categorizations in GHGRP and specific data caveats associated with monitoring methods in the GHGRP has been provided on the GHGRP website.

EPA presents the data collected by the GHGRP through a data publication tool that allows data to be viewed in several formats including maps, tables, charts and graphs for individual facilities or groups of facilities.

[END BOX]

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

Emissions from the combustion of fossil fuels for energy include the gases CO_2, CH_4, and N_2O. Given that CO_2 is the primary gas emitted from fossil fuel combustion and represents the largest share of U.S. total emissions, CO_2 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 CO_2 from fossil fuel combustion also differ from the estimation of CH_4 and N_2O 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 CO_2, CH_4, and N_2O emissions from fossil fuel combustion are presented in Table 3-3 and Table 3-4.

Table 3-3: CO_2, CH_4, and N_2O Emissions from Fossil Fuel Combustion (Tg CO_2 Eq.)

Gas	1990	2005	2006	2007	2008	2009	2010
CO_2	4,738.3	5,746.5	5,653.0	5,757.8	5,571.5	5,206.2	5,387.8
CH_4	12.1	9.1	8.6	8.8	8.7	8.2	8.2
N_2O	56.2	57.6	54.5	50.2	46.4	43.3	43.2
Total	**4,806.7**	**5,813.3**	**5,716.1**	**5,816.8**	**5,626.6**	**5,257.7**	**5,439.3**

Note: Totals may not sum due to independent rounding.

Table 3-4: CO_2, CH_4, and N_2O Emissions from Fossil Fuel Combustion (Gg)

Gas	1990	2005	2006	2007	2008	2009	2010
CO_2	4,738,338	5,746,480	5,653,032	5,757,775	5,571,537	5,206,168	5,387,790
CH_4	578	436	410	417	412	392	392
N_2O	181	186	176	162	150	140	139

Note: Totals may not sum due to independent rounding.

CO_2 from Fossil Fuel Combustion

CO_2 is the primary gas emitted from fossil fuel combustion and represents the largest share of U.S. total greenhouse gas emissions. CO_2 emissions from fossil fuel combustion are presented in Table 3-5. In 2010, CO_2 emissions from fossil fuel combustion increased by 3.7 percent relative to the previous year which represents the largest annual increase in CO_2 emissions from fossil fuel combustion for the twenty-one-year period.[55] The increase in CO_2 emissions from fossil fuel combustion was a result of multiple factors including: (1) an increase in economic output resulting in an increase in energy consumption across all sectors; (2) an increase in the carbon intensity of fuels consumed due to only a slight increase in the price of coal, and a significant increase in the price of petroleum and natural gas; and (3) much warmer summer conditions resulting in an increase in electricity demand. In 2010, CO_2 emissions from fossil fuel combustion were 5,387.8 Tg CO_2 Eq., or 14 percent above emissions in 1990 (see Table 3-5).[56]

Table 3-5: CO_2 Emissions from Fossil Fuel Combustion by Fuel Type and Sector (Tg CO_2 Eq.)

Fuel/Sector	1990	2005	2006	2007	2008	2009	2010
Coal	**1,718.4**	**2,112.3**	**2,076.6**	**2,106.0**	**2,072.5**	**1,834.4**	**1,933.2**
Residential	3.0	0.8	0.6	0.7	0.7	0.7	0.7
Commercial	12.0	9.3	6.2	6.7	6.5	5.9	5.5
Industrial	155.3	115.3	112.6	107.0	102.6	83.3	96.2
Transportation	NE	NE	NE	NE	NE	NE	NE
Electricity Generation	1,547.6	1,983.8	1,953.7	1,987.3	1,959.4	1,740.9	1,827.3
U.S. Territories	0.6	3.0	3.4	4.3	3.3	3.5	3.5
Natural Gas	**1,001.4**	**1,159.6**	**1,151.8**	**1,226.3**	**1,237.9**	**1,216.6**	**1,261.6**
Residential	238.0	262.2	237.3	256.3	265.5	258.8	258.8
Commercial	142.1	162.9	153.8	163.5	171.1	168.9	167.7
Industrial	409.9	381.4	388.2	398.6	401.0	377.3	394.2
Transportation	36.0	33.1	33.1	35.2	36.7	37.9	40.1
Electricity Generation	175.3	318.8	338.0	371.3	361.9	372.2	399.4
U.S. Territories	NO	1.3	1.4	1.4	1.6	1.5	1.5
Petroleum	**2,018.1**	**2,474.2**	**2,424.2**	**2,425.1**	**2,260.8**	**2,154.8**	**2,192.6**
Residential	97.4	94.9	83.6	84.6	83.1	79.4	80.7
Commercial	64.9	51.3	48.5	48.7	47.4	49.7	51.1
Industrial	281.2	319.6	347.3	338.7	302.9	265.9	287.4
Transportation	1,449.9	1,863.5	1,845.0	1,858.7	1,753.2	1,690.0	1,705.4
Electricity Generation	97.5	99.2	54.4	53.9	39.2	33.0	31.3
U.S. Territories	27.2	45.7	45.5	40.4	35.0	36.7	36.7
Geothermal*	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Total	**4,738.3**	**5,746.5**	**5,653.0**	**5,757.8**	**5,571.5**	**5,206.2**	**5,387.8**

NE (Not estimated)

* Although not technically a fossil fuel, geothermal energy-related CO_2 emissions are included for reporting purposes.

Note: Totals may not sum due to independent rounding.

Trends in CO_2 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

[55] This increase also represents the largest absolute and percentage increase since 1988 (EIA 2011a).

[56] An additional discussion of fossil fuel emission trends is presented in the Trends in U.S. Greenhouse Gas Emissions Chapter.

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.

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).

CO_2 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.[57] Table 3-6 shows annual changes in emissions during the last five years for coal, petroleum, and natural gas in selected sectors.

Table 3-6: Annual Change in CO_2 Emissions and Total 2010 Emissions from Fossil Fuel Combustion for Selected Fuels and Sectors (Tg CO_2 Eq. and Percent)

Sector	Fuel Type	2006 to 2007		2007 to 2008		2008 to 2009		2009 to 2010		Total 2010
Electricity Generation	Coal	33.6	1.7%	-27.9	-1.4%	-218.5	-11.2%	86.4	5.0%	1,827.3
Electricity Generation	Natural Gas	33.3	9.9%	-9.3	-2.5%	10.3	2.8%	27.2	7.3%	399.4
Electricity Generation	Petroleum	-0.5	-0.9%	-14.7	-27.2%	-6.3	-15.9%	-1.7	-5.2%	31.3
Transportation[a]	Petroleum	13.7	0.7%	-105.6	-5.7%	-63.1	-3.6%	15.4	0.9%	1,705.4
Residential	Natural Gas	19.0	8.0%	9.3	3.6%	-6.7	-2.5%	0.0	0.0%	258.8
Commercial	Natural Gas	9.7	6.3%	7.6	4.6%	-2.2	-1.3%	-1.2	-0.7%	167.7
Industrial	Coal	-5.6	-5.0%	-4.4	-4.1%	-19.3	-18.8%	12.8	15.4%	96.2
Industrial	Natural Gas	10.4	2.7%	2.4	0.6%	-23.7	-5.9%	16.9	4.5%	394.2
All Sectors[b]	**All Fuels[b]**	**104.7**	**1.9%**	**-186.2**	**-3.2%**	**-365.4**	**-6.6%**	**181.6**	**3.5%**	**5,387.8**

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

In the United States, 85 percent of the energy consumed in 2010 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[58] (6 percent), primarily hydroelectric power and biofuels (EIA 2011a). Specifically, petroleum supplied the largest share of domestic energy demands, accounting for 41 percent of total fossil fuel based energy consumption in 2010. Natural gas and coal followed in order of energy demand importance, accounting for approximately 32 and 27 percent of total consumption, respectively. Petroleum was consumed primarily in the transportation end-use sector and the vast majority of coal was used in electricity generation. Natural gas was broadly consumed in all end-use sectors except transportation (see Figure 3-5) (EIA 2011a).

Figure 3-3: 2010 U.S. Energy Consumption by Energy Source

Figure 3-4: U.S. Energy Consumption (Quadrillion Btu)

Figure 3-5: 2010 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type

Fossil fuels are generally combusted for the purpose of producing energy for useful heat and work. During the

[57] Based on national aggregate carbon content of all coal, natural gas, and petroleum fuels combusted in the United States.
[58] Renewable energy, as defined in EIA's energy statistics, includes the following energy sources: hydroelectric power, geothermal energy, biofuels, solar energy, and wind energy

combustion process, the C stored in the fuels is oxidized and emitted as CO_2 and smaller amounts of other gases, including CH_4, CO, and NMVOCs.[59] These other C containing non-CO_2 gases are emitted as a byproduct of incomplete fuel combustion, but are, for the most part, eventually oxidized to CO_2 in the atmosphere. Therefore, it is assumed that all of the C in fossil fuels used to produce energy is eventually converted to atmospheric CO_2.

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Box 3-1: Weather and Non-Fossil Energy Effects on CO_2 from Fossil Fuel Combustion Trends

In 2010, weather conditions remained fairly constant in the winter and much hotter in the summer compared to 2009, as heating degree days decreased slightly (0.7 percent) and cooling degree days increased by 19 percent. This increase in cooling degree days led to an increase in electricity demand to cool homes. Winter conditions were relatively constant in 2010 compared to 2009, and the winter was slightly warmer than normal, with heating degree days in the United States 1.4 percent below normal (see Figure 3-6). Summer conditions were much warmer in 2010 compared to 2009, and summer temperatures were much warmer than normal, with cooling degree days 17 percent above normal (see Figure 3-7) (EIA 2011a).[60]

Figure 3-6: Annual Deviations from Normal Heating Degree Days for the United States (1950–2010)

Figure 3-7: Annual Deviations from Normal Cooling Degree Days for the United States (1950–2010)

Although no new U.S. nuclear power plants have been constructed in recent years, the utilization (i.e., capacity factors[61]) of existing plants in 2010 remained high at just over 91 percent. Electricity output by hydroelectric power plants decreased in 2010 by approximately 6.0 percent. Electricity generated by nuclear plants in 2010 provided more than 3 times as much of the energy consumed in the United States as hydroelectric plants (EIA 2011a). Nuclear, hydroelectric, and wind power capacity factors since 1990 are shown in Figure 3-8.

Figure 3-8: Nuclear, Hydroelectric, and Wind Power Plant Capacity Factors in the United States (1990–2010)

[END BOX]

Fossil Fuel Combustion Emissions by Sector

In addition to the CO_2 emitted from fossil fuel combustion, CH_4 and N_2O are emitted from stationary and mobile combustion as well. Table 3-7 provides an overview of the CO_2, CH_4, and N_2O emissions from fossil fuel combustion by sector.

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[59] See the sections entitled Stationary Combustion and Mobile Combustion in this chapter for information on non-CO_2 gas emissions from fossil fuel combustion.

[60] 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).

[61] 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 (2011a).

Table 3-7: CO_2, CH_4, and N_2O Emissions from Fossil Fuel Combustion by Sector (Tg CO_2 Eq.)

End-Use Sector	1990	2005	2006	2007	2008	2009	2010
Electricity Generation	**1,828.5**	**2,418.6**	**2,363.1**	**2,430.0**	**2,378.2**	**2,163.7**	**2,277.3**
CO_2	1,820.8	2,402.1	2,346.4	2,412.8	2,360.9	2,146.4	2,258.4
CH_4	0.3	0.5	0.5	0.5	0.5	0.4	0.5
N_2O	7.4	16.0	16.2	16.7	16.9	16.9	18.5
Transportation	**1,534.6**	**1,936.1**	**1,914.2**	**1,925.1**	**1,817.1**	**1,752.4**	**1,768.0**
CO_2	1,485.9	1,896.6	1,878.1	1,893.9	1,789.8	1,727.9	1,745.5
CH_4	4.7	2.5	2.4	2.2	2.1	2.0	1.9
N_2O	43.9	37.0	33.7	29.0	25.2	22.5	20.6
Industrial	**851.3**	**821.0**	**852.9**	**849.0**	**810.8**	**730.4**	**782.0**
CO_2	846.4	816.4	848.1	844.4	806.5	726.6	777.8
CH_4	1.6	1.5	1.5	1.5	1.4	1.2	1.4
N_2O	3.3	3.1	3.2	3.1	2.9	2.5	2.8
Residential	**344.1**	**362.5**	**325.6**	**346.2**	**354.0**	**343.5**	**344.7**
CO_2	338.3	357.9	321.5	341.6	349.3	339.0	340.2
CH_4	4.6	3.6	3.3	3.6	3.7	3.6	3.5
N_2O	1.1	1.0	0.9	0.9	1.0	0.9	0.9
Commercial	**220.2**	**224.8**	**209.8**	**220.1**	**226.4**	**225.9**	**225.5**
CO_2	219.0	223.5	208.6	218.9	225.1	224.6	224.2
CH_4	0.9	0.9	0.9	0.9	0.9	1.0	0.9
N_2O	0.4	0.4	0.3	0.3	0.3	0.3	0.3
U.S. Territories*	**28.0**	**50.2**	**50.5**	**46.3**	**40.0**	**41.8**	**41.8**
Total	**4,806.7**	**5,813.3**	**5,716.1**	**5,816.8**	**5,626.6**	**5,257.7**	**5,439.3**

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.

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

Other than CO_2, gases emitted from stationary combustion include the greenhouse gases CH_4 and N_2O and the indirect greenhouse gases NO_x, CO, and NMVOCs.[62] Methane and N_2O 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. N_2O 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 CH_4 content of the fuel and combustion efficiency.

Mobile combustion produces greenhouse gases other than CO_2, including CH_4, N_2O, and indirect greenhouse gases including NO_x, CO, and NMVOCs. As with stationary combustion, N_2O 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. N_2O 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. CO 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 CH_4 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 CH_4 and N_2O

[62] Sulfur dioxide (SO_2) emissions from stationary combustion are addressed in Annex 6.3.

from transportation.[63] Emissions from U.S. territories are also calculated separately due to a lack of end-use-specific consumption data. This method assumes that emissions from combustion sources are distributed across the four end-use sectors based on the ratio of electricity consumption in that sector. The results of this alternative method are presented in Table 3-8.

Table 3-8: CO_2, CH_4, and N_2O Emissions from Fossil Fuel Combustion by End-Use Sector (Tg CO_2 Eq.)

End-Use Sector	1990	2005	2006	2007	2008	2009	2010
Transportation	**1,537.6**	**1,940.9**	**1,918.8**	**1,930.2**	**1,821.9**	**1,756.9**	**1,772.5**
CO_2	1,489.0	1,901.3	1,882.6	1,899.0	1,794.5	1,732.4	1,750.0
CH_4	4.7	2.5	2.4	2.2	2.1	2.0	1.9
N_2O	44.0	37.0	33.7	29.0	25.3	22.5	20.6
Industrial	**1,540.9**	**1,563.0**	**1,570.0**	**1,569.5**	**1,513.2**	**1,337.2**	**1,424.9**
CO_2	1,533.1	1,553.3	1,560.2	1,559.8	1,503.8	1,328.6	1,415.4
CH_4	1.7	1.7	1.7	1.6	1.5	1.4	1.5
N_2O	6.1	8.1	8.2	8.1	7.9	7.2	8.0
Residential	**939.6**	**1,225.1**	**1,162.4**	**1,215.8**	**1,203.1**	**1,136.3**	**1,195.2**
CO_2	931.4	1,214.7	1,152.4	1,205.2	1,192.2	1,125.5	1,183.7
CH_4	4.7	3.8	3.4	3.8	3.9	3.8	3.7
N_2O	3.5	6.7	6.6	6.9	7.0	7.1	7.8
Commercial	**760.5**	**1,034.0**	**1,014.5**	**1,054.9**	**1,048.4**	**985.4**	**1,004.9**
CO_2	757.0	1,027.2	1,007.6	1,047.7	1,041.1	978.0	997.1
CH_4	1.0	1.1	1.0	1.1	1.1	1.1	1.1
N_2O	2.6	5.7	5.9	6.1	6.2	6.3	6.7
U.S. Territories*	**28.0**	**50.2**	**50.5**	**46.3**	**40.0**	**41.8**	**41.8**
Total	**4,806.7**	**5,813.3**	**5,716.1**	**5,816.8**	**5,626.6**	**5,257.7**	**5,439.3**

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.

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

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 CO_2 emissions from fossil fuel combustion by stationary sources. The CO_2 emitted is closely linked to the type of fuel being combusted in each sector (see Methodology section for CO_2 from fossil fuel combustion). Other than CO_2, gases emitted from stationary combustion include the greenhouse gases CH_4 and N_2O. Table 3-10 and Table 3-11 present CH_4 and N_2O emissions from the combustion of fuels in stationary sources. [64] Methane and N_2O emissions from stationary combustion sources depend upon fuel characteristics, combustion technology, pollution control equipment, ambient environmental conditions, and operation and maintenance practices. N_2O 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 CH_4 content of the fuel and combustion efficiency. The CH_4 and N_2O emission estimation methodology was revised in 2010 to utilize the facility-specific technology and fuel use data reported to EPA's Acid Rain Program (see Methodology section for CH_4 and N_2O from stationary combustion). Please refer to Table 3-7 for the corresponding presentation of all direct emission sources of fuel combustion.

Table 3-9: CO_2 Emissions from Stationary Fossil Fuel Combustion (Tg CO_2 Eq.)

[63] Separate calculations were performed for transportation-related CH_4 and N_2O. The methodology used to calculate these emissions are discussed in the mobile combustion section.

[64] Since emissions estimates for U.S. territories cannot be disaggregated by gas in Table 3-10 and Table 3-11, the percentages for CH_4 and N_2O exclude U.S. territory estimates.

Sector/Fuel Type	1990	2005	2006	2007	2008	2009	2010
Electricity Generation	**1,820.8**	**2,402.1**	**2,346.4**	**2,412.8**	**2,360.9**	**2,146.4**	**2,258.4**
Coal	1,547.6	1,983.8	1,953.7	1,987.3	1,959.4	1,740.9	1,827.3
Natural Gas	175.3	318.8	338.0	371.3	361.9	372.2	399.4
Fuel Oil	97.5	99.2	54.4	53.9	39.2	33.0	31.3
Geothermal	0.4	0.38	0.37	0.38	0.38	0.38	0.40
Industrial	**846.4**	**816.4**	**848.1**	**844.4**	**806.5**	**726.6**	**777.8**
Coal	155.3	115.3	112.6	107.0	102.6	83.3	96.2
Natural Gas	409.9	381.4	388.2	398.6	401.0	377.3	394.2
Fuel Oil	281.2	319.6	347.3	338.7	302.9	265.9	287.4
Commercial	**219.0**	**223.5**	**208.6**	**218.9**	**225.1**	**224.6**	**224.2**
Coal	12.0	9.3	6.2	6.7	6.5	5.9	5.5
Natural Gas	142.1	162.9	153.8	163.5	171.1	168.9	167.7
Fuel Oil	64.9	51.3	48.5	48.7	47.4	49.7	51.1
Residential	**338.3**	**357.9**	**321.5**	**341.6**	**349.3**	**339.0**	**340.2**
Coal	3.0	0.8	0.6	0.7	0.7	0.7	0.7
Natural Gas	238.0	262.2	237.3	256.3	265.5	258.8	258.8
Fuel Oil	97.4	94.9	83.6	84.6	83.1	79.4	80.7
U.S. Territories	**27.9**	**50.0**	**50.3**	**46.1**	**39.8**	**41.7**	**41.6**
Coal	0.6	3.0	3.4	4.3	3.3	3.5	3.5
Natural Gas	NO	1.3	1.4	1.4	1.6	1.5	1.5
Fuel Oil	27.2	45.7	45.5	40.4	35.0	36.7	36.7
Total	**3,252.4**	**3,849.9**	**3,774.9**	**3,863.9**	**3,781.7**	**3,478.3**	**3,642.3**

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

Table 3-10: CH_4 Emissions from Stationary Combustion (Tg CO_2 Eq.)

Sector/Fuel Type	1990	2005	2006	2007	2008	2009	2010
Electricity Generation	**0.3**	**0.5**	**0.5**	**0.5**	**0.5**	**0.4**	**0.5**
Coal	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Fuel Oil	+	+	+	+	+	+	+
Natural Gas	0.1	0.1	0.1	0.1	0.1	0.1	0.2
Wood	+	+	+	+	+	+	+
Industrial	**1.6**	**1.5**	**1.5**	**1.5**	**1.4**	**1.2**	**1.4**
Coal	0.3	0.3	0.3	0.2	0.2	0.2	0.2
Fuel Oil	0.2	0.2	0.2	0.2	0.2	0.1	0.1
Natural Gas	0.2	0.1	0.1	0.1	0.2	0.1	0.1
Wood	0.9	0.9	1.0	0.9	0.9	0.8	0.9
Commercial	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**1.0**	**0.9**
Coal	+	+	+	+	+	+	+
Fuel Oil	0.2	0.2	0.1	0.1	0.1	0.1	0.2
Natural Gas	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Wood	0.4	0.5	0.4	0.5	0.5	0.5	0.5
Residential	**4.6**	**3.6**	**3.3**	**3.6**	**3.7**	**3.6**	**3.5**
Coal	0.2	0.1	+	+	+	+	+
Fuel Oil	0.3	0.3	0.3	0.3	0.3	0.2	0.3
Natural Gas	0.4	0.5	0.4	0.5	0.5	0.5	0.5
Wood	3.7	2.8	2.5	2.8	2.9	2.8	2.7
U.S. Territories	**+**	**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
Natural Gas	+	+	+	+	+	+	+
Wood	+	+	+	+	+	+	+
Total	**7.5**	**6.6**	**6.2**	**6.5**	**6.6**	**6.3**	**6.3**

+ Does not exceed 0.05 Tg CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Table 3-11: N_2O Emissions from Stationary Combustion (Tg CO_2 Eq.)

Sector/Fuel Type	1990	2005	2006	2007	2008	2009	2010
Electricity Generation	**7.4**	**16.0**	**16.2**	**16.7**	**16.8**	**16.8**	**18.5**
Coal	6.3	11.6	11.5	11.4	11.6	11.2	12.5
Fuel Oil	0.1	0.1	0.1	0.1	+	+	+
Natural Gas	1.0	4.3	4.7	5.2	5.2	5.6	5.9
Wood	+	+	+	+	+	+	+
Industrial	**3.3**	**3.1**	**3.2**	**3.1**	**2.9**	**2.5**	**2.8**
Coal	0.8	0.6	0.6	0.5	0.5	0.4	0.5
Fuel Oil	0.5	0.5	0.6	0.6	0.5	0.4	0.4
Natural Gas	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Wood	1.8	1.9	1.9	1.8	1.7	1.5	1.7
Commercial	**0.4**	**0.4**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
Coal	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**	**1.0**	**0.9**	**0.9**
Coal	+	+	+	+	+	+	+
Fuel Oil	0.3	0.3	0.2	0.2	0.2	0.2	0.2
Natural Gas	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wood	0.7	0.6	0.5	0.5	0.6	0.6	0.5
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	**12.3**	**20.6**	**20.8**	**21.2**	**21.1**	**20.7**	**22.6**

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

Electricity Generation

The process of generating electricity is the single largest source of CO_2 emissions in the United States, representing 42 percent of total CO_2 emissions from all CO_2 emissions sources across the United States. Methane and N_2O accounted for a small portion of emissions from electricity generation, representing less than 0.1 percent and 0.8 percent, respectively. Electricity generation also accounted for the largest share of CO_2 emissions from fossil fuel combustion, approximately 42 percent in 2010. Methane and N_2O from electricity generation represented 6 and 43 percent of emissions from CH_4 and N_2O emissions from fossil fuel combustion in 2010, 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).

Figure 3-9: Electricity Generation Retail Sales by End-Use Sector

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 primary business is the production of electricity,[65] 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 2010 increased approximately 6.3 percent and 1.7 percent, respectively. The trend in the residential and commercial sectors can largely be attributed to warmer, more energy-intensive summer weather conditions compared to 2009. Electricity sales to the industrial sector in 2010 increased approximately 5.0 percent. Overall, in 2010, the amount of electricity generated (in kWh) increased by 4.3 percent from the previous year. This increase was due to an increase in economic output, an increase in the carbon intensity of fuels used to generate electricity due to fuel switching as the price of coal only slightly increased, and the price of petroleum and natural gas increased significantly, and a slight decrease in the contribution of non-fossil fuel sources used to generate electricity. As a result, CO_2 emissions from the electric power sector increased by 5.2 percent as the consumption of coal and natural gas for electricity generation increased by 5.0 percent and 7.3 percent, respectively, in 2010 and the consumption of petroleum for electricity generation, decreased by 6.1 percent.

Industrial Sector

The industrial sector accounted for 15 percent of CO_2 emissions from fossil fuel combustion, 17 percent of CH_4 emissions from fossil fuel combustion, and 6 percent of N_2O emissions from fossil fuel combustion. CO_2, CH_4, and N_2O 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, Paper, Primary Metals, Food, and Nonmetallic Mineral Products—represent the vast majority of the energy use (EIA 2011a and EIA 2009c).

In theory, emissions from the industrial sector should be highly correlated with economic growth and industrial

[65] 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).

output, but heating of industrial buildings and agricultural energy consumption are also affected by weather conditions.[66] 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 2009 to 2010, total industrial production and manufacturing output increased by 5.3 and 5.8 percent, respectively (FRB 2011). Over this period, output increased across all production indices for Food, Petroleum Refineries, Chemicals, Paper, Primary Metals, and Nonmetallic Mineral Products (see Figure 3-10).

Figure 3-10: Industrial Production Indices (Index 2007=100)

Despite the growth in industrial output (45 percent) and the overall U.S. economy (63 percent) from 1990 to 2010, CO_2 emissions from fossil fuel combustion in the industrial sector decreased by 8.1 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 2010, CO_2, CH_4, and N_2O emissions from fossil fuel combustion and electricity use within the industrial end-use sector totaled 1,424.9 Tg CO_2 Eq., or approximately 6.6 percent above 2009 emissions.

Residential and Commercial Sectors

The residential and commercial sectors accounted for 6 and 4 percent of CO_2 emissions from fossil fuel combustion, 43 and 11 percent of CH_4 emissions from fossil fuel combustion, and 2 and 1 percent of N_2O 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 cooking needs. Coal consumption was a minor component of energy use in both of these end-use sectors. In 2010, CO_2, CH_4, and N_2O emissions from fossil fuel combustion and electricity use within the residential and commercial end-use sectors were 1,195.2 Tg CO_2 Eq. and 1,004.9 Tg CO_2 Eq., respectively. Total CO_2, CH_4, and N_2O emissions from the residential and commercial sectors increased by 5.2 and 2.0 percent from 2009 to 2010, respectively.

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 about 76 and 75 percent of the direct fossil fuel CO_2 emissions from the residential and commercial sectors, respectively. In 2010, natural gas CO_2 emissions from the residential and commercial sectors remained relatively constant and decreased by 0.3 percent, respectively.

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 in the Methodology section for CO_2 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, CO_2, CH_4, and N_2O emissions are not presented for U.S. Territories in the tables above, though the emissions will include some transportation and mobile combustion sources.

[66] 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.

Transportation Sector

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 emissions associated with the sector's electricity consumption), please see Table 3-7.

Transportation End-Use Sector

The transportation end-use sector accounted for 1,772.5 Tg CO_2 Eq. in 2010, which represented 33 percent of CO_2 emissions, 23 percent of CH_4 emissions, and 48 percent of N_2O emissions from fossil fuel combustion, respectively. Fuel purchased in the U.S. for international aircraft and marine travel accounted for an additional 127.8 Tg CO_2 in 2010; 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 61 percent of CO_2 emissions, medium- and heavy-duty trucks 22 percent, commercial aircraft 7 percent, and other sources 10 percent. Passenger car CO_2 emissions increased by 20 percent from 1990 to 2010, light-duty truck[67] CO_2 emissions decreased by 3 percent and medium- and heavy-duty trucks increased by 74 percent. [68] General aviation aircraft CO_2 emissions also increased by nearly 67 percent (6.5 Tg) from 1990 to 2010. CO_2 from the domestic operation of commercial aircraft decreased by 16 percent (21.4 Tg) from 1990 to 2010. Across all categories of aviation[69], CO_2 emissions decreased by 20.6 percent (36.9 Tg) between 1990 and 2010. This includes a 64 percent (21.9 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. See Table 3-12 for a detailed breakdown of CO_2 emissions by mode and fuel type.

From 1990 to 2010, transportation emissions rose by 19 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 34 percent from 1990 to 2010, as a result of a confluence of factors including population growth, economic growth, urban sprawl, and low fuel prices over much of this period.

From 2009 to 2010, CO_2 emissions from the transportation end-use sector increased 0.9 percent. The increase in emissions can largely be attributed to increased economic activity in 2010 and an associated increase in the demand for transportation. Modes such as medium- and heavy-duty trucks were impacted by the increase in freight transport. In contrast, commercial aircraft emissions continued to fall, having decreased 21 percent since 2007, with increased jet fuel prices being a factor.

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 CO_2 from fossil fuel combustion, which increased by 20 percent from 1990 to 2010. This rise in CO_2 emissions, combined with an increase in HFCs from close to zero emissions in 1990 to 60.2 Tg CO_2 Eq. in 2010, led to an increase in overall emissions from transportation activities of 20 percent.

Transportation Fossil Fuel Combustion CO_2 Emissions

Domestic transportation CO_2 emissions increased by 18 percent (261.0 Tg) between 1990 and 2010, an annualized increase of 0.8 percent. The 1 percent increase in emissions between 2009 and 2010 contrasted with the previous

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[67] Includes "light-duty trucks" fueled by gasoline, diesel and LPG

[68] In 2011 FHWA changed how they defined vehicle types for the purposes of reporting VMT for the years 2007-2010. The old approach to vehicle classification was based on body type and split passenger vehicles into "Passenger Cars" and "Other 2 Axle 4-Tire Vehicles". The new approach is a vehicle classification system based on wheelbase. Vehicles with a wheelbase less than or equal to 121 inches are counted as "Light-duty Vehicles –Short Wheelbase". Passenger vehicles with a Wheelbase greater than 121 inches are counted as "Light-duty Vehicles - Long Wheelbase". This change in vehicle classification has moved some smaller trucks and sport utility vehicles from the light truck category to the passenger vehicle category in this emission inventory. These changes are reflected in a large drop in light-truck emissions between 2006 and 2007.

[69] Includes consumption of jet fuel and aviation gasoline. Does not include aircraft bunkers, which are not included in national emission totals, in line with IPCC methodological guidance and UNFCCC reporting obligations.

year's trend of decreasing emissions. Almost all of the energy consumed by the transportation sector is petroleum-based, including motor gasoline, diesel fuel, jet fuel, and residual oil. [70] Transportation sources also produce CH_4 and N_2O; 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 CO_2, N_2O, CH_4, and HFCs.

Carbon dioxide emissions from passenger cars and light-duty trucks totaled 1,073.5 Tg in 2010, an increase of 13 percent (123.1 Tg) from 1990. CO_2 emissions from passenger cars and light-duty trucks peaked at 1,184.3 Tg in 2004, and since then have declined about 9 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. However, in 2010, fuel VMT grew by 0.3 percent, while average fuel economy decreased slightly. 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 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 44 percent and declined to 23 percent in 2010.

Figure 3-11: Sales-Weighted Fuel Economy of New Passenger Cars and Light-Duty Trucks, 1990–2010

Figure 3-12: Sales of New Passenger Cars and Light-Duty Trucks, 1990–2010

Table 3-12: CO_2 Emissions from Fossil Fuel Combustion in Transportation End-Use Sector (Tg CO_2 Eq.) [a]

Fuel/Vehicle Type	1990		2005	2006	2007 [e]	2008	2009	2010
Gasoline	**983.7**		**1,187.8**	**1,178.2**	**1,181.2**	**1,130.3**	**1,128.5**	**1,117.0**
Passenger Cars	621.4		658.0	635.0	800.2	765.5	762.4	753.8
Light-Duty Trucks	309.1		478.8	491.5	315.5	298.9	304.1	302.2
Medium- and Heavy-Duty Trucks [b]	38.7		34.9	35.5	46.6	47.2	43.6	43.4
Buses	0.3		0.4	0.4	0.7	0.8	0.8	0.7
Motorcycles	1.7		1.6	1.9	4.3	4.4	4.2	3.7
Recreational Boats	12.4		14.1	14.0	13.9	13.5	13.3	13.1
Distillate Fuel Oil (Diesel)	**262.9**		**458.1**	**470.3**	**476.3**	**443.5**	**402.9**	**418.9**
Passenger Cars	7.9		4.2	4.1	4.1	3.7	3.6	3.7
Light-Duty Trucks	11.5		25.8	26.8	13.6	12.1	12.1	12.6
Medium- and Heavy-Duty Trucks [b]	190.5		360.7	370.0	384.6	366.1	332.2	345.3
Buses	8.0		10.6	10.8	15.9	15.2	14.1	14.0
Rail	35.5		45.6	47.8	46.6	43.2	36.3	39.0
Recreational Boats	2.0		3.1	3.2	3.3	0.9	3.5	3.5
Ships and Other Boats	7.5		8.1	7.5	8.2	2.2	1.2	0.7
International Bunker Fuels [c]	*11.7*		*9.4*	*8.8*	*8.2*	*9.0*	*8.3*	*8.8*
Jet Fuel	**176.2**		**194.2**	**169.5**	**168.7**	**155.1**	**139.6**	**140.5**
Commercial Aircraft	135.4		161.2	137.1	138.1	122.2	111.4	114.0
Military Aircraft	34.4		18.1	16.3	16.1	16.2	14.1	12.5
General Aviation	6.4		14.9	16.0	14.5	16.6	14.1	14.0

[70] Biofuel estimates are presented for informational purposes only in the Energy chapter, in line with IPCC methodological guidance and UNFCCC reporting obligations. Net carbon fluxes from changes in biogenic carbon reservoirs in croplands are accounted for in the estimates for Land Use, Land-Use Change, and Forestry (see Chapter 7). More information and additional analyses on biofuels are available at EPA's "Renewable Fuels: Regulations & Standards" web page: http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm

Aircraft								
International Bunker Fuels [c]	*46.4*		*56.8*	*74.6*	*73.8*	*75.5*	*68.6*	*72.5*
Aviation Gasoline	3.1		2.4	2.3	2.2	2.0	1.8	1.9
General Aviation Aircraft	3.1		2.4	2.3	2.2	2.0	1.8	1.9
Residual Fuel Oil	**22.6**		**19.3**	**23.0**	**29.0**	**19.9**	**15.4**	**25.3**
Ships and Other Boats	22.6		19.3	23.0	29.0	19.9	15.4	25.3
International Bunker Fuels [c]	*53.7*		*43.6*	*45.0*	*45.6*	*49.2*	*45.4*	*46.5*
Natural Gas	**36.0**		**33.1**	**33.1**	**35.2**	**36.7**	**37.9**	**40.1**
Passenger Cars	+		+	+	+	+	+	+
Light-Duty Trucks	+		+	+	+	+	+	+
Buses	+		0.8	0.8	1.0	1.1	1.3	1.3
Pipeline	36.0		32.2	32.3	34.2	35.6	36.6	38.8
LPG	**1.4**		**1.7**	**1.7**	**1.4**	**2.5**	**1.7**	**1.8**
Light-Duty Trucks	0.6		1.3	1.2	1.0	1.8	1.2	1.2
Medium- and Heavy-Duty Trucks[b]	0.8		0.4	0.5	0.4	0.7	0.5	0.6
Buses	+		+	+	+	+	+	+
Electricity	**3.0**		**4.7**	**4.5**	**5.1**	**4.7**	**4.5**	**4.5**
Rail	3.0		4.7	4.5	5.1	4.7	4.5	4.5
Total	**1,489.0**		**1,901.3**	**1,882.6**	**1,899.0**	**1,794.5**	**1,732.4**	**1,750.0**
Total (Including Bunkers) [c]	**1,600.8**		**2,011.1**	**2,011.1**	**2,026.6**	**1,928.3**	**1,854.7**	**1,877.8**

[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] Residual fuel oil data for ships and boats is based on EIA's December 2011 Monthly Energy Review
[e] In 2011, FHWA changed how vehicles are classified, moving form a system based on body-type to one that is based on wheelbase. This change in methodology in FHWA's VM-1 table resulted in large changes in fuel consumption data by vehicle class, thus leading to a shift in emissions among on-road vehicle classes in the 2007-2010 time period. Note: Totals may not sum due to independent rounding.
Note: See section 3.10 of this chapter, in line with IPCC methodological guidance and UNFCCC reporting obligations, for more information on ethanol.
+ Less than 0.05 Tg CO_2 Eq.
- Unreported or zero

Mobile Fossil Fuel Combustion CH_4 and N_2O Emissions

Mobile combustion includes emissions of CH_4 and N_2O 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 CH_4 and N_2O emission estimates in Tg CO_2 Eq.[71]

Mobile combustion was responsible for a small portion of national CH_4 emissions (0.3 percent) but was the second largest source of U.S. N_2O emissions (7 percent). From 1990 to 2010, mobile source CH_4 emissions declined by 59 percent, to 1.9 Tg CO_2 Eq. (91 Gg), due largely to control technologies employed in on-road vehicles since the mid-1990s to reduce CO, NO_x, NMVOC, and CH_4 emissions. Mobile source emissions of N_2O decreased by 53 percent, to 20.6 Tg CO_2 Eq. (66 Gg). Earlier generation control technologies initially resulted in higher N_2O emissions, causing a 26 percent increase in N_2O emissions from mobile sources between 1990 and 1998. Improvements in

[71] See Annex 3.2 for a complete time series of emission estimates for 1990 through 2010.

later-generation emission control technologies have reduced N_2O output, resulting in a 63 percent decrease in mobile source N_2O emissions from 1998 to 2010 (Figure 3-13). Overall, CH_4 and N_2O emissions were predominantly from gasoline-fueled passenger cars and light-duty trucks.

Figure 3-13: Mobile Source CH_4 and N_2O Emissions

Table 3-13: CH_4 Emissions from Mobile Combustion (Tg CO_2 Eq.)

Fuel Type/Vehicle Type[a]	1990	2005	2006	2007[e]	2008	2009	2010
Gasoline On-Road	**4.2**	**1.9**	**1.7**	**1.6**	**1.4**	**1.3**	**1.2**
Passenger Cars	2.6	1.1	1.0	1.1	1.0	0.9	0.9
Light-Duty Trucks	1.4	0.7	0.6	0.3	0.3	0.3	0.3
Medium- and Heavy-Duty Trucks and Buses	0.2	0.1	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**	**0.1**	**0.1**	**0.1**
Non-Road	**0.4**	**0.6**	**0.6**	**0.5**	**0.5**	**0.5**	**0.4**
Ships and Boats	+	+	+	+	+	+	+
Rail	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Aircraft	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Agricultural Equipment[b]	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**	**2.5**	**2.4**	**2.2**	**2.1**	**2.0**	**1.9**

[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.
[e] In 2011, FHWA changed how vehicles are classified, moving from a system based on body-type to one that is based on wheelbase. This change in methodology in FHWA's VM-1 table resulted in large changes in VMT by vehicle class, thus leading to a shift in emissions among on-road vehicle classes in the 2007 to 2010 time period.
Note: Totals may not sum due to independent rounding.
+ Less than 0.05 Tg CO_2 Eq.

Table 3-14: N_2O Emissions from Mobile Combustion (Tg CO_2 Eq.)

Fuel Type/Vehicle Type[a]	1990	2005	2006	2007[e]	2008	2009	2010
Gasoline On-Road	**40.1**	**32.1**	**29.0**	**24.1**	**20.7**	**18.3**	**16.1**
Passenger Cars	25.4	17.8	15.7	17.3	14.6	12.4	10.8
Light-Duty Trucks	14.1	13.6	12.6	5.8	5.2	5.1	4.6
Medium- and Heavy-Duty Trucks and Buses	0.6	0.8	0.7	0.9	0.9	0.6	0.6
Motorcycles	+	+	+	+	+	+	+
Diesel On-Road	**0.2**	**0.3**	**0.3**	**0.4**	**0.4**	**0.4**	**0.4**
Passenger Cars	+	+	+	+	+	+	+
Light-Duty Trucks	+	+	+	+	+	+	+

Medium- and Heavy-Duty Trucks and Buses	0.2		0.3	0.3	0.4	0.4	0.4	0.4
Alternative Fuel On-Road	**0.1**		**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Non-Road	**3.6**		**4.3**	**4.2**	**4.3**	**3.8**	**3.6**	**3.8**
Ships and Boats	0.6		0.6	0.7	0.8	0.5	0.5	0.6
Rail	0.3		0.4	0.4	0.4	0.3	0.3	0.3
Aircraft	1.7		1.9	1.6	1.6	1.5	1.3	1.3
Agricultural Equipment[b]	0.2		0.4	0.4	0.4	0.4	0.4	0.4
Construction/Mining Equipment[c]	0.3		0.5	0.5	0.5	0.5	0.5	0.6
Other[d]	0.4		0.6	0.6	0.6	0.6	0.6	0.6
Total	**43.9**		**37.0**	**33.7**	**29.0**	**25.2**	**22.5**	**20.6**

[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.
[e] In 2011, FHWA changed how vehicles are classified, moving from a system based on body-type to one that is based on wheelbase. This change in methodology in FHWA's VM-1 table resulted in large changes in VMT by vehicle class, thus leading to a shift in emissions among on-road vehicle classes in the 2007 to 2010 time period.
Note: Totals may not sum due to independent rounding.
+ Less than 0.05 Tg CO_2 Eq.

CO_2 from Fossil Fuel Combustion

Methodology

The methodology used by the United States for estimating CO_2 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 in line with a Tier 2 method in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (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 2011b). The EIA does not include territories in its national energy statistics, so fuel consumption data for territories were collected separately from Jacobs (2010).[72]

   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

[72] 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 42 Tg CO_2 Eq. in 2010.

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. [73]

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).[74]

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 2011), Coffeyville (2011), U.S. Census Bureau (2011), EIA (2011b), USGS (1991 through 2011), USGS (1994 through 2011), USGS (1995, 1998, 2000 through 2002), USGS (2007), USGS (2009a), USGS (2009b), USGS (2010a), USGS(2010b), USGS (2010c), USGS (2011), USGS (1991 through 2010a), USGS (1991 through 2010b), USGS (2010) and USGS (2011).[75]

3. *Adjust for conversion of fuels and exports of CO_2.* Fossil fuel consumption estimates are adjusted downward to exclude fuels created from other fossil fuels and exports of CO_2.[76] 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.[77] Since October 2000, the Dakota Gasification Plant has been exporting CO_2 to Canada by pipeline. Since this CO_2 is not emitted to the atmosphere in the United States, energy used to produce this CO_2 is subtracted from energy consumption statistics. To make these adjustments, additional data for ethanol were collected from EIA (2011a), data for synthetic natural gas were collected from EIA (2011b), and data for CO_2 exports were collected from the Eastman Gasification Services Company (2011), Dakota Gasification Company (2006), Fitzpatrick (2002), Erickson (2003), EIA (2007b) and DOE (2012).

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 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 (2009 through 2011), Benson (2002 through 2004), DOE (1993 through 2011), EIA (2009a), EIA (1991 through 2011), EPA (2009), and FHWA (1996 through 2012).[78]

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[73] See IPCC Reference Approach for estimating CO_2 emissions from fossil fuel combustion in Annex 4 for a comparison of U.S. estimates using top-down and bottom-up approaches.

[74] 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.

[75] 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.

[76] Energy statistics from EIA (2012) are already adjusted downward to account for ethanol added to motor gasoline, and biogas in natural gas.

[77] These adjustments are explained in greater detail in Annex 2.1.

[78] The source of VMT and fuel consumption is FHWA's VM-1 table. The data collection methodology has undergone substantial revision for only years 2007 to 2010, while prior years have remain unchanged Several of the vehicle type categories have changed. For instance, passenger car has been replaced by "Light duty vehicle, short WB" and other 4 axle- 2 tire has been replaced by "Light duty vehicle, long WB". With this change in methodology, there are substantial differences in activity data among vehicle classes, even though overall VMT and fuel consumption is unchanged. While this is the best data available on

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 (2012).

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).[79] 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 2011) supplied data on military jet fuel and marine fuel use. Commercial jet fuel use was obtained from FAA (2006, 2009, 2011, and 2012); residual and distillate fuel use for civilian marine bunkers was obtained from DOC (1991 through 2011) for 1990 through 2001 and 2007 through 2010, 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 CO_2. The C content coefficients used by the United States were obtained from EIA's Emissions of Greenhouse Gases in the United States 2008 (EIA 2009a), and an EPA analysis of C content coefficients used in the mandatory reporting rule (EPA 2010a). A discussion of the methodology used to develop the C content coefficients are presented in Annexes 2.1 and 2.2.

8. *Estimate CO_2 Emissions.* Total CO_2 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 2012); for each vehicle category, the percent gasoline, diesel, and other (e.g., CNG, LPG) fuel consumption are estimated using data from DOE (1993 through 2011).

    - For non-road vehicles, activity data were obtained from AAR (2009 through 2011), APTA (2007 through 2011), BEA (1991 through 2011), Benson (2002 through 2004), DOE (1993 through 2011), DESC (2011), DOC (1991 through 2011), DOT (1991 through 2011), EIA (2009a), EIA (2011a), EIA (2002), EIA (1991 through 2012), EPA (2011b), and Gaffney (2007).

    - For jet fuel used by aircraft, CO_2 emissions were calculated directly based on reported consumption of

vehicle activity, the time series reflects changes in the definition of vehicle classes between 2006- 2007 when this change in methodology was implemented.

[79] See International Bunker Fuels section in this chapter for a more detailed discussion.

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 2012). [80] Allocation to domestic general aviation was made using FAA Aerospace Forecast data (FAA 2011), and allocation to domestic military uses was made using DoD data (see Annex 3.7).

Heat contents and densities were obtained from EIA (2011a) and USAF (1998). [81]

[BEGIN BOX]

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

Fossil fuels are the dominant source of energy in the United States, and CO_2 is the dominant greenhouse gas emitted as a product from their combustion. Energy-related CO_2 emissions are impacted by not only lower levels of energy consumption 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 CO_2 Eq./QBtu for natural gas to upwards of 95 Tg CO_2 Eq./QBtu for coal and petroleum coke.[82] 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. 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. 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 CO_2 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 CO_2 Eq./QBtu)

Sector	1990		2005	2006	2007	2008	2009	2010
Residential [a]	57.4		56.6	56.5	56.3	56.0	56.0	56.0
Commercial [a]	59.2		57.5	57.2	57.1	56.7	56.9	56.9
Industrial [a]	64.3		64.4	64.5	64.1	63.6	63.0	63.3
Transportation [a]	71.1		71.4	71.6	71.9	71.6	71.5	71.5
Electricity Generation [b]	87.3		85.8	85.4	84.7	84.9	83.7	83.5
U.S. Territories [c]	73.0		73.4	73.5	73.8	73.3	73.1	73.1

[80] 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 incorporated into 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 2006-2010 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. Additional information available at: http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/

[81] For a more detailed description of the data sources used for the analysis of the transportation end use sector see the Mobile Combustion (excluding CO_2) and International Bunker Fuels sections of the Energy chapter, Annex 3.2, and Annex 3.7.

[82] One exajoule (EJ) is equal to 10^{18} joules or 0.9478 QBtu.

All Sectors [c]	**73.0**	**73.6**	**73.5**	**73.3**	**73.1**	**72.4**	**72.5**

[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.

Over the twenty-one-year period of 1990 through 2010, however, the C intensity of U.S. energy consumption has been fairly constant, as the proportion of fossil fuels used by the individual sectors has not changed significantly. Per capita energy consumption fluctuated little from 1990 to 2007, but in 2010 was approximately 8.0 percent below 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 CO_2 emissions per dollar of gross domestic product (GDP) have both declined since 1990 (BEA 2011).

Figure 3-14: U.S. Energy Consumption and Energy-Related CO_2 Emissions Per Capita and Per Dollar GDP

C intensity estimates were developed using nuclear and renewable energy data from EIA (2011a), EPA (2010a), and fossil fuel consumption data as discussed above and presented in Annex 2.1.

[END BOX]

Uncertainty and Time Series Consistency

For estimates of CO_2 from fossil fuel combustion, the amount of CO_2 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 CO_2 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 CO_2 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 CO_2 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 . The amount of CO_2 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 CO_2 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 CO_2 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 Stochastic Simulation technique, with @RISK software. For this uncertainty estimation, the inventory estimation model for CO_2 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 120 input variables were modeled for CO_2 from energy-related Fossil Fuel Combustion (including about 10 for non-energy fuel consumption and about 20 for International Bunker Fuels).

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.[83] 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.[84]

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).[85] 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 3-16. Fossil fuel combustion CO_2 emissions in 2010 were estimated to be between 5,260.8 and 5,638.9 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 2 percent below to 5 percent above the 2010 emission estimate of 5,387.8 Tg CO_2 Eq.

Table 3-16: Tier 2 Quantitative Uncertainty Estimates for CO_2 Emissions from Energy-related Fossil Fuel Combustion by Fuel Type and Sector (Tg CO_2 Eq. and Percent)

Fuel/Sector	2010 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]	**1,933.2**	**1,868.0**	**2,114.1**	**-3%**	**+9%**
Residential	0.7	0.6	0.8	-6%	+15%
Commercial	5.5	5.2	6.3	-5%	+15%
Industrial	96.2	92.6	112.2	-3%	+17%
Transportation	NE	NE	NE	NA	NA
Electricity Generation	1,827.3	1,756.5	2,001.2	-4%	+10%
U.S. Territories	3.5	3.1	4.2	-12%	+19%

[83] 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.

[84] 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.

[85] 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.

Natural Gas [b]	**1,261.6**	**1,261.9**	**1,332.5**	**+0%**	**+6%**
Residential	258.8	250.0	275.2	-3%	+7%
Commercial	167.7	163.2	179.7	-3%	+7%
Industrial	394.2	374.9	412.7	+3%	+13%
Transportation	40.1	35.2	38.8	-3%	+7%
Electricity Generation	399.4	362.3	392.0	-3%	+5%
U.S. Territories	1.5	1.3	1.7	-12%	+17%
Petroleum [b]	**2,192.6**	**2,032.7**	**2,291.3**	**-7%**	**+5%**
Residential	80.7	76.4	84.9	-5%	5%
Commercial	51.1	48.7	53.2	-5%	4%
Industrial	287.4	235.7	335.0	-18%	17%
Transportation	1,705.4	1,565.6	1,791.4	-8%	5%
Electric Utilities	31.3	29.8	33.7	-5%	8%
U.S. Territories	36.7	33.8	40.9	-8%	12%
Total (excluding Geothermal) [b]	**5,387.4**	**5,260.4**	**5,638.5**	**-2%**	**+5%**
Geothermal	0.4	NE	NE	NE	NE
Total (including Geothermal) [b,c]	**5,387.8**	**5,260.8**	**5,638.9**	**-2%**	**+5%**

NA (Not Applicable)
NE (Not Estimated)
[a] Range of emission estimates predicted by Monte Carlo Stochastic 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 CO_2 emissions from geothermal production.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2010. 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 CO_2 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 CO_2 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 2011a) updated energy consumption statistics across the time series, relative to the previous Inventory. These revisions primarily impacted the emission estimates from 2008 to 2009; however revisions to industrial petroleum consumption impacted estimates across the time series. Overall, these changes resulted in an average annual decrease of 0.2 Tg CO_2 Eq. (less than 0.1 percent) in CO_2 emissions from fossil fuel combustion for the period 1990 through 2009.

Planned Improvements

To reduce uncertainty of CO_2 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 CO_2 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.

The availability of facility-level combustion emissions through EPA's Greenhouse Gas Reporting Program (GHGRP) will be examined to help better characterize the industrial sector's energy consumption in the United States, and further classify business establishments according to industrial economic activity type. Most methodologies used in EPA's GHGRP are consistent with IPCC, though for EPA's GHGRP, facilities collect

detailed information specific to their operations according to detailed measurement standards, which may differ with the more aggregated data collected for the Inventory to estimate total, national U.S. emissions. In addition, and unlike the reporting requirements for this chapter under the UNFCCC reporting guidelines,[86] some facility-level fuel combustion emissions reported under the GHGRP may also include industrial process emissions. In line with UNFCCC reporting guidelines, fuel combustion emissions are included in this chapter, while process emissions are included in the Industrial Processes chapter of this report. In examining data from EPA's GHGRP that would be useful to improve the emission estimates for the CO_2 from fossil fuel combustion category, particular attention will also be made to ensure time series consistency, as the facility-level reporting data from EPA's GHGRP are not available for all inventory years as reported in this inventory. Additionally, analyses will focus on aligning reported facility-level fuel types and IPCC fuel types per the national energy statistics, ensuring CO_2 emissions from biomass are separated in the facility-level reported data, and maintaining consistency with national energy statistics provided by EIA. In implementing improvements and integration of data from EPA's GHGRP, the latest guidance from the IPCC on the use of facility-level data in national inventories will be relied upon.[87]

CH_4 and N_2O from Stationary Combustion

Methodology

Methane and N_2O emissions from stationary combustion were estimated by multiplying fossil fuel and wood consumption data by emission factors (by sector and fuel type for industrial, residential, commercial, and U.S. Territories; and by fuel and technology type for the electric power sector). Beginning with this year's Inventory, the electric power sector utilizes a Tier 2 methodology, whereas all other sectors utilize a Tier 1 methodology. The activity data and emission factors used are described in the following subsections.

Industrial, Residential, Commercial, and U.S. Territories

National coal, natural gas, fuel oil, and wood consumption data were grouped by sector: industrial, commercial, residential, and U.S. territories. For the CH_4 and N_2O estimates, wood consumption data for the United States was obtained from EIA's Annual Energy Review (EIA 2011a). 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 2011b). Because the United States does not include territories in its national energy statistics, fuel consumption data for territories were provided separately by Jacobs (2010).[88] Fuel consumption for the industrial sector was adjusted to subtract out construction and agricultural use, which is reported under mobile sources.[89] Construction and agricultural fuel use was obtained from EPA (2010a). Estimates for wood biomass consumption for fuel combustion do not include wood wastes, liquors, municipal solid waste, tires, etc., that are reported as biomass by EIA. Tier 1 default emission factors for these three 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.

Electric Power Sector

In this year's Inventory, the emission estimation methodology for the electric power sector was revised from Tier 1 to Tier 2 as fuel consumption for the electricity generation sector by control-technology type was obtained from EPA's Acid Rain Program Dataset (EPA 2011). This combustion technology- and fuel-use data was available by facility from 1996 to 2010.

Since there was a difference between the EPA (2011) and EIA (2011a) total energy consumption estimates, the

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

[87] See <http://www.ipcc-nggip.iges.or.jp/meeting/pdfiles/1008_Model_and_Facility_Level_Data_Report.pdf>

[88] U.S. territories data also include combustion from mobile activities because data to allocate territories' energy use were unavailable. For this reason, CH_4 and N_2O emissions from combustion by U.S. territories are only included in the stationary combustion totals.

[89] 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.

remainder between total energy consumption using EPA (2011) and EIA (2011a) was apportioned to each combustion technology type and fuel combination using a ratio of energy consumption by technology type from 1996 to 2010.

Energy consumption estimates were not available from 1990 to 1995 in the EPA (2011) dataset, and as a result, consumption was calculated using total electric power consumption from EIA (2011a) and the ratio of combustion technology and fuel types from EPA (2011). The consumption estimates from 1990 to 1995 were estimated by applying the 1996 consumption ratio by combustion technology type to the total EIA consumption for each year from 1990 to 1995. Emissions were estimated by multiplying fossil fuel and wood consumption by technology- and fuel-specific Tier 2 IPCC emission factors.

Lastly, there were significant differences between wood biomass consumption in the electric power sector between the EPA (2011) and EIA (2011a) datasets. The difference in wood biomass consumption in the electric power sector was distributed to the residential, commercial, and industrial sectors according to their percent share of wood biomass energy consumption calculated from EIA (2011a).

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 CH_4 and N_2O 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 Stochastic Simulation technique, with @RISK software.

The uncertainty estimation model for this source category was developed by integrating the CH_4 and N_2O stationary source inventory estimation models with the model for CO_2 from fossil fuel combustion to realistically characterize the interaction (or endogenous correlation) between the variables of these three models. About 55 input variables were simulated for the uncertainty analysis of this source category (about 20 from the CO_2 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 N_2O emission factors, based on the SAIC/EIA (2001) report.[90] For these variables, the uncertainty ranges were assigned to the input variables based on the data reported in SAIC/EIA (2001).[91] However, the CH_4 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 3-17. Stationary combustion CH_4 emissions in 2010 (including biomass) were estimated to be between 3.8 and 14.4 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 40 percent below to 128 percent above the 2010 emission estimate of 6.3 Tg CO_2 Eq.[92] Stationary combustion N_2O emissions in 2010 (*including* biomass) were estimated to be between 9.9 and 38.8 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 56 percent below to 72 percent above the 2010 emissions estimate of 22.6 Tg CO_2 Eq.

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[90] 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.

[91] 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.

[92] The low emission estimates reported in this section have been rounded down to the nearest integer values and the high emission estimates have been rounded up to the nearest integer values.

Table 3-17: Tier 2 Quantitative Uncertainty Estimates for CH_4 and N_2O Emissions from Energy-Related Stationary Combustion, Including Biomass (Tg CO_2 Eq. and Percent)

Source	Gas	2010 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	6.3	3.8	14.4	-40%	+128%
Stationary Combustion	N_2O	22.6	9.9	38.8	-56%	+72%

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

The uncertainties associated with the emission estimates of CH_4 and N_2O are greater than those associated with estimates of CO_2 from fossil fuel combustion, which mainly rely on the carbon content of the fuel combusted. Uncertainties in both CH_4 and N_2O 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.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2010. 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 CH_4, N_2O, 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 CH_4 and N_2O emissions from stationary sources (excluding CO_2) were revised due to a few of changes, impacting the entire time series, relative to the previous Inventory. Slight changes to emission estimates for sectors are due to revised data from EIA (2011). Wood consumption data in EIA (2011) were revised for the residential, commercial, electric power, and industrial sectors from 1990 to 2009. Additionally, a Tier 2 emission estimation methodology was applied to estimate emissions from the electric power sector across the entire time series. This primarily impacted N_2O emission estimates, as the number of coal fluidized bed boilers increased significantly from 2000 through 2005. The combination of the methodological and historical data changes resulted in an average annual increase of less than 0.1 Tg CO_2 Eq. (0.5 percent) in CH_4 emissions from stationary combustion and an average annual increase of 1.9 Tg CO_2 Eq. (13.7 percent) in N_2O emissions from stationary combustion for the period 1990 through 2009.

Planned Improvements

Several items are being evaluated to improve the CH_4 and N_2O 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.

Beginning in 2010, those facilities that emit over 25,000 tons of greenhouse gases (CO_2 Eq.) from stationary combustion across all sectors of the economy are required to calculate and report their greenhouse gas emissions to EPA through its GHGRP. These data will be used in future inventories to improve the emission calculations through

the use of these collected higher tier methodological data.

Future improvements to the CH_4 and N_2O from Stationary Combustion category involve research into the availability of CH_4 and N_2O from stationary combustion data, and analyzing data reported under EPA's GHGRP. In examining data from EPA's GHGRP that would be useful to improve the emission estimates for CH_4 and N_2O from Stationary Combustion category, particular attention will be made to ensure time series consistency, as the facility-level reporting data from EPA's GHGRP are not available for all Inventory years as reported in this inventory. In implementing improvements and integration of data from EPA's GHGRP, the latest guidance from the IPCC on the use of facility-level data in national inventories will be relied upon. [93]

CH_4 and N_2O from Mobile Combustion

Methodology

Estimates of CH_4 and N_2O 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 vehicle miles traveled (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 CH_4 and N_2O emissions from mobile combustion and the emission factors used in the calculations is provided in Annex 3.2.

On-Road Vehicles

Estimates of CH_4 and N_2O 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)[94] 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 greenhouse gases 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 CO_2, CO, HC, NO_x, and PM from vehicles under various conditions, to approximate average driving characteristics.[95]

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 2010 were obtained from the Federal Highway Administration's (FHWA) Highway Performance Monitoring System database as reported in Highway Statistics (FHWA 1996 through

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[93] See <http://www.ipcc-nggip.iges.or.jp/meeting/pdfiles/1008_Model_and_Facility_Level_Data_Report.pdf>

[94] 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.

[95] Additional information regarding the model can be found online at http://www.epa.gov/OMS/m6.htm.

2012).[96] 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 2011) and information on total motor vehicle fuel consumption by fuel type from FHWA (1996 through 2012). VMT for AFVs were taken from Browning (2003). The age distributions of the U.S. vehicle fleet were obtained from EPA (2011a, 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 N_2O and CH_4 per kilogram of fuel consumed).[97] Activity data were obtained from AAR (2009 through 2011), APTA (2007 through 2011), APTA (2006), BEA (1991 through 2005), Benson (2002 through 2004), DHS (2008), DOC (1991 through 2011), DOE (1993 through 2011), DESC (2011), DOT (1991 through 2011), EIA (2008a, 2011, 2012 2002), EIA (2007 through 2011), EIA (1991 through 2012), EPA (2009), Esser (2003 through 2004), FAA (2012, 2011, and 2006), and Gaffney (2007). Emission factors for non-road modes were taken from IPCC/UNEP/OECD/IEA (1997) and Browning (2009).

Uncertainty and Time-Series Consistency

A quantitative uncertainty analysis was conducted for the mobile source sector using the IPCC-recommended Tier 2 uncertainty estimation methodology, Monte Carlo Stochastic Simulation technique, using @RISK software. The uncertainty analysis was performed on 2010 estimates of CH_4 and N_2O emissions, incorporating probability distribution functions associated with the major input variables. For the purposes of this analysis, the uncertainty was modeled for the following four major sets of input variables: (1) vehicle miles traveled (VMT) data, by on-road vehicle and fuel type and (2) emission factor data, by on-road vehicle, fuel, and control technology type, (3) fuel consumption, data, by non-road vehicle and equipment type, and (4) emission factor data, by non-road vehicle and equipment 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 CH_4 and N_2O 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 CO_2 emissions, the emission pathways of CH_4 and N_2O are highly complex.

Mobile combustion CH_4 emissions from all mobile sources in 2010 were estimated to be between 1.7 and 2.1 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 10 percent below to 9 percent above the corresponding 2010 emission estimate of 1.9 Tg CO_2 Eq. Also at a 95 percent confidence level, mobile combustion N_2O emissions from mobile sources in 2010 were estimated to be between 19.3 and 25.9 Tg CO_2 Eq., indicating a range of 6 percent below to 26 percent above the corresponding 2010 emission estimate of 20.6 Tg CO_2 Eq.

Table 3-18: Tier 2 Quantitative Uncertainty Estimates for CH_4 and N_2O Emissions from Mobile Sources (Tg CO_2 Eq. and Percent)

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[96] The source of VMT and fuel consumption is FHWA's VM-1 table. The data collection methodology has undergone substantial revision for only years 2007-2010, while prior years have remain unchanged Several of the vehicle type categories have changed. For instance, passenger car has been replaced by "Light duty vehicle, short WB" and other 4 axle- 2 tire has been replaced by "Light duty vehicle, long WB". With this change in methodology, there are substantial differences in activity data among vehicle classes, even though overall VMT and fuel consumption is unchanged. While this is the best data available on vehicle activity, the time series reflects changes in the definition of vehicle classes between 2006- 2007 when this change in methodology was implemented.

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

Source	Gas	2010 Emission Estimate[a] (Tg CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (Tg CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mobile Sources	CH_4	1.9	1.7	2.1	-10%	+9%
Mobile Sources	N_2O	20.6	19.3	25.9	-6%	+26%

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

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 CH_4 and N_2O please refer to the Uncertainty Annex.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2009. 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 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. Each year, adjustments are made to the methodologies used in calculating emissions in the current Inventory relative to previous Inventory reports.

In 2011, FHWA revised the methodology of their VM-1 table, which provides the source data for on-road vehicle VMT, fuel consumption, and miles per gallon. FHWA's data collection methodology has undergone substantial revision for only years 2007 to 2010, while prior years have remained unchanged. With this revision, several of the vehicle type categories have changed. For instance, passenger car has been replaced by "Light duty vehicle, short wheel-base" and other 4 axle- 2 tire has been replaced by "Light duty vehicle, long wheel-base". With this change in methodology, there are substantial differences in activity data among vehicle classes, even though overall VMT and fuel consumption is unchanged. While this is the best data available on vehicle activity, the time series reflects changes in the definition of vehicle classes between 2006- 2007, when this change in methodology was implemented.

The underlying data used for calculating Alternative Fuel Vehicles VMT has changed substantially. This data is supplied by the U.S. Energy Information Administration, Office of Energy Consumption and Efficiency Statistics, and the DOE/GSA Federal Automotive Statistical Tool (FAST). EIA changed its reporting methodology for 2005-2010, and has provided more detail on alternative fuel vehicle use by vehicle class. The fuel use breakdown by vehicle class had previously been based on estimates of the distribution of fuel use by vehicle class, while the new data from EIA allowed actual data to be used for fuel use, and resulted in greater share of heavy-duty AFV VMT estimated for 2005-2010.

As a result of these changes, estimates of CH_4 emissions were slightly higher than previous Inventory years, while N_2O emissions were slightly higher for 2005 and 2006 and lower for 2007 through 2009. CH_4 emissions for 2006 increased the most, 2 percent (less than 0.1 Tg CO_2 Eq.). N_2O emissions for 2009 decreased 6 percent (1.4 Tg CO_2 Eq.), the greatest decrease relative to the previous inventory.

Planned Improvements

While the data used for this report represent the most accurate information available, four 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 and other sources 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-CO_2 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 N_2O and CH_4 emissions factors for non-road equipment.
3. Examine the feasibility of estimating aircraft N_2O and CH_4 emissions by the number of takeoffs and landings, instead of total fuel consumption. Various studies have indicated that aircraft N_2O and CH_4 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. Domestic fuel consumption is estimated by subtracting fuel sold for international use from the total sold in the United States. It may be possible to more accurately estimate domestic fuel use and emissions by using detailed data on marine ship activity. The feasibility of using domestic marine activity data to improve the estimates will be investigated.
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 (metallurgical) coke (manufactured from coking coal). The non-energy applications of these fuels are equally diverse, including 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).

CO_2 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 62 percent of the total C consumed for non-energy purposes was stored in products, and not released to the atmosphere; the remaining 38 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 CO_2 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 CO_2 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 make adjustments to address the effect of net exports on the mass of C in non-energy applications.

As shown in Table 3-19, fossil fuel emissions in 2010 from the non-energy uses of fossil fuels were 125.1 Tg CO_2 Eq., which constituted approximately 2 percent of overall fossil fuel emissions. In 2010, the consumption of fuels for non-energy uses (after the adjustments described above) was 4,651.0 TBtu, an increase of 4.3 percent since 1990 (see Table 3-20). About 52.3 Tg of the C (191.7 Tg CO_2 Eq.) in these fuels was stored, while the remaining 34.1 Tg C (125.1 Tg CO_2 Eq.) was emitted.

Table 3-19: CO_2 Emissions from Non-Energy Use Fossil Fuel Consumption (Tg CO_2 Eq.)

Year	1990	2005	2006	2007	2008	2009	2010
Potential Emissions	310.9	387.2	381.6	367.0	341.7	310.6	316.9
C Stored	191.3	243.1	237.8	232.1	203.1	186.9	191.7
Emissions as a % of Potential	38%	37%	38%	37%	41%	40%	39%
Emissions	**119.6**	**144.1**	**143.8**	**134.9**	**138.6**	**123.7**	**125.1**

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 (2011) (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 3-20 and Table 3-21 have been adjusted to subtract non-energy uses that are included in the source categories of the Industrial Processes chapter.[98] 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 3-20: Adjusted Consumption of Fossil Fuels for Non-Energy Uses (TBtu)

Year	1990	2005	2006	2007	2008	2009	2010
Industry	**4,197.8**	**5,309.5**	**5,181.3**	**5,012.3**	**4,626.9**	**4,335.1**	**4,453.5**

[98] 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.

Industrial Coking Coal	+	80.5	62.9	2.3	29.2	6.4	64.9
Industrial Other Coal	8.2	11.9	11.9	11.9	11.9	11.9	10.3
Natural Gas to Chemical Plants	263.7	390.1	228.3	223.0	227.3	220.5	222.8
Asphalt & Road Oil	1,170.2	1,323.2	1,261.2	1,197.0	1,012.0	873.1	877.8
LPG	1,168.7	1,667.9	1,754.8	1,703.3	1,609.2	1,702.6	1,817.3
Lubricants	186.3	160.2	156.1	161.2	149.6	134.5	149.5
Pentanes Plus	84.9	105.2	74.3	91.6	64.9	70.1	67.8
Naphtha (<401 ° F)	326.2	680.5	618.3	542.5	467.2	451.3	472.7
Other Oil (>401 ° F)	662.1	500.4	573.6	669.1	599.1	393.0	404.9
Still Gas	21.3	67.7	57.2	44.2	47.3	133.9	147.2
Petroleum Coke	27.2	105.2	134.2	117.8	147.4	112.1	1.1
Special Naphtha	100.9	61.0	68.9	75.4	83.2	44.3	25.6
Distillate Fuel Oil	7.0	11.7	17.5	17.5	17.5	17.5	17.5
Waxes	33.3	31.4	26.1	21.9	19.1	12.2	15.4
Miscellaneous Products	137.8	112.8	136.0	133.5	142.0	151.8	158.8
Transportation	**176.0**	**151.3**	**147.4**	**152.2**	**141.3**	**127.1**	**141.2**
Lubricants	176.0	151.3	147.4	152.2	141.3	127.1	141.2
U.S. Territories	**86.7**	**121.9**	**133.4**	**108.4**	**126.7**	**56.3**	**56.3**
Lubricants	0.7	4.6	6.2	5.9	2.7	1.0	1.0
Other Petroleum (Misc. Prod.)	86.0	117.3	127.2	102.5	124.1	55.2	55.2
Total	**4,460.5**	**5,582.8**	**5,462.1**	**5,272.9**	**4,895.0**	**4,518.4**	**4,651.0**

Table 3-21: 2010 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	**4,453.5**	**-**	**82.4**	**-**	**51.9**	**30.5**	**111.9**
Industrial Coking Coal	64.9	25.61	1.7	0.10	0.2	1.5	5.5
Industrial Other Coal	10.3	25.82	0.3	0.59	0.2	0.1	0.4
Natural Gas to Chemical Plants	222.8	14.47	3.2	0.59	1.9	1.3	4.8
Asphalt & Road Oil	877.8	20.55	18.0	1.00	18.0	0.1	0.3
LPG	1,817.3	17.06	31.0	0.59	18.4	12.6	46.1
Lubricants	149.5	20.20	3.0	0.09	0.3	2.7	10.1
Pentanes Plus	67.8	19.10	1.3	0.59	0.8	0.5	1.9
Naphtha (<401° F)	472.7	18.55	8.8	0.59	5.2	3.6	13.1
Other Oil (>401° F)	404.9	20.17	8.2	0.59	4.9	3.3	12.2
Still Gas	147.2	17.51	2.6	0.59	1.5	1.0	3.8
Petroleum Coke	1.1	27.85	+	0.30	+	+	0.1
Special Naphtha	25.6	19.74	0.5	0.59	0.3	0.2	0.8
Distillate Fuel Oil	17.5	20.17	0.4	0.50	0.2	0.2	0.6
Waxes	15.4	19.80	0.3	0.58	0.2	0.1	0.5
Miscellaneous Products	158.8	20.31	3.2	+	+	3.2	11.8
Transportation	**141.2**	**-**	**2.9**	**-**	**0.3**	**2.6**	**9.5**
Lubricants	141.2	20.20	2.9	0.09	0.3	2.6	9.5
U.S. Territories	**56.3**	**-**	**1.1**	**-**	**0.1**	**1.0**	**3.7**
Lubricants	1.0	20.20	+	0.09	+	+	0.1
Other Petroleum (Misc. Prod.)	55.2	20.00	1.1	0.10	0.1	1.0	3.6
Total	**4,651.0**		**86.4**		**52.3**	**34.1**	**125.1**

+ 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 3-19). 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 energy recovery, Toxics Release Inventory (TRI) releases, hazardous waste incineration, and volatile organic compound, solvent, and non-combustion CO emissions. 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 2010), *Toxics Release Inventory, 1998* (2000b), *Biennial Reporting System* (EPA 2004, 2009), and pesticide sales and use estimates (EPA 1998, 1999, 2002, 2004, 2011); the EIA Manufacturer's Energy Consumption Survey (MECS) (EIA 1994, 1997, 2001, 2005, 2010); the National Petrochemical & Refiners Association (NPRA 2002); the U.S. Bureau of the Census (1999, 2004, 2009); Bank of Canada (2011); Financial Planning Association (2006); INEGI (2006); the United States International Trade Commission (2011); 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 2011); and the American Chemistry Council (ACC 2003-2010, 2011). 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 Stochastic 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 in Table 3-20 and Table 3-21), 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 3-22 (emissions) and Table 3-23 (storage factors). Carbon emitted from non-energy uses of fossil fuels in 2010 was estimated to be between 103.8 and 154.0 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 17 percent below to 23 percent above the 2010 emission estimate of 125.1 Tg CO_2 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.

Table 3-22: Tier 2 Quantitative Uncertainty Estimates for CO_2 Emissions from Non-Energy Uses of Fossil Fuels (Tg CO_2 Eq. and Percent)

Source	Gas	2010 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
Feedstocks	CO_2	83.1	65.2	114.0	-22%	37%
Asphalt	CO_2	0.3	0.1	0.6	-58%	117%
Lubricants	CO_2	19.6	16.2	22.8	-18%	16%
Waxes	CO_2	0.5	0.3	0.8	-28%	63%
Other	CO_2	21.7	13.9	24.5	-36%	13%
Total	**CO_2**	**125.1**	**103.8**	**154.0**	**-17%**	**23%**

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

Table 3-23: Tier 2 Quantitative Uncertainty Estimates for Storage Factors of Non-Energy Uses of Fossil Fuels (Percent)

Source	Gas	2010 Storage Factor (%)	Uncertainty Range Relative to Emission Estimate[a] (%)		(%, Relative)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Feedstocks	CO_2	59%	54%	61%	-10%	3%
Asphalt	CO_2	99.6%	99%	100%	-1%	0%
Lubricants	CO_2	9%	4%	17%	-59%	90%
Waxes	CO_2	58%	49%	71%	-15%	23%
Other	CO_2	16%	10%	44%	-39%	179%

[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).

In Table 3-23, feedstocks and asphalt contribute least to overall storage factor uncertainty on a percentage basis. 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 2010. 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 2011 as well as their trends across the time series.

Petrochemical input data reported by EIA will continue to be investigated in an attempt to address an input/output discrepancy in the NEU model. Since 2001, the C accounted for in the feedstocks C balance outputs (i.e., storage plus emissions) exceeds C inputs. Prior to 2001, the C balance inputs exceed outputs. EPA has reduced a portion of this discrepancy (see Recalculations Discussion below) and has developed two strategies to address the remaining portion (see Planned Improvements below).

Recalculations Discussion

Relative to the previous Inventory, emissions from non-energy uses of fossil fuels decreased by an average of 1.2 Tg CO_2 Eq. (0.7 percent) across the entire time series. Two competing changes contributed to these recalculations. The

larger of the two changes was a decrease in emissions caused by a change in petrochemical input data reported by the Energy Information Administration in its Monthly Energy Review. In particular, a decline in EIA's estimate of petroleum coke consumed for non-energy purposes across the time series explains the majority of the decrease. The smaller of the two changes was an increase in emissions caused by EIA's revision of its methodology for calculating LPG consumed for non-energy uses in consultation with EPA. These estimates had previously been based on the assumption that the portion of LPG used for NEU remained constant at its 2004 level for the rest of the time series. For this year's Inventory, EIA instead retrieved data describing the portion of LPG in NEU from Petroleum Supply Annual for the entire 1990-2010 time series and revised the previous assumption accordingly. Because 2004 was an uncharacteristically low year for non-energy consumption of LPG, this revision resulted in an overall increase in estimates of LPG consumed for NEU and thus an increase in estimated emissions. Combined, the net effect of these two changes was to decrease emission estimates across the time series slightly.

The revision to LPG calculations mentioned above also significantly reduced the input/output discrepancy in the NEU model. Specifically, this discrepancy was reduced by an average of 43% between 2000 and 2010, the years in which the discrepancy had previously been the largest.

Planned Improvements

There are several improvements planned for the future:

- More accurate accounting of C in petrochemical feedstocks. EPA has worked with EIA to determine the cause of an input/output discrepancy in the carbon mass balance contained within the NEU model. In the future, EPA will continue to pursue two strategies to reduce or eliminate this discrepancy. First, EPA will improve its accounting of C in imports and exports. EPA will examine its import/export adjustment methodology to ensure that net exports of intermediaries such as ethylene and propylene are fully accounted for. Second, EPA will reconsider its use of top-down C input calculation in estimating emissions. It will consider alternative approaches that rely more substantially on the bottom-up C output calculation instead.
- 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).
- Reviewing the trends in fossil fuel consumption for non-energy uses. Annual consumption for several fuel types is highly variable across the time series, including industrial coking coal and other petroleum (miscellaneous products). EPA plans to better understand these trends to identify any mischaracterized or misreported fuel consumption for non-energy uses.
- EPA recently researched updating the average carbon content of solvents, since the entire time series depends on one year's worth of solvent composition data. Unfortunately, the data on C emissions from solvents that were readily available do not provide composition data for all categories of solvent emissions and also have conflicting definitions for volatile organic compounds, the source of emissive carbon in solvents. EPA plans to identify additional sources of solvents data in order to update the C content assumptions.

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 or deferring to more updated default storage factors from IPCC where available.

Finally improvements to this category will involve analysis of the data reported under EPA's GHGRP. In examining data from EPA's GHGRP that would be useful to improve the emission estimates for the carbon emitted from non-energy uses of fossil fuels category, particular attention will be made to ensure time series consistency, as the facility-level reporting data from EPA's GHGRP are not available for all Inventory years as reported in this inventory. In implementing improvements and integration of data from EPA's GHGRP, the latest guidance from the

IPCC on the use of facility-level data in national inventories will be relied upon.[99]

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, van Haaren et al. 2010). 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 or industrial 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 CO_2. According to IPCC guidelines, when the CO_2 emitted is of fossil origin, it is counted as a net anthropogenic emission of CO_2 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. Estimates on emissions from hazardous waste incineration can be found in Annex 2.3 and are accounted for as part of the C mass balance for non-energy uses of fossil fuels.

Approximately 26.5 million metric tons of MSW was incinerated in the United States in 2010 (EPA 2011a). CO_2 emissions from incineration of waste rose 51 percent since 1990, to an estimated 12.1 Tg CO_2 Eq. (12,054 Gg) in 2010, as the volume of tires and other fossil C-containing materials in waste increased (see Table 3-24 and Table 3-25). Waste incineration is also a source of N_2O and CH_4 emissions (De Soete 1993; IPCC 2006). N_2O emissions from the incineration of waste were estimated to be 0.4 Tg CO_2 Eq. (1 Gg N_2O) in 2010, and have not changed significantly since 1990. CH_4 emissions from the incineration of waste were estimated to be less than 0.05 Tg CO_2 Eq. (less than 0.5 Gg CH_4) in 2010, and have not changed significantly since 1990.

Table 3-24: CO_2 and N_2O Emissions from the Incineration of Waste (Tg CO_2 Eq.)

Gas/Waste Product	1990	2005	2006	2007	2008	2009	2010
CO_2	**8.0**	**12.5**	**12.5**	**12.7**	**11.9**	**11.7**	**12.1**
Plastics	5.6	6.9	6.7	6.7	6.1	6.2	6.6
Synthetic Rubber in Tires	0.3	1.6	1.7	1.8	1.7	1.6	1.6
Carbon Black in Tires	0.4	2.0	2.1	2.3	2.1	1.9	1.9
Synthetic Rubber in MSW	0.9	0.8	0.8	0.8	0.8	0.8	0.8
Synthetic Fibers	0.8	1.2	1.2	1.2	1.2	1.2	1.2
N_2O	**0.5**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
CH_4	+	+	+	+	+	+	+
Total	**8.5**	**12.9**	**12.9**	**13.1**	**12.3**	**12.1**	**12.4**

+ Does not exceed 0.05 Tg CO_2 Eq.

Table 3-25: CO_2 and N_2O Emissions from the Incineration of Waste (Gg)

Gas/Waste Product	1990	2005	2006	2007	2008	2009	2010
CO_2	**7,989**	**12,468**	**12,531**	**12,727**	**11,888**	**11,703**	**12,054**
Plastics	5,588	6,919	6,722	6,660	6,148	6,233	6,573

[99] See <http://www.ipcc-nggip.iges.or.jp/meeting/pdfiles/1008_Model_and_Facility_Level_Data_Report.pdf>

Synthetic Rubber in Tires	308		1,599	1,712	1,823	1,693	1,560	1,560
Carbon Black in Tires	385		1,958	2,113	2,268	2,085	1,903	1,903
Synthetic Rubber in MSW	872		781	775	791	770	782	787
Synthetic Fibers	838		1,211	1,208	1,185	1,192	1,226	1,230
N_2O	**2**		**1**	**1**	**1**	**1**	**1**	**1**
CH_4	+		+	+	+	+	+	+

+ Does not exceed 0.5 Gg.

Methodology

Emissions of CO_2 from the incineration of waste include CO_2 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 CO_2 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 CO_2 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 2000 through 2003, 2005 through 2011b) 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" (van Haaren et al. 2010). The most recent data provides the proportion of waste incinerated for 2008, so the corresponding proportion in 2010 is assumed to be equal to the proportion in 2008. For synthetic rubber and carbon black in scrap tires, information was obtained from U.S. Scrap Tire Management Summary for 2005 through 2009 data (RMA 2011). For 2010, synthetic rubber mass in tires is assumed to be equal to that in 2009 due to a lack of more recently available data.

Average C contents for the "Other" plastics category and synthetic rubber in municipal solid wastes were calculated from 1998 and 2002 production statistics: carbon content for 1990 through 1998 is based on the 1998 value; content for 1999 through 2001 is the average of 1998 and 2002 values; and content for 2002 to date is based on the 2002 value. Carbon content for synthetic fibers was calculated from 1999 production statistics. Information about scrap tire composition was taken from the Rubber Manufacturers' Association internet site (RMA 2012a).

The assumption that 98 percent of organic C is oxidized (which applies to all waste incineration categories for CO_2 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, including MSW, also results in emissions of N_2O and CH_4. These emissions were calculated as a function of the total estimated mass of waste incinerated and an emission factor. As noted above, N_2O and CH_4 emissions are a function of total waste incinerated in each year; for 1990 through 2008, these data were derived from the information published in BioCycle (van Haaren et al. 2010). Data on total waste incinerated was not available for 2009 or 2010, so this value was assumed to equal the most recent value available (2008).

Table 3-26 provides data on municipal solid waste discarded 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 N_2O and CH_4 emissions per quantity of municipal solid waste combusted are default emission factors for this technology type and were taken from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006).

Table 3-26: Municipal Solid Waste Generation (Metric Tons) and Percent Combusted.

Year	Waste Discarded	Waste Incinerated	Incinerated (% of Discards)
1990	235,733,657	30,632,057	13.0
2005	259,559,787	25,973,520	10.0
2006	267,526,493	25,853,401	9.7
2007	268,279,240	24,788,539	9.2
2008	268,541,088	23,674,017	8.8
2009	268,541,088[a]	23,674,017[a]	8.8[a]
2010	268,541,088[a]	23,674,017[a]	8.8[a]

[a] Assumed equal to 2008 value.
Source: van Haaren et al. (2010).

Uncertainty and Time-Series Consistency

A Tier 2 Monte Carlo analysis was performed to determine the level of uncertainty surrounding the estimates of CO_2 emissions and N_2O emissions from the incineration of waste (given the very low emissions for CH_4, 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 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 N_2O 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 3-27. Waste incineration CO_2 emissions in 2010 were estimated to be between 9.6and 14.9 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 21 percent below to 24 percent above the 2010 emission estimate of 12.1 Tg CO_2 Eq. Also at a 95 percent confidence level, waste incineration N_2O emissions in 2010 were estimated to be between 0.2 and 1.5 Tg CO_2 Eq. This indicates a range of 50 percent below to 320 percent above the 2010 emission estimate of 0.4 Tg CO_2 Eq.

Table 3-27: Tier 2 Quantitative Uncertainty Estimates for CO_2 and N_2O from the Incineration of Waste (Tg CO_2 Eq. and Percent)

Source	Gas	2010 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
Incineration of Waste	CO_2	12.1	9.6	14.9	-21%	+24%
Incineration of Waste	N_2O	0.4	0.2	1.5	-50%	+320%

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

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990

through 2010. 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 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 calculations on incineration of waste.

Recalculations Discussion

Several changes were made to input variables compared to the previous Inventory, resulting in an overall decrease in the total emissions from the incineration of waste. The emissions from carbon black and rubber in scrap tires in 2008 and 2009 were updated based on data obtained from the Rubber Manufacturers' Association U.S. Scrap Tire Management Summary for 2005 through 2009 (RMA 2012b), because the report releases data every other year. The 2009 data was available in this report, so 2008 data was updated using linear interpolation from the 2007 and 2009 data. The change decreased the 2008 and 2009 emissions by 2 percent and 5 percent, respectively, relative to the previous report.

Planned Improvements

The availability of facility-level waste incineration through EPA's GHGRP will be examined to help better characterize waste incineration operations in the United States. This characterization could include future improvements as to the operations involved in waste incineration for energy, whether in the power generation sector or the industrial sector. Additional examinations will be necessary as, unlike the reporting requirements for this chapter under the UNFCCC reporting guidelines,[100] some facility-level waste incineration emissions reported under the GHGRP may also include industrial process emissions. In line with UNFCCC reporting guidelines, emissions for waste incineration with energy recovery are included in this chapter, while process emissions are included in the industrial processes chapter of this report. In examining data from EPA's GHGRP that would be useful to improve the emission estimates for the waste incineration category, particular attention will also be made to ensure time series consistency, as the facility-level reporting data from EPA's GHGRP are not available for all inventory years as reported in this inventory. Additionally, analyses will focus on ensuring CO_2 emissions from the biomass component of waste are separated in the facility-level reported data, and on maintaining consistency with national waste generation and fate statistics currently used to estimate total, national U.S. greenhouse gase emissions. In implementing improvements and integration of data from EPA's GHGRP, the latest guidance from the IPCC on the use of facility-level data in national inventories will be relied upon.[101]

3.4. Coal Mining (IPCC Source Category 1B1a)

Three types of coal mining related activities release CH_4 to the atmosphere: underground mining, surface mining, and post-mining (i.e., coal-handling) activities. Underground coal mines contribute the largest share of CH_4 emissions. In 2010, 164 gassy underground coal mines in the United States employ ventilation systems to ensure that CH_4 levels remain within safe concentrations. These systems can exhaust significant amounts of CH_4 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 CH_4 before, during, or after mining. In 2010, 15 coal mines collected CH_4 from degasification systems and utilized this gas, thus reducing emissions to the atmosphere. Of these mines, 14 coal mines sold CH_4 to the natural gas pipeline and one coal mine used CH_4 from its degasification system to heat mine

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

[101] See <http://www.ipcc-nggip.iges.or.jp/meeting/pdfiles/1008_Model_and_Facility_Level_Data_Report.pdf>

ventilation air on site. In addition, one of the coal mines that sold gas to pipelines also used CH_4 to fuel a thermal coal dryer. Surface coal mines also release CH_4 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 CH_4 retained in the coal after mining is released during processing, storage, and transport of the coal.

Total CH_4 emissions in 2010 were estimated to be 72.6 Tg CO_2 Eq. (3,458 Gg), a decline of 14 percent since 1990 (see Table 3-28 and Table 3-29). Of this amount, underground mines accounted for 71 percent, surface mines accounted for 18 percent, and post-mining emissions accounted for 11 percent. The decline in CH_4 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 CH_4 recovered and used. Since that time, underground coal production and the associated CH_4 emissions have remained fairly level, while surface coal production and its associated emissions have generally increased.

Table 3-28: CH_4 Emissions from Coal Mining (Tg CO_2 Eq.)

Activity	1990		2005	2006	2007	2008	2009	2010
UG Mining	62.3		34.9	34.9	35.7	44.9	49.6	51.6
Liberated	67.9		50.2	50.2	50.9	60.5	66.1	71.4
Recovered & Used	(5.6)		(15.2)	(18.8)	(15.2)	(16.3)	(16.6)	(19.6)
Surface Mining	12.0		13.3	14.0	13.8	14.3	12.9	13.1
Post-Mining (UG)	7.7		6.4	6.3	6.1	6.1	5.6	5.7
Post-Mining (Surface)	2.0		2.2	2.3	2.2	2.3	2.1	2.1
Total	**84.1**		**56.8**	**56.8**	**57.8**	**66.9**	**70.1**	**72.6**

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

Table 3-29: CH_4 Emissions from Coal Mining (Gg)

Activity	1990		2005	2006	2007	2008	2009	2010
UG Mining	2,968		1,663	1,693	1,698	2,102	2,360	2,459
Liberated	3,234		2,389	2,588	2,422	2,881	3,149	3,402
Recovered & Used	(265.9)		(726.0)	(894.7)	(723.7)	(778.5)	(789.2)	(942.9)
Surface Mining	573.6		633.1	668.0	658.9	680.5	614.2	626.2
Post-Mining (UG)	368.3		305.9	298.5	289.6	292.0	266.7	270.2
Post-Mining (Surface)	93.2		102.9	108.5	107.1	110.6	99.8	101.8
Total	**4,003**		**2,705**	**2,768**	**2,754**	**3,186**	**3,340**	**3,458**

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

Methodology

The methodology for estimating CH_4 emissions from coal mining consists of two parts. The first part involves estimating CH_4 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 CH_4 emitted from underground mines was estimated as the sum of CH_4 liberated from ventilation systems and CH_4 liberated by means of degasification systems, minus CH_4 recovered and used. The Mine Safety and Heath Administration (MSHA) samples CH_4 emissions from ventilation systems for all mines with detectable[102] CH_4 concentrations. These mine-by-mine measurements are used to estimate CH_4 emissions from ventilation systems.

Some of the higher-emitting underground mines also use degasification systems (e.g., wells or boreholes) that remove CH_4 before, during, or after mining. This CH_4 can then be collected for use or vented to the atmosphere.

[102] MSHA records coal mine CH_4 readings with concentrations of greater than 50 ppm (parts per million) CH_4. Readings below this threshold are considered non-detectable.

Various approaches were employed to estimate the quantity of CH_4 collected by each of the twenty mines using these systems, depending on available data. For example, some mines report to EPA the amount of CH_4 liberated from their degasification systems. For mines that sell recovered CH_4 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 CH_4 recovered by degasification systems and then used (i.e., not vented) was estimated. In 2010, 14 active coal mines sold recovered CH_4 into the local gas pipeline networks and one coal mine used recovered CH_4 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. Data was not available for CDX wells for 2010, thus underground emissions avoided were estimated for two mines. Emissions avoided were estimated using a 10-year average for the Pinnacle Mine and a 2-year average for the Road Fork 51 Mine.

Surface Mines and Post-Mining Emissions. Surface mining and post-mining CH_4 emissions were estimated by multiplying basin-specific coal production, obtained from the Energy Information Administration's Annual Coal Report (see Table 3-30) (EIA 2011), by basin-specific emission factors. Surface mining emission factors were developed by assuming that surface mines emit two times as much CH_4 as the average in situ CH_4 content of the coal. Revised data on in situ CH_4 content and emissions factors are taken from EPA (2005), EPA (1996), and AAPG (1984). This calculation accounts for CH_4 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 CH_4 content of coals mined in the basin.

Table 3-30: Coal Production (Thousand Metric Tons)

Year	Underground	Surface	Total
1990	384,244	546,808	931,052
2005	334,398	691,448	1,025,846
2006	325,697	728,447	1,054,144
2007	319,139	720,023	1,039,162
2008	323,932	737,832	1,061,764
2009	301,241	671,475	972,716
2010	305,862	693,732	999,594

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 CH_4 emissions (Mutmansky and Wang 2000). Estimates of CH_4 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 3-31. Coal mining CH_4 emissions in 2009 were

estimated to be between 63.0 and 84.4 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 13.2 percent below to 16.3 percent above the 2010 emission estimate of 72.6 Tg CO_2 Eq.

Table 3-31: Tier 2 Quantitative Uncertainty Estimates for CH_4 Emissions from Coal Mining (Tg CO_2 Eq. and Percent)

Source	Gas	2010 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 Mining	CH_4	72.6	63.0	84.4	-13.2%	+16.3%

[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 2010. Details on the emission trends through time are described in more detail in the Methodology section, above.

Recalculations Discussion

For the current inventory, updated mine maps were received for the Oak Grove and Jim Walter Resources (JWR) mines, which provided a more accurate depiction of the dates that certain pre-drainage CMM wells were mined through. As a result, the mined-through dates were adjusted for some wells based on updated mine plans, and underground emissions avoided values changed slightly from 2005 to 2009.

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

Underground coal mines contribute the largest share of CH_4 emissions, with active underground mines the leading source of underground emissions. However, mines also continue to release CH_4 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 CH_4 that may find its way to surface structures through overburden fractures. As work stops within the mines, the CH_4 liberation decreases but it does not stop completely. Following an initial decline, abandoned mines can liberate CH_4 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 CH_4 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;
- CH_4 flow capacity of the mine;
- Mine flooding;
- Presence of vent holes; and
- Mine seals.

Gross abandoned mine CH_4 emissions ranged from 6.0 to 9.1 Tg CO_2 Eq. from 1990 through 2010, 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 CO_2 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 2010, with only five closures in 2010. By 2010, gross abandoned mine emissions decreased slightly to 7.6 Tg CO_2 Eq. (see Table 3-32 and Table 3-33). Gross emissions are reduced by CH_4

recovered and used at 38 mines, resulting in net emissions in 2010 of 5.0 Tg CO_2 Eq.

Table 3-32: CH_4 Emissions from Abandoned Coal Mines (Tg CO_2 Eq.)

Activity	1990		2005	2006	2007	2008	2009	2010
Abandoned Underground Mines	6.0		7.0	7.6	8.9	9.0	8.1	7.6
Recovered & Used	+		1.5	2.2	3.6	3.7	3.0	2.7
Total	**6.0**		**5.5**	**5.5**	**5.3**	**5.3**	**5.1**	**5.0**

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

Table 3-33: CH_4 Emissions from Abandoned Coal Mines (Gg)

Activity	1990		2005	2006	2007	2008	2009	2010
Abandoned Underground Mines	288		334	364	425	429	388	364
Recovered & Used	+		70	103	172	177	143	126
Total	**288**		**264**	**261**	**254**	**253**	**244**	**237**

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

Methodology

Estimating CH_4 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 CH_4 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 CH_4 emission rate before 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 that depends 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 also 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 CH_4 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 CH_4 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 productivity index (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:

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

where,

q = Gas rate at time t in mmcf/d
q_i = Initial gas rate at time zero (t_o) in million cubic feet per day mmcfd)
b = The hyperbolic exponent, dimensionless
D_i = Initial decline rate, 1/yr
t = Elapsed time from t_o (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 CH_4 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).

$$q = q_{ie}^{(-Dt)}$$

where,

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

Seals have an inhibiting effect on the rate of flow of CH_4 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 mcfd account for 98 percent of all CH_4 emissions. This same relationship is assumed for abandoned mines. It was determined that 469 abandoned mines closing after 1972 produced emissions greater than 100 mcfd when active. Further, the status of 273 of the 469 mines (or 58 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 CH_4 flow to the atmosphere). The remaining 42 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).

Table 3-34: 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 Appl.	25	25	48	98	129	227
Illinois	30	3	14	47	26	73
Northern Appl.	42	22	16	80	36	116
Warrior Basin	0	0	16	16	0	16
Western Basins	27	3	2	32	10	42
Total	**124**	**53**	**96**	**273**	**196**	**474**

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 CH_4 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 CH_4 emissions rates during the 1970s (EPA 2003).

Abandoned mines emission estimates are based on all closed mines known to have active mine CH_4 ventilation emission rates greater than 100 mcfd at the time of abandonment. 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. CH_4 degasification amounts were added to the quantity of CH_4 ventilated for the total CH_4 liberation rate for seventeen mines that closed between 1992 and 2010. Since the sample of gassy mines (with active mine emissions greater than 100 mcfd) 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 2010, emission totals were downwardly adjusted to reflect abandoned mine CH_4 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 CH_4 recovery projects during that time.

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) CH_4 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 3-35. Abandoned coal mines CH_4 emissions in 2010 were estimated to be between 3.88 and 6.05 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 22 percent below to 21 percent above the 2010 emission estimate of 4.98 Tg CO_2 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 42 percent of the mines), with a ±51 percent uncertainty.

Table 3-35: Tier 2 Quantitative Uncertainty Estimates for CH_4 Emissions from Abandoned Underground Coal Mines (Tg CO_2 Eq. and Percent)

Source	Gas	2010 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	4.98	3.88	6.05	-22%	+21%

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

Recalculations Discussion

After last year's submission of the 1990-2009 Inventory, a small error in the calculations spreadsheet for Abandoned

Underground Coal Mines was discovered. This error was fixed in preparation of this year's Inventory and as a result some of the emissions estimates for this source category in past years differ from last year's report. No new data or methodologies were used to recalculate these values.

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 215.4 Tg CO_2 Eq. (10,259 Gg) of CH_4 in 2010, a 14 percent increase over 1990 emissions (see Table 3-36 and Table 3-37) and 32.3 Tg CO_2 Eq. (32,301 Gg) of non-combustion CO_2 in 2010, a 14 percent decrease over 1990 emissions (see Table 3-38 and Table 3-39). Improvements in management practices and technology, along with the replacement of older equipment, have helped to stabilize emissions. Methane emissions increased since 2008 due to an increase in production and production wells.

CH_4 and non-combustion CO_2 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 of the four major stages of the natural gas system. Each of the stages is described and the different factors affecting CH_4 and non-combustion CO_2 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. Emissions from pneumatic devices, gas wells with liquids unloading, and gas well completions and re-completions (workovers) with and without hydraulic fracturing account for the majority of CH_4 emissions. Flaring emissions account for the majority of the non-combustion CO_2 emissions. Emissions from field production accounted for approximately 58 percent of CH_4 emissions and about 34 percent of non-combustion CO_2 emissions from natural gas systems in 2010.

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 CH_4 emissions from compressors, including compressor seals, are the primary emission source from this stage. The majority of non-combustion CO_2 emissions come from acid gas removal units, which are designed to remove CO_2 from natural gas. Processing plants account for about 8 percent of CH_4 emissions and approximately 66 percent of non-combustion CO_2 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 CH_4 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 CH_4 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. CH_4 emissions from the transmission and storage sector account for approximately 20 percent of emissions from natural gas systems, while CO_2 emissions from transmission and storage account for less than 1 percent of the non-combustion CO_2 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 1,202,000 miles of distribution mains in 2010, an increase of approximately 258,000 miles since 1990 (OPS 2010b). Distribution system emissions, which account for approximately 13 percent of CH_4

emissions from natural gas systems and less than 1 percent of non-combustion CO_2 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 CH_4 emissions in 2010 were 15 percent lower than 1990 levels.

Table 3-36 and Table 3-37 show total CH_4 emissions for the four major stages of natural gas systems, in Tg CO2 Eq (Table 3-36) and Gg (Table 3-37). Table 3-38 gives more information on how the numbers in 3-36 were calculated. Table 3-38 shows the calculated CH_4 release (i.e. potential emissions before any controls are applied) from each stage, and the amount of that CH_4 that is estimated to have been flared, captured, or otherwise controlled, and therefore not emitted to the atmosphere. Subtracting the CH_4 that is controlled from the quantity of CH_4 that was calculated to be released results in the emissions totals.

Table 3-36: CH_4 Emissions from Natural Gas Systems (Tg CO_2 Eq.)*

Stage	1990		2005	2006	2007	2008	2009	2010
Field Production	89.0		105.2	133.8	117.8	123.2	129.4	126.0
Processing	18.0		14.6	14.8	15.5	16.2	17.8	17.1
Transmission and Storage	49.2		41.4	40.9	42.5	43.3	44.7	43.8
Distribution	33.4		29.3	28.3	29.4	29.9	29.1	28.5
Total	**189.6**		**190.5**	**217.7**	**205.3**	**212.7**	**220.9**	**215.4**

*These values represent CH_4 emitted to the atmosphere. CH_4 that is captured (and not emitted to the atmosphere) has been calculated and removed from emission totals.
Note: Totals may not sum due to independent rounding.

Table 3-37: CH_4 Emissions from Natural Gas Systems (Gg)*

Stage	1990		2005	2006	2007	2008	2009	2010
Field Production	4,240		5,011	6 ,370	5,611	5,869	6,161	6,002
Processing	855		694	704	737	770	837	812
Transmission and Storage	2,343		1,971	1,949	2,024	2,062	2,127	2,086
Distribution	1,591		1,395	1,346	1,402	1,426	1,384	1,359
Total	**9,029**		**9,071**	**10,369**	**9,774**	**10,127**	**10,519**	**10,259**

* These values represent CH_4 emitted to the atmosphere. CH_4 that is captured (and not emitted to the atmosphere) has been calculated and removed from emission totals.
Note: Totals may not sum due to independent rounding.

Table 3-38: Calculated Potential CH_4 and Captured/Combusted CH_4 from Natural Gas Systems (Tg CO_2 Eq.)

	1990		2005	2006	2007	2008	2009	2010
Calculated Potential‡	**189.4**		**240.2**	**295.7**	**274.2**	**293.3**	**288.5**	**288.6**
Field Production	88.9		141.0	197.8	173.7	191.2	186.9	185.9
Processing	17.9		17.3	17.7	18.2	19.0	19.3	20.1
Transmission and Storage	49.2		51.9	51.0	52.0	52.6	52.5	53.0
Distribution	33.4		30.0	29.3	30.2	30.5	29.9	29.6
Captured/Combusted	**(0.2)***		**49.7**	**77.9**	**68.9**	**80.6**	**67.6**	**73.1**
Field Production	+		35.8	64.0	55.9	67.9	57.5	59.8
Processing	+		2.7	2.9	2.8	2.8	1.5	3.0
Transmission and Storage	+		10.5	10.1	9.5	9.2	7.8	9.2
Distribution	+		0.7	1.0	0.8	0.6	0.9	1.1
Net Emissions	**189.6**		**190.5**	**217.7**	**205.3**	**212.7**	**220.9**	**215.4**
Field Production	89.0		105.2	133.8	117.8	123.2	129.4	126.0
Processing	18.0		14.6	14.8	15.5	16.2	17.8	17.1
Transmission and Storage	49.2		41.4	40.9	42.5	43.3	44.7	43.8
Distribution	33.4		29.3	28.3	29.4	29.9	29.1	28.5

Note: Totals may not sum due to independent rounding.
*The base year of the factors used is 1992; for reductions reported between 1990 and 1992, it is assumed that reductions are already taken into account in the Calculated Potential values and the reduction is added back into the estimate for the

appropriate year(s). For 1990, this table shows the value added back into the estimate.
+ Emissions are less than 0.1 Tg CO_2 Eq.
‡ In this context, "potential" means the total emissions calculated before voluntary reductions/regulatory controls are applied.

Table 3-39: Non-combustion CO_2 Emissions from Natural Gas Systems (Tg CO_2 Eq.)

Stage	1990	2005	2006	2007	2008	2009	2010
Field Production	9.7	8.0	9.4	9.7	11.3	10.9	10.8
Processing	27.8	21.7	21.2	21.2	21.4	21.2	21.3
Transmission and Storage	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Distribution	+	+	+	+	+	+	+
Total	**37.6**	**29.9**	**30.8**	**31.0**	**32.8**	**32.2**	**32.3**

Note: Totals may not sum due to independent rounding.
+ Emissions are less than 0.1 Tg CO_2 Eq.

Table 3-40: Non-combustion CO_2 Emissions from Natural Gas Systems (Gg)

Stage	1990	2005	2006	2007	2008	2009	2010
Field Production	9,703	8,049	9,437	9,745	11,335	10,875	10,848
Processing	27,763	21,746	21,214	21,199	21,385	21,188	21,346
Transmission and Storage	62	64	63	64	65	65	65
Distribution	46	41	40	41	42	41	41
Total	**37,574**	**29,901**	**30,754**	**31,049**	**32,826**	**32,169**	**32,301**

Note: Totals may not sum due to independent rounding.

Methodology

The primary basis for estimates of CH_4 and non-combustion-related CO_2 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 CH_4 emission factors to characterize emissions from the various components within the operating stages of the U.S. natural gas system. The same factors were used to estimate both CH_4 and non-combustion CO_2 emissions. CO_2 factors were developed using the CH_4 emission factors and average CO_2 and CH_4 content of gas. 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 factors and activity data drivers from the study, 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 data drivers was developed that can be used to update activity data, where such data is not directly available. 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.

Although the inventory primarily uses EPA/GRI emission factors, significant improvements were made to the emissions estimates for three sources with last year's inventory: gas wells with liquids unloading, condensate storage tanks and centrifugal compressors. In addition, data for two sources not included in the EPA/GRI study – gas well completions and gas well workovers (re-completions) with hydraulic fracturing- were added. In the case of gas wells with liquids unloading, the methodology was revised to use a large sample of well and reservoir characteristics from the HPDI database (HPDI 2009) along with an engineering statics equation (EPA 2006a) to estimate the volume of natural gas necessary to expel a liquid column choking the well production. See Annex 3.4 for more information on the methodology for gas wells with liquids unloading. For condensate storage tanks, sample E&P Tank runs were used as was the case in previous inventories; however, the factor was improved by using a large sample distribution of condensate production by gravity from the HPDI database (HPDI 2009) to weigh the sample simulation flashing emissions rather than assuming a uniform distribution of condensate gravities. Additionally, TERC (TERC 2009) data representing two regions was used in the emission factors for those two regions to estimate the effects of separator dump valves malfunctioning and allowing natural gas to vent through the downstream condensate storage tanks. The EPA/GRI emission factor for centrifugal compressors (used in earlier

inventories) was derived from sampled emissions at the seal face of wet seal compressors. A World Gas Conference publication (WGC 2009) on the seal oil degassing vents was used to update this factor and to also account for the emergence of dry seal centrifugal compressors (EPA 2006b), which eliminates seal oil degassing vents and reduces overall emissions. For more information on this factor, see Annex 3.4. Previous Inventories did not differentiate between wells without hydraulic fracturing and with hydraulic fracturing for completions and workovers. Gas well completions and workovers with hydraulic fracturing were not common at the time the EPA/GRI survey was conducted. Since then, these activities have become more prevalent and emissions data on this activity has become available through a number of sources. Using this data, an emission factor was developed for gas well completions and workovers with hydraulic fracturing. See Annex 3.4 for more detailed information on the methodology and data used to calculate CH_4 and non-combustion CO_2 emissions from natural gas systems.

The emissions factors described above represent expected emissions from an activity, and do not take into account use of technologies that reduce emissions. To take into account use of such technologies, data is collected on regulatory and voluntary reductions. For more information on these reductions, please see the Annex. The numbers presented in tables 3-36 and 3-37 are the CH_4 that is emitted to the atmosphere (i.e., net emissions), not potential emissions without capture or flaring.

Activity data were taken from the following sources: American Gas Association (AGA 1991–1998); Bureau of Ocean Energy Management, Regulation and Enforcement (previous Minerals and Management Service) (BOEMRE 2010a-d); Monthly Energy Review (EIA 2010f); Natural Gas Liquids Reserves Report (EIA 2005); Natural Gas Monthly (EIA 2010b,c,e); the Natural Gas STAR Program annual emissions savings (EPA 2010); Oil and Gas Journal (OGJ 1997–2010); Office of Pipeline Safety (OPS 2010a-b); Federal Energy Regulatory Commission (FERC 2010) and other Energy Information Administration publications (EIA 2001, 2004, 2010a,d); World Oil Magazine (2010a-b). Data for estimating emissions from hydrocarbon production tanks were incorporated (EPA 1999). Coalbed CH_4 well activity factors were taken from the Wyoming Oil and Gas Conservation Commission (Wyoming 2009) and the Alabama State Oil and Gas Board (Alabama 2010). Other state well data was taken from: American Association of Petroleum Geologists (AAPG 2004); Brookhaven College (Brookhaven 2004); Kansas Geological Survey (Kansas 2010); Montana Board of Oil and Gas Conservation (Montana 2010); Oklahoma Geological Survey (Oklahoma 2010); Morgan Stanley (Morgan Stanley 2005); Rocky Mountain Production Report (Lippman 2003); New Mexico Oil Conservation Division (New Mexico 2010, 2005); Texas Railroad Commission (Texas 2010a-d); Utah Division of Oil, Gas and Mining (Utah 2010). Emission factors were taken from EPA/GRI (1996). GTI's Unconventional Natural Gas and Gas Composition Databases (GTI 2001) were used to adapt the CH_4 emission factors into non-combustion related CO_2 emission factors and adjust CH_4 emission factors from the EPA/GRI survey. Methane compositions from GTI 2001 are adjusted year to year using gross production by NEMS for oil and gas supply regions from the EIA. Therefore, emission factors may vary from year to year due to slight changes in the CH_4 composition for each NEMS oil and gas supply module region. Additional information about CO_2 content in transmission quality natural gas was obtained from numerous U.S. transmission companies to help further develop the non-combustion CO_2 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 using the top twelve emission sources for the year 2010.

The results presented below provide with 95 percent certainty the range within which emissions from this source category are likely to fall for the year 2010. 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 CH_4 emissions in 2010 were estimated to be between 174.5 and 280.0 Tg CO_2 Eq. at a 95 percent confidence level. Natural gas systems non-energy CO_2 emissions in 2010 were estimated to be between 26.2 and 42.0 Tg CO_2 Eq. at 95 percent confidence level.

Table 3-41: Tier 2 Quantitative Uncertainty Estimates for CH_4 and Non-energy CO_2 Emissions from Natural Gas Systems (Tg CO_2 Eq. and Percent)

Source	Gas	2010 Emission Estimate (Tg CO_2 Eq.)[c]	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	215.4	174.5	280.0	-19%	+30%
Natural Gas Systems[b]	CO_2	32.3	26.2	42.0	-19%	+30%

[a] Range of emission estimates predicted by Monte Carlo Simulation for a 95 percent confidence interval.
[b] An uncertainty analysis for the non-energy CO_2 emissions was not performed. The relative uncertainty estimated (expressed as a percent) from the CH_4 uncertainty analysis was applied to the point estimate of non-energy CO_2 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.

QA/QC and Verification Discussion

The natural gas inventory is continually being reviewed and assessed to determine whether emission factors and activity factors accurately reflect current industry practice. A QA/QC analysis was performed for data gathering and input, documentation, and calculation. In addition, through regulations, public webcasts, and the Natural Gas STAR Program, EPA performs a QA/QC check to determine the assumptions in the Inventory are consistent with current industry practices. Finally, QA/QC checks are consistently conducted to minimize human error in the model calculations.

As a result of the QA/QC checks, two corrections were made in the current Natural Gas Systems estimates. First, the calculation for the CH_4 content was corrected. The CH_4 content is adjusted for each year by the gross production of natural gas in each state as reported by the EIA. In the previous Inventory, the CH_4 content was adjusted incorrectly by including state production totals for which there was no CH_4 content data. The current Inventory correctly makes a minor adjustment to the CH_4 content using only state productions for which CH_4 content is available. Second, emission factors for fugitive emissions from gas wells (i.e., equipment leaks from valves, connectors, and open ended lines on or associated with the wellhead) were corrected. For several NEMS regions these fugitive emission factors from the 1996 GRI study were missing or inconsistent with the study.

Recalculations Discussion

EPA has received information and data related to the emissions estimates through the inventory preparation process and the formal public notice and comment process of the proposed oil and gas new source performance standards (NSPS) for VOCs. EPA plans to carefully evaluate this and all other relevant information provided. Subsequently, all relevant updates will then be incorporated, as applicable, in the next cycle of the Inventory. See Planned Improvements below. In light of this current review of information and data, for the current Inventory, emissions for the natural gas sector were calculated using the same methodologies, emission factors, and sources of activity data as the 1990-2009 Inventory report. Additionally, EPA has used the estimates for emissions from completions and workovers hydraulically fractured wells from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009* (i.e., maintained the same activity data and voluntary reductions for hydraulically fractured gas well completions and existing hydraulically fractured gas wells), holding constant the 2009 value for the 2010 estimate. Note that the estimates provided in the public review draft were changed because several values for hydraulically fractured well completions had been updated over the time series. Removing these updates resulted in a change of in total sector CH_4 emissions of 0.3 percent over the time series from the public review draft.

Some of the calculated emissions for the 1990 through 2009 times series have changed from the previous Inventory report due to corrections noted above in QA/QC and Verification Discussion.

Planned Improvements

EPA is considering a number of potential improvements for the Natural Gas Systems inventory.

For the production sector, EPA intends to evaluate additional data on emission reductions, particularly those related

to gas wells with liquids unloading, and voluntary and regulatory reductions from well completions and, if appropriate, will incorporate revisions into future inventories. Evaluation of reductions associated with liquids unloading will include review of data on controls such as plunger lifts and other artificial lift technologies as appropriate. Additionally, accounting for the uncertainty of emission reductions to more accurately provide upper and lower bounds within the 95 percent confidence interval will be investigated. EPA also intends to investigate improvements to its estimates of emissions from hydraulic fracturing, including revisiting the estimates for workover frequency and the number of well completions. The current method for determining hydraulically fractured gas well completion counts relies on data from state websites. Using this method, gas well counts are limited to those that are published online and, therefore, the number of wells is not entirely complete. Subsequently, an underestimate of the number of gas well completions is expected.

In the storage sector, the emission factors in the Inventory account for flashing emissions from condensate tanks. Measurement studies and anecdotal evidence suggest that, in some cases, produced gas from the separator will bypass the liquid dump valve and vent through the storage tank, which is not taken into account in the current estimates. New data on this source will be reviewed as it becomes available and emissions will be updated, as appropriate.

Data collected through EPA's Greenhouse Gas Reporting Program (40 CFR Part 98, Mandatory Reporting of Greenhouse Gases; Final Rule, Subpart W) will be reviewed for potential improvements to the natural gas systems emission estimates. The rule will collect actual activity data using improved quantification methods from those used in several of the studies which form the basis of the Natural Gas Systems emission estimates. Data collection for Subpart W began January 1, 2011 with emissions reporting beginning in 2012. These data will be reviewed for inclusion into a future Inventory to improve the accuracy and reduce the uncertainty of the emission estimates.

As discussed above, EPA has received information and data related to the emissions estimates through the inventory preparation process and the formal public notice and comment process of the proposed oil and gas new source performance standards (NSPS) for VOCs. EPA plans to carefully evaluate this and all other relevant information provided to us. Subsequently, all relevant updates will then be incorporated, as applicable, in the next cycle of the Inventory.

Finally, EPA is also considering improvements to the documentation of the Natural Gas Systems source category. EPA is considering including a table matching each emission factor and activity factor with its source or calculation methodology. The purpose of this improvement would be to make the calculation methodologies more transparent. In addition, EPA is considering adding additional tables to Annex 3.4 to show activity data and emission factors for previous years. EPA also plans on revising the emissions tables in Annex 3.4 to show voluntary reductions broken out for key emission sources.

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, CH_4 emissions are released to the atmosphere as fugitive emissions, vented emissions, emissions from operational upsets, and emissions from fuel combustion. Fugitive and vented CO_2 emissions from petroleum systems are primarily associated with crude oil production and refining operations but are negligible in transportation operations. Combustion CO_2 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 CH_4 and CO_2 emissions from petroleum systems in 2010 were 31.1 Tg CO_2 Eq. (1,478 Gg CH_4) and 0.3 Tg CO_2 (337 Gg), respectively. Since 1990, CH_4 emissions have declined by 11.8 percent, due to industry efforts to reduce emissions and a decline in domestic oil production (see Table 3-42 and Table 3-43). CO_2 emissions have also declined by 14.4 percent since 1990 due to similar reasons (see Table 3-44 and Table 3-45).

Production Field Operations. Production field operations account for 98.4 percent of total CH_4 emissions from petroleum systems. Vented CH_4 from field operations account for approximately 90 percent of the emissions from the production sector, uncombusted CH_4 emissions (i.e. unburned fuel) account for 6.4 percent, fugitive emissions are 3.5 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 high bleed pneumatic devices, oil tanks, natural-gas powered low bleed pneumatic devices, gas engines, deep water offshore platforms, and chemical injection pumps. These seven sources alone emit about 94 percent of the production field operations emissions. Offshore platform emissions are a combination of fugitive, vented, and uncombusted fuel

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 oil tanks occur when the CH_4 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 CH_4 that vents with the exhaust. Emissions from chemical injection pumps are due to the 25 percent of such pumps that use associated gas to drive pneumatic pumps. The remaining six 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 CH_4 emissions in production field operations, refer to Annex 3.5.

Vented CO_2 associated with natural gas emissions from field operations account for 99 percent of the total CO_2 emissions from production field operations, while fugitive and process upsets together account for less than 1 percent of the emissions. The most dominant sources of vented emissions are oil tanks, high bleed pneumatic devices, shallow water offshore oil platforms, low bleed pneumatic devices, and chemical injection pumps. These five sources together account for 98.5 percent of the non-combustion CO_2 emissions from production field operations, while the remaining 1.5 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 0.5 percent of total CH_4 emissions from the oil industry. Venting from tanks and marine vessel loading operations accounts for 60.3 percent of CH_4 emissions from crude oil transportation. Fugitive emissions, almost entirely from floating roof tanks, account for 18.5 percent. The remaining 21 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 less than 1.5 percent of total CH_4 emissions from the oil industry because most of the CH_4 in crude oil is removed or escapes before the crude oil is delivered to the refineries. There is an insignificant amount of CH_4 in all refined products. Within refineries, vented emissions account for about 81 percent of the emissions, while fugitive and combustion emissions account for approximately nine and nine and half percent respectively. 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 CH_4 emissions from refineries are from leaks in the fuel gas system. Refinery combustion emissions include small amounts of unburned CH_4 in process heater stack emissions and unburned CH_4 in engine exhausts and flares.

Asphalt blowing from crude oil refining accounts for 4.5 percent of the total non-combustion CO_2 emissions in petroleum systems.

Table 3-42: CH_4 Emissions from Petroleum Systems (Tg CO_2 Eq.)

Activity	1990		2005	2006	2007	2008	2009	2010
Production Field Operations	**34.7**		**28.7**	**28.7**	**29.3**	**29.5**	**30.2**	**30.6**
Pneumatic device venting	10.3		8.3	8.3	8.4	8.7	8.8	8.8
Tank venting	5.3		3.9	3.9	4.0	3.8	4.3	4.5
Combustion & process upsets	1.9		1.5	1.5	1.5	1.6	2.0	2.0
Misc. venting & fugitives	16.8		14.5	14.5	15.0	14.8	14.6	14.7
Wellhead fugitives	0.6		0.4	0.4	0.4	0.5	0.5	0.5
Crude Oil Transportation	**0.1**		**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Refining	**0.4**		**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Total	**35.2**		**29.2**	**29.2**	**29.8**	**30.0**	**30.7**	**31.0**

Note: Totals may not sum due to independent rounding.

Table 3-43: CH_4 Emissions from Petroleum Systems (Gg)

Activity	1990		2005	2006	2007	2008	2009	2010
Production Field Operations	**1,653**		**1,365**	**1,365**	**1,396**	**1,404**	**1,437**	**1,455**
Pneumatic device venting	489		397	396	398	416	419	420
Tank venting	250		187	188	192	182	206	214
Combustion & process upsets	88		71	71	72	75	94	97
Misc. venting & fugitives	799		690	692	714	706	693	700

Wellhead fugitives	26		19	17	20	24	24	24
Crude Oil Transportation	**7**		**5**	**5**	**5**	**5**	**5**	**5**
Refining	**18**		**19**	**19**	**19**	**19**	**18**	**19**
Total	**1,677**		**1,389**	**1,389**	**1,420**	**1,427**	**1,460**	**1,478**

Note: Totals may not sum due to independent rounding.

Table 3-44: CO_2 Emissions from Petroleum Systems (Tg CO_2 Eq.)

Activity	1990		2005	2006	2007	2008	2009	2010
Production Field Operations	**0.4**		**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**
Pneumatic device venting	+		+	+	+	+	+	+
Tank venting	0.3		0.2	0.2	0.3	0.2	0.3	0.3
Misc. venting & fugitives	+		+	+	+	+	+	+
Wellhead fugitives	+		+	+	+	+	+	+
Crude Refining	**+**		**+**	**+**	**+**	**+**	**+**	**+**
Total	**0.39**		**0.31**	**0.31**	**0.31**	**0.30**	**0.33**	**0.34**

+ Does not exceed 0.05 Tg CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Table 3-45: CO_2 Emissions from Petroleum Systems (Gg)

Activity	1990		2005	2006	2007	2008	2009	2010
Production Field Operations	**376**		**285**	**285**	**292**	**280**	**311**	**322**
Pneumatic device venting	27		22	22	22	23	23	23
Tank venting	328		246	246	252	239	270	281
Misc. venting & fugitives	18		16	16	16	16	16	16
Wellhead fugitives	1		1	1	1	1	1	1
Crude Refining	**18**		**20**	**20**	**18**	**16**	**14**	**15**
Total	**394**		**305**	**306**	**310**	**297**	**325**	**337**

Note: Totals may not sum due to independent rounding.

Methodology

The methodology for estimating CH_4 emissions from petroleum systems is a bottom-up approach, based on comprehensive studies of CH_4 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 CH_4 emissions from petroleum systems do not include emissions downstream of oil refineries because these emissions are negligible.

The methodology for estimating CH_4 emissions from the 64 oil industry activities employs emission factors initially developed by EPA (1999). Activity data for the years 1990 through 2010 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 the corresponding activity data (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, BOEMRE 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 2010. The number of platforms in shallow water and the number of platforms in deep water are used as activity data and are taken from Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) (formerly Minerals Management Service) statistics (BOEMRE 2011a-c). For oil storage tanks, the emissions factor was calculated as the total emissions per barrel of crude charge from E&P Tank data weighted by the distribution of produced crude oil gravities from the HPDI production database (EPA 1999, HPDI 2010).

For some years, complete activity data were not available. In such cases, one of three approaches was employed. Where appropriate, the activity data 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 CH_4 emissions) is related to both number of producing wells and annual production. To estimate the activity data for heater treaters, reported statistics for wells and production were used, along with the ratios developed for EPA (1996). In other cases, the activity data was held constant from 1990 through 2010 based on EPA (1999). Lastly, the previous year's data were used when data for the current year were unavailable. The CH_4 and CO_2 sources in the production sector share common activity data. See Annex 3.5 for additional detail.

Key references used to obtain activity data are the Energy Information Administration annual and monthly reports (EIA 1990 through 2010, 1995 through 2010, 1995 through 2010a-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, BOEMRE reports (BOEMRE 2005, 2010a-c), analysis of BOEMRE data (EPA 2005, BOEMRE 2004), the Oil & Gas Journal (OGJ 2011a,b), the Interstate Oil and Gas Compact Commission (IOGCC 2009, and the United States Army Corps of Engineers (1995-2009).

The methodology for estimating CO_2 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 data. The emission factors for CO_2 are estimated by multiplying the CH_4 emission factors by a conversion factor, which is the ratio of CO_2 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 E&P Tank simulation runs, and the emission factor for asphalt blowing, which was derived using the methodology and sample data from API (2009).

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 Stochastic 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 CH_4 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 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. Petroleum systems CH_4 emissions in 2010 were estimated to be between 23.64 and 77.31 Tg CO_2 Eq., while CO_2 emissions were estimated to be between 0.26 and 0.85 Tg CO_2 Eq. at a 95 percent confidence level. This indicates a range of 24 percent below to 149 percent above the 2010 emission estimates of 31.05 and 0.34 Tg CO_2 Eq. for CH_4 and CO_2, respectively.

Table 3-46: Tier 2 Quantitative Uncertainty Estimates for CH_4 Emissions from Petroleum Systems (Tg CO_2 Eq. and Percent)

Source	Gas	2010 Emission Estimate (Tg CO_2 Eq.)[b]	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	31.05	23.64	77.31	-24%	149%
Petroleum Systems	CO_2	0.34	0.26	0.85	-24%	149%

[a] Range of 2010 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.
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 2010. Details on the emission trends through time are described in more detail in the Methodology section, above.

QA/QC and Verification Discussion

The petroleum inventory is continually being reviewed and assessed to determine whether emission factors and activity factors accurately reflect current industry practice. A QA/QC analysis was performed for data gathering and input, documentation, and calculation. The primary focus of the QA/QC checks is determining if the assumptions in the Inventory are consistent with current industry practices through regulations, public webcasts, and the Natural Gas STAR Program. Finally, QA/QC checks are consistently conducted to minimize human error in the model calculations.

A webcast was held by EPA for industry to comment on the ratio of high-bleed to low-bleed pneumatics, among other topics. Two of the top seven emission sources, high-bleed and low-bleed pneumatic devices, use the earlier mentioned industry peer review panel activity source (EPA/GRI 1996c). The Inventory assumes four pneumatic devices per well-site with a heater-treater and separator, and three pneumatic devices per well-site with a separator but without a heater-treater. EPA requested industry's views on the assumption that, for each year of the time series (1990 to 2010), 35 percent of devices are high-bleed pneumatic devices. No new information was raised, nor concerns expressed, about this factor during the webcast and therefore this factor has not changed in the current inventory.

Additionally, the webcast discussed the emission factor for a refinery source, asphalt blowing. EPA requested comment on the current CH_4 emission factor for asphalt blowing (derived from a Radian International Study) versus the 2009 API Compendium's CH_4 emission factor. The emission factor from the current Inventory was not modified as a result of these comments; however, the activity for asphalt blowing was modified by applying a 10 percent factor to the activity obtained through EIA's Petroleum Supply Annual. This was based on asphalt market analysis.

Recalculations Discussion

Most revisions for the current Inventory relative to the previous report 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 with revised data from existing data sources from 1990 onward. Updating the activity data for asphalt blowing reduced CH_4 and CO_2 emissions for this source by a factor of 10, which has a relatively large impact on fugitive emissions from petroleum refineries, but due to the small contribution of refineries to the overall fugitive emissions, a relatively small impact on the overall greenhouse gas emission estimates from petroleum systems.

In addition, when activity data updates are made for a particular emissions source the entire time series is revised or corrected, which may result in slight changes in estimated emissions from past years..

Planned Improvements

In 2010, all U.S. petroleum refineries were required to collect information on their greenhouse gas emissions. This data was reported to EPA through its GHGRP in 2011. Data collected under this program will be evaluated for use in future inventories to improve the calculation of national emissions from petroleum systems. In particular, whether certain emissions sources currently accounted for in the Energy sector should be separately accounted for in the petroleum systems source category estimates (e.g., CO_2 process emissions from hydrogen production) will be investigated.

Improvements to the documentation of the Petroleum Systems source category is also being considered. A table matching each emission factor and activity factor with its source or calculation methodology is being considered. The purpose of this improvement would be to make the calculation methodologies more transparent.

[BEGIN BOX]

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 CO_2 is produced from both naturally-occurring CO_2 reservoirs and from industrial sources such as natural gas processing plants and ammonia plants. In the current Inventory, emissions from naturally-produced CO_2 are estimated based on the application.

In the current Inventory report, the CO_2 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 CO_2 used in EOR operations is assumed to be fully sequestered. Additionally, all anthropogenic CO_2 emitted from natural gas processing and ammonia plants is assumed to be emitted to the atmosphere, regardless of whether the CO_2 is captured or not. These emissions are currently included in the Natural Gas Systems and the Ammonia Production sections of the Inventory report, respectively.

IPCC (IPCC 2006) included, for the first time, methodological guidance to estimate emissions from the capture, transport, injection, and geological storage of CO_2. 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 CO_2 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 (IPCC 2006) notes that if a national regulatory process exists, emissions information available through that process may support development of CO_2 emissions estimates for geologic storage.

As of January 1, 2011, facilities that conduct geologic sequestration of CO_2 and all other facilities that inject CO_2 underground are required to calculate and report greenhouse gas data annually to EPA through its GHGRP. EPA's GHGRP requires greenhouse gas reporting from facilities that inject CO_2 underground for geologic sequestration,

and requires greenhouse gas reporting from all other facilities that inject CO_2 underground for any reason, including enhanced oil and gas recovery. Facilities conducting geologic sequestration of CO_2 are required to develop and implement an EPA-approved site-specific monitoring, reporting and verification (MRV) plan, and to report the amount of CO_2 sequestered using a mass balance approach. Data from this program, which will be reported to EPA starting in 2012, for the 2011 calendar year, will provide additional facility-specific information about the carbon capture, transport and storage chain. That information will be evaluated closely and opportunities for improving the emission estimates will be considered.

Preliminary estimates indicate that the amount of CO_2 captured from industrial and natural sites is 46.2 Tg CO_2 (46,198 Gg CO_2) (see Table 3-47and Table 3-48). Site-specific monitoring and reporting data for CO_2 injection sites (i.e., EOR operations) were not readily available, therefore, these estimates assume all CO_2 is emitted.

Table 3-47: Potential Emissions from CO_2 Capture and Transport (Tg CO_2 Eq.)

Year	1990		2005	2006	2007	2008	2009	2010
Acid Gas Removal Plants	4.8		5.8	6.2	6.4	6.6	7.0	11.6
Naturally Occurring CO_2	20.8		28.3	30.2	33.1	36.1	39.7	34.0
Ammonia Production Plants	+		0.7	0.7	0.7	0.6	0.6	0.7
Pipelines Transporting CO_2	+		+	+	+	+	+	+
Total	**25.6**		**34.7**	**37.1**	**40.1**	**43.3**	**47.3**	**46.2**

+ Does not exceed 0.05 Tg CO_2 Eq.
Note; Totals may not sum due to independent rounding.

Table 3-48: Potential Emissions from CO_2 Capture and Transport (Gg)

Year	1990		2005	2006	2007	2008	2009	2010
Acid Gas Removal Plants	4,832		5,798	6,224	6,088	6,630	7,035	11,554
Naturally Occurring CO_2	20,811		28,267	30,224	33,086	36,102	39,725	33,967
Ammonia Production Plants	+		676	676	676	580	580	677
Pipelines Transporting CO_2	8		7	7	7	8	8	8
Total	**25,643**		**34,742**	**37,124**	**40,141**	**43,311**	**47,340**	**46,198**

+ Does not exceed 0.5 Gg.
Note: Totals do not include emissions from pipelines transporting CO_2
Note; Totals may not sum due to independent rounding.

[END BOX]

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-CH_4 volatile organic compounds (NMVOCs) from energy-related activities from 1990 to 2010 are reported in Table 3-49.

Table 3-49: NO_x, CO, and NMVOC Emissions from Energy-Related Activities (Gg)

Gas/Source	1990		2005	2006	2007	2008	2009	2010
NO_x	**21,106**		**15,319**	**14,473**	**13,829**	**13,012**	**10,887**	**10,887**
Mobile Combustion	10,862		9,012	8,488	7,965	7,441	6,206	6,206
Stationary Combustion	10,023		5,858	5,545	5,432	5,148	4,159	4,159
Oil and Gas Activities	139		321	319	318	318	393	393
Incineration of Waste	82		129	121	114	106	128	128
*International Bunker Fuels**	*2,020*		*1,703*	*1,794*	*1,791*	*1,917*	*1,651*	*1,812*
CO	**125,640**		**69,062**	**65,399**	**61,739**	**58,078**	**49,647**	**49,647**
Mobile Combustion	119,360		62,692	58,972	55,253	51,533	43,355	43,355
Stationary Combustion	5,000		4,649	4,695	4,744	4,792	4,543	4,543

Incineration of Waste	978	1,403	1,412	1,421	1,430	1,403	1,403
Oil and Gas Activities	302	318	319	320	322	345	345
*International Bunker Fuels**	*130*	*132*	*161*	*160*	*165*	*149*	*152*
NMVOCs	**12,620**	**7,798**	**7,702**	**7,604**	**7,507**	**5,333**	**5,333**
Mobile Combustion	10,932	6,330	6,037	5,742	5,447	4,151	4,151
Stationary Combustion	912	716	918	1,120	1,321	424	424
Oil and Gas Activities	554	510	510	509	509	599	599
Incineration of Waste	222	241	238	234	230	159	159
*International Bunker Fuels**	*61*	*54*	*59*	*59*	*62*	*57*	*58*

* These values are presented for informational purposes only and are not included in totals.
Note: Totals may not sum due to independent rounding.

Methodology

Due to the lack of data available at the time of publication, emission estimates for 2010 rely on 2009 data as a proxy. Emission estimates for 2009 were obtained from preliminary data (EPA 2010, 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 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.

Methodological recalculations were applied to the entire time-series to ensure time-series consistency from 1990 through 2010. 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 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.[103] These decisions are reflected in the IPCC methodological guidance, including the 2006 IPCC Guidelines, 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 2006).[104]

Greenhouse gases emitted from the combustion of international bunker fuels, like other fossil fuels, include CO_2,

[103] 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).

[104] Note that the definition of international bunker fuels used by the UNFCCC differs from that used by the International Civil Aviation Organization.

CH_4 and N_2O. Two transport modes are addressed under the IPCC definition of international bunker fuels: aviation and marine.[105] Emissions from ground transport activities—by road vehicles and trains—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.

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.[106]

Emissions of CO_2 from aircraft are essentially a function of fuel use. Methane and N_2O emissions also depend upon engine characteristics, flight conditions, and flight phase (i.e., take-off, climb, cruise, decent, and landing). Methane is the product of incomplete combustion and occurs mainly during the landing and take-off phases. Methane may be emitted by gas turbines during idle and by older technology engines, but recent data suggest that little or no CH_4 is emitted by modern engines (Anderson et al. 2011). In jet engines, N_2O 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., U.S. 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. CO_2 is the primary greenhouse gas emitted from marine shipping.

Overall, aggregate greenhouse gas emissions in 2010 from the combustion of international bunker fuels from both aviation and marine activities were 129.2 Tg CO_2 Eq., or 14 percent above emissions in 1990 (see Table 3-50 and Table 3-51). Emissions from international flights and international shipping voyages departing from the United States have increased by 56 percent and decreased by 15 percent, respectively, since 1990. The majority of these emissions were in the form of CO_2; however, small amounts of CH_4 and N_2O were also emitted.

Table 3-50: CO_2, CH_4, and N_2O Emissions from International Bunker Fuels (Tg CO_2 Eq.)

Gas/Mode	1990		2005	2006	2007	2008	2009	2010
CO_2	**111.8**		**109.8**	**128.4**	**127.6**	**133.7**	**122.3**	**127.8**
Aviation	46.4		56.8	74.6	73.8	75.5	68.6	72.5
Marine	65.4		53.0	53.8	53.9	58.2	53.7	55.3
CH_4	**0.2**		**0.1**	**0.2**	**0.2**	**0.2**	**0.1**	**0.2**
Aviation	+		+	+	+	+	+	+
Marine	0.1		0.1	0.1	0.1	0.1	0.1	0.1
N_2O	**1.1**		**1.0**	**1.2**	**1.2**	**1.2**	**1.1**	**1.2**
Aviation	0.5		0.6	0.8	0.8	0.8	0.7	0.7
Marine	0.5		0.4	0.4	0.4	0.5	0.4	0.4
Total	**113.0**		**110.9**	**129.8**	**129.0**	**135.1**	**123.6**	**129.2**

+ Does not exceed 0.05 Tg CO_2 Eq.
Note: Totals may not sum due to independent rounding. Includes aircraft cruise altitude emissions.

[105] 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).
[106] Naphtha-type jet fuel was used in the past by the military in turbojet and turboprop aircraft engines.

Table 3-51: CO_2, CH_4 and N_2O Emissions from International Bunker Fuels (Gg)

Gas/Mode	1990	2005	2006	2007	2008	2009	2010
CO_2	**111,828**	**109,765**	**128,413**	**127,643**	**133,730**	**122,338**	**127,841**
Aviation	46,399	56,751	74,581	73,788	75,534	68,614	72,542
Marine	65,429	53,014	53,832	53,856	58,196	53,723	55,299
CH_4	**8**	**7**	**8**	**8**	**8**	**7**	**8**
Aviation	2	2	2	2	2	2	2
Marine	7	5	5	5	6	5	6
N_2O	**3**	**3**	**4**	**4**	**4**	**4**	**4**
Aviation	2	2	2	2	2	2	2
Marine	2	1	1	1	1	1	1

Note: Totals may not sum due to independent rounding. Includes aircraft cruise altitude emissions.

Methodology

Emissions of CO_2 were estimated by applying C content and fraction oxidized factors to fuel consumption activity data. This approach is analogous to that described under CO_2 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 (2010) and USAF (1998), and heat content for jet fuel was taken from EIA (2010a). 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 CH_4 and N_2O were calculated by multiplying emission factors by measures of fuel consumption by fuel type and mode. Emission factors used in the calculations of CH_4 and N_2O emissions were obtained from the Revised 1996 IPCC Guidelines (IPCC/UNEP/OECD/IEA 1997) and the 2006 IPCC Guidelines (IPCC 2006). For aircraft emissions, the following values, in units of grams of pollutant per kilogram of fuel consumed (g/kg), were employed: 0.09 for CH_4 and 0.1 for N_2O (IPCC 2006). For marine vessels consuming either distillate diesel or residual fuel oil the following values (g/MJ), were employed: 0.32 for CH_4 and 0.08 for N_2O. 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 incorporated into 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 (FAA 2010). Data for inventory years 2006 through 2010 were developed using AEDT. Activity data on commercial aircraft fuel consumption for years 2000 through 2009 were developed with "domestic" defined as only the 50 states and "international bunkers" as departures from the 50 states to a destination outside of the 50 states. For year 2010 the data was provided both with domestic defined as the 50 states -and- separately as the 50 states and U.S. Territories. The 2010 data formats will be produced for future inventories and recalculations of prior inventories.

International aviation bunker fuel consumption from 1990 to 2010 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 (2010a). 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 2011). 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 2011) for 1990 through 2001, 2007, through 2010, 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 (2011). The total amount of 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.

Table 3-52: Aviation Jet Fuel Consumption for International Transport (Million Gallons)

Nationality	1990		2005	2006	2007	2008	2009	2010
U.S. and Foreign Carriers	4,934		5,944	7,812	7,729	7,912	7,187	7,598
U.S. Military	862		464	403	413	389	370	359
Total	**5,796**		**6,408**	**8,215**	**8,142**	**8,301**	**7,557**	**7,957**

Note: Totals may not sum due to independent rounding.

Table 3-53: Marine Fuel Consumption for International Transport (Million Gallons)

Fuel Type	1990		2005	2006	2007	2008	2009	2010
Residual Fuel Oil	4,781		3,881	4,004	4,059	4,373	4,040	4,141
Distillate Diesel Fuel & Other	617		444	446	358	445	426	476
U.S. Military Naval Fuels	522		471	414	444	437	384	377
Total	**5,920**		**4,796**	**4,864**	**4,861**	**5,254**	**4,850**	**4,994**

Note: Totals may not sum due to independent rounding.

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.[107] 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

[107] See uncertainty discussions under Carbon Dioxide Emissions from Fossil Fuel Combustion.

been used in vehicles or equipment other than that which was assumed for each fuel type.

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 CO_2 in the 2006 IPCC Guidelines is to use data by specific aircraft type, number of individual flights and, ideally, movement data to better differentiate between domestic and international aviation and to facilitate estimating the effects of changes in technologies. 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 CO_2.[108]

There is also concern regarding the reliability of the existing DOC (2011) 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 2009. 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 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 CO_2, CH_4, and N_2O 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 2009 relative to the previous inventory, which averaged to an annual decrease in emissions from international bunker fuels of 0.03 Tg CO_2 Eq. (less than 0.1 percent) in CO_2 emissions, an annual decrease of less than 0.01 Tg CO_2 Eq. (0.01 percent) in CH_4 emissions, and an annual decrease of less than 0.01 Tg CO_2 Eq. (0.01 percent) in N_2O 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 CO_2 in addition to CH_4 and N_2O already covered in this chapter. In line with the reporting requirements for inventories submitted under the UNFCCC, CO_2 emissions from biomass combustion have been estimated separately from fossil fuel CO_2 emissions and are not directly included in the energy sector contributions to U.S. totals. In accordance with IPCC methodological guidelines, any such emissions are calculated by accounting for net carbon (C) fluxes from changes in biogenic C reservoirs in wooded or crop lands. For a more

[108] 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.

complete description of this methodological approach, see the *Land Use, Land-Use Change, and Forestry* chapter (Chapter 7), which accounts for the contribution of any resulting CO_2 emissions to U.S. totals within the Land Use, Land-Use Change and Forestry sector's approach.

In 2010, total CO_2 emissions from the burning of woody biomass in the industrial, residential, commercial, and electricity generation sectors were approximately 191.6 Tg CO_2 Eq. (191,591 Gg) (see Table 3-54 and Table 3-55). As the largest consumer of woody biomass, the industrial sector was responsible for 70 percent of the CO_2 emissions from this source. Emissions from this sector increased from 2009 to 2010 due to a corresponding increase 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.

Table 3-54: CO_2 Emissions from Wood Consumption by End-Use Sector (Tg CO_2 Eq.)

End-Use Sector	1990		2005	2006	2007	2008	2009	2010
Industrial	143.2		148.4	150.0	143.9	136.3	122.9	133.9
Residential	63.3		48.3	43.7	48.1	50.1	48.4	47.3
Commercial	7.2		7.8	7.2	7.8	8.1	8.2	7.9
Electricity Generation	0.7		1.2	1.7	2.4	2.8	2.4	2.6
Total	**214.4**		**205.7**	**202.7**	**202.2**	**197.4**	**181.8**	**191.6**

Note: Totals may not sum due to independent rounding.

Table 3-55: CO_2 Emissions from Wood Consumption by End-Use Sector (Gg)

End-Use Sector	1990		2005	2006	2007	2008	2009	2010
Industrial	143,219		148,386	150,033	143,929	136,324	122,851	133,871
Residential	63,286		48,283	43,657	48,113	50,147	48,440	47,260
Commercial	7,173		7,821	7,246	7,768	8,133	8,160	7,908
Electricity Generation	733		1,182	1,744	2,394	2,754	2,355	2,552
Total	**214,410**		**205,671**	**202,680**	**202,204**	**197,358**	**181,806**	**191,591**

Note: Totals may not sum due to independent rounding.

Biomass-derived fuel consumption in the United States transportation sector consisted primarily of ethanol use. 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.

In 2010, the United States consumed an estimated 1,089 trillion Btu of ethanol, and as a result, produced approximately 74.5 Tg CO_2 Eq. (74,519 Gg) (see Table 3-56 and Table 3-57) of CO_2 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.

Table 3-56: CO_2 Emissions from Ethanol Consumption (Tg CO_2 Eq.)

End-Use Sector	1990		2005	2006	2007	2008	2009	2010
Transportation	4.1		22.4	30.2	38.1	53.8	61.2	73.2
Industrial	0.1		0.5	0.7	0.7	0.8	0.9	1.1
Commercial	+		0.1	0.1	0.1	0.1	0.2	0.2
Total	**4.2**		**22.9**	**31.0**	**38.9**	**54.7**	**62.3**	**74.5**

+ Does not exceed 0.05 Tg CO_2 Eq.

Table 3-57: CO_2 Emissions from Ethanol Consumption (Gg)

End-Use Sector	1990		2005	2006	2007	2008	2009	2010
Transportation[a]	4,136		22,414	30,237	38,116	53,796	61,191	73,225
Industrial	56		468	662	674	797	888	1,062
Commercial	34		60	86	135	146	194	232