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Inventory of U.S. Greenhouse Gas Emissions and Sinks:

1990 – 2013

APRIL 15, 2015

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All data tables of this document are available for the full time series 1990 through 2013, inclusive, at the internet site mentioned above.

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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 2013. 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 *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). The structure of this report is consistent with the UNFCCC guidelines for inventory reporting.[4]

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

[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 2006).

[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/2013/cop19/eng/10a03.pdf >.

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

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 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. The manner that emissions and sinks are provided in this Inventory is one of many ways U.S. emissions and sinks could be examined; 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.[7] Reporting is at the facility level, except for certain suppliers of fossil fuels and industrial greenhouse gases. The GHGRP dataset and the data presented in this Inventory report are complementary and, as indicated in the respective methodological and planned improvements sections in this report's chapters, EPA is using the data, as applicable, to improve the national estimates presented in this Inventory.

ES.1. Background Information

Greenhouse gases trap heat and make the planet warmer. The most important greenhouse gases directly emitted by humans include CO_2, CH_4, N_2O, and several other fluorine-containing halogenated substances. 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 2013, concentrations of these greenhouse gases have increased globally by 43, 152, and 20 percent, respectively (IPCC 2007 and NOAA/ESRL 2015). This annual report estimates the total national greenhouse gas emissions and removals associated with human activities across the United States.

Global Warming Potentials

Gases in the atmosphere can contribute to climate change 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).[8] 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 2013). 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 million metric tons of CO_2 equivalent (MMT CO_2 Eq.).[9,10] All gases in this

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[6] See < http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/8108.php >.

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

[8] 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.

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

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

Executive Summary are presented in units of MMT CO_2 Eq. Emissions by gas in unweighted mass tons are provided in the Trends chapter of this report.

Revised UNFCCC reporting guidelines for national inventories now require the use of GWP values from the *IPCC Fourth Assessment Report (AR4)* (IPCC 2007).[11] Therefore, to comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using AR4 GWP values, which have replaced the previously required use of SAR GWP values in the U.S. Inventory. All estimates are provided throughout the report in both CO_2 equivalents and unweighted units. A comparison of emission values using the AR4 GWP values versus the *IPCC Second Assessment Report (SAR)* (IPCC 1996), *IPCC Third Assessment Report (TAR)* (IPCC 2001), and the *IPCC Fifth Assessment Report (AR5)* (IPCC 2013) GWP values 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. The use of IPCC AR4 GWP values in this and in future year inventories will apply across the entire time series of the Inventory (i.e., from 1990 to 2013 in this year's report).

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

Gas	GWP
CO_2	1
CH_4[a]	25
N_2O	298
HFC-23	14,800
HFC-32	675
HFC-125	3,500
HFC-134a	1,430
HFC-143a	4,470
HFC-152a	124
HFC-227ea	3,220
HFC-236fa	9,810
HFC-4310mee	1,640
CF_4	7,390
C_2F_6	12,200
C_4F_{10}	8,860
C_6F_{14}	9,300
SF_6	22,800
NF_3	17,200

Source: IPCC (2007)

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

[11] See < http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf >.

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

In 2013, total U.S. greenhouse gas emissions were 6,673.0 MMT, or million metric tons, CO_2 Eq. Total U.S. emissions have increased by 5.9 percent from 1990 to 2013, and emissions increased from 2012 to 2013 by 2.0 percent (127.9 MMT CO_2 Eq.). The increase from 2012 to 2013 was due to an increase in the carbon intensity of fuels consumed to generate electricity due to an increase in coal consumption, with decreased natural gas consumption. Additionally, relatively cool winter conditions led to an increase in fuels for the residential and commercial sectors for heating. In 2013 there also was an increase in industrial production across multiple sectors resulting in increases in industrial sector emissions. Lastly, transportation emissions increased as a result of a small increase in vehicle miles traveled (VMT) and fuel use across on-road transportation modes. Since 1990, U.S. emissions have increased at an average annual rate of 0.3 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 2013.

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

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

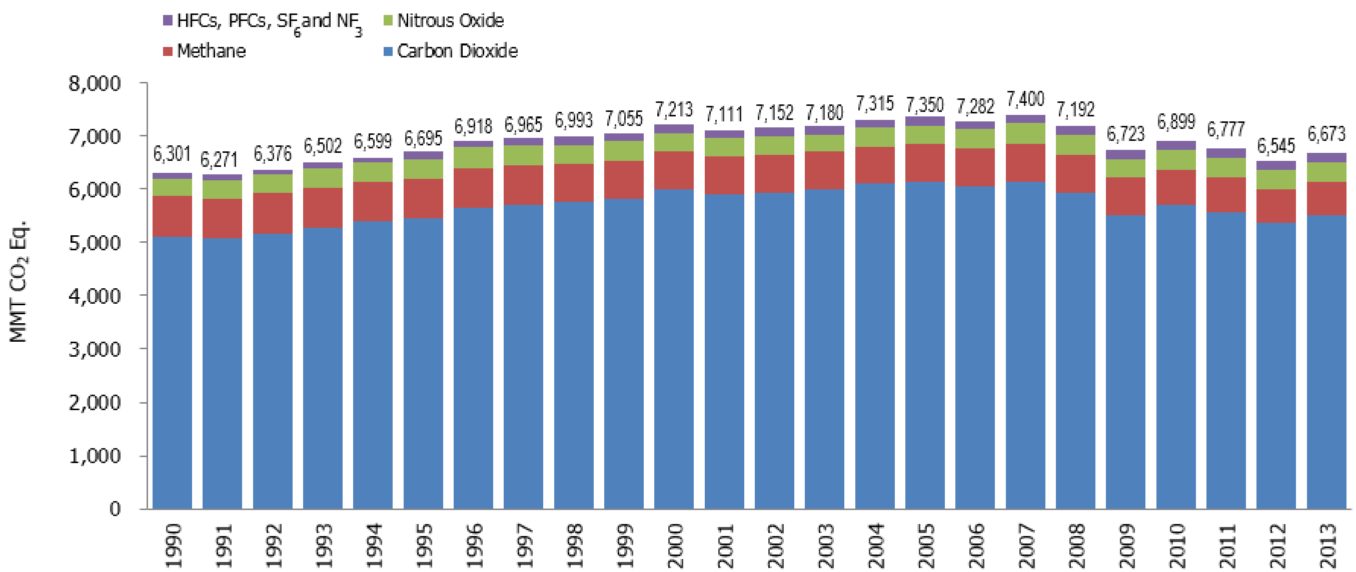


Figure ES-2: Annual Percent Change in U.S. Greenhouse Gas Emissions

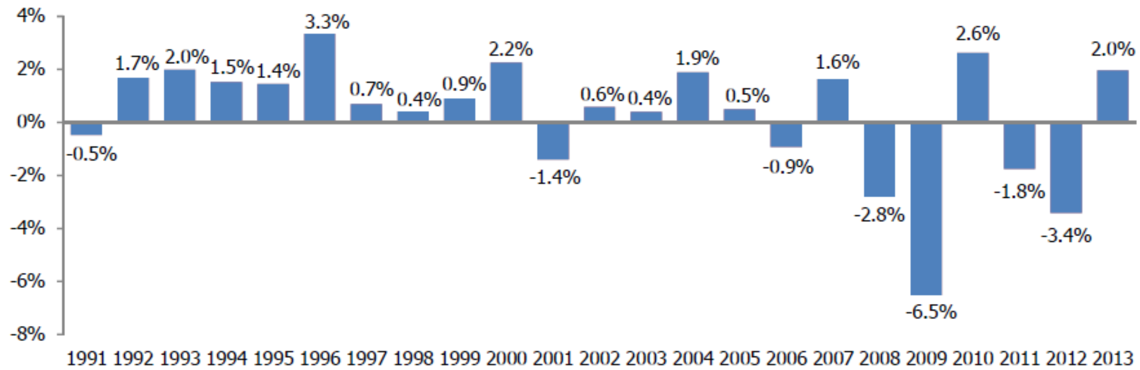


Figure ES-3: Annual Greenhouse Gas Emissions Relative to 1990 (1990=0)

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

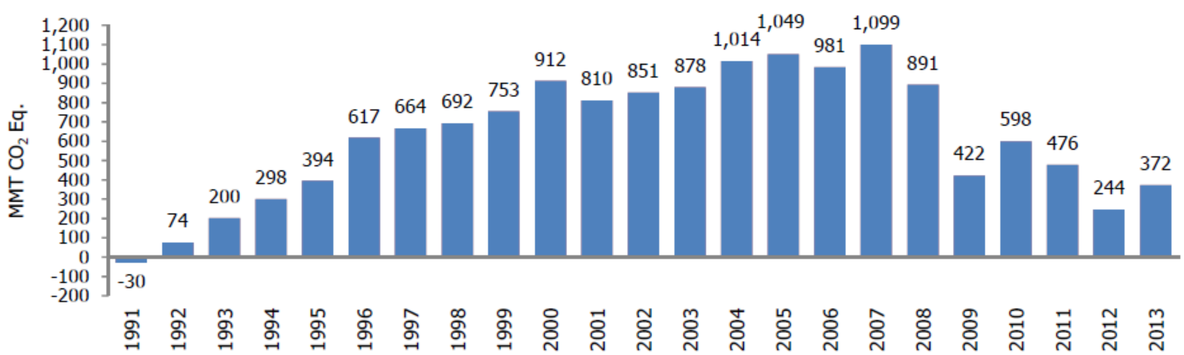


Table ES-2: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (MMT CO_2 Eq.)

Gas/Source	1990	2005	2009	2010	2011	2012	2013
CO_2	**5,123.7**	**6,134.0**	**5,500.6**	**5,704.5**	**5,568.9**	**5,358.3**	**5,505.2**
Fossil Fuel Combustion	4,740.7	5,747.7	5,197.1	5,367.1	5,231.3	5,026.0	5,157.7
Electricity Generation	1,820.8	2,400.9	2,145.7	2,258.4	2,157.7	2,022.2	2,039.8
Transportation	1,493.8	1,887.8	1,720.3	1,732.0	1,711.5	1,700.8	1,718.4
Industrial	842.5	827.8	727.7	775.7	774.1	784.2	817.3
Residential	338.3	357.8	336.4	334.7	327.2	283.1	329.6
Commercial	217.4	223.5	223.5	220.2	221.0	197.1	220.7
U.S. Territories	27.9	49.9	43.5	46.2	39.8	38.6	32.0
Non-Energy Use of Fuels	117.7	138.9	106.0	114.6	108.4	104.9	119.8
Iron and Steel Production & Metallurgical Coke Production	99.8	66.7	43.0	55.7	60.0	54.3	52.3
Natural Gas Systems	37.6	30.0	32.2	32.3	35.6	34.8	37.8
Cement Production	33.3	45.9	29.4	31.3	32.0	35.1	36.1
Petrochemical Production	21.6	28.1	23.7	27.4	26.4	26.5	26.5
Lime Production	11.7	14.6	11.4	13.4	14.0	13.7	14.1
Ammonia Production	13.0	9.2	8.5	9.2	9.3	9.4	10.2
Incineration of Waste	8.0	12.5	11.3	11.0	10.5	10.4	10.1
Petroleum Systems	4.4	4.9	4.7	4.2	4.5	5.1	6.0
Liming of Agricultural Soils	4.7	4.3	3.7	4.8	3.9	5.8	5.9
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	3.4	4.7	4.0	4.4	4.7

Other Process Uses of Carbonates	4.9	6.3	7.6	9.6	9.3	8.0	4.4
Urea Fertilization	2.4	3.5	3.6	3.8	4.1	4.2	4.0
Aluminum Production	6.8	4.1	3.0	2.7	3.3	3.4	3.3
Soda Ash Production and Consumption	2.7	2.9	2.5	2.6	2.6	2.7	2.7
Ferroalloy Production	2.2	1.4	1.5	1.7	1.7	1.9	1.8
Titanium Dioxide Production	1.2	1.8	1.6	1.8	1.7	1.5	1.6
Zinc Production	0.6	1.0	0.9	1.2	1.3	1.5	1.4
Phosphoric Acid Production	1.6	1.4	1.0	1.1	1.2	1.1	1.2
Glass Production	1.5	1.9	1.0	1.5	1.3	1.2	1.2
Carbon Dioxide Consumption	1.5	1.4	1.8	1.2	0.8	0.8	0.9
Peatlands Remaining Peatlands	1.1	1.1	1.0	1.0	0.9	0.8	0.8
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Silicon Carbide Production and Consumption	0.4	0.2	0.1	0.2	0.2	0.2	0.2
Magnesium Production and Processing	+	+	+	+	+	+	+
Land Use, Land-Use Change, and Forestry (Sink)[a]	*(775.8)*	*(911.9)*	*(870.9)*	*(871.6)*	*(881.0)*	*(880.4)*	*(881.7)*
Wood Biomass and Ethanol Consumption[b]	*219.4*	*229.8*	*250.5*	*265.1*	*268.1*	*267.7*	*283.3*
International Bunker Fuels[c]	*103.5*	*113.1*	*106.4*	*117.0*	*111.7*	*105.8*	*99.8*
CH_4	**745.5**	**707.8**	**709.5**	**667.2**	**660.9**	**647.6**	**636.3**
Enteric Fermentation	164.2	168.9	172.7	171.1	168.7	166.3	164.5
Natural Gas Systems	179.1	176.3	168.0	159.6	159.3	154.4	157.4
Landfills	186.2	165.5	158.1	121.8	121.3	115.3	114.6
Coal Mining	96.5	64.1	79.9	82.3	71.2	66.5	64.6
Manure Management	37.2	56.3	59.7	60.9	61.4	63.7	61.4
Petroleum Systems	31.5	23.5	21.5	21.3	22.0	23.3	25.2
Wastewater Treatment	15.7	15.9	15.6	15.5	15.3	15.2	15.0
Rice Cultivation	9.2	8.9	9.4	11.1	8.5	9.3	8.3
Stationary Combustion	8.5	7.4	7.4	7.1	7.1	6.6	8.0
Abandoned Underground Coal Mines	7.2	6.6	6.4	6.6	6.4	6.2	6.2
Forest Fires	2.5	8.3	5.8	4.7	14.6	15.7	5.8
Mobile Combustion	5.6	3.0	2.3	2.3	2.3	2.2	2.1
Composting	0.4	1.9	1.9	1.8	1.9	1.9	2.0
Iron and Steel Production & Metallurgical Coke Production	1.1	0.9	0.4	0.6	0.7	0.7	0.7
Field Burning of Agricultural Residues	0.3	0.2	0.3	0.3	0.3	0.3	0.3
Petrochemical Production	0.2	0.1	+	0.1	+	0.1	0.1
Ferroalloy Production	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+
Peatlands Remaining Peatlands	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[c]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O	**329.9**	**355.9**	**356.1**	**360.1**	**371.9**	**365.6**	**355.2**
Agricultural Soil Management	224.0	243.6	264.1	264.3	265.8	266.0	263.7
Stationary Combustion	11.9	20.2	20.4	22.2	21.3	21.4	22.9
Mobile Combustion	41.2	38.1	24.6	23.7	22.5	20.2	18.4
Manure Management	13.8	16.4	17.0	17.1	17.3	17.3	17.3
Nitric Acid Production	12.1	11.3	9.6	11.5	10.9	10.5	10.7
Wastewater Treatment	3.4	4.3	4.6	4.7	4.8	4.9	4.9
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Adipic Acid Production	15.2	7.1	2.7	4.2	10.2	5.5	4.0
Forest Fires	1.7	5.5	3.8	3.1	9.6	10.3	3.8

Settlement Soils	1.4	2.3	2.2	2.4	2.5	2.5	2.4
Composting	0.3	1.7	1.7	1.6	1.7	1.7	1.8
Forest Soils	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Incineration of Waste	0.5	0.4	0.3	0.3	0.3	0.3	0.3
Semiconductor Manufacture	+	0.1	0.1	0.1	0.2	0.2	0.2
Field Burning of Agricultural Residues	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Peatlands Remaining Peatlands	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.9*	*1.0*	*0.9*	*1.0*	*1.0*	*0.9*	*0.9*
HFCs	**46.6**	**131.4**	**142.9**	**152.6**	**157.4**	**159.2**	**163.0**
Substitution of Ozone Depleting Substances[d]	0.3	111.1	136.0	144.4	148.4	153.5	158.6
HCFC-22 Production	46.1	20.0	6.8	8.0	8.8	5.5	4.1
Semiconductor Manufacture	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Magnesium Production and Processing	0.0	0.0	+	+	+	+	0.1
PFCs	**24.3**	**6.6**	**3.9**	**4.4**	**6.9**	**6.0**	**5.8**
Aluminum Production	21.5	3.4	1.9	1.9	3.5	2.9	3.0
Semiconductor Manufacture	2.8	3.2	2.0	2.6	3.4	3.0	2.9
SF_6	**31.1**	**14.0**	**9.3**	**9.5**	**10.0**	**7.7**	**6.9**
Electrical Transmission and Distribution	25.4	10.6	7.3	7.0	6.8	5.7	5.1
Magnesium Production and Processing	5.2	2.7	1.6	2.1	2.8	1.6	1.4
Semiconductor Manufacture	0.5	0.7	0.3	0.4	0.4	0.4	0.4
NF_3	**+**	**0.5**	**0.4**	**0.5**	**0.7**	**0.6**	**0.6**
Semiconductor Manufacture	+	0.5	0.4	0.5	0.7	0.6	0.6
Total Emissions	**6,301.1**	**7,350.2**	**6,722.7**	**6,898.8**	**6,776.6**	**6,545.1**	**6,673.0**
Total Sinks[a]	**(775.8)**	**(911.9)**	**(870.9)**	**(871.6)**	**(881.0)**	**(880.4)**	**(881.7)**
Net Emissions (Sources and Sinks)	**5,525.2**	**6,438.3**	**5,851.9**	**6,027.2**	**5,895.6**	**5,664.7**	**5,791.2**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

\+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Parentheses indicate negative values or sequestration. Sinks (i.e., CO_2 removals) are only included in the Net Emissions total. Refer to Table ES-5 for a breakout of emissions and removals for Land Use, Land-Use Change, and Forestry by gas and source category.

[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.

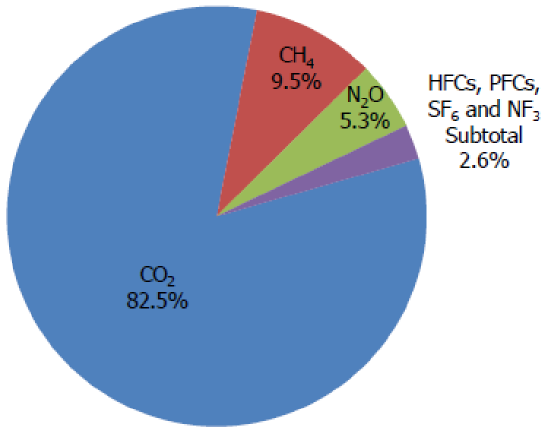
[c] Emissions from International Bunker Fuels are not included in totals.

[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 2013. The primary greenhouse gas emitted by human activities in the United States was CO_2, representing approximately 82.5 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 14.6 percent since 1990, resulted primarily from enteric fermentation associated with domestic livestock, natural gas systems, and decomposition of wastes in landfills. Agricultural soil management, manure 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 as a byproduct of primary aluminum production and from semiconductor manufacturing, while electrical transmission and distribution systems accounted for most SF_6 emissions.

Figure ES-4: 2013 Greenhouse Gas Emissions by Gas (Percentages based on MMT CO_2 Eq.)



Overall, from 1990 to 2013, total emissions of CO_2 increased by 381.5 MMT CO_2 Eq. (7.4 percent), while total emissions of CH_4 decreased by 109.2 MMT CO_2 Eq. (14.6 percent), and N_2O increased by 25.3 MMT CO_2 Eq. (7.7 percent). During the same period, aggregate weighted emissions of HFCs, PFCs, SF_6 and NF_3 rose by 74.3 MMT CO_2 Eq. (72.9 percent). From 1990 to 2013, HFCs increased by 116.4 MMT CO_2 Eq. (249.8 percent), PFCs decreased by 18.4 MMT CO_2 Eq. (76.0 percent), SF_6 decreased by 24.1 MMT CO_2 Eq. (77.7 percent), and NF_3 increased by 0.5 MMT CO_2 Eq. (1,070.1 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, SF_6 and NF_3 are significant because many of these gases have extremely high global warming potentials and, in the cases of PFCs and SF_6, long atmospheric lifetimes. Conversely, U.S. greenhouse gas emissions were partly offset by carbon sequestration in forests, trees in urban areas, agricultural soils, and landfilled yard trimmings and food scraps, which, in aggregate, offset 13.2 percent of total emissions in 2013. 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.[12] Since the Industrial Revolution (i.e., about 1750), global atmospheric concentrations of CO_2 have risen approximately 43 percent (IPCC 2007 and NOAA/ESRL 2015), principally due to the combustion of fossil fuels. Within the United States, fossil fuel combustion accounted for 93.7 percent of CO_2 emissions in 2013. Globally, approximately 32,310 MMT of CO_2 were added to the atmosphere through the combustion of fossil fuels in 2012, of which the United States accounted for about 16 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). Although fossil fuel combustion is the greatest source of CO_2 emissions, there are 25 additional sources of CO_2 emissions (Figure ES-5).

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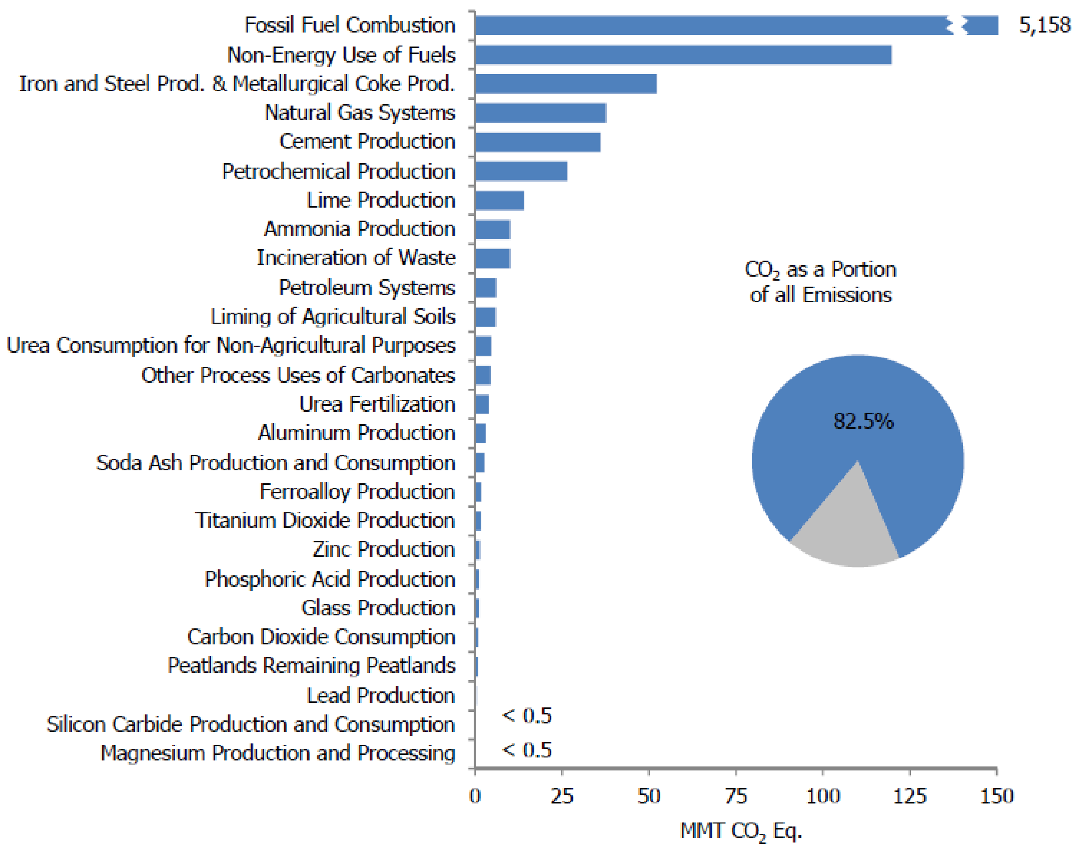
[12] The term "flux" is used to describe the net emissions of greenhouse gases to the atmosphere accounting for both the emissions of CO_2 to and the removals of CO_2 from the atmosphere. Removal of CO_2 from the atmosphere is also referred to as "carbon sequestration."

[13] Global CO_2 emissions from fossil fuel combustion were taken from Energy Information Administration *International Energy Statistics 2013* < http://tonto.eia.doe.gov/cfapps/ipdbproject/IEDIndex3.cfm> EIA (2013).

Figure ES-5: 2013 Sources of CO_2 Emissions

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



Note: Electricity generation also includes emissions of less than 0.05 MMT CO_2 Eq. from geothermal-based generation.

As the largest source of U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion has accounted for approximately 77 percent of GWP-weighted emissions since 1990, and is approximately 77 percent of total GWP-weighted emissions in 2013. Emissions of CO_2 from fossil fuel combustion increased at an average annual rate of 0.4 percent from 1990 to 2013. The fundamental factors influencing this trend include (1) a generally growing domestic economy over the last 24 years, (2) an overall growth in emissions from electricity generation and transportation activities, along with (3) a general decline in the carbon intensity of fuels combusted for energy in recent years by most sectors of the economy. Between 1990 and 2013, CO_2 emissions from fossil fuel combustion increased from 4,740.7 MMT CO_2 Eq. to 5,157.7 MMT CO_2 Eq., an 8.8 percent total increase over the twenty-four-year period. From 2012 to 2013, these emissions increased by 131.7 MMT CO_2 Eq. (2.6 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, energy fuel choices, 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: 2013 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

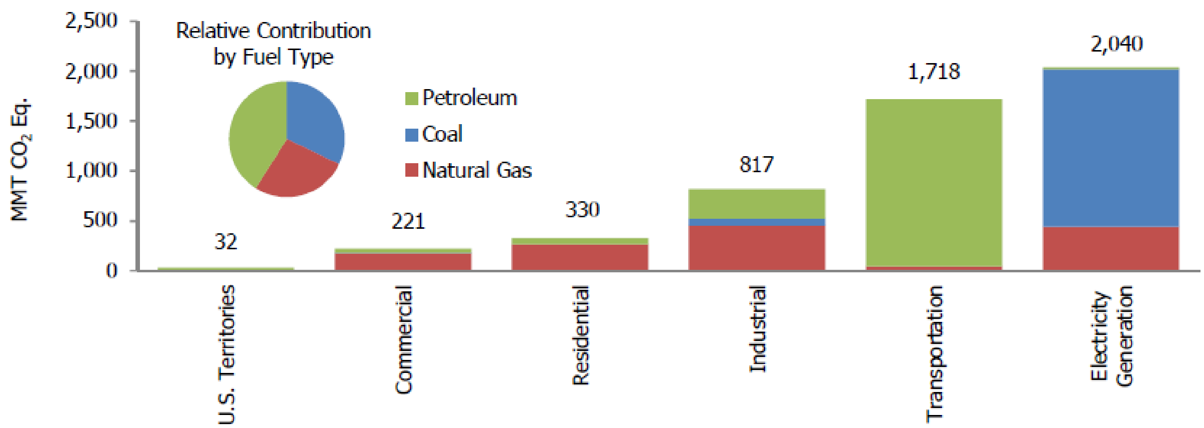
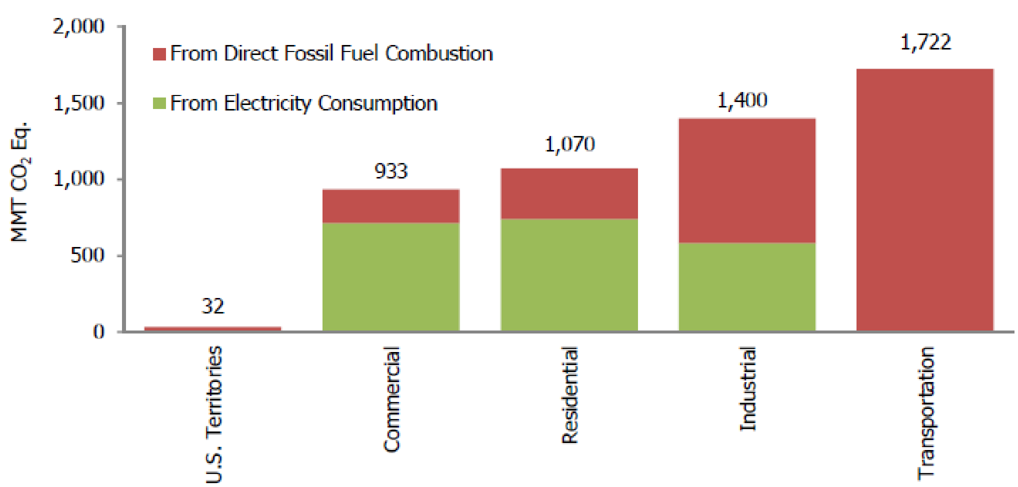


Figure ES-7: 2013 End-Use Sector Emissions of CO_2 from Fossil Fuel Combustion

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



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

Note that emissions from U.S. territories are calculated separately due to a lack of specific consumption data for the individual end-use sectors. Figure ES-6, Figure ES-7, and Table ES-3 summarize CO_2 emissions from fossil fuel combustion by end-use sector.

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

End-Use Sector	1990	2005	2009	2010	2011	2012	2013
Transportation	**1,496.8**	**1,892.5**	**1,724.8**	**1,736.5**	**1,715.8**	**1,704.6**	**1,722.4**
Combustion	1,493.8	1,887.8	1,720.3	1,732.0	1,711.5	1,700.8	1,718.4
Electricity	3.0	4.7	4.5	4.5	4.3	3.9	4.0
Industrial	**1,529.2**	**1,564.4**	**1,329.5**	**1,416.5**	**1,398.8**	**1,377.0**	**1,399.8**
Combustion	842.5	827.8	727.7	775.7	774.1	784.2	817.3
Electricity	686.7	736.6	601.8	640.8	624.7	592.8	582.5
Residential	**931.4**	**1,214.1**	**1,122.6**	**1,174.8**	**1,117.9**	**1,008.4**	**1,070.2**
Combustion	338.3	357.8	336.4	334.7	327.2	283.1	329.6
Electricity	593.0	856.3	786.2	840.1	790.7	725.3	740.6
Commercial	**755.4**	**1,026.7**	**976.7**	**993.2**	**959.1**	**897.4**	**933.3**
Combustion	217.4	223.5	223.5	220.2	221.0	197.1	220.7
Electricity	538.0	803.3	753.2	773.0	738.0	700.3	712.6
U.S. Territories[a]	**27.9**	**49.9**	**43.5**	**46.2**	**39.8**	**38.6**	**32.0**
Total	**4,740.7**	**5,747.7**	**5,197.1**	**5,367.1**	**5,231.3**	**5,026.0**	**5,157.7**
Electricity Generation	**1,820.8**	**2,400.9**	**2,145.7**	**2,258.4**	**2,157.7**	**2,022.2**	**2,039.8**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
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. When electricity-related emissions are distributed to economic end-use sectors, transportation activities accounted for 33.4 percent of U.S. CO_2 emissions from fossil fuel combustion in 2013. The largest sources of transportation CO_2 emissions in 2013 were passenger cars (42.7 percent), freight trucks (22.8 percent), light duty trucks, which include sport utility vehicles, pickup trucks, and minivans (17.0 percent), commercial aircraft (6.6 percent), pipelines (2.8 percent), rail (2.6 percent), and ships and boats (2.3 percent). Annex 3.2 presents the total emissions from all transportation and mobile sources, including CO_2, CH_4, N_2O, and HFCs.

In terms of the overall trend, from 1990 to 2013, total transportation CO_2 emissions rose by 15 percent due, in large part, to increased demand for travel as fleet wide light-duty vehicle fuel economy was relatively stable (average new vehicle fuel economy declined slowly from 1990 through 2004 and then increased more rapidly from 2005 through 2013). The number of vehicle miles traveled by light-duty motor vehicles (passenger cars and light-duty trucks) increased 35 percent from 1990 to 2013, as a result of a confluence of factors including population growth, economic growth, urban sprawl, and low fuel prices during the beginning of this period. 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.

Industrial End-Use Sector. Industrial CO_2 emissions, resulting both directly from the combustion of fossil fuels and indirectly from the generation of electricity that is consumed by industry, accounted for 27 percent of CO_2 from fossil fuel combustion in 2013. Approximately 58 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 21 and 18 percent, respectively, of CO_2 emissions from fossil fuel combustion in 2013. Both sectors relied heavily on electricity for meeting energy demands, with 69 and 76 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 the residential and commercial end-use sectors have increased by 15 percent and 24 percent since 1990, respectively, due to increasing electricity consumption for lighting, heating, air conditioning, and operating appliances.

Electricity Generation. The United States relies on electricity to meet a significant portion of its energy demands. Electricity generators consumed 34 percent of total U.S. energy uses from fossil fuels and emitted 40 percent of the CO_2 from fossil fuel combustion in 2013. The type of fuel combusted by electricity generators has a significant effect on their emissions. For example, some electricity is generated through non-fossil fuel options such as nuclear, hydroelectric, or geothermal energy. Including all electricity generation modes, generators relied on coal for approximately 39 percent of their total energy requirements in 2013.[14] In addition, the coal used by electricity generators accounted for 93 percent of all coal consumed for energy in the United States in 2013.[15] Recently a decrease in the carbon intensity of fuels consumed to generate electricity has occurred due to a decrease in coal consumption, and increased natural gas consumption and other generation sources. Including all electricity generation modes, electricity generators used natural gas for approximately 27 percent of their total energy requirements in 2013.[16]. Across the time series, changes in electricity demand and the carbon intensity of fuels used for electricity generation have a significant impact on CO_2 emissions.

Other significant CO_2 trends included the following:

- CO_2 emissions from non-energy use of fossil fuels have increased by 2.2 MMT CO_2 Eq. (1.9 percent) from 1990 through 2013. Emissions from non-energy uses of fossil fuels were 119.8 MMT CO_2 Eq. in 2013, which constituted 2.2 percent of total national CO_2 emissions, approximately the same proportion as in 1990.
- CO_2 emissions from cement production increased every year from 1991 through 2006 (with the exception of a slight decrease in 1997), but decreased in the following years until 2009. Emissions from cement production were at their lowest levels in 2009 (2009 emissions are approximately 29 percent lower than 2008 emissions and 12 percent lower than 1990). Since 2010, emissions have increased slightly. In 2013, emissions from cement production increased by 3.1 percent from the 2012 levels.
- CO_2 sequestration from Land Use, Land-Use Change, and Forestry increased by 105.9 MMT CO_2 Eq. (13.6 percent) from 1990 through 2013. 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.

Box ES- 2: Use of Ambient Measurements Systems for Validation of Emission Inventories

In following the UNFCCC requirement under Article 4.1 to develop and submit national greenhouse gas emission 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.[17] Several recent studies have measured emissions at the national or regional level (e.g., Petron 2012, Miller et al. 2013) with results that differ from EPA's estimate of emissions. A recent study (Brandt et al. 2014) reviewed technical literature on methane emissions and estimated methane emissions from all anthropogenic sources (e.g., livestock, oil and gas, waste emissions) to be greater than EPA's estimate. EPA has engaged with researchers on how remote sensing, ambient measurement, and inverse modeling techniques for greenhouse gas emissions could assist in improving the understanding of inventory estimates. An area of particular interest in EPA's outreach efforts is how these data can be used in a manner consistent with this Inventory report's transparency on its calculation methodologies, and the ability of these techniques to attribute emissions and removals from remote sensing to anthropogenic sources, as defined by the

[14] See < http://www.eia.gov/energyexplained/index.cfm?page=electricity_in_the_united_states >.

[15] See Table 6.2 Coal Consumption by Sector of EIA 2015a.

[16] See < http://www.eia.gov/energyexplained/index.cfm?page=electricity_in_the_united_states >.

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

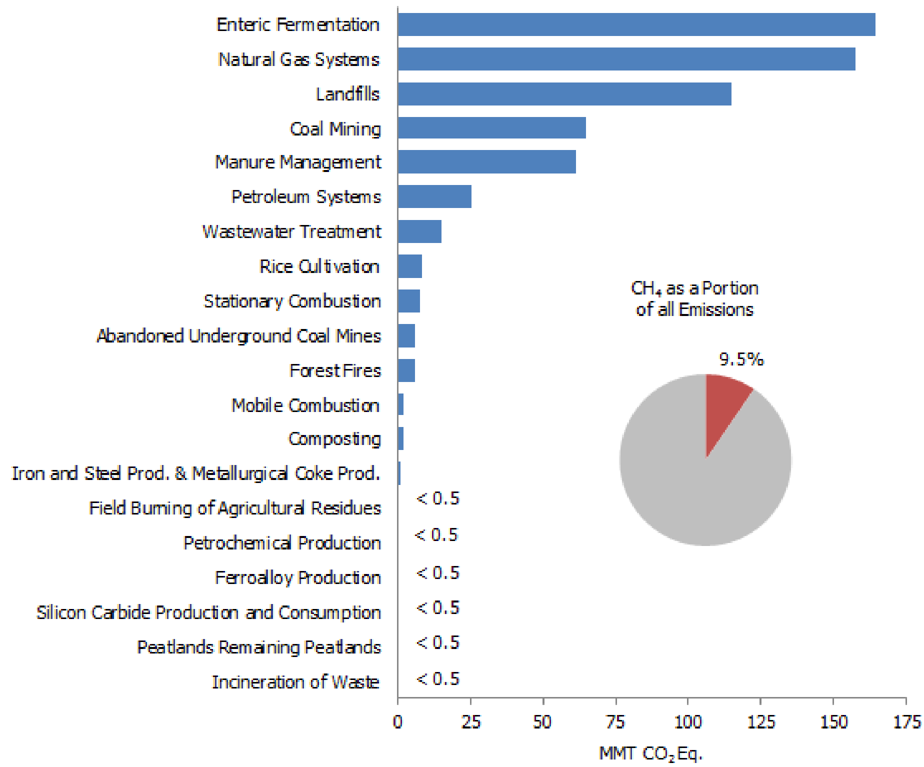
IPCC for this report, versus natural sources and sinks. In working with the research community on ambient measurement and remote sensing techniques to improve national greenhouse gas inventories, EPA relies upon guidance from the IPCC on the use of measurements and modeling to validate emission inventories.[18]

Methane Emissions

Methane (CH_4) is 25 times as effective as CO_2 at trapping heat in the atmosphere (IPCC 2007). Over the last two hundred and fifty years, the concentration of CH_4 in the atmosphere increased by 152 percent (IPCC 2007 and NOAA/ESRL 2015). 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: 2013 Sources of CH_4 Emissions

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



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

- Enteric fermentation is the largest anthropogenic source of CH_4 emissions in the United States. In 2013, enteric fermentation CH_4 emissions were 164.5 MMT CO_2 Eq. (25.9 percent of total CH_4 emissions), which represents an increase of 0.4 MMT CO_2 Eq. (0.2 percent) since 1990. This increase in emissions from 1990 to 2013 in enteric generally follows the increasing trends in cattle populations. From 1990 to 1995 emissions increased and then decreased from 1996 to 2001, mainly due to fluctuations in beef cattle populations and increased digestibility of feed for feedlot cattle. Emissions generally increased from 2005 to 2007, though with a slight decrease in 2004, as both dairy and beef populations underwent increases and

[18] See < http://www.ipcc-nggip.iges.or.jp/meeting/pdfiles/1003_Uncertainty%20meeting_report.pdf >.

the literature for dairy cow diets indicated a trend toward a decrease in feed digestibility for those years. Emissions decreased again from 2008 to 2013 as beef cattle populations again decreased.

- Natural gas systems were the second largest anthropogenic source category of CH_4 emissions in the United States in 2013 with 157.4 MMT CO_2 Eq. of CH_4 emitted into the atmosphere. Those emissions have decreased by 21.8 MMT CO_2 Eq. (12.2 percent) since 1990. The decrease in CH_4 emissions is largely due to the decrease in emissions from production and distribution. The decrease in production emissions is due to increased use of plunger lifts for liquids unloading, from regulatory reductions such as reductions from hydraulically fractured gas well completions and workovers resulting from the 2012 New Source Performance Standards (NSPS) for oil and gas, and from a variety of voluntary reduction activities. The decrease in distribution emissions is due to a decrease in unprotected steel and cast iron pipelines and their replacement with plastic pipelines. Emissions from field production account for 30 percent of CH_4 emissions and 42 percent of non-combustion CO_2 emissions from natural gas systems in 2013. CH_4 emissions from field production decreased by 21 percent from 1990 to 2013; however, the trend was not stable over the time series – emissions from production generally increased through 2006 due primarily to increases in emissions from pneumatic controllers and hydraulically fractured gas well completions and workovers, and then declined from 2007 to 2013. Reasons for the 2007 to 2013 trend include an increase in plunger lift use for liquids unloading, increased voluntary reductions over that time period (including those associated with pneumatic controllers), and increased reduced emissions completions (RECs) use for well completions and workovers with hydraulic fracturing.
- Landfills are the third largest anthropogenic source of CH_4 emissions in the United States (114.6 MMT CO_2 Eq.), accounting for 18.0 percent of total CH_4 emissions in 2013. From 1990 to 2013, CH_4 emissions from landfills decreased by 71.6 MMT CO_2 Eq. (38.4 percent), with small increases occurring in some interim years. This downward trend in overall emissions can be attributed to a 21 percent reduction in the amount of decomposable materials (i.e., paper and paperboard, food scraps, and yard trimmings) discarded in MSW landfills over the time series (EPA 2010) and an increase in the amount of landfill gas collected and combusted (i.e., used for energy or flared),[19] which has more than offset the additional CH_4 emissions resulting from an increase in the amount of municipal solid waste landfilled.
- Methane emissions from manure management increased by 65.2 percent since 1990, from 37.2 MMT CO_2 Eq. in 1990 to 61.4 MMT CO_2 Eq. in 2013. 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.

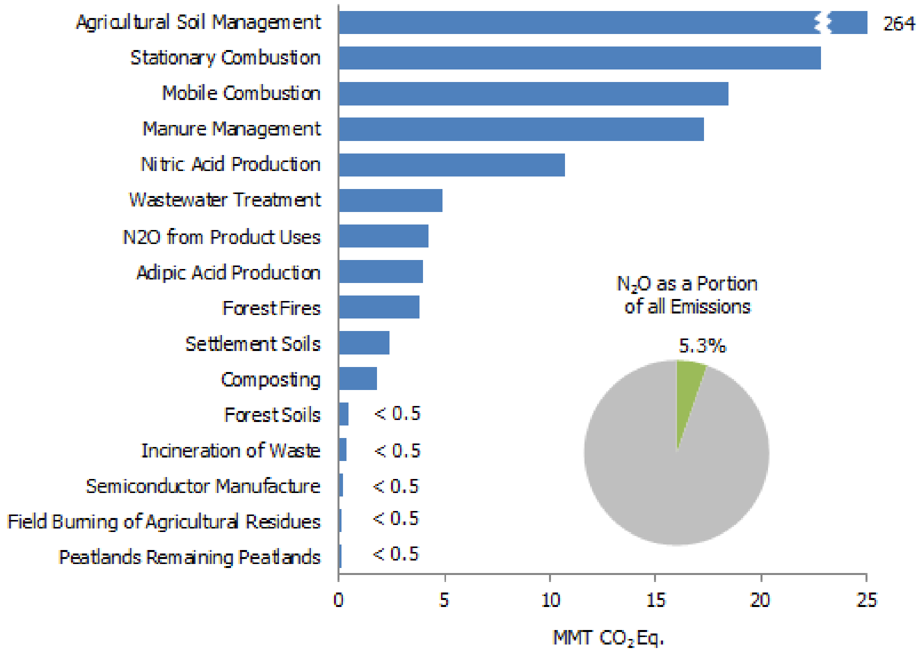
Nitrous Oxide Emissions

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 2007). Since 1750, the global atmospheric concentration of N_2O has risen by approximately 20 percent (IPCC 2007 and NOAA/ESRL 2015). The main anthropogenic activities producing N_2O in the United States are agricultural soil management, stationary fuel combustion, fuel combustion in motor vehicles, manure management and nitric acid production (see Figure ES-9).

[19] Carbon dioxide emissions from landfills are not included specifically in summing waste 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.

Figure ES-9: 2013 Sources of N_2O Emissions

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



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

- Agricultural soils accounted for approximately 74.2 percent of N_2O emissions and 4.0 percent of total emissions in the United States in 2013. Estimated emissions from this source in 2013 were 263.7 MMT CO_2 Eq. Annual N_2O emissions from agricultural soils fluctuated between 1990 and 2013, although overall emissions were 17.7 percent higher in 2013 than in 1990. Year-to-year fluctuations are largely a reflection of annual variation in weather patterns, synthetic fertilizer use, and crop production.
- N_2O emissions from stationary combustion increased 11.0 MMT CO_2 Eq. (91.9 percent) from 1990 through 2013. 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.
- In 2013, total N_2O emissions from manure management were estimated to be 17.3 MMT CO_2 Eq.; emissions were 13.8 MMT CO_2 Eq. in 1990. These values include both direct and indirect N_2O emissions from manure management. Nitrous oxide emissions have remained fairly steady since 1990. Small changes in N_2O emissions from individual animal groups exhibit the same trends as the animal group populations, with the overall net effect that N_2O emissions showed a 25.4 percent increase from 1990 to 2013 and a 0.1 percent decrease from 2012 through 2013. Overall shifts toward liquid systems have driven down the emissions per unit of nitrogen excreted.
- N_2O emissions from adipic acid production were 4.0 MMT CO_2 Eq. in 2013, and have decreased significantly since 1990 due to both the widespread installation of pollution control measures in the late 1990s and plant idling in the late 2000s. Emissions from adipic acid production have decreased by 73.8 percent since 1990 and by 76.4 percent since a peak in 1995.

HFC, PFC, SF_6, and NF_3 Emissions

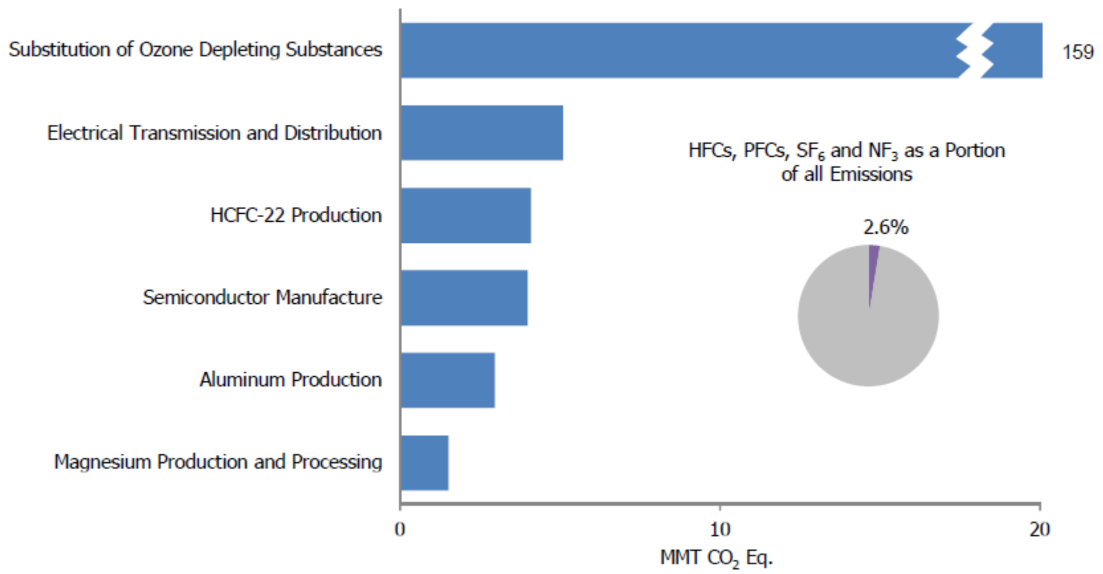
HFCs and PFCs are families of synthetic chemicals that are used as alternatives to Ozone Depleting Substances, which are being phased out under the Montreal Protocol and Clean Air Act Amendments of 1990. HFCs and PFCs do not deplete the stratospheric ozone layer, and are therefore acceptable alternatives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

These compounds, however, along with SF_6 and NF_3, 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 2013).

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

Figure ES-10: 2013 Sources of HFCs, PFCs, SF_6, and NF_3 Emissions

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



Some significant trends in U.S. HFC, PFC, SF_6, and NF_3 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 158.6 MMT CO_2 Eq. in 2013. This increase was in large part the result of 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 continue over the next decade as HCFCs, which are interim substitutes in many applications, are themselves phased-out under the provisions of the Copenhagen Amendments to the *Montreal Protocol*.
- GWP-weighted PFC, HFC, SF_6, and NF_3 emissions from semiconductor manufacture have increased by 12 percent from 1990 to 2013, due to industrial growth and the adoption of emissions reduction technologies. Within that time span, emissions peaked in 1999, the initial year of the EPA's PFC Reduction / Climate Partnership for the Semiconductor Industry, but have since declined to 4.0 MMT CO_2 Eq. in 2013 (a 56 percent decrease relative to 1999).
- SF_6 emissions from electric power transmission and distribution systems decreased by 79.9 percent (20.3 MMT CO_2 Eq.) from 1990 to 2013. There are two potential causes for this decrease: (1) a sharp increase in the price of SF_6 during the 1990s and (2) a growing awareness of the environmental impact of SF_6 emissions through programs such as EPA's SF_6 Emission Reduction Partnership for Electric Power Systems.
- PFC emissions from aluminum production decreased by 86.2 percent (18.5 MMT CO_2 Eq.) from 1990 to 2013. This decline is due both to reductions in domestic aluminum production and to actions taken by aluminum smelting companies to reduce the frequency and duration of anode effects.

ES.3. Overview of Sector Emissions and Trends

In accordance with the UNFCCC decision to set the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) as the standard for Annex I countries at the Nineteenth Conference of the Parties (UNFCCC 2014), 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-four-year period of 1990 to 2013, total emissions in the Energy, Industrial Processes and Product Use, and Agriculture sectors grew by 346.2 MMT CO_2 Eq. (6.5 percent), 17.0 MMT CO_2 Eq. (5.0 percent), and 67.0 MMT CO_2 Eq. (14.9 percent), respectively. Emissions from the Waste sector decreased by 67.7 MMT CO_2 Eq. (32.9 percent). 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 removals from all LULUCF source categories) increased by 96.4 MMT CO_2 Eq. (12.7 percent).

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

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

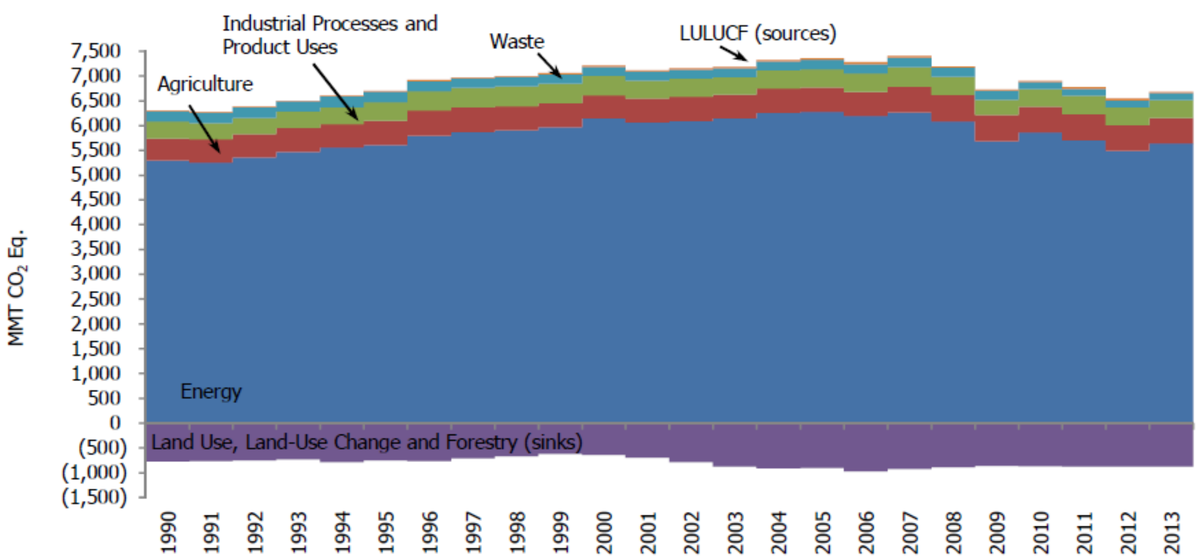


Table ES-4: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (MMT CO_2 Eq.)

Chapter/IPCC Sector	1990	2005	2009	2010	2011	2012	2013
Energy	**5,290.5**	**6,273.6**	**5,682.1**	**5,854.6**	**5,702.6**	**5,482.2**	**5,636.6**
Fossil Fuel Combustion	4,740.7	5,747.7	5,197.1	5,367.1	5,231.3	5,026.0	5,157.7
Natural Gas Systems	216.8	206.3	200.2	191.9	194.8	189.2	195.2
Non-Energy Use of Fuels	117.7	138.9	106.0	114.6	108.4	104.9	119.8
Coal Mining	96.5	64.1	79.9	82.3	71.2	66.5	64.6
Petroleum Systems	36.0	28.4	26.2	25.5	26.4	28.3	31.2
Stationary Combustion	20.4	27.6	27.8	29.3	28.4	28.0	30.8
Mobile Combustion	46.9	41.1	26.9	26.0	24.8	22.4	20.6
Incineration of Waste	8.4	12.8	11.6	11.4	10.9	10.7	10.4
Abandoned Underground Coal Mines	7.2	6.6	6.4	6.6	6.4	6.2	6.2
Industrial Processes and Product Use	**342.1**	**367.4**	**314.9**	**353.6**	**371.0**	**361.2**	**359.1**
Substitution of Ozone Depleting Substances	0.3	111.1	136.0	144.4	148.4	153.5	158.6
Iron and Steel Production & Metallurgical Coke Production	100.9	67.5	43.5	56.4	60.7	55.1	53.0
Cement Production	33.3	45.9	29.4	31.3	32.0	35.1	36.1
Petrochemical Production	21.9	28.3	23.8	27.4	26.4	26.5	26.6
Lime Production	11.7	14.6	11.4	13.4	14.0	13.7	14.1

Nitric Acid Production	12.1	11.3	9.6	11.5	10.9	10.5	10.7
Ammonia Production	13.0	9.2	8.5	9.2	9.3	9.4	10.2
Aluminum Production	28.3	7.6	4.9	4.6	6.8	6.4	6.2
Electrical Transmission and Distribution	25.4	10.6	7.3	7.0	6.8	5.7	5.1
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	3.4	4.7	4.0	4.4	4.7
Other Process Uses of Carbonates	4.9	6.3	7.6	9.6	9.3	8.0	4.4
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Semiconductor Manufacture	3.6	4.7	3.1	3.8	4.9	4.5	4.2
HCFC-22 Production	46.1	20.0	6.8	8.0	8.8	5.5	4.1
Adipic Acid Production	15.2	7.1	2.7	4.2	10.2	5.5	4.0
Soda Ash Production and Consumption	2.7	2.9	2.5	2.6	2.6	2.7	2.7
Ferroalloy Production	2.2	1.4	1.5	1.7	1.7	1.9	1.8
Titanium Dioxide Production	1.2	1.8	1.6	1.8	1.7	1.5	1.6
Magnesium Production and Processing	5.2	2.7	1.6	2.1	2.8	1.7	1.5
Zinc Production	0.6	1.0	0.9	1.2	1.3	1.5	1.4
Phosphoric Acid Production	1.6	1.4	1.0	1.1	1.2	1.1	1.2
Glass Production	1.5	1.9	1.0	1.5	1.3	1.2	1.2
Carbon Dioxide Consumption	1.5	1.4	1.8	1.2	0.8	0.8	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Silicon Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.2	0.2
Agriculture	**448.7**	**494.5**	**523.3**	**524.8**	**522.1**	**523.0**	**515.7**
Agricultural Soil Management	224.0	243.6	264.1	264.3	265.8	266.0	263.7
Enteric Fermentation	164.2	168.9	172.7	171.1	168.7	166.3	164.5
Manure Management	51.0	72.8	76.7	78.0	78.7	81.0	78.7
Rice Cultivation	9.2	8.9	9.4	11.1	8.5	9.3	8.3
Field Burning of Agricultural Residues	0.4	0.3	0.4	0.4	0.4	0.4	0.4
Land Use, Land-Use Change, and Forestry	**13.8**	**25.5**	**20.6**	**20.3**	**36.1**	**39.8**	**23.3**
Forest Fires	4.2	13.8	9.7	7.9	24.2	26.0	9.7
Liming of Agricultural Soils	4.7	4.3	3.7	4.8	3.9	5.8	5.9
Urea Fertilization	2.4	3.5	3.6	3.8	4.1	4.2	4.0
Settlement Soils	1.4	2.3	2.2	2.4	2.5	2.5	2.4
Peatlands Remaining Peatlands	1.1	1.1	1.0	1.0	0.9	0.8	0.8
Forest Soils	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Waste	**206.0**	**189.2**	**181.8**	**145.5**	**144.9**	**138.9**	**138.3**
Landfills	186.2	165.5	158.1	121.8	121.3	115.3	114.6
Wastewater Treatment	19.0	20.2	20.2	20.2	20.1	20.0	20.0
Composting	0.7	3.5	3.6	3.5	3.5	3.7	3.7
Total Emissions	**6,301.1**	**7,350.2**	**6,722.7**	**6,898.8**	**6,776.6**	**6,545.1**	**6,673.0**
Total Sinks[a]	**(775.8)**	**(911.9)**	**(870.9)**	**(871.6)**	**(881.0)**	**(880.4)**	**(881.7)**
Net Emissions (Sources and Sinks)	**5,525.2**	**6,438.3**	**5,851.9**	**6,027.2**	**5,895.6**	**5,664.7**	**5,791.2**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

[a] Sinks (i.e., CO_2 removals) are only included in Net Emissions total. Refer to Table ES-5 for a breakout of emissions and removals for Land Use, Land-Use Change, and Forestry by gas and source category.

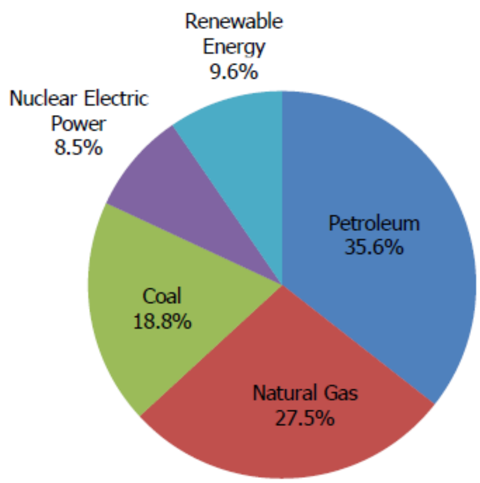
Note: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

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 2013. In 2013, approximately 82 percent of the energy consumed in the United States (on a Btu basis) was produced through the combustion of fossil fuels. The remaining 18 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 (41 percent and 12 percent of total U.S. emissions of each gas, respectively). Overall, emission sources in the Energy chapter account for a combined 84.5 percent of total U.S. greenhouse gas emissions in 2013.

Figure ES-12: 2013 U.S. Energy Consumption by Energy Source



Industrial Processes and Product Use

The Industrial Processes and Product Use (IPPU) section includes greenhouse gas emissions occurring from industrial processes and from the use of greenhouse gases in products. This section includes sources of emissions formerly represented in the "Industrial Processes" and "Solvent and Other Product Use" sectors in prior versions of this report.

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, other process uses of carbonates (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, zinc production, and N_2O from product uses. Industrial processes also release HFCs, PFCs, SF_6, and NF_3. In addition to their use as ODS substitutes, HFCs, PFCs, SF_6, NF_3, 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. Overall, emission sources in the Industrial Process and Product Use chapter account for 5.4 percent of U.S. greenhouse gas emissions in 2013.

Agriculture

The Agriculture chapter contains anthropogenic emissions from agricultural activities (except fuel combustion, which is addressed in the Energy chapter, and agricultural CO_2 fluxes, which are addressed in the Land Use, Land-Use Change, and Forestry chapter). Agricultural activities contribute directly to emissions of greenhouse gases through a variety of processes, including the following source categories: enteric fermentation in domestic livestock, livestock manure management, rice cultivation, agricultural soil management, and field burning of agricultural residues. CH_4 and N_2O were the primary greenhouse gases emitted by agricultural activities. CH_4 emissions from enteric fermentation and manure management represented 25.9 percent and 9.6 percent of total CH_4 emissions from anthropogenic activities, respectively, in 2013. Agricultural soil management activities such as fertilizer application and other cropping practices were the largest source of U.S. N_2O emissions in 2013, accounting for 74.2 percent. In 2013, emission sources accounted for in the Agricultural chapters were responsible for 7.7 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 removal of CO_2 (sequestration of C) in the United States. Forests (including vegetation, soils, and harvested wood) accounted for 88 percent of total 2013 CO_2 removals, urban trees accounted for 10 percent, mineral and organic soil carbon stock changes accounted for less than 0.5 percent, and landfilled yard trimmings and food scraps accounted for 1.4 percent of the total CO_2 removals in 2013. 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 2.4 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 2013 resulted in a C sequestration (i.e., total sinks) of 881.7 MMT CO_2 Eq. (Table ES-5).[20] This represents an offset of 13.2 percent of total (i.e., gross) greenhouse gas emissions in 2013. Emissions from land use, land-use change and forestry activities in 2013 represent 0.3 percent of total greenhouse gas emissions.[21] Between 1990 and 2013, total land use, land-use change, and forestry C sequestration increased by 13.6 percent, 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.

CO_2 removals are presented in Table ES-5 along with CO_2, CH_4, and N_2O emissions for Land Use, Land-Use Change, and Forestry source categories. Liming of agricultural soils and urea fertilization in 2013 resulted in CO_2 emissions of 9.9 MMT CO_2 Eq. (9,936 kt). Lands undergoing peat extraction (i.e., *Peatlands Remaining Peatlands*) resulted in CO_2 emissions of 0.8 MMT CO_2 Eq. (770 kt) and CH_4 and N_2O emissions of less than 0.05 MMT CO_2 Eq. each. The application of synthetic fertilizers to forest soils in 2013 resulted in N_2O emissions of 0.5 MMT CO_2 Eq. (2 kt). 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, N_2O emissions from fertilizer application to settlement soils in 2013 accounted for 2.4 MMT CO_2 Eq. (8 kt). This represents an increase of 77 percent since 1990. Forest fires in 2013 resulted in CH_4 emissions of 5.8 MMT CO_2 Eq. (233 kt), and in N_2O emissions of 3.8 MMT CO_2 Eq. (13 kt).

Table ES-5: Emissions and Removals (Flux) from Land Use, Land-Use Change, and Forestry (MMT CO_2 Eq.)

Gas/Land-Use Category	1990	2005	2009	2010	2011	2012	2013
CO_2	**(767.7)**	**(903.0)**	**(862.6)**	**(862.0)**	**(872.1)**	**(869.6)**	**(871.0)**
Forest Land Remaining Forest Land: Changes in Forest Carbon Stock[a]	(639.4)	(807.1)	(764.9)	(765.4)	(773.8)	(773.1)	(775.7)

[20] The total sinks value includes the positive C sequestration reported for *Forest Land Remaining Forest Land, Cropland Remaining Cropland, Land Converted to Grassland, Settlements Remaining Settlements,* and *Other Land* plus the loss in C sequestration reported for *Land Converted to Cropland* and *Grassland Remaining Grassland*.

[21] The emissions value includes the CO_2, CH_4, and N_2O emissions reported for *Forest Fires, Forest Soils, Liming of Agricultural Soils, Urea Fertilization, Settlement Soils,* and *Peatlands Remaining Peatlands*.

Cropland Remaining Cropland: Changes in Agricultural Soil Carbon Stock	(65.2)	(28.0)	(27.5)	(25.9)	(25.8)	(25.0)	(23.4)
Cropland Remaining Cropland: Liming of Agricultural Soils	4.7	4.3	3.7	4.8	3.9	5.8	5.9
Cropland Remaining Cropland: Urea Fertilization	2.4	3.5	3.6	3.8	4.1	4.2	4.0
Land Converted to Cropland	24.5	19.8	16.2	16.2	16.2	16.1	16.1
Grassland Remaining Grassland	(1.9)	4.2	11.7	11.7	11.7	11.5	12.1
Land Converted to Grassland	(7.4)	(9.0)	(8.9)	(8.9)	(8.9)	(8.8)	(8.8)
Settlements Remaining Settlements: Changes in Urban Tree Carbon Stock[b]	(60.4)	(80.5)	(85.0)	(86.1)	(87.3)	(88.4)	(89.5)
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	1.1	1.1	1.0	1.0	0.9	0.8	0.8
Other: Landfilled Yard Trimmings and Food Scraps	(26.0)	(11.4)	(12.5)	(13.2)	(13.2)	(12.8)	(12.6)
CH_4	**2.5**	**8.3**	**5.8**	**4.8**	**14.6**	**15.7**	**5.8**
Forest Land Remaining Forest Land: Forest Fires	2.5	8.3	5.8	4.7	14.6	15.7	5.8
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
N_2O	**3.1**	**8.3**	**6.5**	**6.0**	**12.6**	**13.3**	**6.7**
Forest Land Remaining Forest Land: Forest Fires	1.7	5.5	3.8	3.1	9.6	10.3	3.8
Forest Land Remaining Forest Land: Forest Soils[c]	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Settlements Remaining Settlements: Settlement Soils[d]	1.4	2.3	2.2	2.4	2.5	2.5	2.4
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
Total Flux[e]	**(762.1)**	**(886.4)**	**(850.2)**	**(851.3)**	**(844.9)**	**(840.6)**	**(858.5)**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
\+ Less than 0.05 MMT CO_2 Eq.
[a] Estimates include C stock changes on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.
[b] Estimates include C stock changes on both *Settlements Remaining Settlements* and *Land Converted to Settlements*.
[c] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land*, and *Land Converted to Forest Land*, but not from land-use conversion.
[d] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements*, and *Land Converted to Settlements*, but not from land-use conversion.
[e] "Total Flux" is defined as the sum of positive emissions (i.e., sources) of greenhouse gases to the atmosphere plus removals of CO_2 (i.e., sinks or negative emissions) from the atmosphere.
Note: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

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 82.9 percent of this chapter's emissions, and 18.0 percent of total U.S. CH_4 emissions.[22] Additionally, wastewater treatment accounts for 14.4 percent of Waste emissions, 2.4 percent of U.S. CH_4 emissions, and 1.4 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 2.0 MMT CO_2 Eq. and 1.8 MMT CO_2 Eq., respectively. Overall, emission sources accounted for in the Waste chapter generated 2.1 percent of total U.S. greenhouse gas emissions in 2013.

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

ES.4. Other Information

Emissions by Economic Sector

Throughout the Inventory of U.S. Greenhouse Gas Emissions and Sinks report, emission estimates are grouped into five sectors (i.e., chapters) defined by the IPCC: Energy; Industrial Processes and 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 economic sectors: Residential, Commercial, Industry, Transportation, Electricity Generation, Agriculture, and U.S. Territories.

Table ES-6 summarizes emissions from each of these sectors, and Figure ES-13 shows the trend in emissions by sector from 1990 to 2013.

Figure ES-13: Emissions Allocated to Economic Sectors

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

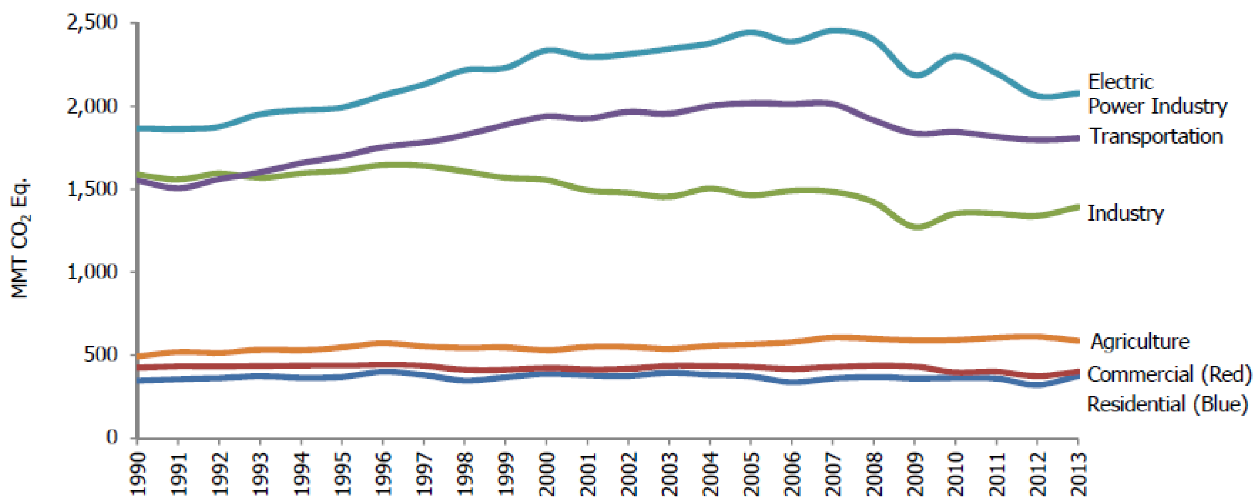


Table ES-6: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (MMT CO_2 Eq.)

Implied Sectors	1990	2005	2009	2010	2011	2012	2013
Electric Power Industry	1,864.8	2,443.9	2,185.7	2,300.5	2,198.1	2,060.8	2,077.0
Transportation	1,551.3	2,017.7	1,835.3	1,843.5	1,815.4	1,795.9	1,806.2
Industry	1,587.7	1,462.8	1,272.5	1,353.3	1,353.0	1,338.9	1,392.1
Agriculture	492.5	565.0	588.8	590.8	605.5	611.6	586.8
Commercial	424.8	429.8	431.9	396.4	400.7	374.3	401.1
Residential	346.3	372.8	360.9	363.7	360.5	321.5	375.0
U.S. Territories	33.7	58.2	47.6	50.6	43.5	42.1	34.8
Total Emissions	**6,301.1**	**7,350.2**	**6,722.7**	**6,898.8**	**6,776.6**	**6,545.1**	**6,673.0**
Total Sinks[a]	**(775.8)**	**(911.9)**	**(870.9)**	**(871.6)**	**(881.0)**	**(880.4)**	**(881.7)**
Net Emissions (Sources and Sinks)	**5,525.2**	**6,438.3**	**5,851.9**	**6,027.2**	**5,895.6**	**5,664.7**	**5,791.2**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

[a] Sinks (i.e., CO_2 removals) are only included in the Net Emissions total. Refer to Table ES-5 for a breakout of emissions and removals for Land Use, Land-Use Change, and Forestry by gas and source category.

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

Using this categorization, emissions from electricity generation accounted for the largest portion (31 percent) of U.S. greenhouse gas emissions in 2013. Transportation activities, in aggregate, accounted for the second largest portion (27 percent), while emissions from industry accounted for the third largest portion (21 percent) of U.S. greenhouse gas emissions in 2013. 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 21 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 9 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 each accounted for 6 percent of emissions and U.S. Territories accounted for 1 percent of emissions; emissions from these sectors primarily consisted of CO_2 emissions from fossil fuel combustion. CO_2 was also emitted and sequestered by a variety of activities related to forest management practices, tree planting in urban areas, the management of agricultural soils, and landfilling of yard trimmings.

Electricity is ultimately consumed in the economic sectors described above. Table ES-7 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.[23] 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 and transportation account for the largest shares of U.S. greenhouse gas emissions (29 percent and 27 percent, respectively) in 2013. The residential and commercial sectors contributed the next largest shares of total U.S. greenhouse gas emissions in 2013. 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 2013.

Table ES-7: U.S Greenhouse Gas Emissions by Economic Sector with Electricity-Related Emissions Distributed (MMT CO_2 Eq.)

Implied Sectors	1990	2005	2009	2010	2011	2012	2013
Industry	2,229.7	2,148.5	1,817.7	1,937.7	1,923.9	1,880.9	1,922.6
Transportation	1,554.4	2,022.5	1,839.9	1,848.1	1,819.7	1,799.8	1,810.3
Residential	953.6	1,244.4	1,161.8	1,219.5	1,166.0	1,060.6	1,129.1
Commercial	975.8	1,247.5	1,199.2	1,183.8	1,152.6	1,088.0	1,126.7
Agriculture	553.9	629.1	656.6	659.2	670.9	673.7	649.4
U.S. Territories	33.7	58.2	47.6	50.6	43.5	42.1	34.8
Total Emissions	**6,301.1**	**7,350.2**	**6,722.7**	**6,898.8**	**6,776.6**	**6,545.1**	**6,673.0**
Total Sinks[a]	**(775.8)**	**(911.9)**	**(870.9)**	**(871.6)**	**(881.0)**	**(880.4)**	**(881.7)**
Net Emissions (Sources and Sinks)	**5,525.2**	**6,438.3**	**5,851.9**	**6,027.2**	**5,895.6**	**5,664.7**	**5,791.2**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

Note: Emissions from electricity generation are allocated based on aggregate electricity consumption in each end-use sector.

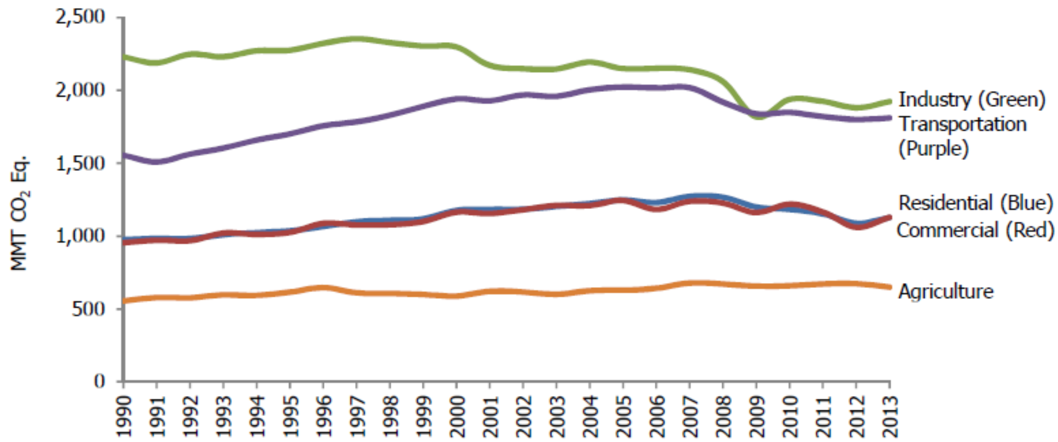
[a] Sinks (i.e., CO_2 removals) are only included in the Net Emissions total. Refer to Table ES-5 for a breakout of emissions and removals for Land Use, Land-Use Change, and Forestry by gas and source category.

[23] 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.

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration. See Table 2-12 for more detailed data.

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

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



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 non-utilities combined—was the largest source of U.S. greenhouse gas emissions in 2013; (4) emissions per unit of total gross domestic product as a measure of national economic activity; and (5) emissions per capita.

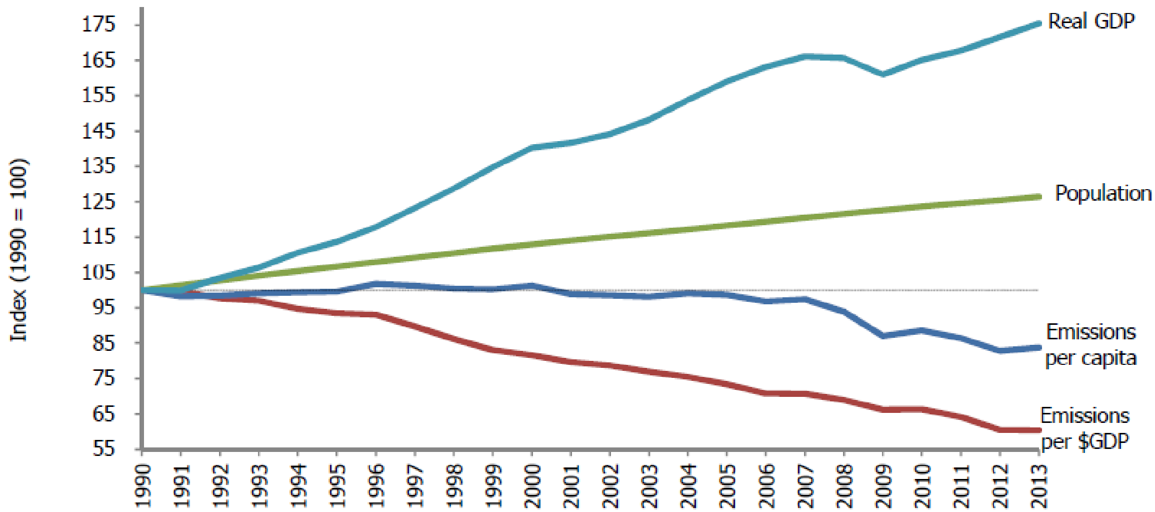
Table ES-8 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. Greenhouse gas emissions in the United States have grown at an average annual rate of 0.3 percent since 1990. Since 1990, this rate is slightly slower than that for total energy 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-8: Recent Trends in Various U.S. Data (Index 1990 = 100)

Variable	1990	2005	2009	2010	2011	2012	2013	Avg. Annual Growth Rate
Greenhouse Gas Emissions[a]	100	117	107	109	108	104	106	0.3%
Energy Consumption[b]	100	118	112	116	115	112	115	0.6%
Fossil Fuel Consumption[b]	100	119	108	112	110	107	110	0.4%
Electricity Consumption[b]	100	134	131	137	137	135	135	1.3%
GDP[c]	100	159	161	165	168	172	175	2.5%
Population[d]	100	118	123	124	125	125	126	1.0%

[a] GWP-weighted values
[b] Energy content-weighted values (EIA 2015a)
[c] Gross Domestic Product in chained 2009 dollars (BEA 2014)
[d] U.S. Census Bureau (2014)

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



Source: BEA (2014), U.S. Census Bureau (2014), and emission estimates in this report.

Key Categories

The *2006 IPCC Guidelines* (IPCC 2006) defines a key category as a "[category] that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals."[24] 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 2013 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: Key Categories and Annex 1.

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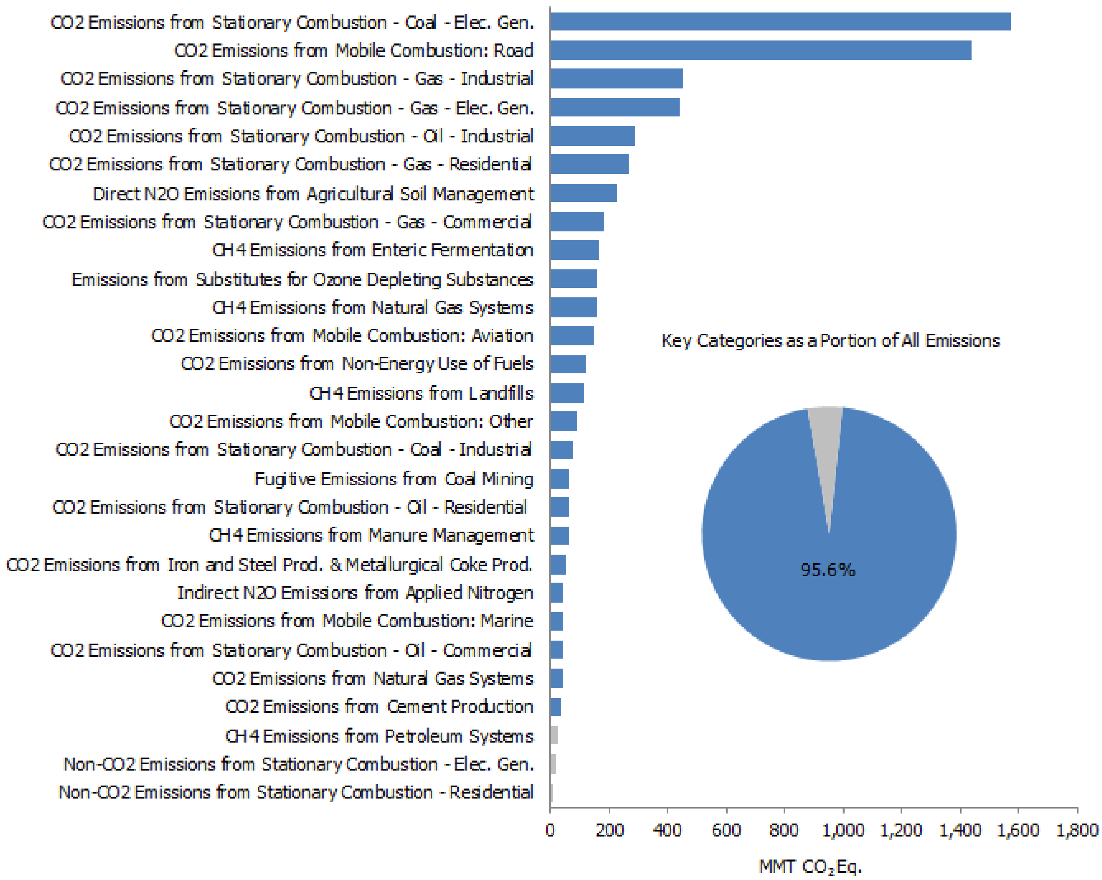
[24] See Chapter 4 "Methodological Choice and Identification of Key Categories" in IPCC (2006). <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html>

Figure ES-16: 2013 Key Categories



Note: For a complete discussion of the key category analysis, see Annex 1. Blue bars indicate either an Approach 1, or Approach 1 *and* Approach 2 level assessment key category. Gray bars indicate solely an Approach 2 level assessment key category.

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 *2006 IPCC Guidelines* (IPCC 2006) and require that countries provide single estimates of uncertainty for source and sink categories.

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

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 2013) 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.

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 2013. 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[1] in order to show the relative contribution of each gas to global average radiative forcing. This report also discusses the methods and data used to calculate these emission estimates.

In 1992, the United States signed and ratified the United Nations Framework Convention on Climate Change (UNFCCC). As stated in Article 2 of the UNFCCC, "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."[2,3]

Parties to the Convention, by ratifying, "shall develop, periodically update, publish and make available…national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies…"[4] The United States views this report as an opportunity to fulfill these commitments under the UNFCCC.

In 1988, preceding the creation of the UNFCCC, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) jointly established the Intergovernmental Panel on Climate Change (IPCC). The role of the IPCC is to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation (IPCC 2003). Under Working Group 1 of the IPCC, nearly 140 scientists and national experts from more than thirty countries collaborated in the creation of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) to ensure that the emission inventories submitted to the UNFCCC are consistent and comparable between nations. The *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* and the *IPCC Good Practice Guidance for Land Use, Land-Use Change, and Forestry* further expanded upon the methodologies in the *Revised 1996 IPCC Guidelines*. In 2006, the IPCC accepted the *2006 Guidelines for National Greenhouse Gas Inventories* at its Twenty-Fifth Session (Mauritius, April 2006). The *2006 IPCC Guidelines* built

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[1] More information provided in "Global Warming Potentials" section of this chapter on the use of *IPCC Fourth Assessment Report* (AR4) GWP values.

[2] The term "anthropogenic," in this context, refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities (IPCC 2006).

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

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

upon the previous bodies of work and include new sources and gases "…as well as updates to the previously published methods whenever scientific and technical knowledge have improved since the previous guidelines were issued. The UNFCCC adopted the *2006 IPCC Guidelines* as the standard methodological approach for Annex I countries at the Nineteenth Conference of the Parties (Warsaw, November 11-23, 2013). This report presents information in accordance with these guidelines.

Overall, this Inventory of anthropogenic greenhouse gas emissions and sinks 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.[5] The structure of this report is consistent with the current UNFCCC Guidelines on Annual Inventories (UNFCCC 2014).

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 emission 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.[6] 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.[7] 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. The manner that emissions and sinks are provided in this Inventory is one of many ways U.S. emissions and sinks could be examined; this Inventory report presents emissions and sinks in a common format consistent with how countries are to report inventories under the UNFCCC. 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.[8] Reporting is at the facility level, except for certain suppliers of fossil fuels and industrial greenhouse gases. 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 the data for use, as applicable, to improve the national estimates presented in this Inventory.

1.1 Background Information

Science

For over the past 200 years, the burning of fossil fuels such as coal and oil, deforestation, land-use changes, and other sources have caused the concentrations of heat-trapping "greenhouse gases" to increase significantly in our

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

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

7 See <http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf#page=2 >.

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

atmosphere (NOAA 2014). These gases in the atmosphere absorb some of the energy being radiated from the surface of the Earth and then re-radiate this energy with some returning to the Earth's surface, 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, with a portion of these gases occurring naturally from such sources as respiration and volcanic eruptions, without natural concentrations of greenhouse gases the planet's surface would be about 60 ºF cooler than present (EPA 2009). But, as the concentrations of these gases continue to increase in the atmosphere from man-made sources, the Earth's temperature is climbing above past levels. The Earth's averaged land and ocean surface temperature has increased by about 1.2 to 1.9 ºF since 1880. The last three decades have each been the warmest decade successively at the Earth's surface since 1850 (IPCC 2013). 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.

If greenhouse gases continue to increase, climate models predict that the average temperature at the Earth's surface is likely to increase from 0.5 to 8.6 ºF above 1986 through 2005 levels by the end of this century (IPCC 2013). 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. However, they are not sure by how much it will change, at what rate it will change, or what the exact effects will be.[9]

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), methane (CH_4), nitrous oxide (N_2O), and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the Earth (IPCC 2013). Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans.[10] A gauge of these changes is called radiative forcing, which is a measure of the influence a perturbation has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system (IPCC 2013). 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).

> *Human activities are continuing to affect the Earth's energy budget by changing the emissions and resulting atmospheric concentrations of radiatively important gases and aerosols and by changing land surface properties (IPCC 2013).*

Naturally occurring greenhouse gases include water vapor, CO_2, CH_4, 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.[11] Some other fluorine-containing halogenated substances—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)—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 other substances that influence the global radiation budget but are short-lived and therefore not well-mixed. These substances include carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and

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

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

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

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 suspended in the Earth's atmosphere that are often composed of sulfur compounds, carbonaceous combustion products (e.g., black carbon), crustal materials (e.g., dust) and other human induced pollutants. They can affect the absorptive characteristics of the atmosphere (e.g., scattering incoming sunlight away from the Earth's surface) and can play a role in affecting cloud formation and lifetime affecting the radiative forcing of clouds and precipitation patterns. Comparatively, however, while the understanding of aerosols has increased in recent years, they still account for the largest contribution to uncertainty estimates in global energy budgets (IPCC 2013).

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, 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	399 ppm	1.762-1.893 ppm[a]	0.324-0.326 ppm[a]	7.39-7.79 ppt[a]	79 ppt[f]
Rate of concentration change	1.4 ppm/yr	0.005 ppm/yr[b]	0.26%/yr	Linear[c]	Linear[c]
Atmospheric lifetime (years)	See footnote[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 (2015).

[a] The range is the annual arithmetic averages from a mid-latitude Northern-Hemisphere site and a mid-latitude Southern-Hemisphere site for 2012 (CDIAC 2014).

[b] The growth rate for atmospheric CH_4 decreased from over 10 ppb/yr in the 1980s to nearly zero in the early 2000s; recently, the growth rate has been about 5 ppb/yr.

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

[d] For a given amount of carbon dioxide emitted, some fraction of the atmospheric increase in concentration is quickly absorbed by the oceans and terrestrial vegetation, some fraction of the atmospheric increase will only slowly decrease over a number of years, and a small portion of the increase will remain for many centuries or more.

[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.

[f] The 2011 CF_4 global mean atmospheric concentration is from the Advanced Global Atmospheric Gases Experiment (IPCC 2013).

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). Water vapor is the largest contributor to the natural greenhouse effect. Water vapor is fundamentally different from other greenhouse gases in that it can condense and rain out when it reaches high concentrations, and the total amount of water vapor in the atmosphere is a function of the Earth's temperature. While some human activities such as evaporation from irrigated crops or power plant cooling release water vapor into the air, this has been determined to have a negligible effect on climate (IPCC 2013). The lifetime of water vapor in the troposphere is on the order of 10 days. Water vapor can also contribute to cloud formation, and clouds can have both warming and cooling effects by either trapping or reflecting heat. Because of the relationship between water vapor levels and temperature, water vapor and clouds serve as a feedback to climate change, such that for any given increase in other greenhouse gases, the total warming is greater than would happen in the absence of water vapor. Aircraft contrails, which consist of water vapor and other substances, are aviation-induced clouds with the same radiative forcing effects as high-altitude cirrus clouds (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 398 ppmv in 2013, a 42.4 percent increase (IPCC 2007 and NOAA/ESRL 2015).[12,13] The IPCC definitively states that "the increase of CO_2 … is caused by anthropogenic emissions from the use of fossil fuel as a source of energy and from land use and land use changes, in particular agriculture" (IPCC 2013). 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 Fifth Assessment Report, the IPCC stated "it is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together," of which CO_2 is the most important (IPCC 2013).

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 mining and incomplete fossil fuel combustion. Atmospheric concentrations of CH_4 have increased by about 152 percent since 1750, from a pre-industrial value of about 700 ppb to 1,762 – 1,893 ppb in 2012,[14] although the rate of increase decreased to near zero in the early 2000s, and has recently increased again to about 5 ppb/year. 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 primarily 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 increases the atmospheric lifetime of CH_4 (IPCC 2013).

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 20 percent since 1750, from a pre-industrial value of about 270 ppb to 324-326 ppb in 2012,[15] 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).

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

[13] 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).

[14] The range is the annual arithmetic averages from a mid-latitude Northern-Hemisphere site and a mid-latitude Southern-Hemisphere site for October 2012 through September 2013 (CDIAC 2014).

[15] The range is the annual arithmetic averages from a mid-latitude Northern-Hemisphere site and a mid-latitude Southern-Hemisphere site for October 2012 through September 2013 (CDIAC 2014).

Ozone (O_3). Ozone is present in both the upper stratosphere,[16] where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,[17] 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 2013). The depletion of stratospheric ozone and its radiative forcing was expected to reach a maximum in about 2000 before starting to recover.

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 2013).

Halocarbons, Perfluorocarbons, Sulfur Hexafluoride, and Nitrogen Triflouride. 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 importation of HCFCs by non-Article 5[18] 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, SF_6, and NF_3 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 2013). PFCs, SF_6, and NF_3 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, SF_6, and NF_3 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 2013).

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.

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[16] 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.

[17] 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.

[18] 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.

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, are a precursor to nitrate particles (i.e., aerosols) and, to a lesser degree, lower stratosphere, where they have positive radiative forcing effects.[19] Additionally, NO_x emissions are also likely to decrease CH_4 concentrations, thus having a negative radiative forcing effect (IPCC 2013). 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 that are either directly emitted into or are created through chemical reactions in the Earth's atmosphere. Aerosols or their chemical precursors can be emitted by natural events such as dust storms and volcanic activity, or by anthropogenic processes such as fuel combustion and biomass burning. Various categories of aerosols exist, including naturally produced aerosols such as soil dust, sea salt, biogenic aerosols, sulfates, nitrates, and volcanic aerosols, and anthropogenically manufactured aerosols such as industrial dust and carbonaceous[20] aerosols (e.g., black carbon, organic carbon) from transportation, coal combustion, cement manufacturing, waste incineration, and biomass burning. Aerosols can be removed from the atmosphere relatively rapidly by precipitation or through more complex processes under dry conditions.

Aerosols affect radiative forcing differently than greenhouse gases. Their radiative effects occur through direct and indirect mechanisms: directly by scattering and absorbing solar radiation (and to a lesser extent scattering, absorption, and emission of terrestrial radiation); and indirectly by increasing cloud droplets and ice crystals that modify the formation, precipitation efficiency, and radiative properties of clouds (IPCC 2013). Despite advances in understanding of cloud-aerosol interactions, the contribution of aerosols to radiative forcing are difficult to quantify because aerosols generally have short atmospheric lifetimes, and have number concentrations, size distributions, and compositions that vary regionally, spatially, and temporally (IPCC 2013).

The net effect of aerosols on the Earth's radiative forcing is believed to be negative (i.e., net cooling effect on the climate). In fact, "despite the large uncertainty ranges on aerosol forcing, there is high confidence that aerosols have offset a substantial portion of GHG forcing" (IPCC 2013).[21] Although because they remain in the atmosphere for only days to weeks, their concentrations respond rapidly to changes in emissions.[22] Not all aerosols have a cooling effect. Current research suggests that another constituent of aerosols, black carbon, has a positive radiative forcing by heating the Earth's atmosphere and causing surface warming when deposited on ice and snow (IPCC 2013). Black carbon also influences cloud development, but the direction and magnitude of this forcing is an area of active research.

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 2007). Direct radiative effects occur when the gas itself absorbs radiation. Indirect radiative forcing occurs when chemical

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

[20] Carbonaceous aerosols are aerosols that are comprised mainly of organic substances and forms of black carbon (or soot) (IPCC 2013).

[21] The IPCC (2014) defines high confidence as an indication of strong scientific evidence and agreement in this statement.

[22] 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).

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 million metric tons of CO_2 equivalent (MMT CO_2 Eq.).[23] The relationship between kilotons (kt) of a gas and MMT CO_2 Eq. can be expressed as follows:

$$MMT\ CO_2\ Eq. = (kt\ of\ gas) \times (GWP) \times \left(\frac{MMT}{1{,}000\ kt}\right)$$

where,

MMT CO_2 Eq. = Million metric tons of CO_2 equivalent

kt = Kilotons (equivalent to a thousand metric tons)

GWP = Global warming potential

MMT = Million metric tons

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. Parties to the UNFCCC have also agreed to use GWPs based upon a 100-year time horizon, although other time horizon values are available.

> *…the global warming potential values used by Parties included in Annex I to the Convention (Annex I Parties) to calculate the carbon dioxide equivalence of anthropogenic emissions by sources and removals by sinks of greenhouse gases shall be those listed in the column entitled "Global warming potential for given time horizon" in table 2.14 of the errata to the contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, based on the effects of greenhouse gases over a 100-year time horizon...*[24]

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3) 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. Parties to the UNFCCC have not agreed upon GWP values for 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[c]
CO_2	[b]	1
CH_4[a]	12	25
N_2O	114	298
HFC-23	270	14,800
HFC-32	4.9	675
HFC-125	29	3,500
HFC-134a	14	1,430
HFC-143a	52	4,470
HFC-152a	1.4	124
HFC-227ea	34.2	3,220
HFC-236fa	240	9,810
HFC-4310mee	15.9	1,640

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

[24] Framework Convention on Climate Change; < http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf >; 31 January 2014; Report of the Conference of the Parties at its nineteenth session; held in Warsaw from 11 to 23 November 2013; Addendum; Part two: Action taken by the Conference of the Parties at its nineteenth session; Decision 24/CP.19; Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention; p. 2. (UNFCCC 2014)

CF_4	50,000	7,390
C_2F_6	10,000	12,200
C_4F_{10}	2,600	8,860
C_6F_{14}	3,200	9,300
SF_6	3,200	22,800
NF_3	740	17,200

Source: (IPCC 2007)

[a] 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.

[b] For a given amount of carbon dioxide emitted, some fraction of the atmospheric increase in concentration is quickly absorbed by the oceans and terrestrial vegetation, some fraction of the atmospheric increase will only slowly decrease over a number of years, and a small portion of the increase will remain for many centuries or more.

[c] 100-year time horizon.

Box 1-2: The IPCC *Fifth Assessment Report* and Global Warming Potentials

In 2013, the IPCC published its *Fifth Assessment Report* (AR5), which provided an updated and more comprehensive scientific assessment of climate change. Within the AR5 report, the GWP values of several gases were revised relative to previous IPCC reports, namely the *IPCC Second Assessment Report* (SAR) (IPCC 1996), the *IPCC Third Assessment Report* (TAR) (IPCC 2001), and the *IPCC Fourth Assessment Report* (AR4) (IPCC 2007). Although the AR4 GWP values are used throughout this report, consistent with UNFCCC reporting requirements, it is interesting to review the changes to the GWP values and the impact improved understanding has on the total GWP-weighted emissions of the United States. In the AR5, the IPCC has applied an improved calculation of CO_2 radiative forcing and an improved CO_2 response function in presenting updated GWP values. Additionally, the atmospheric lifetimes of some gases have been recalculated, and updated background concentrations were used. In addition, the values for radiative forcing and lifetimes have been recalculated for a variety of halocarbons. Table 1-3 presents the new GWP values, relative to those presented in the AR4 and using the 100-year time horizon common to UNFCCC reporting.

Table 1-3: Comparison of 100-Year GWP values

Gas	SAR	TAR	AR4	AR5[b]	Comparison to AR4		
					SAR	TAR	AR5
CO_2	1	1	1	1	NC	NC	NC
CH_4[a]	21	23	25	28	(4)	(2)	3
N_2O	310	296	298	265	12	(2)	(33)
HFC-23	11,700	12,000	14,800	12,400	(3,100)	(2,800)	(2,400)
HFC-32	650	550	675	677	(25)	(125)	2
HFC-125	2,800	3,400	3,500	3,170	(700)	(100)	(330)
HFC-134a	1,300	1,300	1,430	1,300	(130)	(130)	(130)
HFC-143a	3,800	4,300	4,470	4,800	(670)	(170)	330
HFC-152a	140	120	124	138	16	(4)	14
HFC-227ea	2,900	3,500	3,220	3,350	(320)	280	130
HFC-236fa	6,300	9,400	9,810	8,060	(3,510)	(410)	(1,750)
HFC-4310mee	1,300	1,500	1,640	1,650	(340)	(140)	10
CF_4	6,500	5,700	7,390	6,630	(890)	(1,690)	(760)
C_2F_6	9,200	11,900	12,200	11,100	(3,000)	(300)	(1,100)
C_4F_{10}	7,000	8,600	8,860	9,200	(1,860)	(260)	340
C_6F_{14}	7,400	9,000	9,300	7,910	(1,900)	(300)	(1,390)
SF_6	23,900	22,200	22,800	23,500	1,100	(600)	700
NF_3	NA	10,800	17,200	16,100	NA	(6,400)	700

Source: (IPCC 2013, IPCC 2007, IPCC 2001, IPCC 1996)

NC (No Change)
NA (Not Applicable)
Note: Parentheses indicate negative values.
[a] 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.
[b] The GWPs presented here are the ones most consistent with the methodology used in the AR4 report. The AR5 report has also calculated GWPs (not shown here) where climate-carbon feedbacks have been included for the non-CO_2 gases in order to be consistent with the approach used in calculating the CO_2 lifetime. Additionally, the AR5 reported separate values for fossil versus biogenic methane in order to account for the CO_2 oxidation product.

To comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using AR4 GWP values, as required by the 2013 revision to the UNFCCC reporting guidelines for national inventories.[25] All estimates provided throughout this report are also presented in unweighted units. For informational purposes, emission estimates that use GWPs from other IPCC Assessment Reports are presented in detail in Annex 6.1 of this report. It should be noted that this Inventory represents the first time that the official U.S. greenhouse gas emissions are reported using the AR4 GWP values. The use of IPCC AR4 GWP values for the current Inventory applies across the entire time series of the Inventory (i.e., from 1990 to 2013).[26]

1.2 National Inventory 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, planning methodological approaches and improvements, reviewing, or preparing portions of the U.S. Inventory—including federal and state government authorities, research and academic institutions, industry associations, and private consultants.

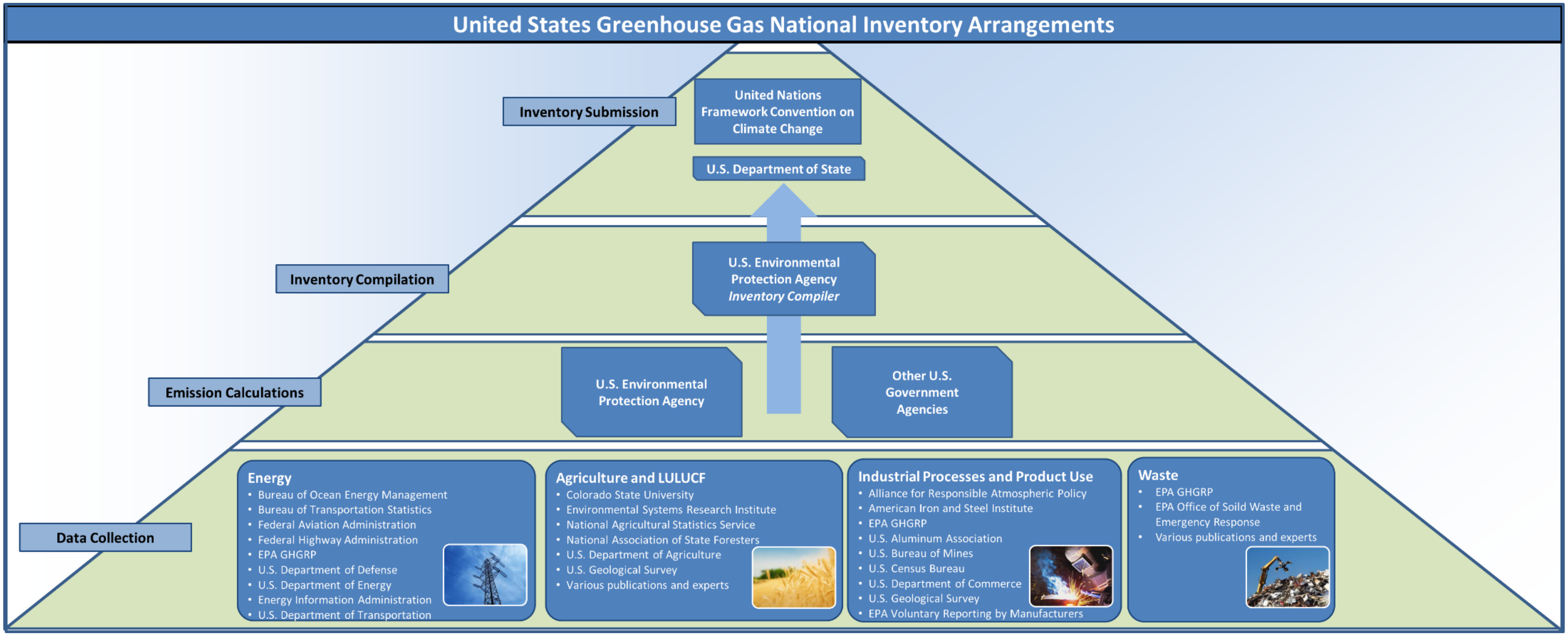
Within EPA, the Office of Atmospheric Programs (OAP) is the lead office responsible for the emission calculations provided in the Inventory, as well as the completion of the National Inventory Report and the Common Reporting Format tables. EPA's Office of Transportation and Air Quality (OTAQ) is also involved in calculating emissions for the Inventory. While the U.S. Department of State officially submits the annual Inventory to the UNFCCC, EPA's OAP serves as the Inventory 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

[25] See < http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf >.
[26] ''Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention,'' FCCC/CP/2011/9/Add.2, Decision 6/CP 17, 15 March 2012, available at <http://unfccc.int/resource/docs/2011/cop17/eng/09a02.pdf#page=23>.

voluntary outreach efforts with EPA. Finally, the U.S. Department of State officially submits the Inventory to the UNFCCC each April. Figure 1-1 diagrams the National Inventory Arrangements.

Figure 1-1: National Inventory Arrangements Diagram



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 *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, 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 and posted online, available for the public.[1]

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 *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

[1] See http://epa.gov/climatechange/ghgemissions/usinventoryreport.html.

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 *2006 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 country-specific methodologies and data where possible. Choices made regarding the methodologies and data sources used are provided in conjunction with the discussion of each source category in the main body of the report. Complete documentation is provided in the annexes on the detailed methodologies and data sources utilized in the calculation of each source category.

Box 1-3: 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.

1.5 Key Categories

The *2006 IPCC Guidelines* (IPCC 2006) defines a key category as a "[category] that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals."[2] By definition, key categories include those categories that have the greatest contribution to the absolute level of national emissions. In addition, when an entire time series of emission and removal 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.

Approach 1, as defined in the 2006 *IPCC Guidelines* (IPCC 2006), 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 Approach 1, Approach 2, as defined in the *2006 IPCC Guidelines* (IPCC 2006), was then implemented to identify any additional key categories not already identified in Approach 1 assessment. This analysis, which includes each source category's uncertainty assessments (or proxies) in its calculations, was also performed twice to include or exclude LULUCF categories.

In addition to conducting Approach 1 and 2 level and trend assessments, a qualitative assessment of the source categories, as described in the *2006 IPCC Guidelines* (IPCC 2006), 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

[2] See Chapter 4 "Methodological Choice and Identification of Key Categories" in IPCC (2006). See < http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>.

with IPCC guidelines. If these emissions were included in the totals, bunker fuels would qualify as a key category according to Approach 1. 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 Approach 2. 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 2013. The table also indicates the criteria used in identifying these categories (i.e., level, trend, Approach 1, Approach 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 (1990-2013)

IPCC Source Categories	Gas	Approach 1				Approach 2				Qual[a]	2013 Emissions (MMT CO_2 Eq.)
		Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF		
Energy											
CO_2 Emissions from Stationary Combustion - Coal - Electricity Generation	CO_2	•	•	•	•	•	•	•	•		1,575.0
CO_2 Emissions from Mobile Combustion: Road	CO_2	•	•	•	•	•	•	•	•		1,438.9
CO_2 Emissions from Stationary Combustion - Gas - Industrial	CO_2	•	•	•	•	•		•			450.8
CO_2 Emissions from Stationary Combustion - Gas - Electricity Generation	CO_2	•	•	•	•	•	•	•	•		441.9
CO_2 Emissions from Stationary Combustion - Oil - Industrial	CO_2	•		•	•	•		•			290.6
CO_2 Emissions from Stationary Combustion - Gas - Residential	CO_2	•	•	•	•	•		•			267.1
CO_2 Emissions from Stationary Combustion - Gas - Commercial	CO_2	•	•	•	•	•	•	•			178.2
CO_2 Emissions from Mobile Combustion: Aviation	CO_2	•	•	•	•	•	•	•	•		148.7
CO_2 Emissions from Non-Energy Use of Fuels	CO_2	•	•	•		•		•			119.8
CO_2 Emissions from Mobile Combustion: Other	CO_2	•	•	•	•						92.0
CO_2 Emissions from Stationary Combustion - Coal - Industrial	CO_2	•	•	•	•	•	•	•	•		75.8

CO_2 Emissions from Stationary Combustion - Oil - Residential	CO_2	•	•	•	•		•				62.5
CO_2 Emissions from Mobile Combustion: Marine	CO_2	•	•	•	•						38.9
CO_2 Emissions from Stationary Combustion - Oil - Commercial	CO_2	•	•	•	•						38.6
CO_2 Emissions from Natural Gas Systems	CO_2	•		•		•		•			37.8
CO_2 Emissions from Stationary Combustion - Oil - U.S. Territories	CO_2			•							26.0
CO_2 Emissions from Stationary Combustion - Oil - Electricity Generation	CO_2	•	•	•	•	•	•	•	•		22.4
CO_2 Emissions from Petroleum Systems	CO_2						•				6.0
CO_2 Emissions from Stationary Combustion - Coal - Commercial	CO_2		•		•						3.9
CO_2 Emissions from Stationary Combustion - Gas - U.S. Territories	CO_2						•				2.6
CO_2 Emissions from Stationary Combustion - Coal - Residential	CO_2						•		•		0.0
CH_4 Emissions from Natural Gas Systems	CH_4	•	•	•	•	•	•	•	•		157.4
Fugitive Emissions from Coal Mining	CH_4	•	•	•	•	•	•	•	•		64.6
CH_4 Emissions from Petroleum Systems	CH_4	•	•	•	•	•	•	•	•		25.2
Non-CO_2 Emissions from Stationary Combustion - Residential	CH_4					•		•			5.0
Non-CO_2 Emissions from Stationary Combustion - Electricity Generation	N_2O		•		•	•	•	•	•		19.1
N_2O Emissions from Mobile Combustion: Road	N_2O	•	•	•	•		•		•		14.5
Non-CO_2 Emissions from Stationary Combustion - Industrial	N_2O						•				2.4
International Bunker Fuels[b]	Several									•	100.7
Industrial Processes and Product Use											
CO_2 Emissions from Iron and Steel Production &	CO_2	•	•	•	•	•	•	•	•		52.3

Metallurgical Coke Production											
CO_2 Emissions from Cement Production	CO_2	•		•							36.1
CO_2 Emissions from Petrochemical Production	CO_2			•							26.5
N_2O Emissions from Adipic Acid Production	N_2O		•		•						4.0
Emissions from Substitutes for Ozone Depleting Substances	HiGWP	•	•	•	•	•	•	•	•		158.6
SF_6 Emissions from Electrical Transmission and Distribution	HiGWP		•		•		•		•		5.1
HFC-23 Emissions from HCFC-22 Production	HiGWP	•	•	•	•		•		•		4.1
PFC Emissions from Aluminum Production	HiGWP		•		•						3.0
Agriculture											
CH_4 Emissions from Enteric Fermentation	CH_4	•	•	•	•	•		•			164.5
CH_4 Emissions from Manure Management	CH_4	•	•	•	•	•	•	•	•		61.4
CH_4 Emissions from Rice Cultivation	CH_4					•					8.3
Direct N_2O Emissions from Agricultural Soil Management	N_2O	•	•	•	•	•	•	•	•		224.7
Indirect N_2O Emissions from Applied Nitrogen	N_2O	•		•		•	•	•	•		39.0
Waste											
CH_4 Emissions from Landfills	CH_4	•	•	•	•	•	•	•	•		114.6
Land Use, Land Use Change, and Forestry											
CO_2 Emissions from Land Converted to Cropland	CO_2				•			•	•		16.1
CO_2 Emissions from Grassland Remaining Grassland	CO_2				•			•	•		12.1
CO_2 Emissions from Landfilled Yard Trimmings and Food Scraps	CO_2				•			•	•		(12.6)
CO_2 Emissions from Cropland Remaining Cropland	CO_2			•	•			•	•		(23.4)
CO_2 Emissions from Urban Trees	CO_2			•	•			•	•		(89.5)
CO_2 Emissions from Changes in Forest Carbon Stocks	CO_2			•	•			•	•		(775.7)
CH_4 Emissions from Forest Fires	CH_4							•	•		5.8
N_2O Emissions from Forest Fires	N_2O								•		3.8

Subtotal Without LULUCF	**6,455.5**
Total Emissions Without LULUCF	**6,649.7**
Percent of Total Without LULUCF	**97%**
Subtotal With LULUCF	**5,625.3**
Total Emissions With LULUCF	**5,791.2**
Percent of Total With LULUCF	**97%**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
[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 1-2. These attributes include:

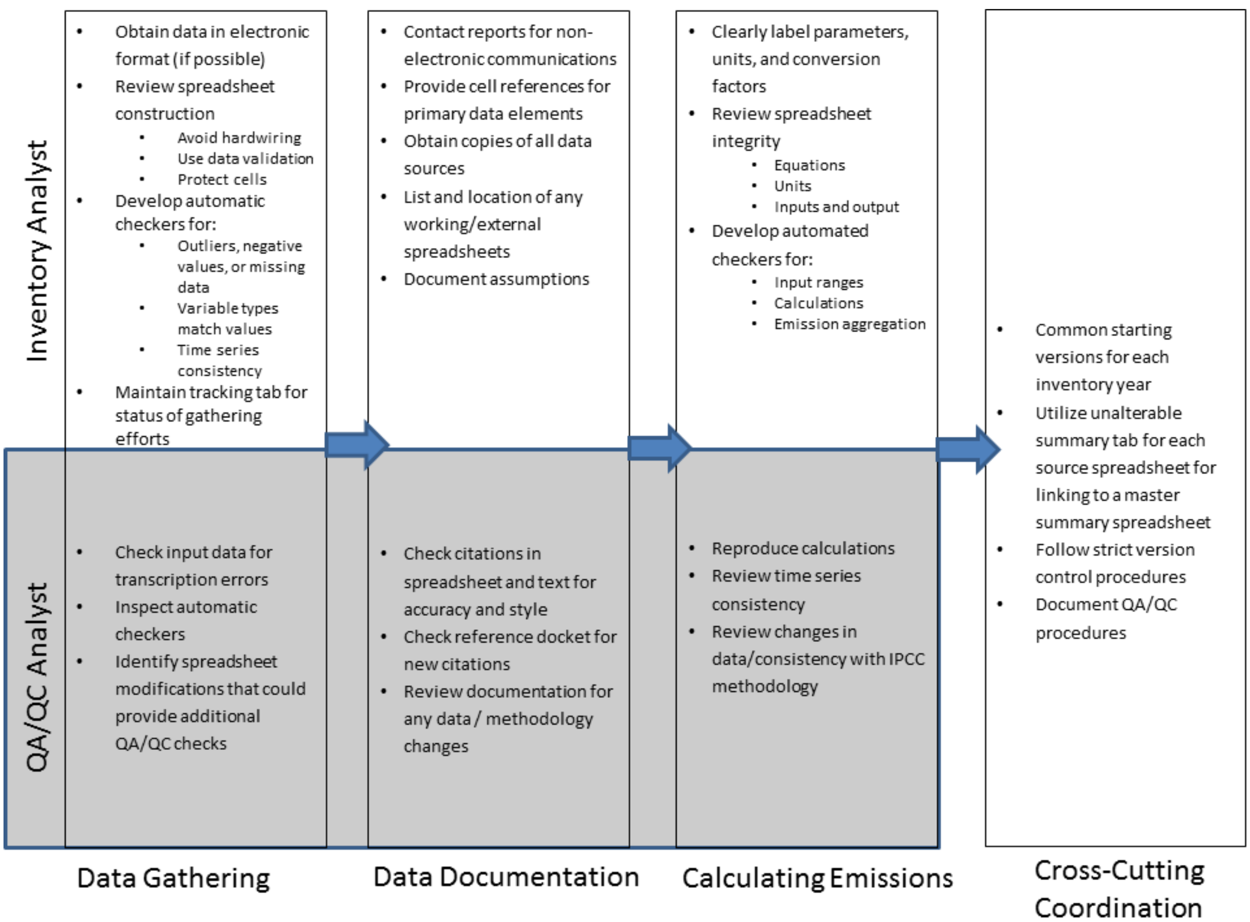
- *Procedures and Forms:* detailed and specific systems that serve to standardize the process of documenting and archiving information, as well as to guide the implementation of QA/QC and the analysis of uncertainty
- *Implementation of Procedures:* application of QA/QC procedures throughout the whole inventory development process from initial data collection, through preparation of the emission estimates, to publication of the Inventory
- *Quality Assurance:* expert and public reviews for both the inventory estimates and the Inventory report (which is the primary vehicle for disseminating the results of the inventory development process)
- *Quality Control*: consideration of secondary data and source-specific checks (Tier 2 QC) in parallel and coordination with the uncertainty assessment; the development of protocols and templates, which provides for more structured communication and integration with the suppliers of secondary information
- *Tier 1 (general) and Tier 2 (source-specific) Checks:* quality controls and checks, as recommended by IPCC Good Practice Guidance
- *Record Keeping:* provisions to track which procedures have been followed, the results of the QA/QC, uncertainty analysis, and feedback mechanisms for corrective action based on the results of the investigations which provide for continual data quality improvement and guided research efforts
- *Multi-Year Implementation*: a schedule for coordinating the application of QA/QC procedures across multiple years
- *Interaction and Coordination:* promoting communication 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 Management 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 1-2: 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. The UNFCCC reporting guidelines follow the recommendation in the *2006 IPCC Guidelines* (IPCC 2006) 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 total U.S. greenhouse gas emissions was developed using the IPCC Approach 2 uncertainty estimation methodology. Estimates of quantitative uncertainty for the total U.S. greenhouse gas emissions are shown below, in Table 1-5.

The IPCC provides good practice guidance on two approaches—Approach 1 and Approach 2—to estimating uncertainty for individual source categories. Approach 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 *2006 IPCC Guidelines* (IPCC 2006), 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 (MMT CO_2 Eq. and Percent)

Gas	2013 Emission Estimate[a] (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[b] (MMT CO_2 Eq.)		(%)		Mean[c] (MMT CO_2 Eq.)	Standard Deviation[c]
		Lower Bound[d]	Upper Bound[d]	Lower Bound	Upper Bound		
CO_2	5,505	5,400	5,766	-2%	5%	5,584	95
CH_4[e]	636	573	751	-10%	18%	656	45
N_2O[e]	355	320	445	-10%	25%	376	32
PFC, HFC, SF_6, and NF_3[e]	171	170	190	-1%	11%	180	5
Total	**6,667**	**6,584**	**7,008**	**-1%**	**5%**	**6,795**	**110**

Net Emissions (Sources and Sinks)	**5,785.5**	**5,613**	**6,220**	**-3%**	**8%**	**5,916**	**154**

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 5.7 MMT 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 2.5[th] percentile and the upper bound corresponding to 97.5[th] 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 2013.

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 tables, 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 2013. Although this report is intended to be comprehensive, certain sources have been identified which were 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 revision of the UNFCCC reporting guidelines agreed to at the nineteenth Conference of the Parties (UNFCCC 2014), this Inventory of U.S. Greenhouse Gas Emissions and Sinks is segregated into five 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, and non-energy use of fossil fuels.
Industrial Processes and Product Use	Emissions resulting from industrial processes and product use of greenhouse gases.
Agriculture	Anthropogenic emissions from agricultural activities except fuel combustion, which is addressed under Energy.

Land Use, Land-Use Change, and Forestry	Emissions and removals of CO_2, CH_4, and N_2O from forest management, other land-use activities, and land-use change.
Waste	Emissions from waste management activities.

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 and Timeseries Consistency: 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 Emissions from Commercial Aircraft Jet Fuel Consumption
3.4.	Methodology for Estimating CH_4 Emissions from Coal Mining
3.5.	Methodology for Estimating CH_4 and CO_2 Emissions from Petroleum Systems
3.6.	Methodology for Estimating CH_4 Emissions from Natural Gas Systems
3.7.	Methodology for Estimating CO_2 and N_2O Emissions from Incineration of Waste
3.8.	Methodology for Estimating Emissions from International Bunker Fuels used by the U.S. Military
3.9.	Methodology for Estimating HFC and PFC Emissions from Substitution of Ozone Depleting Substances
3.10.	Methodology for Estimating CH_4 Emissions from Enteric Fermentation
3.11.	Methodology for Estimating CH_4 and N_2O Emissions from Manure Management
3.12.	Methodology for Estimating N_2O Emissions and Soil Organic C Stock Changes from Agricultural Soil Management (Cropland and Grassland)
3.13.	Methodology for Estimating Net Carbon Stock Changes in Forest Lands Remaining Forest Lands
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
ANNEX 8 QA/QC Procedures	
8.1.	Background
8.2.	Purpose
8.3.	Assessment Factors

2. Trends in Greenhouse Gas Emissions

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

In 2013, total U.S. greenhouse gas emissions were 6,673.0 MMT or million metric tons CO_2 Eq. Total U.S. emissions have increased by 5.9 percent from 1990 to 2013, and emissions increased from 2012 to 2013 by 2.0 percent (127.9 MMT CO_2 Eq.). The increase from 2012 to 2013 was due to an increase in the carbon intensity of fuels consumed to generate electricity due to an increase in coal consumption, with decreased natural gas consumption. Additionally, cold winter conditions lead to an increase in fuels for the residential and commercial sectors for heating. In 2013 there also was an increase in industrial production across multiple sectors resulting in increases in industrial sector emissions. Lastly, transportation emissions increased as a result of a small increase in vehicle miles traveled (VMT) and fuel use across on-road transportation modes. Since 1990, U.S. emissions have increased at an average annual rate of 0.3 percent. Figure 2-1 through Figure 2-3 illustrate the overall trend in total U.S. emissions by gas, annual changes, and absolute changes since 1990.

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

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

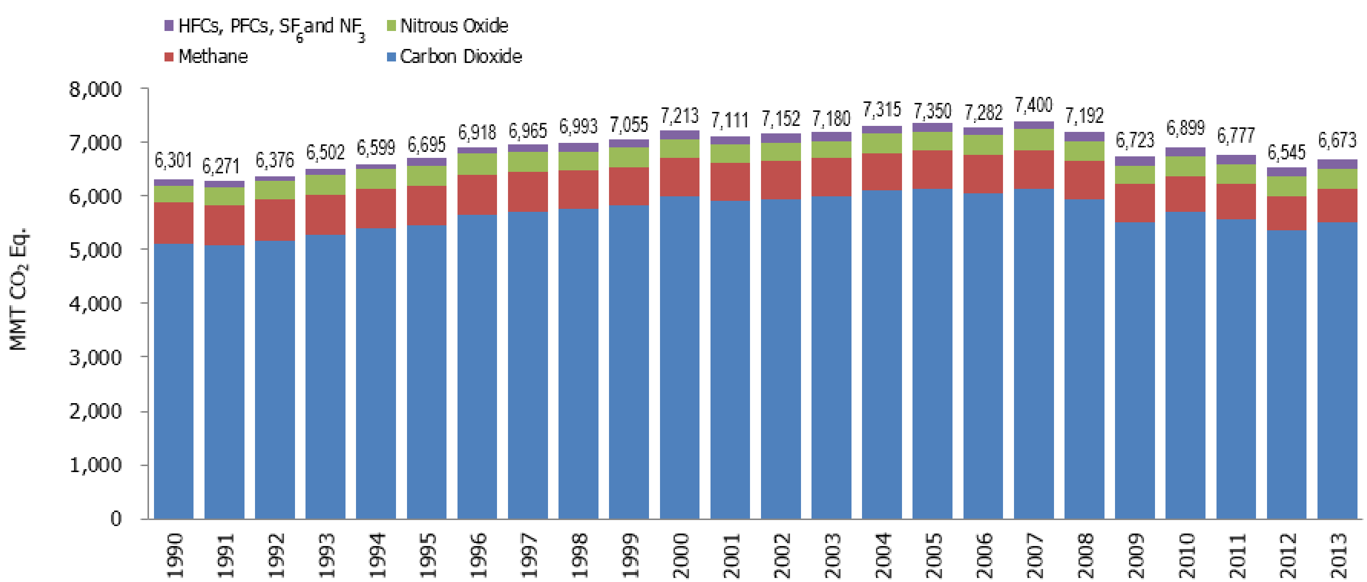


Figure 2-2: Annual Percent Change in U.S. Greenhouse Gas Emissions

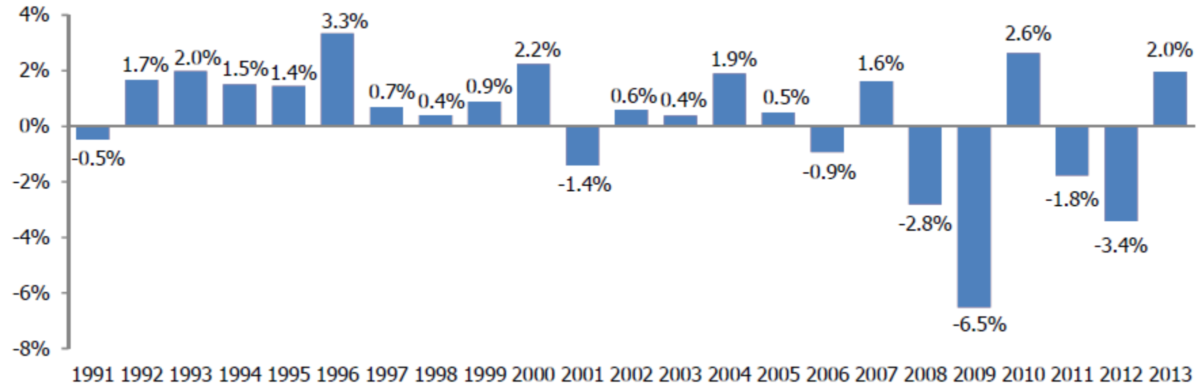
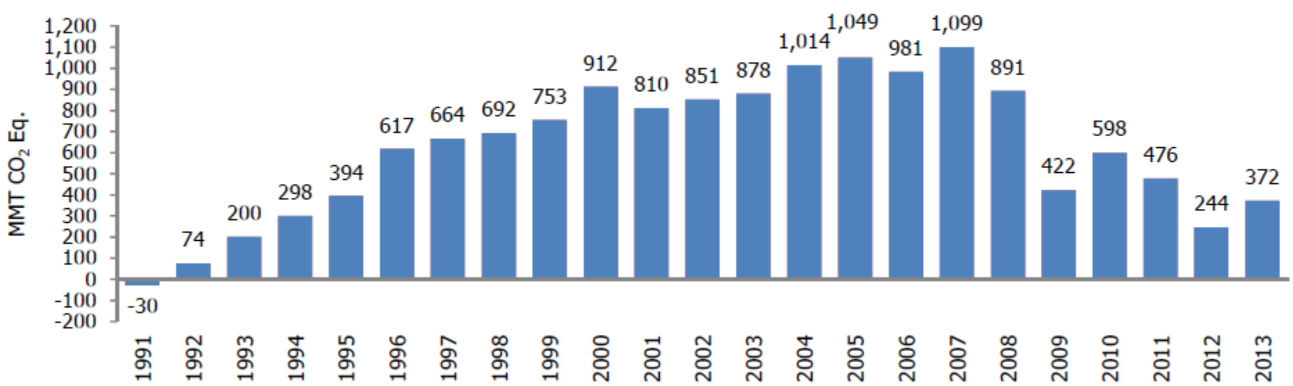


Figure 2-3: Cumulative Change in Annual U.S. Greenhouse Gas Emissions Relative to 1990

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



Overall, from 1990 to 2013, total emissions of CO_2 increased by 381.5 MMT CO_2 Eq. (7.4 percent), while total emissions of CH_4 decreased by 109.2 MMT CO_2 Eq. (14.6 percent), and total emissions of N_2O increased 25.3 MMT CO_2 Eq. (7.7 percent). During the same period, aggregate weighted emissions of HFCs, PFCs, SF_6, and NF_3 rose by 74.3 MMT CO_2 Eq. (72.9 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, SF_6, and NF_3 are significant because many of them have extremely high GWPs and, in the cases of PFCs SF_6, and NF_3, 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 13.2 percent of total emissions in 2013.

As the largest contributor to U.S. greenhouse gas emissions, carbon dioxide (CO_2) from fossil fuel combustion has accounted for approximately 77 percent of global warming potential (GWP) weighted emissions for the entire time series since 1990, from 75 percent of total GWP-weighted emissions in 1990 to 77 percent in 2013. Emissions from this source category grew by 8.8 percent (417.0 MMT CO_2 Eq.) from 1990 to 2013 and were responsible for most of the increase in national emissions during this period. From 2012 to 2013, these emissions increased by 2.6 percent (131.7 MMT 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 2009.

From 2009 to 2010, CO_2 emissions from fossil fuel combustion increased by 3.3 percent, which represents one of the largest annual increases in CO_2 emissions from fossil fuel combustion for the twenty four-year period from 1990 to 2013. This increase is primarily due to an increase in economic output from 2009 to 2010, and increased industrial production and manufacturing output (FRB 2014). Carbon dioxide emissions from fossil fuel combustion in the industrial sector increased by 6.6 percent, including increased emissions from the combustion of fuel oil, natural gas and coal. Overall, coal consumption increased by 5.8 percent, the largest annual increase in coal consumption for the twenty four-year period between 1990 and 2013. 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 by 0.4 percent and cooling degree days increased by 17.3 percent to their highest levels in the twenty one-year period from 1990 to 2010. 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 6.0 percent and 1.8 percent, respectively.

From 2010 to 2011, CO_2 emissions from fossil fuel combustion decreased by 2.5 percent. This decrease is a result of multiple factors including: (1) a decrease in the carbon intensity of fuels consumed to generate electricity due to a decrease in coal consumption, with increased natural gas consumption and a significant increase in hydropower used; (2) a decrease in transportation-related energy consumption due to higher fuel costs, improvements in fuel efficiency, and a reduction in miles traveled; and (3) relatively mild winter conditions resulting in an overall decrease in energy demand in most sectors. Changing fuel prices played a role in the decreasing emissions. A significant increase in the price of motor gasoline in the transportation sector was a major factor leading to a decrease in energy consumption by 1.2 percent. In addition, an increase in the price of coal and a concurrent decrease in natural gas prices led to a 5.7 percent decrease and a 2.5 percent increase in fuel consumption of these fuels by electric generators. This change in fuel prices also reduced the carbon intensity of fuels used to produce electricity in 2011, further contributing to the decrease in fossil fuel combustion emissions.

From 2011 to 2012, CO_2 emissions from fossil fuel combustion decreased by 3.9 percent, with emissions from fossil fuel combustion at their lowest level since 1994. This decrease from 2011 to 2012 is primarily a result of the decrease in the carbon intensity of fuels used to generate electricity due to a slight increase in the price of coal, and a significant decrease in the price of natural gas. The consumption of coal used to generate electricity decreased by 12.3 percent, while consumption of natural gas for electricity generation increased by 20.4 percent. Also, emissions declined in the transportation sector largely due to a small increase in fuel efficiency across different transportation modes and limited new demand for passenger transportation. In 2012, weather conditions remained fairly constant in the summer and were much warmer in the winter compared to 2011, as cooling degree days increased by 1.7 percent while heating degree days decreased 12.6 percent. This decrease in heating degree days resulted in a decreased demand for heating fuel in the residential and commercial sector, which had a decrease in natural gas consumption of 11.7 and 8.0 percent, respectively.

From 2012 to 2013, CO_2 emissions from fossil fuel combustion increased by 2.6 percent, this increase is primarily a result of the increased energy consumption in the residential and commercial sectors, as heating degree days increased 18.5 percent in 2013 as compared to 2012. The cooler weather led to an increase of 16.9 and 12.4 percent direct use of fuels in the residential and commercial sectors, respectively. In addition, there was an increase of 1.2 and 0.9 percent in electricity consumption in the residential and commercial sectors, respectively, due to regions that heat their homes with electricity. The consumption of natural gas used to generate electricity decreased by 10.2 percent due to an increase in the price of natural gas. Electric power plants shifted some consumption from natural gas to coal, and as a result increased coal consumption to generate electricity by 4.2 percent. Lastly, industrial production increased 2.9 percent from 2012 to 2013, resulting in an increase in the in CO_2 emissions from fossil fuel combustion from the industrial sector by 4.2 percent.

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

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

Gas/Source	1990	2005	2009	2010	2011	2012	2013
CO_2	**5,123.7**	**6,134.0**	**5,500.6**	**5,704.5**	**5,568.9**	**5,358.3**	**5,505.2**
Fossil Fuel Combustion	4,740.7	5,747.7	5,197.1	5,367.1	5,231.3	5,026.0	5,157.7
Electricity Generation	1,820.8	2,400.9	2,145.7	2,258.4	2,157.7	2,022.2	2,039.8
Transportation	1,493.8	1,887.8	1,720.3	1,732.0	1,711.5	1,700.8	1,718.4
Industrial	842.5	827.8	727.7	775.7	774.1	784.2	817.3
Residential	338.3	357.8	336.4	334.7	327.2	283.1	329.6
Commercial	217.4	223.5	223.5	220.2	221.0	197.1	220.7
U.S. Territories	27.9	49.9	43.5	46.2	39.8	38.6	32.0
Non-Energy Use of Fuels	117.7	138.9	106.0	114.6	108.4	104.9	119.8
Iron and Steel Production & Metallurgical Coke Production	99.8	66.7	43.0	55.7	60.0	54.3	52.3
Natural Gas Systems	37.6	30.0	32.2	32.3	35.6	34.8	37.8
Cement Production	33.3	45.9	29.4	31.3	32.0	35.1	36.1
Petrochemical Production	21.6	28.1	23.7	27.4	26.4	26.5	26.5
Lime Production	11.7	14.6	11.4	13.4	14.0	13.7	14.1
Ammonia Production	13.0	9.2	8.5	9.2	9.3	9.4	10.2
Incineration of Waste	8.0	12.5	11.3	11.0	10.5	10.4	10.1
Petroleum Systems	4.4	4.9	4.7	4.2	4.5	5.1	6.0
Liming of Agricultural Soils	4.7	4.3	3.7	4.8	3.9	5.8	5.9
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	3.4	4.7	4.0	4.4	4.7
Other Process Uses of Carbonates	4.9	6.3	7.6	9.6	9.3	8.0	4.4
Urea Fertilization	2.4	3.5	3.6	3.8	4.1	4.2	4.0
Aluminum Production	6.8	4.1	3.0	2.7	3.3	3.4	3.3
Soda Ash Production and Consumption	2.7	2.9	2.5	2.6	2.6	2.7	2.7
Ferroalloy Production	2.2	1.4	1.5	1.7	1.7	1.9	1.8
Titanium Dioxide Production	1.2	1.8	1.6	1.8	1.7	1.5	1.6
Zinc Production	0.6	1.0	0.9	1.2	1.3	1.5	1.4
Phosphoric Acid Production	1.6	1.4	1.0	1.1	1.2	1.1	1.2
Glass Production	1.5	1.9	1.0	1.5	1.3	1.2	1.2
Carbon Dioxide Consumption	1.5	1.4	1.8	1.2	0.8	0.8	0.9
Peatlands Remaining Peatlands	1.1	1.1	1.0	1.0	0.9	0.8	0.8
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Silicon Carbide Production and Consumption	0.4	0.2	0.1	0.2	0.2	0.2	0.2
Magnesium Production and Processing	+	+	+	+	+	+	+
Land Use, Land-Use Change, and Forestry (Sink)[a]	*(775.8)*	*(911.9)*	*(870.9)*	*(871.6)*	*(881.0)*	*(880.4)*	*(881.7)*
Wood Biomass and Ethanol Consumption[b]	*219.4*	*229.8*	*250.5*	*265.1*	*268.1*	*267.7*	*283.3*
International Bunker Fuels[c]	*103.5*	*113.1*	*106.4*	*117.0*	*111.7*	*105.8*	*99.8*
CH_4	**745.5**	**707.8**	**709.5**	**667.2**	**660.9**	**647.6**	**636.3**
Enteric Fermentation	164.2	168.9	172.7	171.1	168.7	166.3	164.5
Natural Gas Systems	179.1	176.3	168.0	159.6	159.3	154.4	157.4
Landfills	186.2	165.5	158.1	121.8	121.3	115.3	114.6
Coal Mining	96.5	64.1	79.9	82.3	71.2	66.5	64.6
Manure Management	37.2	56.3	59.7	60.9	61.4	63.7	61.4

Petroleum Systems	31.5	23.5	21.5	21.3	22.0	23.3	25.2
Wastewater Treatment	15.7	15.9	15.6	15.5	15.3	15.2	15.0
Rice Cultivation	9.2	8.9	9.4	11.1	8.5	9.3	8.3
Stationary Combustion	8.5	7.4	7.4	7.1	7.1	6.6	8.0
Abandoned Underground Coal Mines	7.2	6.6	6.4	6.6	6.4	6.2	6.2
Forest Fires	2.5	8.3	5.8	4.7	14.6	15.7	5.8
Mobile Combustion	5.6	3.0	2.3	2.3	2.3	2.2	2.1
Composting	0.4	1.9	1.9	1.8	1.9	1.9	2.0
Iron and Steel Production & Metallurgical Coke Production	1.1	0.9	0.4	0.6	0.7	0.7	0.7
Field Burning of Agricultural Residues	0.3	0.2	0.3	0.3	0.3	0.3	0.3
Petrochemical Production	0.2	0.1	+	0.1	+	0.1	0.1
Ferroalloy Production	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+
Peatlands Remaining Peatlands	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[c]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O	**329.9**	**355.9**	**356.1**	**360.1**	**371.9**	**365.6**	**355.2**
Agricultural Soil Management	224.0	243.6	264.1	264.3	265.8	266.0	263.7
Stationary Combustion	11.9	20.2	20.4	22.2	21.3	21.4	22.9
Mobile Combustion	41.2	38.1	24.6	23.7	22.5	20.2	18.4
Manure Management	13.8	16.4	17.0	17.1	17.3	17.3	17.3
Nitric Acid Production	12.1	11.3	9.6	11.5	10.9	10.5	10.7
Wastewater Treatment	3.4	4.3	4.6	4.7	4.8	4.9	4.9
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Adipic Acid Production	15.2	7.1	2.7	4.2	10.2	5.5	4.0
Forest Fires	1.7	5.5	3.8	3.1	9.6	10.3	3.8
Settlement Soils	1.4	2.3	2.2	2.4	2.5	2.5	2.4
Composting	0.3	1.7	1.7	1.6	1.7	1.7	1.8
Forest Soils	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Incineration of Waste	0.5	0.4	0.3	0.3	0.3	0.3	0.3
Semiconductor Manufacture	+	0.1	0.1	0.1	0.2	0.2	0.2
Field Burning of Agricultural Residues	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Peatlands Remaining Peatlands	+	+	+	+	+	+	+
International Bunker Fuels[c]	*0.9*	*1.0*	*0.9*	*1.0*	*1.0*	*0.9*	*0.9*
HFCs	**46.6**	**131.4**	**142.9**	**152.6**	**157.4**	**159.2**	**163.0**
Substitution of Ozone Depleting Substances[d]	0.3	111.1	136.0	144.4	148.4	153.5	158.6
HCFC-22 Production	46.1	20.0	6.8	8.0	8.8	5.5	4.1
Semiconductor Manufacture	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Magnesium Production and Processing	0.0	0.0	+	+	+	+	0.1
PFCs	24.3	6.6	3.9	4.4	6.9	6.0	5.8
Aluminum Production	21.5	3.4	1.9	1.9	3.5	2.9	3.0
Semiconductor Manufacture	2.8	3.2	2.0	2.6	3.4	3.0	2.9
SF_6	**31.1**	**14.0**	**9.3**	**9.5**	**10.0**	**7.7**	**6.9**
Electrical Transmission and Distribution	25.4	10.6	7.3	7.0	6.8	5.7	5.1
Magnesium Production and Processing	5.2	2.7	1.6	2.1	2.8	1.6	1.4
Semiconductor Manufacture	0.5	0.7	0.3	0.4	0.4	0.4	0.4
NF_3	**+**	**0.5**	**0.4**	**0.5**	**0.7**	**0.6**	**0.6**
Semiconductor Manufacture	+	0.5	0.4	0.5	0.7	0.6	0.6
Total Emissions	**6,301.1**	**7,350.2**	**6,722.7**	**6,898.8**	**6,776.6**	**6,545.1**	**6,673.0**
Total Sinks[a]	**(775.8)**	**(911.9)**	**(870.9)**	**(871.6)**	**(881.0)**	**(880.4)**	**(881.7)**

Net Emissions (Sources and Sinks)	**5,525.2**		**6,438.3**		**5,851.9**	**6,027.2**	**5,895.6**	**5,664.7**	**5,791.2**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
+ Does not exceed 0.05 MMT CO_2 Eq.
[a] Parentheses indicate negative values or sequestration. Sinks (i.e., CO_2 removals) are only included in the Net Emissions total. Refer to Table 2-8 for a breakout of emissions and removals for Land Use, Land-Use Change, and Forestry by gas and source category.
[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 (kt)

Gas/Source	1990	2005	2009	2010	2011	2012	2013
CO_2	**5,123,695**	**6,133,969**	**5,500,602**	**5,704,531**	**5,568,891**	**5,358,276**	**5,505,178**
Fossil Fuel Combustion	4,740,670	5,747,683	5,197,058	5,367,144	5,231,341	5,026,000	5,157,697
Electricity Generation	1,820,818	2,400,874	2,145,658	2,258,399	2,157,688	2,022,181	2,039,750
Transportation	1,493,758	1,887,799	1,720,314	1,731,971	1,711,538	1,700,782	1,718,406
Industrial	842,473	827,808	727,724	775,674	774,101	784,227	817,252
Residential	338,347	357,827	336,375	334,734	327,211	283,095	329,609
Commercial	217,393	223,453	223,492	220,195	221,022	197,097	220,714
U.S. Territories	27,882	49,923	43,495	46,172	39,781	38,617	31,965
Non-Energy Use of Fuels	117,658	138,877	106,018	114,554	108,359	104,917	119,850
Iron and Steel Production & Metallurgical Coke Production	99,781	66,666	43,029	55,746	60,008	54,327	52,288
Natural Gas Systems	37,645	29,995	32,201	32,334	35,551	34,764	37,808
Cement Production	33,278	45,910	29,432	31,256	32,010	35,051	36,146
Petrochemical Production	21,633	28,124	23,706	27,388	26,396	26,477	26,514
Lime Production	11,700	14,552	11,411	13,381	13,981	13,715	14,072
Ammonia Production	13,047	9,196	8,454	9,188	9,292	9,377	10,152
Incineration of Waste	7,972	12,454	11,295	11,026	10,550	10,363	10,137
Petroleum Systems	4,445	4,904	4,656	4,153	4,467	5,060	6,001
Liming of Agricultural Soils	4,667	4,349	3,669	4,784	3,871	5,776	5,925
Urea Consumption for Non-Agricultural Purposes	3,784	3,653	3,427	4,730	4,029	4,449	4,663
Other Process Uses of Carbonates	4,907	6,339	7,583	9,560	9,335	8,022	4,424
Urea Fertilization	2,417	3,504	3,555	3,778	4,099	4,225	4,011
Aluminum Production	6,831	4,142	3,009	2,722	3,292	3,439	3,255
Soda Ash Production and Consumption	2,741	2,868	2,488	2,612	2,624	2,672	2,712
Ferroalloy Production	2,152	1,392	1,469	1,663	1,735	1,903	1,785
Titanium Dioxide Production	1,195	1,755	1,648	1,769	1,729	1,528	1,608
Zinc Production	632	1,030	943	1,182	1,286	1,486	1,429
Phosphoric Acid Production	1,586	1,395	1,016	1,130	1,198	1,138	1,173
Glass Production	1,535	1,928	1,045	1,481	1,299	1,248	1,160
Carbon Dioxide Consumption	1,472	1,375	1,795	1,206	802	841	903
Peatlands Remaining Peatlands	1,055	1,101	1,024	1,022	926	812	770
Lead Production	516	553	525	542	538	527	525
Silicon Carbide Production and Consumption	375	219	145	181	170	158	169
Magnesium Production and Processing	1	3	1	1	3	2	2
Land Use, Land-Use Change, and Forestry (Sink)[a]	*(775,835)*	*(911,929)*	*(870,879)*	*(871,609)*	*(880,999)*	*(880,394)*	*(881,732)*
Wood Biomass and Ethanol Consumption[b]	*219,413*	*229,844*	*250,491*	*265,110*	*268,064*	*267,730*	*283,337*
International Bunker Fuels[c]	*103,463*	*113,139*	*106,410*	*116,992*	*111,660*	*105,805*	*99,763*
CH_4	**29,820**	**28,314**	**28,380**	**26,687**	**26,437**	**25,905**	**25,453**
Enteric Fermentation	6,566	6,755	6,908	6,844	6,750	6,653	6,581
Natural Gas Systems	7,165	7,053	6,722	6,382	6,371	6,176	6,295
Landfills	7,450	6,620	6,324	4,873	4,851	4,611	4,585
Coal Mining	3,860	2,565	3,194	3,293	2,849	2,658	2,584
Manure Management	1,486	2,254	2,388	2,437	2,457	2,548	2,456
Petroleum Systems	1,261	939	860	854	878	931	1,009
Wastewater Treatment	626	635	623	619	610	606	601
Rice Cultivation	366	358	378	444	339	372	332
Stationary Combustion	339	296	295	283	283	264	318

Abandoned Underground Coal Mines	288	264	254	263	257	249	249
Forest Fires	101	332	233	190	584	626	233
Mobile Combustion	225	121	93	92	91	88	86
Composting	15	75	75	73	75	77	79
Iron and Steel Production & Metallurgical Coke Production	46	34	17	25	28	29	28
Field Burning of Agricultural Residues	13	9	12	11	12	12	12
Petrochemical Production	9	6	2	2	2	3	3
Ferroalloy Production	1	+	+	+	+	1	+
Silicon Carbide Production and Consumption	1	+	+	+	+	+	+
Peatlands Remaining Peatlands	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[c]	*7*	*5*	*5*	*6*	*5*	*4*	*3*
N_2O	**1,107**	**1,194**	**1,195**	**1,208**	**1,248**	**1,227**	**1,192**
Agricultural Soil Management	752	817	886	887	892	892	885
Stationary Combustion	40	68	69	74	71	72	77
Mobile Combustion	138	128	82	80	76	68	62
Manure Management	46	55	57	57	58	58	58
Nitric Acid Production	41	38	32	39	37	35	36
Wastewater Treatment	11	15	16	16	16	16	17
N_2O from Product Uses	14	14	14	14	14	14	14
Adipic Acid Production	51	24	9	14	34	19	13
Forest Fires	6	18	13	11	32	35	13
Settlement Soils	5	8	8	8	8	8	8
Composting	1	6	6	5	6	6	6
Forest Soils	+	2	2	2	2	2	2
Incineration of Waste	2	1	1	1	1	1	1
Semiconductor Manufacture	+	+	+	+	1	1	1
Field Burning of Agricultural Residues	+	+	+	+	+	+	+
Peatlands Remaining Peatlands	+	+	+	+	+	+	+
International Bunker Fuels[c]	*3*	*3*	*3*	*3*	*3*	*3*	*3*
HFCs	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Substitution of Ozone Depleting Substances[d]	M	M	M	M	M	M	M
HCFC-22 Production	3	1	+	1	1	+	+
Semiconductor Manufacture	+	+	+	+	+	+	+
Magnesium Production and Processing	0	0	+	+	+	+	+
PFCs	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Aluminum Production	M	M	M	M	M	M	M
Semiconductor Manufacture	M	M	M	M	M	M	M
SF_6	**1**	**+**	**+**	**+**	**+**	**+**	**+**
Electrical Transmission and Distribution	1	+	+	+	+	+	+
Magnesium Production and Processing	+	+	+	+	+	+	+
Semiconductor Manufacture	+	+	+	+	+	+	+
NF_3	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Semiconductor Manufacture	+	+	+	+	+	+	+

+ Does not exceed 0.5 kt.
M Mixture of multiple gases
[a] Refer to Table 2-8 for a breakout of emissions and removals for Land Use, Land-Use Change, and Forestry by gas and source category.

[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. Parentheses indicate negative values or sequestration.

Emissions of all gases can be summed from each source category into a set of five sectors defined by the Intergovernmental Panel on Climate Change (IPCC). Over the twenty four-year period of 1990 to 2013, total emissions in the Energy, Industrial Processes and Product Use, and Agriculture sectors grew by 346.2 MMT CO_2 Eq. (6.5 percent), 17.0 MMT CO_2 Eq. (5.0 percent), and 67.0 MMT CO_2 Eq. (14.9 percent), respectively. Emissions from the Waste sector decreased by 67.7 MMT CO_2 Eq. (32.9 percent). Over the same period, estimates of net C sequestration for the Land Use, Land-Use Change, and Forestry sector increased by 96.4 MMT CO_2 Eq. (12.7 percent).

Figure 2-4: U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector
Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

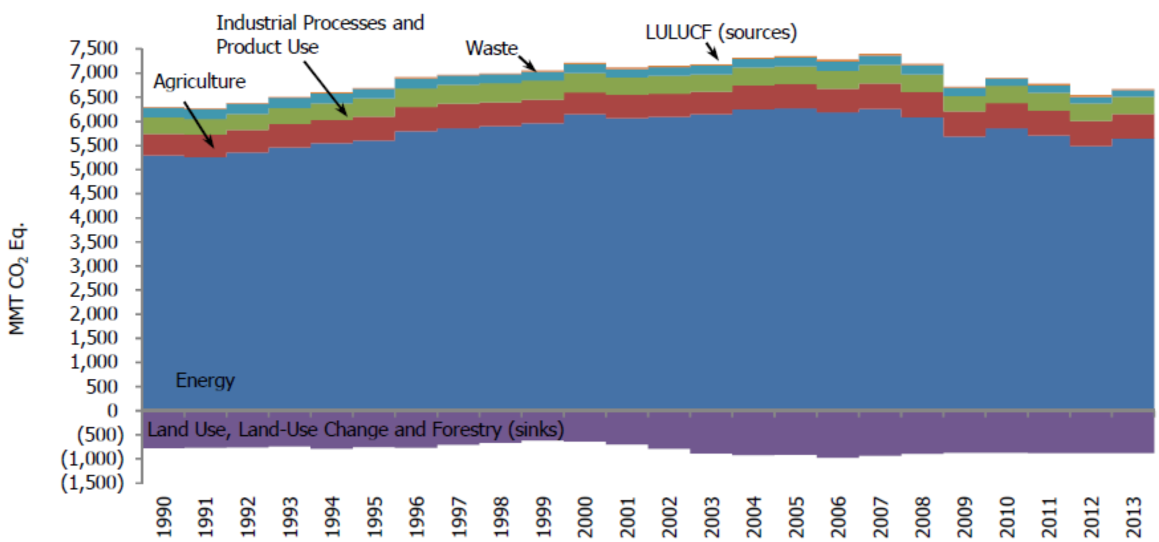


Table 2-3: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (MMT CO_2 Eq.)

Chapter/IPCC Sector	1990	2005	2009	2010	2011	2012	2013
Energy	**5,290.5**	**6,273.6**	**5,682.1**	**5,854.6**	**5,702.6**	**5,482.2**	**5,636.6**
Fossil Fuel Combustion	4,740.7	5,747.7	5,197.1	5,367.1	5,231.3	5,026.0	5,157.7
Natural Gas Systems	216.8	206.3	200.2	191.9	194.8	189.2	195.2
Non-Energy Use of Fuels	117.7	138.9	106.0	114.6	108.4	104.9	119.8
Coal Mining	96.5	64.1	79.9	82.3	71.2	66.5	64.6
Petroleum Systems	36.0	28.4	26.2	25.5	26.4	28.3	31.2
Stationary Combustion	20.4	27.6	27.8	29.3	28.4	28.0	30.8
Mobile Combustion	46.9	41.1	26.9	26.0	24.8	22.4	20.6
Incineration of Waste	8.4	12.8	11.6	11.4	10.9	10.7	10.4
Abandoned Underground Coal Mines	7.2	6.6	6.4	6.6	6.4	6.2	6.2
Industrial Processes and Product Use	**342.1**	**367.4**	**314.9**	**353.6**	**371.0**	**361.2**	**359.1**
Substitution of Ozone Depleting Substances	0.3	111.1	136.0	144.4	148.4	153.5	158.6
Iron and Steel Production & Metallurgical Coke Production	100.9	67.5	43.5	56.4	60.7	55.1	53.0

Cement Production	33.3	45.9	29.4	31.3	32.0	35.1	36.1
Petrochemical Production	21.9	28.3	23.8	27.4	26.4	26.5	26.6
Lime Production	11.7	14.6	11.4	13.4	14.0	13.7	14.1
Nitric Acid Production	12.1	11.3	9.6	11.5	10.9	10.5	10.7
Ammonia Production	13.0	9.2	8.5	9.2	9.3	9.4	10.2
Aluminum Production	28.3	7.6	4.9	4.6	6.8	6.4	6.2
Electrical Transmission and Distribution	25.4	10.6	7.3	7.0	6.8	5.7	5.1
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	3.4	4.7	4.0	4.4	4.7
Other Process Uses of Carbonates	4.9	6.3	7.6	9.6	9.3	8.0	4.4
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Semiconductor Manufacture	3.6	4.7	3.1	3.8	4.9	4.5	4.2
HCFC-22 Production	46.1	20.0	6.8	8.0	8.8	5.5	4.1
Adipic Acid Production	15.2	7.1	2.7	4.2	10.2	5.5	4.0
Soda Ash Production and Consumption	2.7	2.9	2.5	2.6	2.6	2.7	2.7
Ferroalloy Production	2.2	1.4	1.5	1.7	1.7	1.9	1.8
Titanium Dioxide Production	1.2	1.8	1.6	1.8	1.7	1.5	1.6
Magnesium Production and Processing	5.2	2.7	1.6	2.1	2.8	1.7	1.5
Zinc Production	0.6	1.0	0.9	1.2	1.3	1.5	1.4
Phosphoric Acid Production	1.6	1.4	1.0	1.1	1.2	1.1	1.2
Glass Production	1.5	1.9	1.0	1.5	1.3	1.2	1.2
Carbon Dioxide Consumption	1.5	1.4	1.8	1.2	0.8	0.8	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Silicon Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.2	0.2
Agriculture	**448.7**	**494.5**	**523.3**	**524.8**	**522.1**	**523.0**	**515.7**
Agricultural Soil Management	224.0	243.6	264.1	264.3	265.8	266.0	263.7
Enteric Fermentation	164.2	168.9	172.7	171.1	168.7	166.3	164.5
Manure Management	51.0	72.8	76.7	78.0	78.7	81.0	78.7
Rice Cultivation	9.2	8.9	9.4	11.1	8.5	9.3	8.3
Field Burning of Agricultural Residues	0.4	0.3	0.4	0.4	0.4	0.4	0.4
Land Use, Land-Use Change, and Forestry	**13.8**	**25.5**	**20.6**	**20.3**	**36.1**	**39.8**	**23.3**
Forest Fires	4.2	13.8	9.7	7.9	24.2	26.0	9.7
Liming of Agricultural Soils	4.7	4.3	3.7	4.8	3.9	5.8	5.9
Urea Fertilization	2.4	3.5	3.6	3.8	4.1	4.2	4.0
Settlement Soils	1.4	2.3	2.2	2.4	2.5	2.5	2.4
Peatlands Remaining Peatlands	1.1	1.1	1.0	1.0	0.9	0.8	0.8
Forest Soils	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Waste	**206.0**	**189.2**	**181.8**	**145.5**	**144.9**	**138.9**	**138.3**
Landfills	186.2	165.5	158.1	121.8	121.3	115.3	114.6
Wastewater Treatment	19.0	20.2	20.2	20.2	20.1	20.0	20.0
Composting	0.7	3.5	3.6	3.5	3.5	3.7	3.7
Total Emissions	**6,301.1**	**7,350.2**	**6,722.7**	**6,898.8**	**6,776.6**	**6,545.1**	**6,673.0**
Total Sinks[a]	**(775.8)**	**(911.9)**	**(870.9)**	**(871.6)**	**(881.0)**	**(880.4)**	**(881.7)**
Net Emissions (Sources and Sinks)	**5,525.2**	**6,438.3**	**5,851.9**	**6,027.2**	**5,895.6**	**5,664.7**	**5,791.2**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

[a] Sinks (i.e., CO_2 removals) are only included in the Net Emissions total. Refer to Table 2-8 for a breakout of emissions and removals for Land Use, Land-Use Change, and Forestry by gas and source category.

Note: Totals may not sum due to independent rounding. 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 2013. In 2013, approximately 82 percent of the energy consumed in the United States (on a Btu basis) was produced through the combustion of fossil fuels. The remaining 18 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 (41 percent and 12 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: 2013 Energy Chapter Greenhouse Gas Sources

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

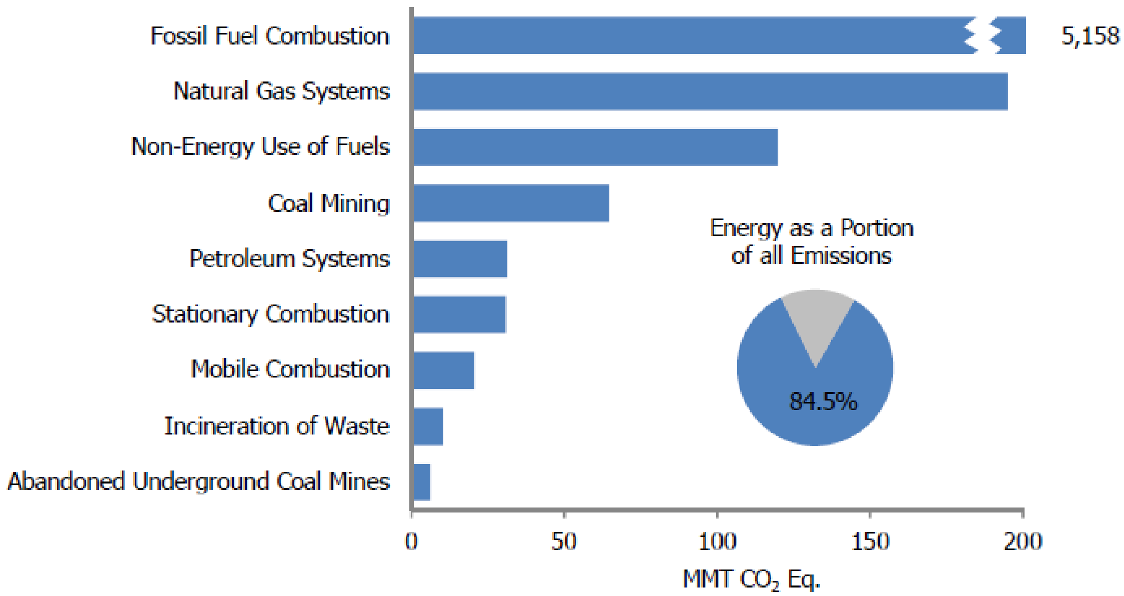


Figure 2-6: 2013 U.S. Fossil Carbon Flows (MMT CO_2 Eq.)

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

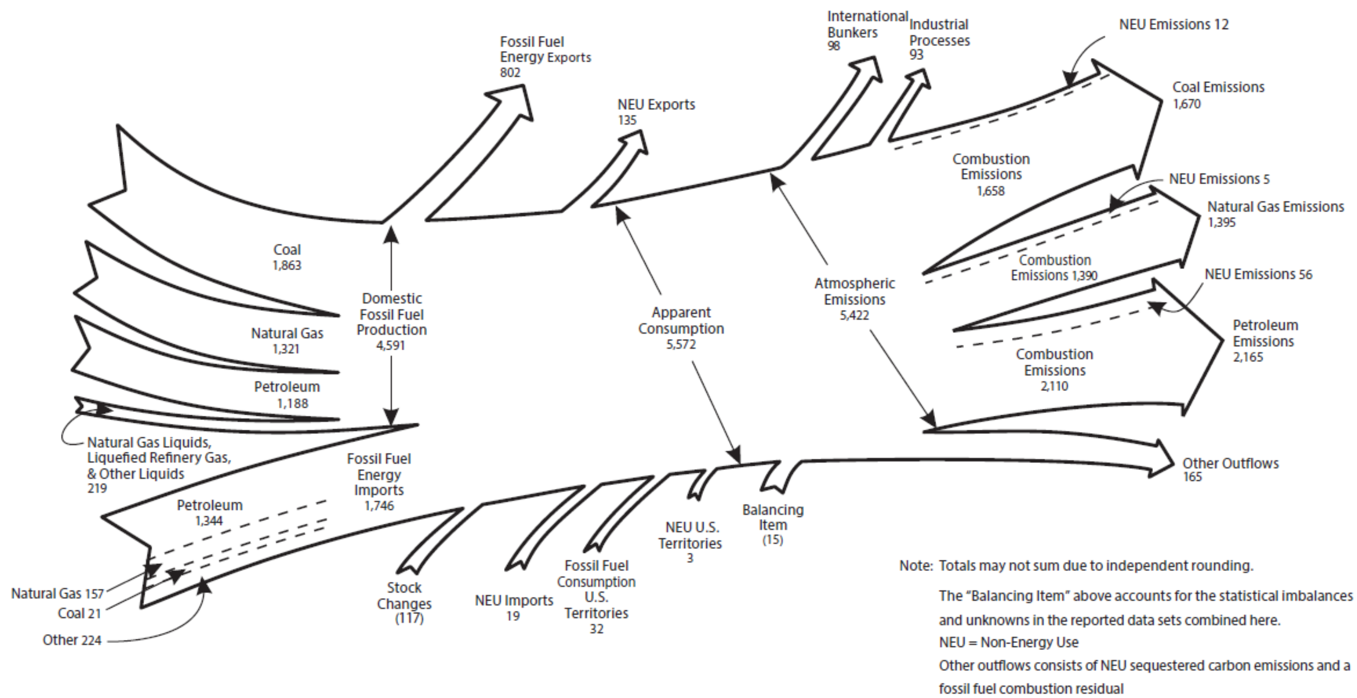


Table 2-4: Emissions from Energy (MMT CO_2 Eq.)

Gas/Source	1990	2005	2009	2010	2011	2012	2013
CO_2	**4,908.4**	**5,933.9**	**5,351.2**	**5,529.2**	**5,390.3**	**5,181.1**	**5,331.5**
Fossil Fuel Combustion	4,740.7	5,747.7	5,197.1	5,367.1	5,231.3	5,026.0	5,157.7
Electricity Generation	1,820.8	2,400.9	2,145.7	2,258.4	2,157.7	2,022.2	2,039.8
Transportation	1,493.8	1,887.8	1,720.3	1,732.0	1,711.5	1,700.8	1,718.4
Industrial	842.5	827.8	727.7	775.7	774.1	784.2	817.3
Residential	338.3	357.8	336.4	334.7	327.2	283.1	329.6
Commercial	217.4	223.5	223.5	220.2	221.0	197.1	220.7
U.S. Territories	27.9	49.9	43.5	46.2	39.8	38.6	32.0
Non-Energy Use of Fuels	117.7	138.9	106.0	114.6	108.4	104.9	119.8
Natural Gas Systems	37.6	30.0	32.2	32.3	35.6	34.8	37.8
Incineration of Waste	8.0	12.5	11.3	11.0	10.5	10.4	10.1
Petroleum Systems	4.4	4.9	4.7	4.2	4.5	5.1	6.0
Biomass - Wood[a]	*215.2*	*206.9*	*188.2*	*192.5*	*195.2*	*194.9*	*208.6*
International Bunker Fuels[b]	*103.5*	*113.1*	*106.4*	*117.0*	*111.7*	*105.8*	*99.8*
Biomass - Ethanol[a]	*4.2*	*22.9*	*62.3*	*72.6*	*72.9*	*72.8*	*74.7*
CH_4	**328.5**	**280.9**	**285.5**	**279.2**	**268.2**	**259.2**	**263.5**
Natural Gas Systems	179.1	176.3	168.0	159.6	159.3	154.4	157.4
Coal Mining	96.5	64.1	79.9	82.3	71.2	66.5	64.6
Petroleum Systems	31.5	23.5	21.5	21.3	22.0	23.3	25.2
Stationary Combustion	8.5	7.4	7.4	7.1	7.1	6.6	8.0
Abandoned Underground Coal Mines	7.2	6.6	6.4	6.6	6.4	6.2	6.2
Mobile Combustion	5.6	3.0	2.3	2.3	2.3	2.2	2.1
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O	**53.6**	**58.7**	**45.3**	**46.2**	**44.1**	**41.9**	**41.6**
Stationary Combustion	11.9	20.2	20.4	22.2	21.3	21.4	22.9
Mobile Combustion	41.2	38.1	24.6	23.7	22.5	20.2	18.4

Incineration of Waste	0.5		0.4		0.3	0.3	0.3	0.3	0.3
International Bunker Fuels[b]	*0.9*		*1.0*		*0.9*	*1.0*	*1.0*	*0.9*	*0.9*
Total	**5,290.5**		**6,273.6**		**5,682.1**	**5,854.6**	**5,702.6**	**5,482.2**	**5,636.6**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
Note: Totals may not sum due to independent rounding.
+ Does not exceed 0.05 MMT 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.

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 and Figure 2-7 summarize CO_2 emissions from fossil fuel combustion by end-use sector. Figure 2-8 further describes the total emissions from fossil fuel combustion, separated by end-use sector, including CH_4 and N_2O in addition to CO_2.

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

End-Use Sector	1990		2005		2009	2010	2011	2012	2013
Transportation	**1,496.8**		**1,892.5**		**1,724.8**	**1,736.5**	**1,715.8**	**1,704.6**	**1,722.4**
Combustion	1,493.8		1,887.8		1,720.3	1,732.0	1,711.5	1,700.8	1,718.4
Electricity	3.0		4.7		4.5	4.5	4.3	3.9	4.0
Industrial	**1,529.2**		**1,564.4**		**1,329.5**	**1,416.5**	**1,398.8**	**1,377.0**	**1,399.8**
Combustion	842.5		827.8		727.7	775.7	774.1	784.2	817.3
Electricity	686.7		736.6		601.8	640.8	624.7	592.8	582.5
Residential	**931.4**		**1,214.1**		**1,122.6**	**1,174.8**	**1,117.9**	**1,008.4**	**1,070.2**
Combustion	338.3		357.8		336.4	334.7	327.2	283.1	329.6
Electricity	593.0		856.3		786.2	840.1	790.7	725.3	740.6
Commercial	**755.4**		**1,026.7**		**976.7**	**993.2**	**959.1**	**897.4**	**933.3**
Combustion	217.4		223.5		223.5	220.2	221.0	197.1	220.7
Electricity	538.0		803.3		753.2	773.0	738.0	700.3	712.6
U.S. Territories[a]	**27.9**		**49.9**		**43.5**	**46.2**	**39.8**	**38.6**	**32.0**
Total	**4,740.7**		**5,747.7**		**5,197.1**	**5,367.1**	**5,231.3**	**5,026.0**	**5,157.7**
Electricity Generation	**1,820.8**		**2,400.9**		**2,145.7**	**2,258.4**	**2,157.7**	**2,022.2**	**2,039.8**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
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.

Figure 2-7: 2013 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

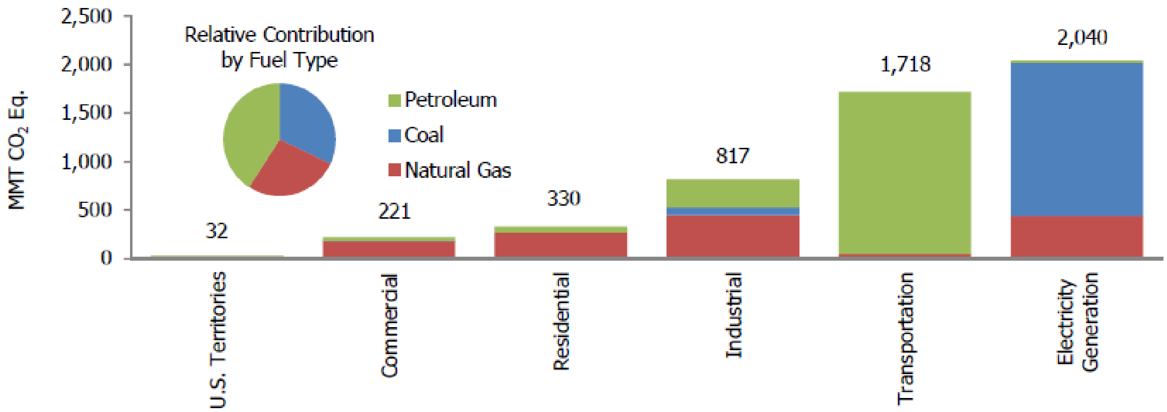
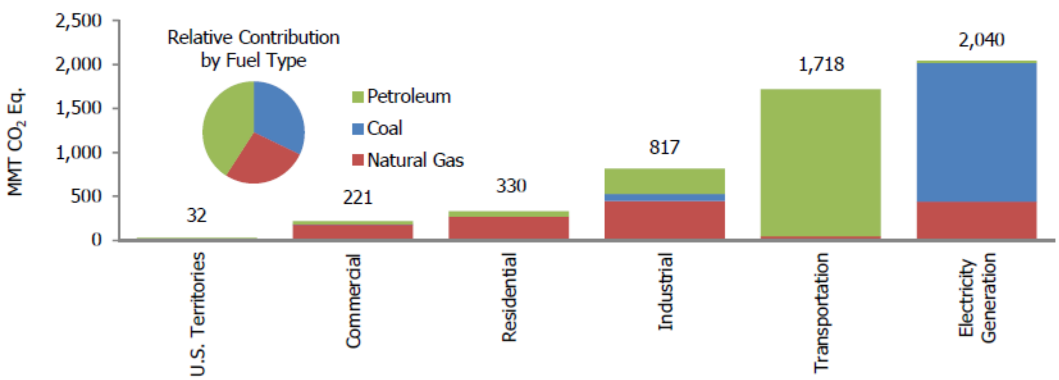


Figure 2-8: 2013 End-Use Sector Emissions of CO_2 from Fossil Fuel Combustion

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



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 34 percent of U.S. energy from fossil fuels and emitted 40 percent of the CO_2 from fossil fuel combustion in 2013. 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 1,722.4 MMT CO_2 Eq. in 2013 or approximately 33 percent of total CO_2 emissions from fossil fuel combustion. The industrial end-use sector accounted for 27 percent of CO_2 emissions from fossil fuel combustion. The residential and commercial end-use sectors accounted for 21 and 18 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 69 and 76 percent of emissions from the residential and commercial end-use sectors, respectively. Significant trends in emissions from energy source categories over the twenty four-year period from 1990 through 2013 included the following:

- Total CO_2 emissions from fossil fuel combustion increased from 4,740.7 MMT CO_2 Eq. in 1990 to 5,157.7 MMT CO_2 Eq. in 2013 – an 8.8 percent total increase over the twenty four-year period. From 2012 to 2013, these emissions increased by 131.7 MMT CO_2 Eq. (2.6 percent).
- CH_4 emissions from natural gas systems were the second largest anthropogenic source of CH_4 emissions in the United States with 157.4 MMT CO_2 Eq. emitted into the atmosphere in 2013; emissions have decreased by 21.8 MMT CO_2 Eq. (12.2 percent) since 1990.

- CO_2 emissions from non-energy use of fossil fuels increased by 2.2 MMT CO_2 Eq. (1.9 percent) from 1990 through 2013. Emissions from non-energy uses of fossil fuels were 119.8 MMT CO_2 Eq. in 2013, which constituted 2.2 percent of total national CO_2 emissions.
- N_2O emissions from stationary combustion increased by 11.0 MMT CO_2 Eq. (91.9 percent) from 1990 through 2013. 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.
- CO_2 emissions from incineration of waste (10.1 MMT CO_2 Eq. in 2013) increased by 2.2 MMT CO_2 Eq. (27.2 percent) from 1990 through 2013, as the volume of plastics and other fossil carbon-containing materials in municipal solid waste grew.

The increase in CO_2 emissions from fossil fuel combustion in 2013 was a result of multiple factors including: (1) the increase in the price of natural gas led to an increase of coal-fired generation in the electric power sector; (2) much colder winter conditions resulted in an increased demand for heating fuel in the residential and commercial sectors; (3) an increase in industrial production across multiple sectors which resulted in increases in industrial sector emissions,[1] and (4) an increase in transportation emissions resulting from a small increase in vehicle miles traveled (VMT) and fuel use across on-road transportation modes.

Industrial Processes and Product Use

The Industrial Processes and Product Use (IPPU) chapter includes greenhouse gas emissions occurring from industrial processes and from the use of greenhouse gases in products. This section includes sources of emissions formerly represented in the “Industrial Processes” and “Solvent and Other Product Use” sectors in prior versions of this report.

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, other process uses of carbonates (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, zinc production, and N_2O from product uses (see Figure 2-9). Industrial processes also release HFCs, PFCs, SF_6, and NF_3. In addition to their use as ODS substitutes, HFCs, PFCs, SF_6, NF_3, 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.

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[1] Further details on industrial sector combustion emissions are provided by EPA’s GHGRP (http://ghgdata.epa.gov/ghgp/main.do).

Figure 2-9: 2013 Industrial Processes and Product Use Chapter Greenhouse Gas Sources

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

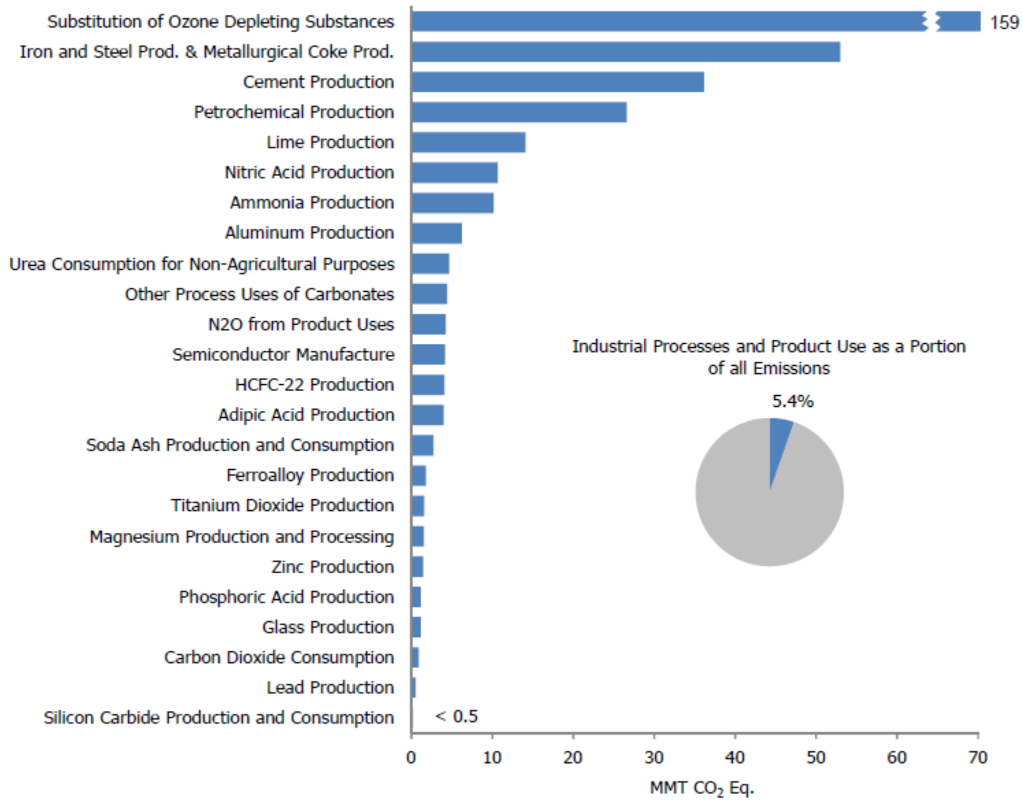

Table 2-6: Emissions from Industrial Processes and Product Use (MMT CO_2 Eq.)

Gas/Source	1990	2005	2009	2010	2011	2012	2013
CO_2	**207.2**	**191.1**	**141.1**	**165.7**	**169.7**	**166.4**	**163.0**
Iron and Steel Production & Metallurgical Coke Production	99.8	66.7	43.0	55.7	60.0	54.3	52.3
Iron and Steel Production	*97.3*	*64.6*	*42.1*	*53.7*	*58.6*	*53.8*	*50.5*
Metallurgical Coke Production	*2.5*	*2.0*	*1.0*	*2.1*	*1.4*	*0.5*	*1.8*
Cement Production	33.3	45.9	29.4	31.3	32.0	35.1	36.1
Petrochemical Production	21.6	28.1	23.7	27.4	26.4	26.5	26.5
Lime Production	11.7	14.6	11.4	13.4	14.0	13.7	14.1
Ammonia Production	13.0	9.2	8.5	9.2	9.3	9.4	10.2
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	3.4	4.7	4.0	4.4	4.7
Other Process Uses of Carbonates	4.9	6.3	7.6	9.6	9.3	8.0	4.4
Aluminum Production	6.8	4.1	3.0	2.7	3.3	3.4	3.3
Soda Ash Production and Consumption	2.7	2.9	2.5	2.6	2.6	2.7	2.7
Ferroalloy Production	2.2	1.4	1.5	1.7	1.7	1.9	1.8
Titanium Dioxide Production	1.2	1.8	1.6	1.8	1.7	1.5	1.6
Zinc Production	0.6	1.0	0.9	1.2	1.3	1.5	1.4
Phosphoric Acid Production	1.6	1.4	1.0	1.1	1.2	1.1	1.2
Glass Production	1.5	1.9	1.0	1.5	1.3	1.2	1.2
Carbon Dioxide Consumption	1.5	1.4	1.8	1.2	0.8	0.8	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Silicon Carbide Production and Consumption	0.4	0.2	0.1	0.2	0.2	0.2	0.2
Magnesium Production and Processing	+	+	+	+	+	+	+
CH_4	**1.4**	**1.0**	**0.5**	**0.7**	**0.8**	**0.8**	**0.8**

Iron and Steel Production & Metallurgical Coke Production	1.1	0.9	0.4	0.6	0.7	0.7	0.7
Iron and Steel Production	*1.1*	*0.9*	*0.4*	*0.6*	*0.7*	*0.7*	*0.7*
Metallurgical Coke Production	+	+	+	+	+	+	+
Petrochemical Production	0.2	0.1	+	0.1	+	0.1	0.1
Ferroalloy Production	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+
N_2O	**31.6**	**22.8**	**16.7**	**20.1**	**25.5**	**20.4**	**19.1**
Nitric Acid Production	12.1	11.3	9.6	11.5	10.9	10.5	10.7
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Adipic Acid Production	15.2	7.1	2.7	4.2	10.2	5.5	4.0
Semiconductor Manufacturing	+	0.1	0.1	0.1	0.2	0.2	0.2
HFCs	**46.6**	**131.4**	**142.9**	**152.6**	**157.4**	**159.2**	**163.0**
Substitution of Ozone Depleting Substances[a]	0.3	111.1	136.0	144.4	148.4	153.5	158.6
HCFC-22 Production	46.1	20.0	6.8	8.0	8.8	5.5	4.1
Semiconductor Manufacturing	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Magnesium Production and Processing	0	+	+	+	+	+	0.1
PFCs	**24.3**	**6.6**	**3.9**	**4.4**	**6.9**	**6.0**	**5.8**
Aluminum Production	21.5	3.4	1.9	1.9	3.5	2.9	3.0
Semiconductor Manufacturing	2.8	3.2	2.0	2.6	3.4	3.0	2.9
SF_6	**31.1**	**14.0**	**9.3**	**9.5**	**10.0**	**7.7**	**6.9**
Electrical Transmission and Distribution	25.4	10.6	7.3	7.0	6.8	5.7	5.1
Magnesium Production and Processing	5.2	2.7	1.6	2.1	2.8	1.6	1.4
Semiconductor Manufacturing	0.5	0.7	0.3	0.4	0.4	0.4	0.4
NF_3	**+**	**0.5**	**0.4**	**0.5**	**0.7**	**0.6**	**0.6**
Semiconductor Manufacturing	+	0.5	0.4	0.5	0.7	0.6	0.6
Total	**342.1**	**367.4**	**314.9**	**353.6**	**371.0**	**361.2**	**359.1**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
+ Does not exceed 0.05 MMT 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 IPPU sector increased by 5.0 percent from 1990 to 2013. Significant trends in emissions from IPPU source categories over the twenty four-year period from 1990 through 2013 included the following:

- HFC emissions from ODS substitutes have been increasing from small amounts in 1990 to 158.6 MMT CO_2 Eq. in 2013. This increase was in large part the result of 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 continue over the next decade as HCFCs, which are interim substitutes in many applications, are themselves phased-out under the provisions of the Copenhagen Amendments to the *Montreal Protocol*.
- Combined CO_2 and CH_4 emissions from iron and steel production and metallurgical coke production decreased by 3.8 percent to 53.0 MMT CO_2 Eq. from 2012 to 2013, and have declined overall by 47.9 MMT CO_2 Eq. (47.5 percent) from 1990 through 2013, due to restructuring of the industry, technological improvements, and increased scrap steel utilization.
- CO_2 emissions from ammonia production (10.2 MMT CO_2 Eq. in 2013) decreased by 2.9 MMT CO_2 Eq. (22.2 percent) since 1990. Ammonia production relies on natural gas as both a feedstock and a fuel, and as such, market fluctuations and volatility in natural gas prices affect the production of ammonia.
- Urea consumption for non-agricultural purposes (4.7 MMT CO_2 Eq. in 2013) increased by 0.9 MMT CO_2 Eq. (23.2 percent) since 1990.
- In 2013, N_2O emissions from product uses constituted 1.2 percent of U.S. N_2O emissions. From 1990 to 2013, emissions from this source category decreased by 0.4 percent, though slight increases occurred in intermediate years.

- N_2O emissions from adipic acid production were 4.0 MMT CO_2 Eq. in 2013, and have decreased significantly since 1990 due to both the widespread installation of pollution control measures in the late 1990s and plant idling in the late 2000s. Emissions from adipic acid production have decreased by 73.8 percent since 1990 and by 76.4 percent since a peak in 1995.
- PFC emissions from aluminum production decreased by 86.2 percent (18.5 MMT CO_2 Eq.) from 1990 to 2013, due to both industry emission reduction efforts and lower domestic aluminum production.

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 2013, agricultural activities were responsible for emissions of 515.7 MMT CO_2 Eq., or 7.7 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 25.9 percent and 9.6 percent of total CH_4 emissions from anthropogenic activities, respectively, in 2013. Agricultural soil management activities, such as fertilizer use and other cropping practices, were the largest source of U.S. N_2O emissions in 2013, accounting for 74.2 percent.

Figure 2-10: 2013 Agriculture Chapter Greenhouse Gas Sources

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

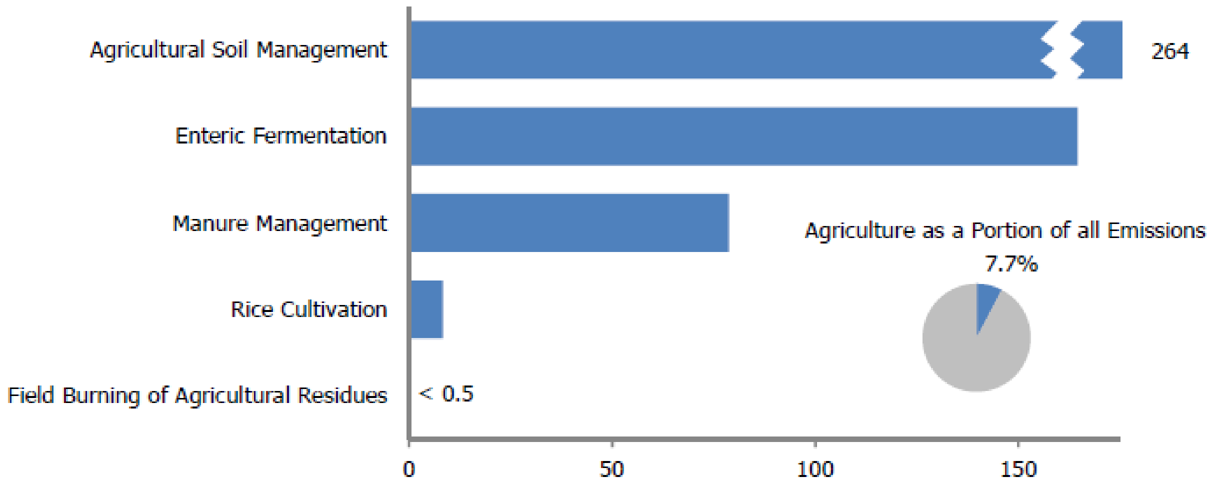

Table 2-7: Emissions from Agriculture (MMT CO_2 Eq.)

Gas/Source	1990	2005	2009	2010	2011	2012	2013
CH_4	**210.8**	**234.4**	**242.1**	**243.4**	**238.9**	**239.6**	**234.5**
Enteric Fermentation	164.2	168.9	172.7	171.1	168.7	166.3	164.5
Manure Management	37.2	56.3	59.7	60.9	61.4	63.7	61.4
Rice Cultivation	9.2	8.9	9.4	11.1	8.5	9.3	8.3
Field Burning of Agricultural Residues	0.3	0.2	0.3	0.3	0.3	0.3	0.3
N_2O	**237.9**	**260.1**	**281.2**	**281.4**	**283.2**	**283.4**	**281.1**
Agricultural Soil Management	224.0	243.6	264.1	264.3	265.8	266.0	263.7
Manure Management	13.8	16.4	17.0	17.1	17.3	17.3	17.3
Field Burning of Agricultural Residues	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**448.7**	**494.5**	**523.3**	**524.8**	**522.1**	**523.0**	**515.7**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
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 74.2 percent of N_2O emissions in the United States in 2013. Estimated emissions from this source in 2013 were 263.7 MMT CO_2 Eq. Annual N_2O emissions from agricultural soils fluctuated between 1990 and 2013, although overall emissions were 17.7 percent higher in 2013 than in 1990. Year-to-year fluctuations are largely a reflection of annual variation in weather patterns, synthetic fertilizer use, and crop production.
- Enteric fermentation is the largest anthropogenic source of CH_4 emissions in the United States. In 2013, enteric fermentation CH_4 emissions were 164.5 MMT CO_2 Eq. (25.9 percent of total CH_4 emissions), which represents an increase of 0.4 MMT CO_2 Eq. (0.2 percent) since 1990. This increase in emissions from 1990 to 2013 in enteric generally follows the increasing trends in cattle populations. From 1990 to 1995 emissions increased and then generally decreased from 1996 to 2004, mainly due to fluctuations in beef cattle populations and increased digestibility of feed for feedlot cattle. Emissions increased from 2005 to 2007, as both dairy and beef populations underwent increases and the literature for dairy cow diets indicated a trend toward a decrease in feed digestibility for those years. Emissions decreased again from 2008 to 2013 as beef cattle populations again decreased.
- Overall, emissions from manure management increased 54.4 percent between 1990 and 2013. This encompassed an increase of 65.2 percent for CH_4, from 37.2 MMT CO_2 Eq. in 1990 to 61.4 MMT CO_2 Eq. in 2013; and an increase of 25.4 percent for N_2O, from 13.8 MMT CO_2 Eq. in 1990 to 17.3 MMT CO_2 Eq. in 2013. The majority of the increase observed in CH_4 resulted from swine and dairy cow manure, where emissions increased 48 and 115 percent, respectively, from 1990 to 2013. From 2012 to 2013, there was a 3.6 percent decrease in total CH_4 emissions from manure management, mainly due to minor shifts in the animal populations and the resultant effects on manure management system allocations.

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 a net removal of CO_2 (sequestration of C) in the United States. Forests (including vegetation, soils, and harvested wood) accounted for approximately 88 percent of total 2013 CO_2 removals, urban trees accounted for 10 percent, mineral and organic soil carbon stock changes accounted for less than 0.5 percent, and landfilled yard trimmings and food scraps accounted for 1.4 percent of total CO_2 removals in 2013. 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 2.4 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 2013 resulted in a C sequestration (i.e., total sinks) of 881.7 MMT CO_2 Eq. (Table 2-3).[2] This represents an offset of approximately 13.2 percent of total (i.e., gross) greenhouse gas emissions in 2013. Emissions from land use, land-use change and forestry activities in 2013 represent 0.3 percent of total greenhouse gas emissions.[3] Between 1990 and 2013, total land use, land-use change, and forestry C sequestration increased by 13.6 percent, 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.

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[2] The total sinks value includes the positive C sequestration reported for *Forest Land Remaining Forest Land, Cropland Remaining Cropland, Land Converted to Grassland, Settlements Remaining Settlements,* and *Other Land* plus the loss in C sequestration reported for *Land Converted to Cropland* and *Grassland Remaining Grassland*.

[3] The emissions value includes the CO_2, CH_4, and N_2O emissions reported for *Forest Fires, Forest Soils, Liming of Agricultural Soils, Urea Fertilization, Settlement Soils,* and *Peatlands Remaining Peatlands*.

CO_2 removals are presented in Table 2-8 along with CO_2, CH_4, and N_2O emissions for Land Use, Land-Use Change, and Forestry source categories. Liming of agricultural soils and urea fertilization resulted in CO_2 emissions of 9.9 MMT CO_2 Eq. in 2013, an increase of about 40.3 percent relative to 1990. Lands undergoing peat extraction (i.e., *Peatlands Remaining Peatlands*) resulted in CO_2 emissions of 0.8 MMT CO_2 Eq. and CH_4 and N_2O emissions of less than 0.05 MMT CO_2 Eq. each. N_2O emissions from the application of synthetic fertilizers to forest soils have increased from 0.1 MMT CO_2 Eq. in 1990 to 0.5 MMT CO_2 Eq. in 2013. Settlement soils in 2013 resulted in N_2O emissions of 2.4 MMT CO_2 Eq., a 76.7 percent increase relative to 1990. Emissions from forest fires in 2013 resulted in CH_4 emissions of 5.8 MMT CO_2 and in N_2O emissions of 3.8 MMT CO_2 (see Table 2-8).

Table 2-8: Emissions and Removals (Flux) from Land Use, Land-Use Change, and Forestry (MMT CO_2 Eq.)

Gas/Land-Use Category	1990	2005	2009	2010	2011	2012	2013
CO_2	**(767.7)**	**(903.0)**	**(862.6)**	**(862.0)**	**(872.1)**	**(869.6)**	**(871.0)**
Forest Land Remaining Forest Land: Changes in Forest Carbon Stock[a]	(639.4)	(807.1)	(764.9)	(765.4)	(773.8)	(773.1)	(775.7)
Cropland Remaining Cropland: Changes in Agricultural Soil Carbon Stock	(65.2)	(28.0)	(27.5)	(25.9)	(25.8)	(25.0)	(23.4)
Cropland Remaining Cropland: Liming of Agricultural Soils	4.7	4.3	3.7	4.8	3.9	5.8	5.9
Cropland Remaining Cropland: Urea Fertilization	2.4	3.5	3.6	3.8	4.1	4.2	4.0
Land Converted to Cropland	24.5	19.8	16.2	16.2	16.2	16.1	16.1
Grassland Remaining Grassland	(1.9)	4.2	11.7	11.7	11.7	11.5	12.1
Land Converted to Grassland	(7.4)	(9.0)	(8.9)	(8.9)	(8.9)	(8.8)	(8.8)
Settlements Remaining Settlements: Changes in Urban Tree Carbon Stock[b]	(60.4)	(80.5)	(85.0)	(86.1)	(87.3)	(88.4)	(89.5)
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	1.0	1.1	1.0	1.0	0.9	0.8	0.8
Other: Landfilled Yard Trimmings and Food Scraps	(24.2)	(12.0)	(12.9)	(13.6)	(13.5)	(13.0)	(12.8)
CH_4	**2.5**	**8.3**	**5.8**	**4.8**	**14.6**	**15.7**	**5.8**
Forest Land Remaining Forest Land: Forest Fires	2.5	8.3	5.8	4.7	14.6	15.7	5.8
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
N_2O	**3.1**	**8.3**	**6.5**	**6.0**	**12.6**	**13.3**	**6.7**
Forest Land Remaining Forest Land: Forest Fires	1.7	5.5	3.8	3.1	9.6	10.3	3.8
Forest Land Remaining Forest Land: Forest Soils[c]	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Settlements Remaining Settlements: Settlement Soils[d]	1.4	2.3	2.2	2.4	2.5	2.5	2.4
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
Total Flux [e]	**(762.1)**	**(886.4)**	**(850.2)**	**(851.3)**	**(844.9)**	**(840.6)**	**(858.5)**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
+ Less than 0.05 MMT CO_2 Eq.
[a] Estimates include C stock changes on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.
[b] Estimates include C stock changes on both *Settlements Remaining Settlements* and *Land Converted to Settlements*.
[c] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land*, and *Land Converted to Forest Land*, but not from land-use conversion.
[d] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements*, and *Land Converted to Settlements*, but not from land-use conversion.

[e] "Total Flux" is defined as the sum of positive emissions (i.e., sources) of greenhouse gases to the atmosphere plus removals of CO_2 (i.e., sinks or negative emissions) from the atmosphere.
Note: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Other significant trends from 1990 to 2013 in emissions from land use, land-use change, and forestry source categories include:

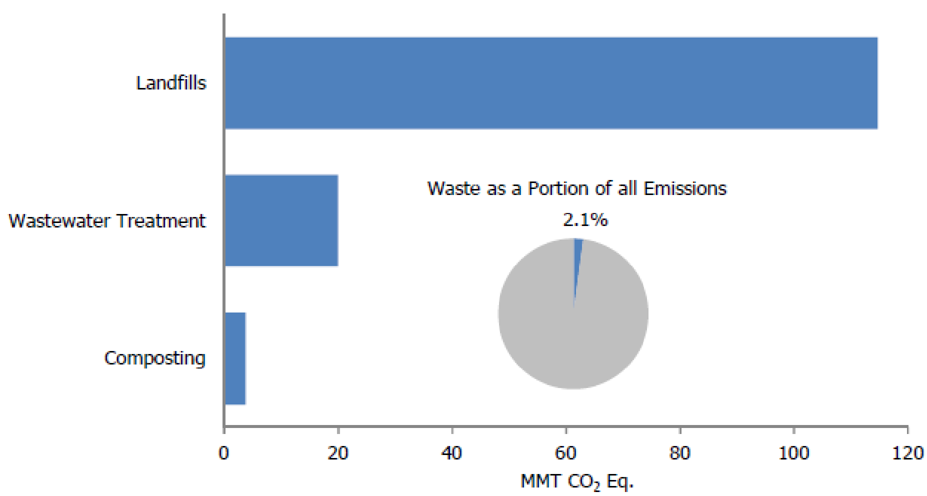
- Annual C sequestration by forest land (i.e., annual carbon stock accumulation in the five carbon pools) has increased by approximately 21 percent. This is primarily due to increased forest management and the effects of previous reforestation. The increase in intensive forest management resulted in 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 twenty four-years, although only at an average rate of 0.1 percent per year.
- Annual C sequestration by urban trees has increased by 48.1 percent over the period from 1990 to 2013. 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 51.6 percent since 1990. Food scrap generation has grown by 53 percent since 1990, and though the proportion of food scraps discarded in landfills has decreased slightly from 82 percent in 1990 to 78 percent in 2013, the tonnage disposed in landfills has increased considerably (by 46 percent). Overall, the decrease in the landfill disposal rate of yard trimmings has more than compensated for the increase in food scrap disposal in landfills.

Waste

Waste management and treatment activities are sources of greenhouse gas emissions (see Figure 2-11). In 2013, landfills were the third largest source of U.S. anthropogenic CH_4 emissions, accounting for 18.0 percent of total U.S. CH_4 emissions.[4] Additionally, wastewater treatment accounts for 14.4 percent of Waste emissions, 2.4 percent of U.S. CH_4 emissions, and 1.4 percent of N_2O emissions. Emissions of CH_4 and N_2O from composting grew from 1990 to 2013, and resulted in emissions of 3.7 MMT CO_2 Eq. in 2013. A summary of greenhouse gas emissions from the Waste chapter is presented in Table 2-9.

Figure 2-11: 2013 Waste Chapter Greenhouse Gas Sources

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



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

Overall, in 2013, waste activities generated emissions of 138.3 MMT CO_2 Eq., or 2.1 percent of total U.S. greenhouse gas emissions.

Table 2-9: Emissions from Waste (MMT CO_2 Eq.)

Gas/Source	1990	2005	2009	2010	2011	2012	2013
CH_4	**202.3**	**183.2**	**175.5**	**139.1**	**138.4**	**132.4**	**131.6**
Landfills	186.2	165.5	158.1	121.8	121.3	115.3	114.6
Wastewater Treatment	15.7	15.9	15.6	15.5	15.3	15.2	15.0
Composting	0.4	1.9	1.9	1.8	1.9	1.9	2.0
N_2O	**3.7**	**6.0**	**6.3**	**6.4**	**6.5**	**6.6**	**6.7**
Wastewater Treatment	3.4	4.3	4.6	4.7	4.8	4.9	4.9
Composting	0.3	1.7	1.7	1.6	1.7	1.7	1.8
Total	**206.0**	**189.2**	**181.8**	**145.5**	**144.9**	**138.9**	**138.3**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
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 2013, net CH_4 emissions from landfills decreased by 71.6 MMT CO_2 Eq. (38.4 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 as well as reduction in the amount of decomposable materials (i.e., paper and paperboard, food scraps, and yard trimmings) discarded in MSW landfills over the time series,[5] 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 MMT CO_2 Eq. to 3.7 MMT CO_2 Eq. in 2013, which represents slightly more than a five-fold increase over the time series. The growth in composting since the 1990s is attributable to primarily two factors: (1) steady growth in population and residential housing, and (2) the enactment of legislation by state and local governments that discouraged the disposal of yard trimmings in landfills.
- From 1990 to 2013, CH_4 and N_2O emissions from wastewater treatment decreased by 0.6 MMT CO_2 Eq. (4.0 percent) and increased by 1.6 MMT CO_2 Eq. (46.5 percent), respectively. Methane emissions from domestic wastewater treatment have decreased since 1999 due to decreasing percentages of wastewater being treated in anaerobic systems, including reduced use of on-site septic systems and central anaerobic treatment systems. Nitrous oxide emissions from wastewater treatment processes gradually increased across the time series as a result of increasing U.S. population and protein consumption.

2.1 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 (31 percent) of U.S. greenhouse gas emissions in 2013. Transportation activities, in aggregate, accounted for the second largest portion (27 percent). Emissions from industry accounted for about 21 percent of U.S. greenhouse gas emissions in

[5] 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.

2013. 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 21 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 6 percent, and primarily consisted of CO_2 emissions from fossil fuel combustion. Activities related to agriculture accounted for roughly 9 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. Carbon dioxide 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 2-10 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 2013.

Figure 2-12: Emissions Allocated to Economic Sectors

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

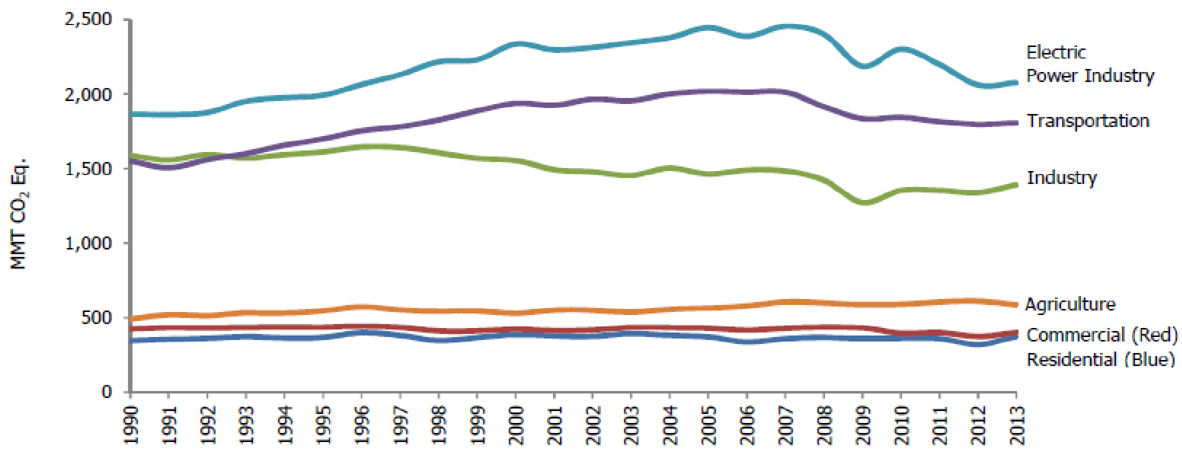


Table 2-10: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (MMT CO_2 Eq. and Percent of Total in 2013)

Sector/Source	1990	2005	2009	2010	2011	2012	2013	Percent[a]
Electric Power Industry	**1,864.8**	**2,443.9**	**2,185.7**	**2,300.5**	**2,198.1**	**2,060.8**	**2,077.0**	**31.1%**
CO_2 from Fossil Fuel Combustion	1,820.8	2,400.9	2,145.7	2,258.4	2,157.7	2,022.2	2,039.8	30.6%
Stationary Combustion	7.7	16.5	17.2	18.9	18.0	18.2	19.5	0.3%
Incineration of Waste	8.4	12.8	11.6	11.4	10.9	10.7	10.4	0.2%
Electrical Transmission and Distribution	25.4	10.6	7.3	7.0	6.8	5.7	5.1	0.1%
Other Process Uses of Carbonates	2.5	3.2	3.8	4.8	4.7	4.0	2.2	+
Transportation	**1,551.3**	**2,017.7**	**1,835.3**	**1,843.5**	**1,815.4**	**1,795.9**	**1,806.2**	**27.1%**
CO_2 from Fossil Fuel Combustion	1,493.8	1,887.8	1,720.3	1,732.0	1,711.5	1,700.8	1,718.4	25.8%
Substitution of Ozone Depleting Substances	+	80.4	81.4	77.9	72.0	66.3	60.5	0.9%
Mobile Combustion	45.7	39.4	25.1	24.1	22.9	20.5	18.6	0.3%
Non-Energy Use of Fuels	11.8	10.2	8.5	9.5	9.0	8.3	8.8	0.1%
Industry	**1,587.7**	**1,462.8**	**1,272.5**	**1,353.3**	**1,353.0**	**1,338.9**	**1,392.1**	**20.9%**
CO_2 from Fossil Fuel Combustion	811.4	781.0	681.2	728.2	724.9	733.5	767.6	11.5%
Natural Gas Systems	216.8	206.3	200.2	191.9	194.8	189.2	195.2	2.9%
Non-Energy Use of Fuels	100.1	120.6	93.5	100.9	95.8	93.3	108.4	1.6%

Coal Mining	96.5	64.1	79.9	82.3	71.2	66.5	64.6	1.0%
Iron and Steel Production	100.9	67.5	43.5	56.4	60.7	55.1	53.0	0.8%
Cement Production	33.3	45.9	29.4	31.3	32.0	35.1	36.1	0.5%
Petroleum Systems	36.0	28.4	26.2	25.5	26.4	28.3	31.2	0.5%
Petrochemical Production	21.9	28.3	23.8	27.4	26.4	26.5	26.6	0.4%
Substitution of Ozone Depleting Substances	+	7.3	12.4	15.3	17.0	18.7	20.4	0.3%
Lime Production	11.7	14.6	11.4	13.4	14.0	13.7	14.1	0.2%
Nitric Acid Production	12.1	11.3	9.6	11.5	10.9	10.5	10.7	0.2%
Ammonia Production	13.0	9.2	8.5	9.2	9.3	9.4	10.2	0.2%
Abandoned Underground Coal Mines	7.2	6.6	6.4	6.6	6.4	6.2	6.2	0.1%
Aluminum Production	28.3	7.6	4.9	4.6	6.8	6.4	6.2	0.1%
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	3.4	4.7	4.0	4.4	4.7	0.1%
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2	0.1%
Semiconductor Manufacture	3.6	4.7	3.1	3.8	4.9	4.5	4.2	0.1%
HCFC-22 Production	46.1	20.0	6.8	8.0	8.8	5.5	4.1	0.1%
Adipic Acid Production	15.2	7.1	2.7	4.2	10.2	5.5	4.0	0.1%
Stationary Combustion	4.9	4.6	3.6	3.9	3.9	3.9	3.9	0.1%
Soda Ash Production and Consumption	2.7	2.9	2.5	2.6	2.6	2.7	2.7	+
Other Process Uses of Carbonates	2.5	3.2	3.8	4.8	4.7	4.0	2.2	+
Ferroalloy Production	2.2	1.4	1.5	1.7	1.7	1.9	1.8	+
Titanium Dioxide Production	1.2	1.8	1.6	1.8	1.7	1.5	1.6	+
Magnesium Production and Processing	5.2	2.7	1.6	2.1	2.8	1.7	1.5	+
Mobile Combustion	0.9	1.3	1.3	1.4	1.4	1.4	1.5	+
Zinc Production	0.6	1.0	0.9	1.2	1.3	1.5	1.4	+
Phosphoric Acid Production	1.6	1.4	1.0	1.1	1.2	1.1	1.2	+
Glass Production	1.5	1.9	1.0	1.5	1.3	1.2	1.2	+
Carbon Dioxide Consumption	1.5	1.4	1.8	1.2	0.8	0.8	0.9	+
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5	+
Silicon Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.2	0.2	+
Agriculture	**492.5**	**565.0**	**588.8**	**590.8**	**605.5**	**611.6**	**586.8**	**8.8%**
N_2O from Agricultural Soil Management	224.0	243.6	264.1	264.3	265.8	266.0	263.7	4.0%
Enteric Fermentation	164.2	168.9	172.7	171.1	168.7	166.3	164.5	2.5%
Manure Management	51.0	72.8	76.7	78.0	78.7	81.0	78.7	1.2%
CO_2 from Fossil Fuel Combustion	31.0	46.8	46.5	47.5	49.2	50.7	49.7	0.7%
CH_4 and N_2O from Forest Fires	4.2	13.8	9.7	7.9	24.2	26.0	9.7	0.1%
Rice Cultivation	9.2	8.9	9.4	11.1	8.5	9.3	8.3	0.1%
Liming of Agricultural Soils	4.7	4.3	3.7	4.8	3.9	5.8	5.9	0.1%
Urea Fertilization	2.4	3.5	3.6	3.8	4.1	4.2	4.0	0.1%
CO_2, CH_4 and N_2O from Managed Peatlands	1.1	1.1	1.0	1.0	0.9	0.8	0.8	+
Mobile Combustion	0.3	0.5	0.5	0.5	0.5	0.6	0.5	+
Field Burning of Agricultural Residues	0.4	0.3	0.4	0.4	0.4	0.4	0.4	+
N_2O from Forest Soils	0.1	0.5	0.5	0.5	0.5	0.5	0.5	+
Stationary Combustion	+	+	+	+	+	+	+	+
Commercial	**424.8**	**429.8**	**431.9**	**396.4**	**400.7**	**374.3**	**401.1**	**6.0%**
CO_2 from Fossil Fuel Combustion	217.4	223.5	223.5	220.2	221.0	197.1	220.7	3.3%
Landfills	186.2	165.5	158.1	121.8	121.3	115.3	114.6	1.7%
Substitution of Ozone Depleting Substances	+	15.7	25.2	29.3	33.4	37.1	40.8	0.6%
Wastewater Treatment	15.7	15.9	15.6	15.5	15.3	15.2	15.0	0.2%
Human Sewage	3.4	4.3	4.6	4.7	4.8	4.9	4.9	0.1%
Composting	0.7	3.5	3.6	3.5	3.5	3.7	3.7	0.1%
Stationary Combustion	1.4	1.4	1.4	1.4	1.4	1.2	1.3	+
Residential	**346.3**	**372.8**	**360.9**	**363.7**	**360.5**	**321.5**	**375.0**	**5.6%**
CO_2 from Fossil Fuel Combustion	338.3	357.8	336.4	334.7	327.2	283.1	329.6	4.9%

	1990	2005	2009	2010	2011	2012	2013	
Substitution of Ozone Depleting Substances	0.3	7.7	17.0	21.8	25.9	31.4	37.0	0.6%
Stationary Combustion	6.3	4.9	5.3	4.8	4.9	4.5	5.9	0.1%
Settlement Soil Fertilization	1.4	2.3	2.2	2.4	2.5	2.5	2.4	+
U.S. Territories	**33.7**	**58.2**	**47.6**	**50.6**	**43.5**	**42.1**	**34.8**	**0.5%**
CO_2 from Fossil Fuel Combustion	27.9	49.9	43.5	46.2	39.8	38.6	32.0	0.5%
Non-Energy Use of Fuels	5.7	8.1	3.9	4.2	3.6	3.3	2.7	+
Stationary Combustion	0.1	0.2	0.2	0.2	0.2	0.2	0.1	+
Total Emissions	**6,301.1**	**7,350.2**	**6,722.7**	**6,898.8**	**6,776.6**	**6,545.1**	**6,673.0**	**100.0%**
Sinks	**(775.8)**	**(911.9)**	**(870.9)**	**(871.6)**	**(881.0)**	**(880.4)**	**(881.7)**	**-13.2%**
CO_2 Flux from Forests[b]	(639.4)	(807.1)	(764.9)	(765.4)	(773.8)	(773.1)	(775.7)	-11.6%
Urban Trees	(60.4)	(80.5)	(85.0)	(86.1)	(87.3)	(88.4)	(89.5)	-1.3%
Landfilled Yard Trimmings and Food Scraps	(26.0)	(11.4)	(12.5)	(13.2)	(13.2)	(12.8)	(12.6)	-0.2%
CO_2 Flux from Agricultural Soil Carbon Stocks	(50.0)	(13.0)	(8.5)	(6.9)	(6.7)	(6.1)	(4.0)	-0.1%
Net Emissions	**5,525.2**	**6,438.3**	**5,851.9**	**6,027.2**	**5,895.6**	**5,664.7**	**5,791.2**	**86.8%**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

Note: Includes all emissions of CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3. Parentheses indicate negative values or sequestration. Totals may not sum due to independent rounding.

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

[a] Percent of total emissions for year 2013.

[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 31 percent of total U.S. greenhouse gas emissions in 2013. Emissions increased by 11 percent since 1990, as electricity demand grew and fossil fuels remained the dominant energy source for generation. Electricity generation-related emissions increased from 2012 to 2013 by 0.8 percent, primarily due to increased CO_2 emissions from fossil fuel combustion. Electricity sales to the residential and commercial end-use sectors in 2013 increased approximately 1.2 percent and 0.9 percent, respectively. The trend in the residential and commercial sectors can largely be attributed to colder more energy-intensive winter conditions compared to 2012. Electricity sales to the industrial sector in 2013 decreased by approximately 3.1 percent. Overall, in 2013, the amount of electricity generated (in kWh) decreased by 0.1 percent from the previous year. Despite the decrease in generation, CO_2 emissions from the electric power sector increased by 0.8 percent as the consumption of CO_2 intensive coal and petroleum for electricity generation increased by 4.2 percent and 18.8 percent, respectively, in 2013 and the consumption of natural gas for electricity generation, decreased by 10.2 percent. Table 2-11 provides a detailed summary of emissions from electricity generation-related activities.

Table 2-11: Electricity Generation-Related Greenhouse Gas Emissions (MMT CO_2 Eq.)

Gas/Fuel Type or Source	1990	2005	2009	2010	2011	2012	2013
CO_2	**1,831.2**	**2,416.5**	**2,160.7**	**2,274.2**	**2,172.9**	**2,036.6**	**2,052.1**
Fossil Fuel Combustion	1,820.8	2,400.9	2,145.7	2,258.4	2,157.7	2,022.2	2,039.8
Coal	*1,547.6*	*1,983.8*	*1,740.9*	*1,827.6*	*1,722.7*	*1,511.2*	*1,575.0*
Natural Gas	*175.3*	*318.8*	*372.2*	*399.0*	*408.8*	*492.2*	*441.9*
Petroleum	*97.5*	*97.9*	*32.2*	*31.4*	*25.8*	*18.3*	*22.4*
Geothermal	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*
Incineration of Waste	8.0	12.5	11.3	11.0	10.5	10.4	10.1
Other Process Uses of Carbonates	2.5	3.2	3.8	4.8	4.7	4.0	2.2
CH_4	**0.3**	**0.5**	**0.4**	**0.5**	**0.4**	**0.4**	**0.4**

Stationary Combustion[a]	0.3	0.5	0.4	0.5	0.4	0.4	0.4
Incineration of Waste	+	+	+	+	+	+	+
N_2O	**7.8**	**16.4**	**17.1**	**18.8**	**17.9**	**18.1**	**19.4**
Stationary Combustion[a]	7.4	16.0	16.8	18.5	17.6	17.8	19.1
Incineration of Waste	0.5	0.4	0.3	0.3	0.3	0.3	0.3
SF_6	**25.4**	**10.6**	**7.3**	**7.0**	**6.8**	**5.7**	**5.1**
Electrical Transmission and Distribution	25.4	10.6	7.3	7.0	6.8	5.7	5.1
Total	**1,864.8**	**2,443.9**	**2,185.7**	**2,300.5**	**2,198.1**	**2,060.8**	**2,077.0**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
Note: Totals may not sum due to independent rounding.
[a] Includes only stationary combustion emissions related to the generation of electricity.
+ Does not exceed 0.05 MMT CO_2 Eq.

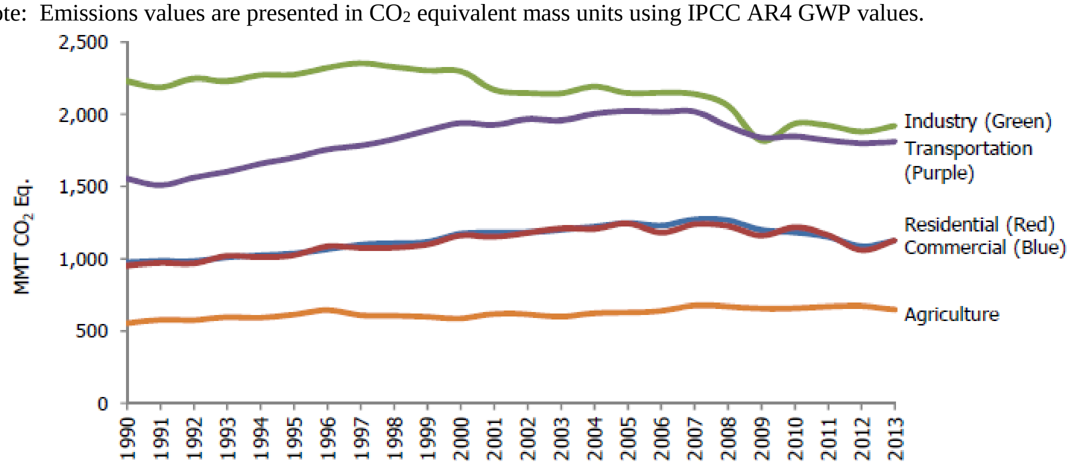
To distribute electricity emissions among economic end-use sectors, emissions from the source categories assigned to the electricity generation sector were allocated to the residential, commercial, industry, transportation, and agriculture economic sectors according to each economic sector's share of retail sales of electricity consumption (EIA 2015, Duffield 2006). These source categories include CO_2 from Fossil Fuel Combustion, CH_4 and N_2O from Stationary Combustion, Incineration of Waste, Other Process Uses of Carbonates, and SF_6 from Electrical Transmission and Distribution Systems. Note that only 50 percent of the Other Process Uses of Carbonates emissions were associated with electricity generation and distributed as described; the remainder of Other Process Uses of Carbonates emissions were attributed to the industrial processes economic end-use sector.[6]

When emissions from electricity are distributed among these sectors, industrial activities account for the largest share of total U.S. greenhouse gas emissions (28.8 percent), followed closely by emissions from transportation (27.1 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 2-12 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 2013.

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

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



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

Table 2-12: U.S. Greenhouse Gas Emissions by Economic Sector and Gas with Electricity-Related Emissions Distributed (MMT CO_2 Eq.) and Percent of Total in 2013

Sector/Gas	1990	2005	2009	2010	2011	2012	2013	Percent[a]
Industry	**2,229.7**	**2,148.5**	**1,817.7**	**1,937.7**	**1,923.9**	**1,880.9**	**1,922.6**	**28.8%**
Direct Emissions	**1,587.7**	**1,462.8**	**1,272.5**	**1,353.3**	**1,353.0**	**1,338.9**	**1,392.1**	**20.9%**
CO_2	1,158.3	1,124.5	948.9	1,026.5	1,025.7	1,029.0	1,080.6	16.2%
CH_4	317.7	273.4	277.8	272.2	261.3	252.9	255.9	3.8%
N_2O	35.3	26.6	19.9	23.6	28.9	23.8	22.5	0.3%
HFCs, PFCs, SF_6, and NF_3	76.3	38.3	25.8	31.1	37.0	33.3	33.1	0.5%
Electricity-Related	**642.0**	**685.7**	**545.2**	**584.4**	**571.0**	**542.0**	**530.5**	**8.0%**
CO_2	630.4	678.0	539.0	577.7	564.4	535.6	524.2	7.9%
CH_4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	+
N_2O	2.7	4.6	4.3	4.8	4.7	4.8	5.0	0.1%
SF_6	8.7	3.0	1.8	1.8	1.8	1.5	1.3	+
Transportation	**1,554.4**	**2,022.5**	**1,839.9**	**1,848.1**	**1,819.7**	**1,799.8**	**1,810.3**	**27.1%**
Direct Emissions	**1,551.3**	**2,017.7**	**1,835.3**	**1,843.5**	**1,815.4**	**1,795.9**	**1,806.2**	**27.1%**
CO_2	1,505.6	1,898.0	1,728.9	1,741.5	1,720.5	1,709.1	1,727.2	25.9%
CH_4	5.4	2.7	2.0	1.9	1.9	1.8	1.7	+
N_2O	40.26	36.70	23.12	22.20	20.98	18.68	16.84	0.3%
HFCs[b]	+	80.4	81.4	77.9	72.0	66.3	60.5	0.9%
Electricity-Related	**3.1**	**4.8**	**4.6**	**4.6**	**4.3**	**3.9**	**4.1**	**0.1%**
CO_2	3.1	4.8	4.5	4.5	4.3	3.9	4.0	0.1%
CH_4	+	+	+	+	+	+	+	+
N_2O	+	+	+	+	+	+	+	+
SF_6	+	+	+	+	+	+	+	+
Commercial	**975.8**	**1,247.5**	**1,199.2**	**1,183.8**	**1,152.6**	**1,088.0**	**1,126.7**	**16.9%**
Direct Emissions	**424.8**	**429.8**	**431.9**	**396.4**	**400.7**	**374.3**	**401.1**	**6.0%**
CO_2	217.4	223.5	223.5	220.2	221.0	197.1	220.7	3.3%
CH_4	203.3	184.3	176.6	140.2	139.4	133.3	132.7	2.0%
N_2O	4.1	6.3	6.6	6.7	6.8	6.8	7.0	0.1%
HFCs	+	15.7	25.2	29.3	33.4	37.1	40.8	0.6%
Electricity-Related	**551.0**	**817.7**	**767.2**	**787.4**	**751.9**	**713.6**	**725.6**	**10.9%**
CO_2	541.1	808.5	758.5	778.4	743.3	705.2	716.9	10.7%
CH_4	0.1	0.2	0.2	0.2	0.1	0.1	0.1	+
N_2O	2.3	5.5	6.0	6.4	6.1	6.3	6.8	0.1%
SF_6	7.5	3.5	2.6	2.4	2.3	2.0	1.8	+
Residential	**953.6**	**1,244.4**	**1,161.8**	**1,219.5**	**1,166.0**	**1,060.6**	**1,129.1**	**16.9%**
Direct Emissions	**346.3**	**372.8**	**360.9**	**363.7**	**360.5**	**321.5**	**375.0**	5.6%
CO_2	338.3	357.8	336.4	334.7	327.2	283.1	329.6	4.9%
CH_4	5.2	4.1	4.4	4.0	4.0	3.7	5.0	0.1%
N_2O	2.4	3.2	3.2	3.2	3.3	3.3	3.4	0.1%
HFCs	0.3	7.7	17.0	21.8	25.9	31.4	37.0	0.6%
Electricity-Related	**607.3**	**871.6**	**800.9**	**855.8**	**805.5**	**739.1**	**754.2**	**11.3%**
CO_2	596.4	861.9	791.7	846.0	796.3	730.4	745.1	11.2%
CH_4	0.1	0.2	0.2	0.2	0.2	0.2	0.2	+
N_2O	2.5	5.8	6.3	7.0	6.6	6.5	7.1	0.1%
SF_6	8.3	3.8	2.7	2.6	2.5	2.0	1.9	+
Agriculture	**553.9**	**629.1**	**656.6**	**659.2**	**670.9**	**673.7**	**649.4**	**9.7%**
Direct Emissions	**492.5**	**565.0**	**588.8**	**590.8**	**605.5**	**611.6**	**586.8**	**8.8%**
CO_2	39.2	55.7	54.8	57.1	58.1	61.5	60.4	0.9%
CH_4	213.4	242.9	248.2	248.4	253.7	255.5	240.6	3.6%
N_2O	239.9	266.4	285.9	285.4	293.6	294.6	285.8	4.3%
Electricity-Related	**61.3**	**64.1**	**67.8**	**68.4**	**65.4**	**62.1**	**62.6**	**0.9%**
CO_2	60.2	63.4	67.0	67.6	64.7	61.4	61.9	0.9%
CH_4	+	+	+	+	+	+	+	+
N_2O	0.3	0.4	0.5	0.6	0.5	0.5	0.6	+
SF_6	0.8	0.3	0.2	0.2	0.2	0.2	0.2	+

U.S. Territories	**33.7**	**58.2**	**47.6**	**50.6**	**43.5**	**42.1**	**34.8**	**0.5%**
Total	**6,301.1**	**7,350.2**	**6,722.7**	**6,898.8**	**6,776.6**	**6,545.1**	**6,673.0**	**100.0%**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

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 MMT CO_2 Eq. or 0.05 percent.

[a] Percent of total emissions for year 2013.

[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 byproduct 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, SF_6, and NF_3 byproduct 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. 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 2013. The largest sources of transportation greenhouse gases in 2013 were passenger cars (42.2 percent), freight trucks (22.5 percent), light duty trucks, which include sport utility vehicles, pickup trucks, and minivans (17.9 percent), commercial aircraft (6.4 percent), rail (2.6 percent), pipelines (2.6 percent), and ships and boats (2.2 percent). These figures include direct CO_2, CH_4, and N_2O emissions from fossil fuel combustion used in transportation and emissions from non-energy use (i.e., lubricants) used in transportation, as well as HFC emissions from mobile air conditioners and refrigerated transport allocated to these vehicle types.

In terms of the overall trend, from 1990 to 2013, total transportation emissions rose by 16.5 percent due, in large part, to increased demand for travel as fleetwide light-duty vehicle fuel economy was relatively stable (average new vehicle fuel economy declined slowly from 1990 through 2004 and then increased more rapidly from 2005 through 2013). The number of vehicle miles traveled by light-duty motor vehicles (passenger cars and light-duty trucks) increased 35 percent from 1990 to 2013, as a result of a confluence of factors including population growth, economic growth, urban sprawl, and low fuel prices during the beginning of this period. The decline in new light-duty vehicle fuel economy between 1990 and 2004 reflected the increasing market share of light-duty trucks, which grew from about 30 percent of new vehicle sales in 1990 to 48 percent in 2004. Starting in 2005, the rate of VMT growth slowed considerably (and declined rapidly in 2008) while average new vehicle fuel economy began to increase. Average new vehicle fuel economy has improved almost every year since 2005, and the truck share has decreased to about 37 percent of new vehicles in MY 2013 (EPA 2014). Between 2012 and 2013, VMT increased by only 0.6 percent. Table 2-13 provides a detailed summary of greenhouse gas emissions from transportation-related activities with electricity-related emissions included in the totals.

From 2008 to 2009, CO_2 emissions from the transportation end-use sector declined 4.2 percent. The decrease in emissions could 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. From 2009 to 2013, CO_2 emissions from the transportation end-use sector stabilized even as economic activity rebounded slightly.

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 15 percent from 1990 to 2013. This rise in CO_2 emissions, combined with an increase in HFCs from close to zero emissions in 1990 to 60.5 MMT CO_2 Eq. in 2013, led to an increase in overall emissions from transportation activities of 16 percent.

Table 2-13: Transportation-Related Greenhouse Gas Emissions (MMT CO_2 Eq.)

Gas/Vehicle	1990	2005	2009	2010	2011	2012	2013
Passenger Cars	**656.7**	**711.2**	**792.9**	**783.6**	**774.3**	**768.0**	**763.3**
CO_2	629.3	660.1	748.0	742.0	736.9	735.6	735.5
CH_4	3.2	1.4	1.2	1.2	1.2	1.1	1.1
N_2O	24.1	18.0	13.8	12.9	12.3	10.7	9.4
HFCs	+	31.7	29.9	27.5	23.9	20.6	17.3
Light-Duty Trucks	**335.6**	**553.3**	**351.6**	**349.0**	**332.1**	**326.2**	**323.4**
CO_2	321.1	504.3	310.2	308.9	295.0	292.0	292.4
CH_4	1.7	0.9	0.4	0.4	0.4	0.4	0.3
N_2O	12.8	14.8	5.8	5.5	5.1	4.4	3.9
HFCs	+	33.3	35.2	34.2	31.7	29.3	26.7
Medium- and Heavy-Duty Trucks	**231.1**	**409.8**	**389.6**	**403.0**	**401.3**	**401.4**	**407.7**
CO_2	230.1	395.9	375.1	388.4	386.8	386.8	393.2
CH_4	0.3	0.1	0.1	0.1	0.1	0.1	0.1
N_2O	0.7	1.1	1.2	1.2	1.1	1.1	1.1
HFCs	+	12.7	13.2	13.2	13.3	13.3	13.3
Buses	**8.4**	**12.1**	**16.2**	**15.9**	**16.9**	**18.0**	**18.3**
CO_2	8.4	11.8	15.6	15.4	16.4	17.4	17.7
CH_4	+	+	+	+	+	+	+
N_2O	+	+	0.1	0.1	0.1	0.1	0.1
HFCs	+	0.3	0.4	0.4	0.4	0.4	0.4
Motorcycles	**1.8**	**1.7**	**4.2**	**3.7**	**3.6**	**4.2**	**4.0**
CO_2	1.7	1.6	4.1	3.6	3.6	4.1	3.9
CH_4	+	+	+	+	+	+	+
N_2O	+	+	+	+	+	+	+
Commercial Aircraft[a]	**110.9**	**133.9**	**120.6**	**114.3**	**115.6**	**114.3**	**115.4**
CO_2	109.9	132.7	119.5	113.3	114.6	113.3	114.3
CH_4	+	+	+	+	+	+	+
N_2O	1.0	1.2	1.1	1.0	1.1	1.0	1.1
Other Aircraft[b]	**78.3**	**59.6**	**36.8**	**40.4**	**34.2**	**32.1**	**34.7**
CO_2	77.5	59.1	36.4	40.1	33.9	31.8	34.4
CH_4	0.1	0.1	+	+	+	+	+
N_2O	0.7	0.5	0.3	0.4	0.3	0.3	0.3
Ships and Boats[c]	**44.9**	**45.2**	**38.9**	**45.0**	**46.7**	**40.4**	**39.6**
CO_2	44.3	44.5	38.4	44.2	45.8	39.6	38.9
CH_4	+	+	+	+	+	+	+
N_2O	0.6	0.6	0.5	0.8	0.8	0.7	0.7
HFCs	+	+	+	+	+	+	+
Rail	**39.0**	**53.3**	**43.7**	**46.5**	**48.1**	**46.8**	**47.5**
CO_2	38.5	50.3	40.7	43.4	45.0	43.7	44.4
CH_4	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N_2O	0.3	0.4	0.3	0.3	0.3	0.3	0.3
HFCs	+	2.5	2.6	2.6	2.6	2.6	2.6
Other Emissions from Electricity Generation[d]	0.1	0.1	+	+	+	+	+
Pipelines[e]	**36.0**	**32.2**	**36.7**	**37.1**	**37.8**	**40.3**	**47.7**
CO_2	36.0	32.2	36.7	37.1	37.8	40.3	47.7
Lubricants	**11.8**	**10.2**	**8.5**	**9.5**	**9.0**	**8.3**	**8.8**

CO_2	11.8	10.2	8.5	9.5	9.0	8.3	8.8
Total Transportation	**1,554.4**	**2,022.5**	**1,839.9**	**1,848.1**	**1,819.7**	**1,799.8**	**1,810.3**
International Bunker Fuels[f]	*104.5*	*114.2*	*107.5*	*118.1*	*112.8*	*106.8*	*100.7*

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

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 8,500 lbs; medium- and heavy-duty trucks include vehicles larger than 8,500 lbs. HFC emissions primarily reflect HFC-134a.

\+ Does not exceed 0.05 MMT 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 issues with data sources.

[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 Other Process Uses of Carbonates (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 U.S. 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 decreasing 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 2013, agricultural soil management was the largest source of N_2O emissions, and enteric fermentation was the 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 is less reliant on electricity than the other sectors.

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 Other Process Uses of Carbonates (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 Substances 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 Substances 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 Other Process Uses of Carbonates (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 Substances 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 Substances 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.

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 2013; (4) emissions per unit of total gross domestic product as a measure of national economic activity; or (5) emissions per capita.

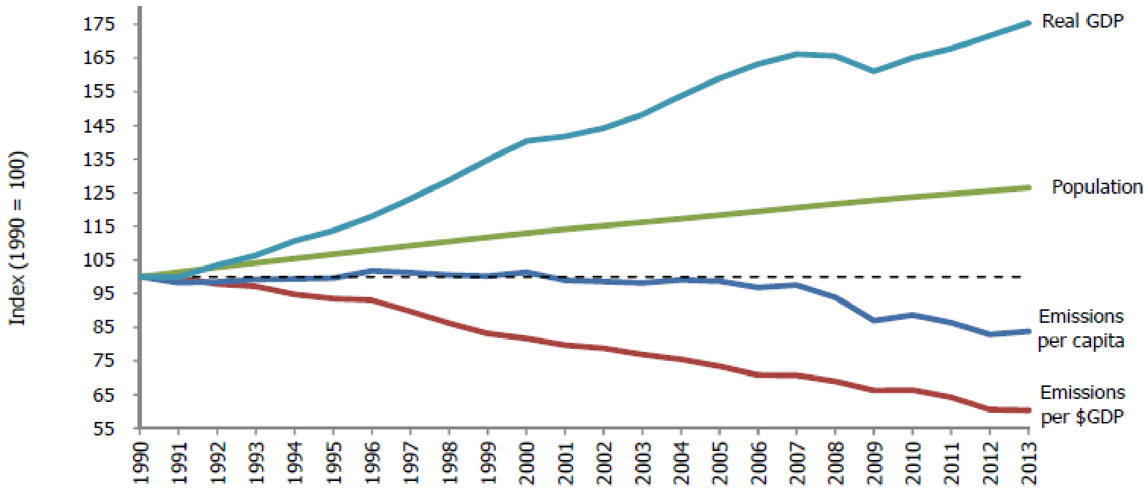
Table 2-14 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. Greenhouse gas emissions in the United States have grown at an average annual rate of 0.3 percent since 1990. Since 1990, this rate is slightly slower than that for total energy and for fossil fuel consumption, and much slower than that for electricity consumption, overall gross domestic product and national population (see Table 2-14).

Table 2-14: Recent Trends in Various U.S. Data (Index 1990 = 100)

Chapter/IPCC Sector	1990	2005	2009	2010	2011	2012	2013	Growth[a]
Greenhouse Gas Emissions [b]	100	117	107	109	108	104	106	0.3%
Energy Consumption [c]	100	118	112	116	115	112	115	0.6%
Fossil Fuel Consumption [c]	100	119	108	112	110	107	110	0.4%
Electricity Consumption [c]	100	134	131	137	137	135	135	1.3%
GDP [d]	100	159	161	165	168	172	175	2.5%
Population [e]	100	118	123	124	125	125	126	1.0%

[a] Average annual growth rate
[b] GWP-weighted values
[c] Energy-content-weighted values (EIA 2015)
[d] Gross Domestic Product in chained 2009 dollars (BEA 2014)
[e] U.S. Census Bureau (2014)

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



Source: BEA (2014), U.S. Census Bureau (2014), and emission estimates in this report.

2.2 Indirect Greenhouse Gas Emissions (CO, NO_x, NMVOCs, and SO_2)

The reporting requirements of the UNFCCC[7] 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. 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.

[7] See < http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf#page=2>.

Since 1970, the United States has published estimates of emissions of CO, NO_x, NMVOCs, and SO_2 (EPA 2015),[8] which are regulated under the Clean Air Act. Table 2-15 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 2-15: Emissions of NO_x, CO, NMVOCs, and SO_2 (kt)

Gas/Activity	1990	2005	2009	2010	2011	2012	2013
NO_x	**21,771**	**17,394**	**13,450**	**12,607**	**12,630**	**11,912**	**11,167**
Mobile Fossil Fuel Combustion	10,862	10,295	7,797	7,290	7,294	6,788	6,283
Stationary Fossil Fuel Combustion	10,023	5,858	4,452	4,092	3,807	3,567	3,579
Oil and Gas Activities	139	321	468	545	622	622	622
Industrial Processes and Product Use	592	572	493	472	452	452	452
Forest Fires	64	212	149	121	373	400	149
Waste Combustion	82	128	81	77	73	73	73
Agricultural Burning	8	6	8	8	8	8	8
Waste	+	2	1	1	1	1	1
CO	**132,337**	**74,283**	**51,716**	**50,996**	**58,868**	**58,022**	**47,265**
Mobile Fossil Fuel Combustion	119,360	58,615	39,256	39,475	38,305	36,491	34,676
Forest Fires	2,300	7,550	5,313	4,323	13,291	14,262	5,310
Stationary Fossil Fuel Combustion	5,000	4,648	4,036	4,103	4,170	4,170	4,170
Industrial Processes and Product Use	4,129	1,557	1,331	1,280	1,229	1,229	1,229
Waste Combustion	978	1,403	1,164	1,084	1,003	1,003	1,003
Oil and Gas Activities	302	318	363	487	610	610	610
Agricultural Burning	268	184	247	241	255	253	262
Waste	1	7	5	5	5	5	5
NMVOCs	**20,930**	**13,154**	**11,586**	**11,641**	**11,726**	**11,416**	**11,107**
Mobile Fossil Fuel Combustion	10,932	5,724	4,650	4,591	4,562	4,252	3,942
Industrial Processes and Product Use	7,638	5,849	4,337	4,133	3,929	3,929	3,929
Oil and Gas Activities	554	510	1,894	2,205	2,517	2,517	2,517
Stationary Fossil Fuel Combustion	912	716	553	576	599	599	599
Waste Combustion	222	241	103	92	81	81	81
Waste	673	114	49	44	38	38	38
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA
SO_2	**20,935**	**13,196**	**8,246**	**7,015**	**5,877**	**4,711**	**4,625**
Stationary Fossil Fuel Combustion	18,407	11,541	7,228	6,120	5,008	3,859	3,790
Industrial Processes and Product Use	1,307	831	654	618	605	605	605
Oil and Gas Activities	390	180	126	117	108	108	108
Mobile Fossil Fuel Combustion	793	619	220	144	142	125	108
Waste Combustion	38	25	17	16	15	15	15
Waste	+	1	1	+	+	+	+
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA

Source: (EPA 2015) 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 kt.

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)

[8] NO_x and CO emission estimates from Field Burning of Agricultural Residues were estimated separately, and therefore not taken from EPA (2015).

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 64.4 percent in 2013. 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.

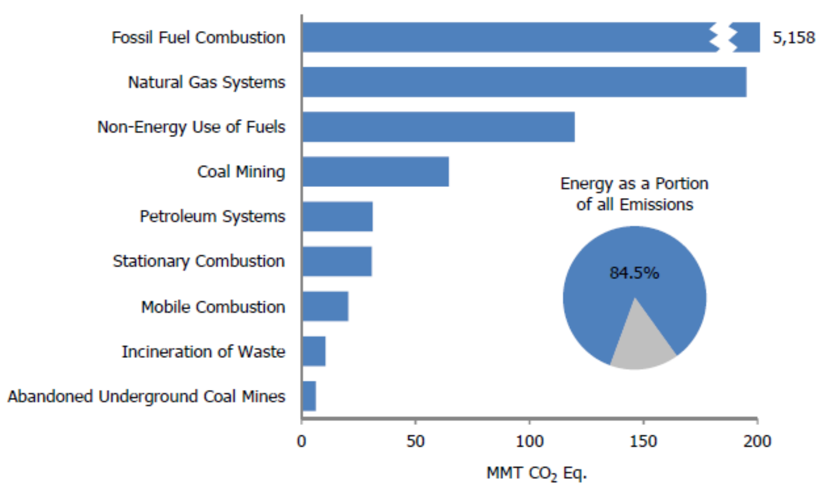
3. Energy

Energy-related activities were the primary sources of U.S. anthropogenic greenhouse gas emissions, accounting for 84.5 percent of total greenhouse gas emissions on a carbon dioxide (CO_2) equivalent basis in 2013.[1] This included 97, 41, and 12 percent of the nation's CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions, respectively. Energy-related CO_2 emissions alone constituted 79.9 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 (4.6 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 32,310 MMT of CO_2 were added to the atmosphere through the combustion of fossil fuels in 2012, of which the United States accounted for approximately 16 percent.[2] 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: 2013 Energy Chapter Greenhouse Gas Sources

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

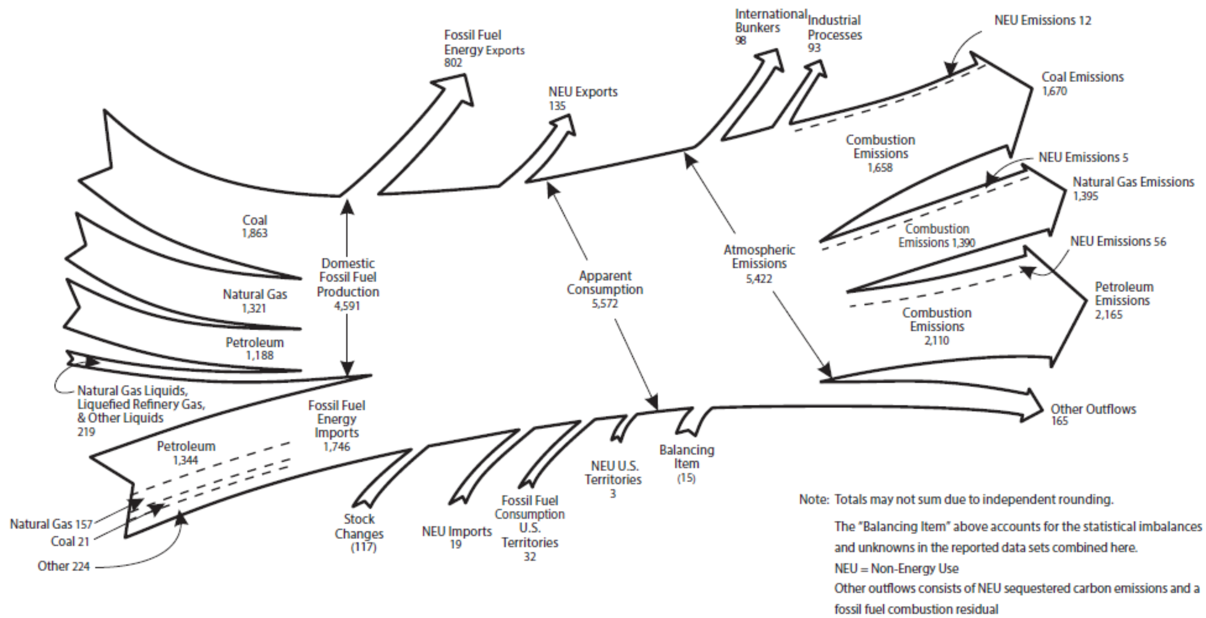


[1] Estimates are presented in units of million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.), which weight each gas by its global warming potential, or GWP, value. See section on global warming potentials in the Executive Summary.

[2] Global CO_2 emissions from fossil fuel combustion were taken from Energy Information Administration *International Energy Statistics 2013* <http://tonto.eia.doe.gov/cfapps/ipdbproject/IEDIndex3.cfm> EIA (2013).

Figure 3-2: 2013 U.S. Fossil Carbon Flows (MMT CO_2 Eq.)

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.



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 million metric tons of CO_2 equivalents (MMT CO_2 Eq.), while unweighted gas emissions in kilotons (kt) are provided in Table 3-2. Overall, emissions due to energy-related activities were 5,636.6 MMT CO_2 Eq. in 2013,[3] an increase of 6.5 percent since 1990.

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

Gas/Source	1990	2005	2009	2010	2011	2012	2013
CO_2	**4,908.4**	**5,933.9**	**5,351.2**	**5,529.2**	**5,390.3**	**5,181.1**	**5,331.5**
Fossil Fuel Combustion	4,740.7	5,747.7	5,197.1	5,367.1	5,231.3	5,026.0	5,157.7
Electricity Generation	1,820.8	2,400.9	2,145.7	2,258.4	2,157.7	2,022.2	2,039.8
Transportation	1,493.8	1,887.8	1,720.3	1,732.0	1,711.5	1,700.8	1,718.4
Industrial	842.5	827.8	727.7	775.7	774.1	784.2	817.3
Residential	338.3	357.8	336.4	334.7	327.2	283.1	329.6
Commercial	217.4	223.5	223.5	220.2	221.0	197.1	220.7
U.S. Territories	27.9	49.9	43.5	46.2	39.8	38.6	32.0
Non-Energy Use of Fuels	117.7	138.9	106.0	114.6	108.4	104.9	119.8
Natural Gas Systems	37.6	30.0	32.2	32.3	35.6	34.8	37.8
Incineration of Waste	8.0	12.5	11.3	11.0	10.5	10.4	10.1
Petroleum Systems	4.4	4.9	4.7	4.2	4.5	5.1	6.0
Biomass – Wood[a]	*215.2*	*206.9*	*188.2*	*192.5*	*195.2*	*194.9*	*208.6*
International Bunker Fuels[a]	*103.5*	*113.1*	*106.4*	*117.0*	*111.7*	*105.8*	*99.8*
Biomass – Ethanol[a]	*4.2*	*22.9*	*62.3*	*72.6*	*72.9*	*72.8*	*74.7*
CH_4	**328.5**	**280.9**	**285.5**	**279.2**	**268.2**	**259.2**	**263.5**
Natural Gas Systems	179.1	176.3	168.0	159.6	159.3	154.4	157.4
Coal Mining	96.5	64.1	79.9	82.3	71.2	66.5	64.6

[3] Following the revised reporting requirements under the UNFCCC, this Inventory report presents CO_2 equivalent values based on the *IPCC Fourth Assessment Report* (AR4) GWP values. See the Introduction chapter for more information.

Petroleum Systems	31.5	23.5	21.5	21.3	22.0	23.3	25.2
Stationary Combustion	8.5	7.4	7.4	7.1	7.1	6.6	8.0
Abandoned Underground Coal Mines	7.2	6.6	6.4	6.6	6.4	6.2	6.2
Mobile Combustion	5.6	3.0	2.3	2.3	2.3	2.2	2.1
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[a]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O	**53.6**	**58.7**	**45.3**	**46.2**	**44.1**	**41.9**	**41.6**
Stationary Combustion	11.9	20.2	20.4	22.2	21.3	21.4	22.9
Mobile Combustion	41.2	38.1	24.6	23.7	22.5	20.2	18.4
Incineration of Waste	0.5	0.4	0.3	0.3	0.3	0.3	0.3
International Bunker Fuels[a]	*0.9*	*1.0*	*0.9*	*1.0*	*1.0*	*0.9*	*0.9*
Total	**5,290.5**	**6,273.6**	**5,682.1**	**5,854.6**	**5,702.6**	**5,482.2**	**5,636.6**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
+ Does not exceed 0.05 MMT CO_2 Eq.
[a] 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 (kt)

Gas/Source	1990	2005	2009	2010	2011	2012	2013
CO_2	**4,908,390**	**5,933,912**	**5,351,228**	**5,529,210**	**5,390,268**	**5,181,104**	**5,331,493**
Fossil Fuel Combustion	4,740,670	5,747,683	5,197,058	5,367,144	5,231,341	5,026,000	5,157,697
Non-Energy Use of Fuels	117,658	138,877	106,018	114,554	108,359	104,917	119,850
Natural Gas Systems	37,645	29,995	32,201	32,334	35,551	34,764	37,808
Incineration of Waste	7,972	12,454	11,295	11,026	10,550	10,363	10,137
Petroleum Systems	4,445	4,904	4,656	4,153	4,467	5,060	6,001
Biomass –Wood[a]	*215,186*	*206,901*	*188,220*	*192,462*	*195,182*	*194,903*	*208,594*
International Bunker Fuels[a]	*103,463*	*113,139*	*106,410*	*116,992*	*111,660*	*105,805*	*99,763*
Biomass – Ethanol[a]	*4,227*	*22,943*	*62,272*	*72,647*	*72,881*	*72,827*	*74,743*
CH_4	**13,139**	**11,237**	**11,419**	**11,168**	**10,729**	**10,366**	**10,541**
Natural Gas Systems	7,165	7,053	6,722	6,382	6,371	6,176	6,295
Coal Mining	3,860	2,565	3,194	3,293	2,849	2,658	2,584
Petroleum Systems	1,261	939	860	854	878	931	1,009
Stationary Combustion	339	296	295	283	283	264	318
Abandoned Underground Coal Mines	288	264	254	263	257	249	249
Mobile Combustion	225	121	93	92	91	88	86
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[a]	*7*	*5*	*5*	*6*	*5*	*4*	*3*
N_2O	**180**	**197**	**152**	**155**	**148**	**141**	**140**
Stationary Combustion	40	68	69	74	71	72	77
Mobile Combustion	138	128	82	80	76	68	62
Incineration of Waste	2	1	1	1	1	1	1
International Bunker Fuels[a]	*3*	*3*	*3*	*3*	*3*	*3*	*3*

+ Does not exceed 0.5 kt
[a] 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.

Box 3-1: 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 emission inventories, the emissions and sinks presented in this report and this chapter, are organized by source and sink categories and calculated using internationally-accepted methods provided by the Intergovernmental Panel on Climate Change (IPCC). 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. 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 presents emissions and sinks in a common format consistent with how countries are to report Inventories under the UNFCCC. The report itself, and this chapter, 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.

Box 3-2: 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. Data reporting by affected facilities included the reporting of emissions from fuel combustion at that affected facility. In general, the threshold for reporting is 25,000 metric tons or more of CO_2 Eq. per year.

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 (see, also, Box 3-4). 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. It should be noted that the definitions and provisions for reporting fuel types in EPA's 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 EPA's GHGRP and specific data caveats associated with monitoring methods in EPA's GHGRP has been provided on the GHGRP website.

EPA presents the data collected by its 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.

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 (MMT CO_2 Eq.)

Gas	1990		2005		2009	2010	2011	2012	2013
CO_2	4,740.7		5,747.7		5,197.1	5,367.1	5,231.3	5,026.0	5,157.7
CH_4	14.1		10.4		9.7	9.4	9.3	8.8	10.1
N_2O	53.1		58.4		45.0	45.9	43.8	41.6	41.3
Total	**4,807.9**		**5,816.5**		**5,251.8**	**5,422.5**	**5,284.5**	**5,076.4**	**5,209.1**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

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

Gas	1990		2005		2009	2010	2011	2012	2013
CO_2	4,740,670		5,747,683		5,197,058	5,367,144	5,231,341	5,026,000	5,157,697
CH_4	565		416		389	375	374	352	404
N_2O	178		196		151	154	147	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 2013, CO_2 emissions from fossil fuel combustion increased by 2.6 percent relative to the previous year. The increase in CO_2 emissions from fossil fuel combustion was a result of multiple factors, including: (1) an increase in the price of natural gas leading to increased coal-fired generation in the electric power sector; (2) much colder winter conditions resulting in an increased demand for heating fuel in the residential and commercial sectors; (3) an increase in industrial production across multiple sectors resulting in increases in industrial sector emissions;[4] and (4) an increase in transportation emissions resulting from an increase in vehicle miles traveled (VMT) and fuel use across on-road transportation modes. In 2013, CO_2 emissions from fossil fuel combustion were 5,157.7 MMT CO_2 Eq., or 8.8 percent above emissions in 1990 (see Table 3-5).[5]

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

Fuel/Sector	1990		2005		2009	2010	2011	2012	2013
Coal	**1,718.4**		**2,112.3**		**1,834.2**	**1,927.7**	**1,813.9**	**1,592.8**	**1,658.1**
Residential	3.0		0.8		0.0	0.0	0.0	0.0	0.0
Commercial	12.0		9.3		6.9	6.6	5.8	4.1	3.9
Industrial	155.3		115.3		83.0	90.1	82.0	74.1	75.8
Transportation	NE		NE		NE	NE	NE	NE	NE
Electricity Generation	1,547.6		1,983.8		1,740.9	1,827.6	1,722.7	1,511.2	1,575.0
U.S. Territories	0.6		3.0		3.4	3.4	3.4	3.4	3.4
Natural Gas	**1,000.3**		**1,166.7**		**1,216.9**	**1,272.1**	**1,291.5**	**1,352.6**	**1,389.5**
Residential	238.0		262.2		258.8	258.6	254.7	224.8	267.1
Commercial	142.1		162.9		168.9	167.7	170.5	156.9	178.2
Industrial	408.9		388.5		377.6	407.2	417.3	434.8	450.8
Transportation	36.0		33.1		37.9	38.1	38.9	41.3	48.8
Electricity Generation	175.3		318.8		372.2	399.0	408.8	492.2	441.9
U.S. Territories	NO		1.3		1.5	1.5	1.4	2.6	2.6
Petroleum	**2,021.5**		**2,468.4**		**2,145.5**	**2,167.0**	**2,125.5**	**2,080.2**	**2,109.6**

[4] Further details on industrial sector combustion emissions are provided by EPA's GHGRP (http://ghgdata.epa.gov/ghgp/main.do).

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

Residential	97.4	94.9	77.6	76.2	72.6	58.3	62.5
Commercial	63.3	51.3	47.7	45.9	44.7	36.1	38.6
Industrial	278.3	324.0	267.0	278.4	274.8	275.4	290.6
Transportation	1,457.7	1,854.7	1,682.4	1,693.9	1,672.7	1,659.5	1,669.6
Electricity Generation	97.5	97.9	32.2	31.4	25.8	18.3	22.4
U.S. Territories	27.2	45.6	38.6	41.3	34.9	32.6	26.0
Geothermal[a]	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Total	**4,740.7**	**5,747.7**	**5,197.1**	**5,367.1**	**5,231.3**	**5,026.0**	**5,157.7**

+ Does not exceed 0.05 MMT CO_2 Eq.
NE (Not estimated)
NO (Not occurring)
[a] 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 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.[6] 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 2013 Emissions from Fossil Fuel Combustion for Selected Fuels and Sectors (MMT CO_2 Eq. and Percent)

Sector	Fuel Type	2009 to 2010		2010 to 2011		2011 to 2012		2012 to 2013		Total 2013
Electricity Generation	Coal	86.7	5.0%	-104.9	-5.7%	-211.5	-12.3%	63.8	4.2%	1,575.0
Electricity Generation	Natural Gas	26.8	7.2%	9.8	2.5%	83.5	20.4%	-50.3	-10.2%	441.9
Electricity Generation	Petroleum	-0.8	-2.4%	-5.6	-17.8%	-7.5	-29.0%	4.1	22.2%	22.4
Transportation[a]	Petroleum	11.4	0.7%	-21.2	-1.3%	-13.2	-0.8%	10.2	0.6%	1,669.6
Residential	Natural Gas	-0.3	-0.1%	-3.9	-1.5%	-29.8	-11.7%	42.3	18.8%	267.1
Commercial	Natural Gas	-1.2	-0.7%	2.7	1.6%	-13.6	-8.0%	21.4	13.6%	178.2
Industrial	Coal	7.0	8.5%	-8.1	-9.0%	-7.9	-9.7%	1.8	2.4%	75.8
Industrial	Natural Gas	29.6	7.8%	10.1	2.5%	17.5	4.2%	16.0	3.7%	450.8
All Sectors[b]	**All Fuels[b]**	**170.1**	**3.3%**	**-135.8**	**-2.5%**	**-205.3**	**-3.9%**	**131.7**	**2.6%**	**5,157.7**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
[a] Excludes emissions from International Bunker Fuels.
[b] Includes fuels and sectors not shown in table.

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

In the United States, 82 percent of the energy consumed in 2013 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 (10 percent), primarily hydroelectric power, wind energy and biofuels (EIA 2015).[7] Specifically, petroleum supplied the largest share of domestic energy demands, accounting for 36 percent of total U.S. energy consumption in 2013. Natural gas and coal followed in order of energy demand importance, accounting for approximately 28 percent and 19 percent of total U.S. energy 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 2015).

Figure 3-3: 2013 U.S. Energy Consumption by Energy Source (percent)

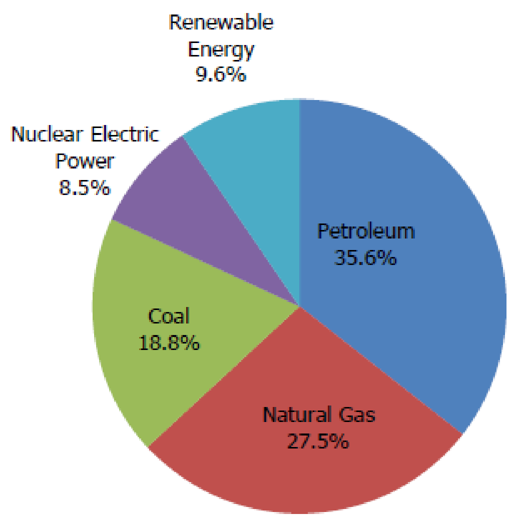
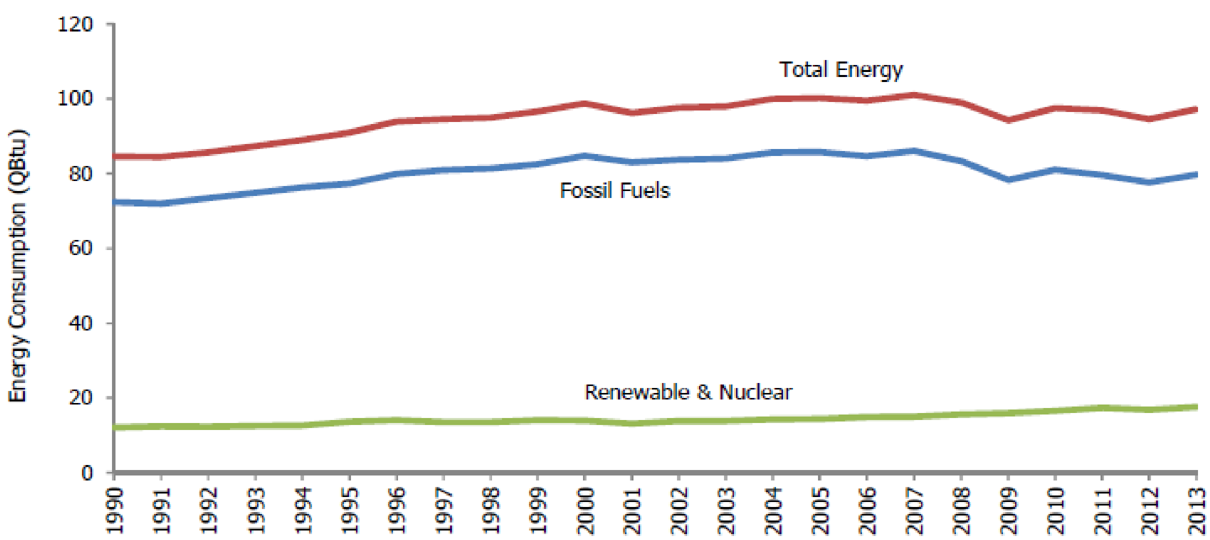
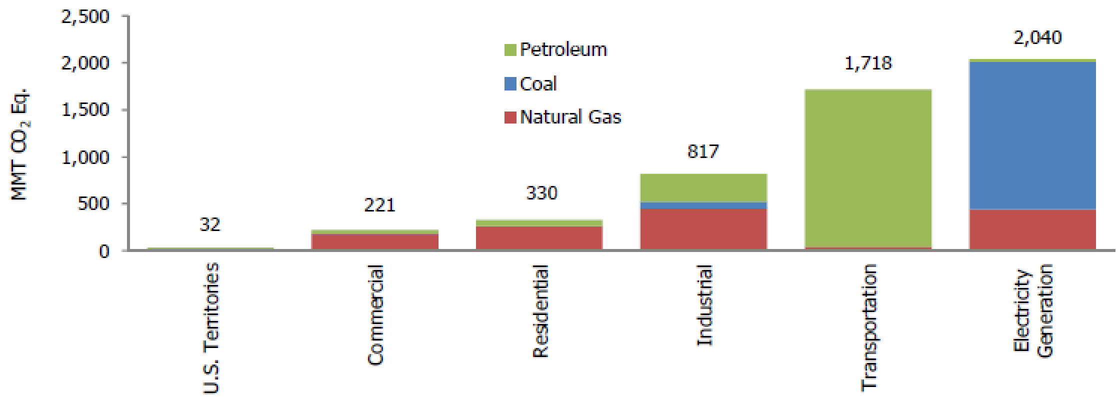


Figure 3-4: U.S. Energy Consumption (Quadrillion Btu)



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

Figure 3-5: 2013 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type (MMT CO_2 Eq.)



Fossil fuels are generally combusted for the purpose of producing energy for useful heat and work. During the combustion process, the C stored in the fuels is oxidized and emitted as CO_2 and smaller amounts of other gases, including CH_4, CO, and NMVOCs.[8] 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 all of the C in fossil fuels used to produce energy is eventually converted to atmospheric CO_2.

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

In 2013, weather conditions, and a very cold first quarter of the year in particular, caused a significant increase in energy demand for heating fuels and is reflected in the increased residential emissions during the early part of the year (EIA 2015). The United States in 2013 also experienced a cooler winter overall compared to 2012, as heating degree days increased (18.5 percent). Cooling degree days decreased by 12.8 percent and despite this decrease in cooling degree days, electricity demand to cool homes still increased slightly. While colder winter conditions compared to 2012 resulted in a significant increase in the amount of energy required for heating, heating degree days in the United States were 1.2 percent below normal (see Figure 3-6). Summer conditions were slightly cooler in 2013 compared to 2012, and summer temperatures were warmer than normal, with cooling degree days 7.1 percent above normal (see Figure 3-7) (EIA 2015).[9]

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

[9] 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 effect 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).

Figure 3-6: Annual Deviations from Normal Heating Degree Days for the United States (1950–2013)

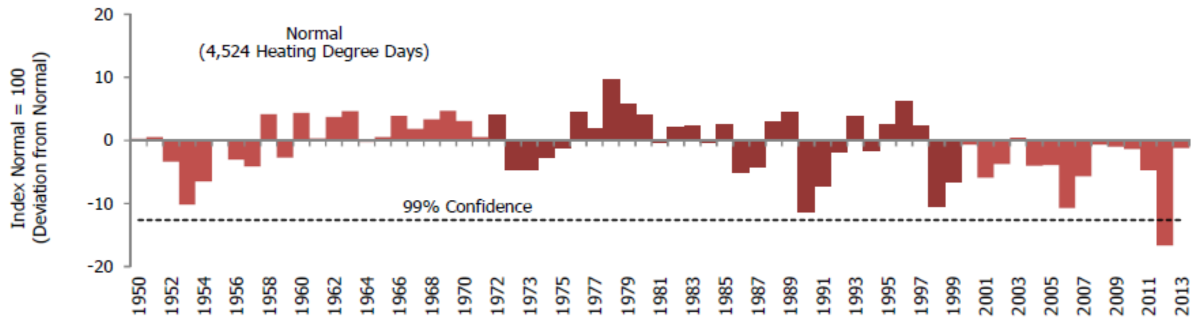
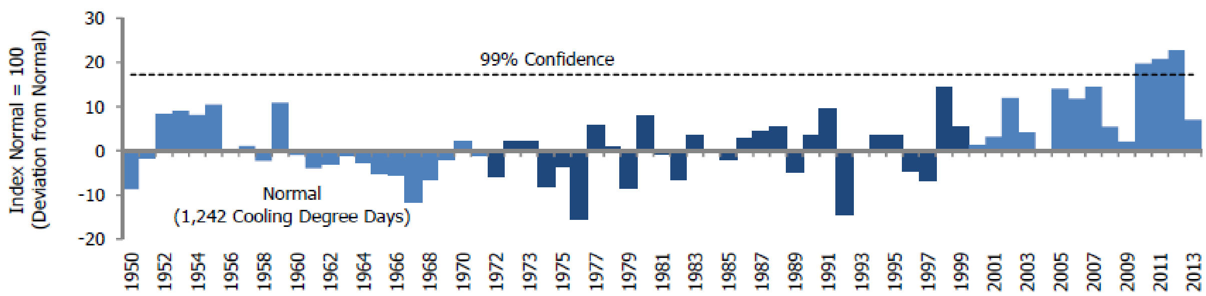


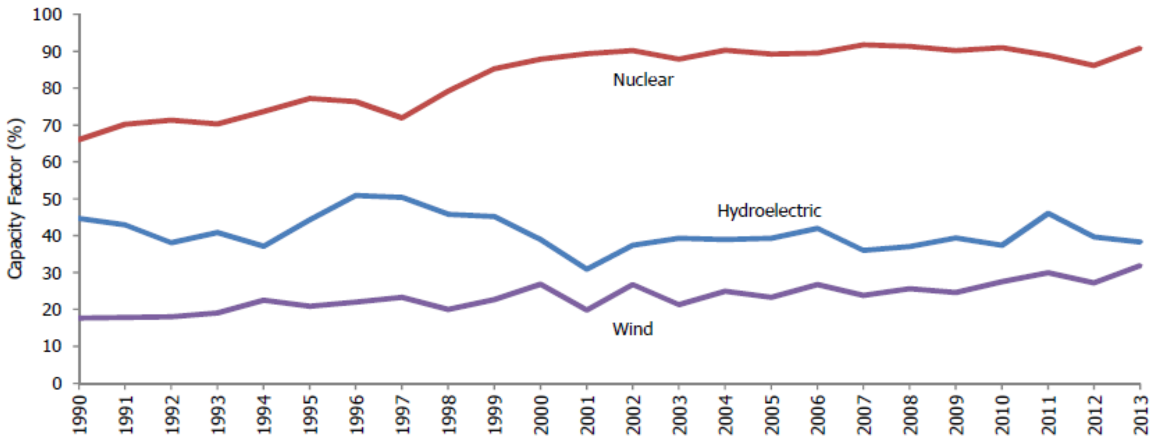
Figure 3-7: Annual Deviations from Normal Cooling Degree Days for the United States (1950–2013)



Although no new U.S. nuclear power plants have been constructed in recent years, the utilization (i.e., capacity factors)[10] of existing plants in 2013 remained high at 91 percent. Electricity output by hydroelectric power plants decreased in 2013 by approximately 3 percent. In recent years, the wind power sector has been showing strong growth, such that, on the margin, it is becoming a relatively important electricity source. Electricity generated by nuclear plants in 2013 provided nearly 3 times as much of the energy generated in the United States from hydroelectric plants (EIA 2015). Nuclear, hydroelectric, and wind power capacity factors since 1990 are shown in Figure 3-8.

[10] 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 (2015).

Figure 3-8: Nuclear, Hydroelectric, and Wind Power Plant Capacity Factors in the United States (1990–2013)



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.

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

End-Use Sector	1990	2005	2009	2010	2011	2012	2013
Electricity Generation	**1,828.5**	**2,417.4**	**2,162.9**	**2,277.4**	**2,175.8**	**2,040.4**	**2,059.3**
CO_2	1,820.8	2,400.9	2,145.7	2,258.4	2,157.7	2,022.2	2,039.8
CH_4	0.3	0.5	0.4	0.5	0.4	0.4	0.4
N_2O	7.4	16.0	16.8	18.5	17.6	17.8	19.1
Transportation	**1,540.6**	**1,928.9**	**1,747.2**	**1,758.0**	**1,736.3**	**1,723.2**	**1,739.0**
CO_2	1,493.8	1,887.8	1,720.3	1,732.0	1,711.5	1,700.8	1,718.4
CH_4	5.6	3.0	2.3	2.3	2.3	2.2	2.1
N_2O	41.2	38.1	24.6	23.7	22.5	20.2	18.4
Industrial	**847.4**	**832.4**	**731.4**	**779.6**	**778.0**	**788.2**	**821.2**
CO_2	842.5	827.8	727.7	775.7	774.1	784.2	817.3
CH_4	1.8	1.7	1.4	1.5	1.5	1.5	1.5
N_2O	3.1	2.9	2.3	2.5	2.4	2.4	2.4
Residential	**344.6**	**362.8**	**341.7**	**339.6**	**332.1**	**287.6**	**335.5**
CO_2	338.3	357.8	336.4	334.7	327.2	283.1	329.6
CH_4	5.2	4.1	4.4	4.0	4.0	3.7	5.0
N_2O	1.0	0.9	0.9	0.8	0.8	0.7	1.0
Commercial	**218.8**	**224.9**	**224.9**	**221.6**	**222.4**	**198.3**	**222.1**
CO_2	217.4	223.5	223.5	220.2	221.0	197.1	220.7
CH_4	1.0	1.1	1.1	1.1	1.0	0.9	1.0
N_2O	0.4	0.3	0.3	0.3	0.3	0.3	0.3
U.S. Territories[a]	**28.0**	**50.1**	**43.7**	**46.4**	**39.9**	**38.8**	**32.1**
Total	**4,807.9**	**5,816.5**	**5,251.8**	**5,422.5**	**5,284.5**	**5,076.4**	**5,209.1**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

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.
[a] 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.[11] 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. Carbon monoxide emissions are highest when air-fuel mixtures have less oxygen than required for complete combustion. These emissions occur especially in idle, low speed, and cold start conditions. Methane and NMVOC emissions from motor vehicles are a function of the 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 from transportation.[12] 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 (MMT CO_2 Eq.)

End-Use Sector	1990		2005		2009	2010	2011	2012	2013
Transportation	**1,543.7**		**1,933.7**		**1,751.7**	**1,762.5**	**1,740.6**	**1,727.1**	**1,743.0**
CO_2	1,496.8		1,892.5		1,724.8	1,736.5	1,715.8	1,704.6	1,722.4
CH_4	5.6		3.0		2.3	2.3	2.3	2.2	2.1
N_2O	41.2		38.1		24.6	23.8	22.5	20.3	18.5
Industrial	**1,537.0**		**1,574.1**		**1,338.0**	**1,425.8**	**1,407.9**	**1,386.3**	**1,409.3**
CO_2	1,529.2		1,564.4		1,329.5	1,416.5	1,398.8	1,377.0	1,399.8
CH_4	2.0		1.9		1.5	1.6	1.6	1.6	1.6
N_2O	5.9		7.8		7.0	7.7	7.6	7.7	7.9
Residential	**940.2**		**1,224.9**		**1,134.3**	**1,186.7**	**1,129.4**	**1,019.4**	**1,083.3**
CO_2	931.4		1,214.1		1,122.6	1,174.8	1,117.9	1,008.4	1,070.2
CH_4	5.4		4.2		4.6	4.2	4.2	3.9	5.1
N_2O	3.4		6.6		7.1	7.7	7.3	7.1	7.9
Commercial	**759.1**		**1,033.7**		**984.2**	**1,001.0**	**966.6**	**904.9**	**941.5**

11 Sulfur dioxide (SO_2) emissions from stationary combustion are addressed in Annex 6.3.

12 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.

CO_2	755.4		1,026.7		976.7	993.2	959.1	897.4	933.3
CH_4	1.1		1.2		1.2	1.2	1.2	1.1	1.2
N_2O	2.5		5.7		6.2	6.6	6.3	6.4	7.0
U.S. Territories[a]	**28.0**		**50.1**		**43.7**	**46.4**	**39.9**	**38.8**	**32.1**
Total	**4,807.9**		**5,816.5**		**5,251.8**	**5,422.5**	**5,284.5**	**5,076.4**	**5,209.1**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
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.
[a] 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 of 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.[13] 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 (MMT CO_2 Eq.)

Sector/Fuel Type	1990		2005		2009	2010	2011	2012	2013
Electricity Generation	**1,820.8**		**2,400.9**		**2,145.7**	**2,258.4**	**2,157.7**	**2,022.2**	**2,039.8**
Coal	1,547.6		1,983.8		1,740.9	1,827.6	1,722.7	1,511.2	1,575.0
Natural Gas	175.3		318.8		372.2	399.0	408.8	492.2	441.9
Fuel Oil	97.5		97.9		32.2	31.4	25.8	18.3	22.4
Geothermal	0.4		0.4		0.4	0.4	0.4	0.4	0.4
Industrial	**842.5**		**827.8**		**727.7**	**775.7**	**774.1**	**784.2**	**817.3**
Coal	155.3		115.3		83.0	90.1	82.0	74.1	75.8
Natural Gas	408.9		388.5		377.6	407.2	417.3	434.8	450.8
Fuel Oil	278.3		324.0		267.0	278.4	274.8	275.4	290.6
Commercial	**217.4**		**223.5**		**223.5**	**220.2**	**221.0**	**197.1**	**220.7**
Coal	12.0		9.3		6.9	6.6	5.8	4.1	3.9
Natural Gas	142.1		162.9		168.9	167.7	170.5	156.9	178.2
Fuel Oil	63.3		51.3		47.7	45.9	44.7	36.1	38.6
Residential	**338.3**		**357.8**		**336.4**	**334.7**	**327.2**	**283.1**	**329.6**
Coal	3.0		0.8		+	+	+	+	+
Natural Gas	238.0		262.2		258.8	258.6	254.7	224.8	267.1
Fuel Oil	97.4		94.9		77.6	76.2	72.6	58.3	62.5
U.S. Territories	**27.9**		**49.9**		**43.5**	**46.2**	**39.8**	**38.6**	**32.0**
Coal	0.6		3.0		3.4	3.4	3.4	3.4	3.4

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

Natural Gas	NO		1.3		1.5	1.5	1.4	2.6	2.6
Fuel Oil	27.2		45.6		38.6	41.3	34.9	32.6	26.0
Total	**3,246.9**		**3,859.9**		**3,476.7**	**3,635.2**	**3,519.8**	**3,325.2**	**3,439.3**

+ Does not exceed 0.05 MMT CO_2 Eq.
NO: Not occurring

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

Sector/Fuel Type	1990		2005		2009	2010	2011	2012	2013
Electric Power	**0.3**		**0.5**		**0.4**	**0.5**	**0.4**	**0.4**	**0.4**
Coal	0.3		0.3		0.3	0.3	0.3	0.2	0.2
Fuel Oil	+		+		+	+	+	+	+
Natural gas	0.1		0.1		0.1	0.2	0.2	0.2	0.2
Wood	+		+		+	+	+	+	+
Industrial	**1.8**		**1.7**		**1.4**	**1.5**	**1.5**	**1.5**	**1.5**
Coal	0.4		0.3		0.2	0.2	0.2	0.2	0.2
Fuel Oil	0.2		0.2		0.1	0.2	0.1	0.1	0.2
Natural gas	0.2		0.2		0.2	0.2	0.2	0.2	0.2
Wood	1.0		1.0		0.8	0.9	0.9	1.0	0.9
Commercial/Institutional	**1.0**		**1.1**		**1.1**	**1.1**	**1.0**	**0.9**	**1.0**
Coal	+		+		+	+	+	+	+
Fuel Oil	0.2		0.2		0.2	0.2	0.2	0.1	0.1
Natural gas	0.3		0.4		0.4	0.4	0.4	0.4	0.4
Wood	0.5		0.5		0.5	0.5	0.5	0.4	0.5
Residential	**5.2**		**4.1**		**4.4**	**4.0**	**4.0**	**3.7**	**5.0**
Coal	0.2		0.1		+	+	+	+	+
Fuel Oil	0.3		0.3		0.3	0.3	0.3	0.2	0.2
Natural Gas	0.5		0.6		0.6	0.6	0.6	0.5	0.6
Wood	4.1		3.1		3.6	3.1	3.2	3.0	4.1
U.S. Territories	**+**		**0.1**		**0.1**	**0.1**	**0.1**	**0.1**	**+**
Coal	+		+		+	+	+	+	+
Fuel Oil	+		0.1		0.1	0.1	0.1	0.1	+
Natural Gas	+		+		+	+	+	+	+
Wood	+		+		+	+	+	+	+
Total	**8.5**		**7.4**		**7.4**	**7.1**	**7.1**	**6.6**	**8.0**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
+ Does not exceed 0.05 MMT CO_2 Eq.
Note: Totals may not sum due to independent rounding.

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

Sector/Fuel Type	1990		2005		2009	2010	2011	2012	2013
Electricity Generation	**7.4**		**16.0**		**16.8**	**18.5**	**17.6**	**17.8**	**19.1**
Coal	6.3		11.6		11.2	12.5	11.5	10.2	12.1
Fuel Oil	0.1		0.1		+	+	+	+	+
Natural Gas	1.0		4.3		5.6	5.9	6.1	7.5	7.0
Wood	+		+		+	+	+	+	+
Industrial	**3.1**		**2.9**		**2.3**	**2.5**	**2.4**	**2.4**	**2.4**
Coal	0.7		0.5		0.4	0.4	0.4	0.4	0.4
Fuel Oil	0.5		0.5		0.4	0.4	0.4	0.3	0.4
Natural Gas	0.2		0.2		0.2	0.2	0.2	0.2	0.2
Wood	1.6		1.6		1.3	1.4	1.5	1.5	1.4
Commercial/Institutional	**0.4**		**0.3**		**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

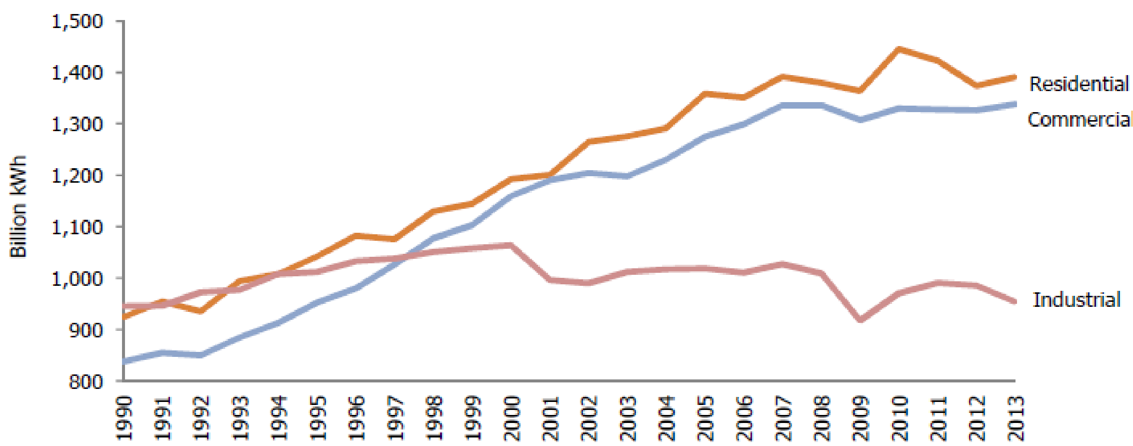
Wood	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Residential	**1.0**	**0.9**	**0.9**	**0.8**	**0.8**	**0.7**	**1.0**
Coal	+	+	+	+	+	+	+
Fuel Oil	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Natural Gas	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wood	0.7	0.5	0.6	0.5	0.5	0.5	0.7
U.S. Territories	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Coal	+	+	+	+	+	+	+
Fuel Oil	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Natural Gas	+	+	+	+	+	+	+
Wood	+	+	+	+	+	+	+
Total	**11.9**	**20.2**	**20.4**	**22.2**	**21.3**	**21.4**	**22.9**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.
+ Does not exceed 0.05 MMT 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 37 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 0.9 percent, respectively. Electricity generation also accounted for the largest share of CO_2 emissions from fossil fuel combustion, approximately 39.5 percent in 2013. Methane and N_2O from electricity generation represented 4.2 and 46.3 percent of total methane and N_2O emissions from fossil fuel combustion in 2013, 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). Electricity generators, including those using low-CO_2 emitting technologies, relied on coal for approximately 39 percent of their total energy requirements in 2013. Recently an increase in the carbon intensity of fuels consumed to generate electricity has occurred due to an increase in coal consumption, and decreased natural gas consumption and other generation sources. Total U.S. electricity generators used natural gas for approximately 27 percent of their total energy requirements in 2013 (EIA 2014a).

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, while the other sectors consist of those producers that indicate their primary business is something other than the production of electricity.[14]

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 2013 increased approximately 1.2 percent and 0.9 percent, respectively. The trend in the residential and commercial sectors can largely be attributed to colder, more energy-intensive winter conditions compared to 2012. Electricity sales to the industrial sector in 2013 decreased approximately 3.1 percent. Overall, in 2013, the amount of electricity generated (in kWh) decreased approximately 0.1 percent relative to the previous year, while CO_2 emissions from the electric power sector increased by 0.9 percent. The increase in CO_2 emissions, despite the decrease in sales and electricity generation was a result of an increase in the consumption of coal and petroleum for electricity generation by 4.2 percent and 18.8 percent, respectively, in 2013, and a decrease in the consumption of natural gas for electricity generation by 10.2 percent.

Industrial Sector

Industrial sector CO_2, CH_4, and N_2O, emissions accounted for 16, 15, and 6 percent of CO_2, CH_4, and N_2O, emissions from fossil fuel combustion, respectively. 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 2015 and EIA 2009b).

In theory, emissions from the industrial sector should be highly correlated with economic growth and industrial output, but heating of industrial buildings and agricultural energy consumption are also affected by weather conditions.[15] 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 2012 to 2013, total industrial production and manufacturing output increased by 2.9 percent (FRB 2014). Over this period, output increased across production indices for Food, Petroleum Refineries, Chemicals, Primary Metals, and Nonmetallic Mineral Products, and decreased slightly for Paper (see Figure 3-10). Through EPA's Greenhouse Gas Reporting Program (GHGRP), industrial trends can be discerned from the overall EIA industrial fuel consumption data used for these calculations. For example, from 2012 to 2013 the underlying EIA data showed increased consumption of natural gas and petroleum fuels in the industrial sector. EPA's GHGRP data highlights that petroleum refineries, chemical manufacturing, and non-metallic mineral products were contributors to these trends.[16]

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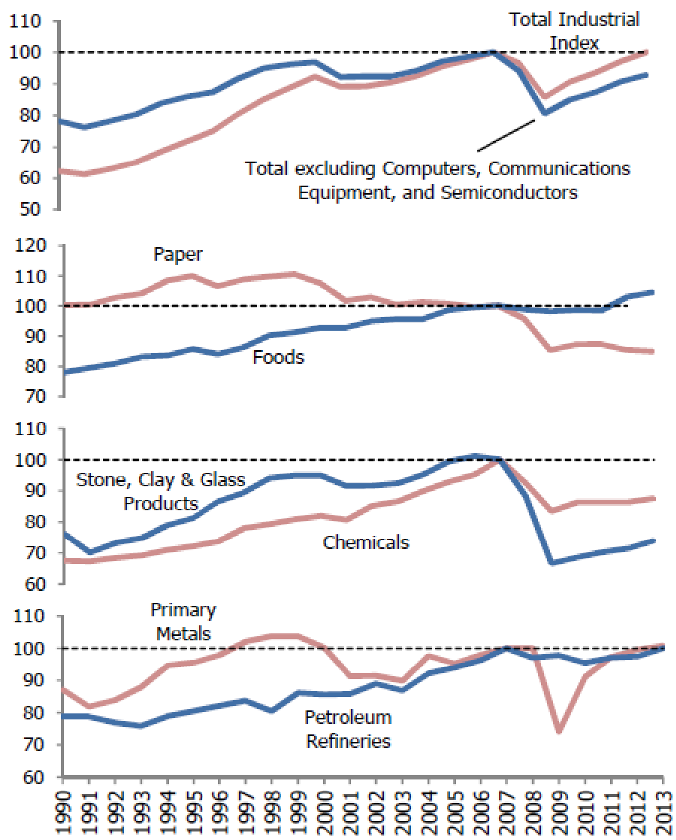
[14] Utilities primarily generate power for the U.S. electric grid for sale to retail customers. Nonutilities produce electricity for their own use, to sell to large consumers, or to sell on the wholesale electricity market (e.g., to utilities for distribution and resale to customers).

[15] 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.

[16] Further details on industrial sector combustion emissions are provided by EPA's GHGRP (<http://ghgdata.epa.gov/ghgp/main.do>).

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



Despite the growth in industrial output (61 percent) and the overall U.S. economy (75 percent) from 1990 to 2013, CO_2 emissions from fossil fuel combustion in the industrial sector decreased by 3.0 percent over the same time series. 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 2013, CO_2, CH_4, and N_2O emissions from fossil fuel combustion and electricity use within the industrial end-use sector totaled 1,409.3 MMT CO_2 Eq., or approximately 1.7 percent above 2012 emissions.

Residential and Commercial Sectors

Residential and commercial sector CO_2 emissions accounted for 6 and 4 percent of CO_2 emissions from fossil fuel combustion, CH_4 emissions accounted for 49 and 10 percent of CH_4 emissions from fossil fuel combustion, and N_2O emissions accounted for 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 2013, CO_2, CH_4, and N_2O emissions from fossil fuel combustion and electricity use within the residential and commercial end-use sectors were 1,083.3 MMT CO_2 Eq. and 941.5 MMT CO_2 Eq., respectively. Total CO_2, CH_4, and N_2O emissions from fossil fuel combustion and electricity use within the residential and commercial end-use sectors increased by 6.3 and 4.0 percent from 2012 to 2013, 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).

In 2013, combustion emissions from natural gas consumption represent 81 percent of the direct fossil fuel CO_2 emissions from both the residential and commercial sectors. Natural gas combustion CO_2 emissions from the residential and commercial sectors in 2013 increased by 18.8 percent and 13.6 percent from 2012 levels, 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.

Transportation Sector and Mobile Combustion

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

Transportation End-Use Sector

The transportation end-use sector accounted for 1,743.0 MMT CO_2 Eq. in 2013, which represented 33 percent of CO_2 emissions, 21 percent of CH_4 emissions, and 45 percent of N_2O emissions from fossil fuel combustion, respectively.[17] Fuel purchased in the United States for international aircraft and marine travel accounted for an additional 100.7 MMT CO_2 Eq. in 2013; these emissions are recorded as international bunkers and are not included in U.S. totals according to UNFCCC reporting protocols.

From 1990 to 2013, transportation emissions from fossil fuel combustion rose by 13 percent due, in large part, to increased demand for travel with limited gains in fuel efficiency for much of this time period. The number of vehicle miles traveled (VMT) by light-duty motor vehicles (passenger cars and light-duty trucks) increased 35 percent from 1990 to 2013, as a result of a confluence of factors including population growth, economic growth, urban sprawl, and low fuel prices during the beginning of this period.

From 2012 to 2013, CO_2 emissions from the transportation end-use sector increased by 1.0 percent.[18] The increase in emissions can largely be attributed to small increases in VMT and fuel use across on-road transportation modes, as well as increases in other non-road sectors such as pipelines. Commercial aircraft emissions increased slightly between 2012 and 2013, but have decreased 18 percent since 2007. Decreases in jet fuel emissions (excluding bunkers) since 2007 are due in part to improved operational efficiency that results in more direct flight routing, improvements in aircraft and engine technologies to reduce fuel burn and emissions, and the accelerated retirement of older, less fuel efficient aircraft.

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 15 percent from 1990 to 2013. Annex 3.2 presents the total emissions from all transportation and mobile sources, including CO_2, N_2O, CH_4, and HFCs.

[17] Note that these totals include CH_4 and N_2O emissions from some sources in the U.S. Territories (ships and boats, recreational boats, non-transportation mobile sources) and CH_4 and N_2O emissions from transportation rail electricity.

[18] Note that this value does not include lubricants.

Transportation Fossil Fuel Combustion CO_2 Emissions

Domestic transportation CO_2 emissions increased by 15 percent (225.6 MMT CO_2) between 1990 and 2013, an annualized increase of 0.6 percent. Among domestic transportation sources, light duty vehicles (including passenger cars and light-duty trucks) represented 60 percent of CO_2 emissions from fossil fuel combustion, medium- and heavy-duty trucks 23 percent, commercial aircraft 7 percent, and other sources 11 percent. See Table 3-12 for a detailed breakdown of transportation CO_2 emissions by mode and fuel type.

Almost all of the energy consumed by the transportation sector is petroleum-based, including motor gasoline, diesel fuel, jet fuel, and residual oil. CO_2 emissions from the combustion of ethanol and biodiesel for transportation purposes, along with the emissions associated with the agricultural and industrial processes involved in the production of biofuel, are captured in other Inventory sectors.[19] Ethanol consumption from the transportation sector has increased from 0.7 billion gallons in 1990 to 12.6 billion gallons in 2013, while biodiesel consumption has increased from 0.01 billion gallons in 2001 to 1.4 billion gallons in 2013. For further information, see the section on biofuel consumption at the end of this chapter and Table A-93 in Annex 3.2.

CO_2 emissions from passenger cars and light-duty trucks totaled 1,028.0 MMT CO_2 in 2013, an increase of 8 percent (77.6 MMT CO_2) from 1990 due, in large part, to increased demand for travel as fleetwide light-duty vehicle fuel economy was relatively stable (average new vehicle fuel economy declined slowly from 1990 through 2004 and then increased more rapidly from 2005 through 2013). CO_2 emissions from passenger cars and light-duty trucks peaked at 1,181.2 MMT CO_2 in 2004, and since then have declined about 13 percent. The decline in new light-duty vehicle fuel economy between 1990 and 2004 (Figure 3-11) reflected the increasing market share of light-duty trucks, which grew from about 30 percent of new vehicle sales in 1990 to 48 percent in 2004 (Figure 3-12). Starting in 2005, the rate of VMT growth slowed considerably (and declined rapidly in 2008) while average new vehicle fuel economy began to increase. Average new vehicle fuel economy has improved almost every year since 2005, and the truck share has decreased to about 37 percent of new vehicles in model year 2013 (EPA 2014d).

Medium- and heavy-duty truck CO_2 emissions increased by 71 percent from 1990 to 2013. This increase was largely due to a substantial growth in medium- and heavy-duty truck VMT, which increased by 92 percent between 1990 and 2013.[20] Carbon dioxide from the domestic operation of commercial aircraft increased by 4 percent (4.4 MMT CO_2) from 1990 to 2013. Across all categories of aviation, excluding international bunkers, CO_2 emissions decreased by 21 percent (38.7 MMT CO_2) between 1990 and 2013.[21] This includes a 69 percent (24.0 MMT CO_2) decrease in CO_2 emissions from domestic military operations.

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, CH_4, N_2O, and HFCs.

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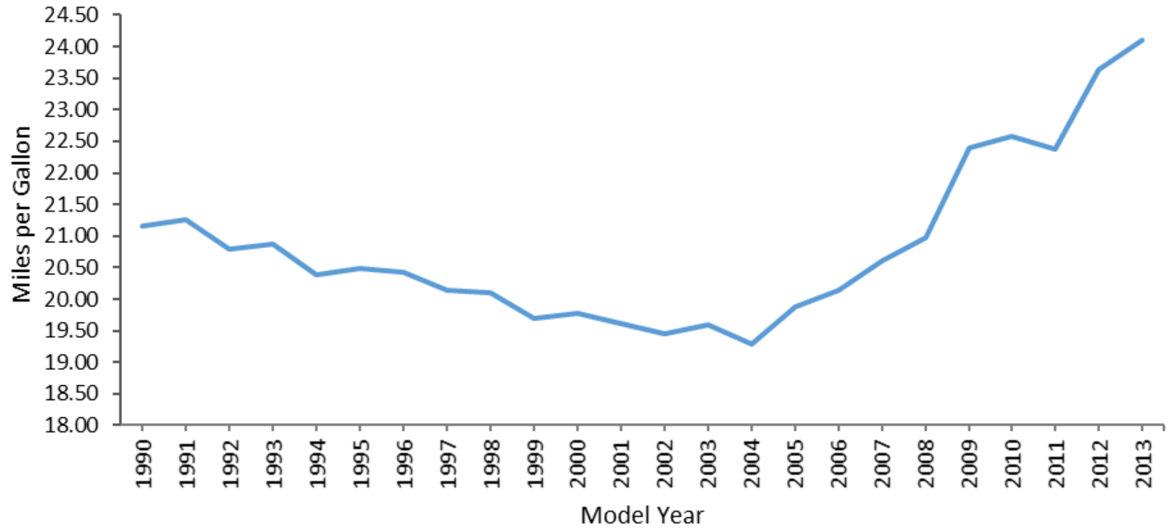
[19] Biofuel estimates are presented in the Energy chapter for informational purposes only, in line with IPCC methodological guidance and UNFCCC reporting obligations. Net carbon fluxes from changes in biogenic carbon reservoirs in croplands are accounted for in the estimates for Land Use, Land-Use Change, and Forestry (see Chapter 6). More information and additional analyses on biofuels are available at EPA's "Renewable Fuels: Regulations & Standards;" See <http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm>.

[20] While FHWA data shows consistent growth in medium- and heavy-duty truck VMT over the 1990 to 2013 time period, part of the growth reflects a method change for estimating VMT starting in 2007. 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 VMT and emissions among on-road vehicle classes in the 2007 to 2013 time period. During the time period prior to the method change (1990-2006), VMT for medium- and heavy-duty trucks increased by 51 percent.

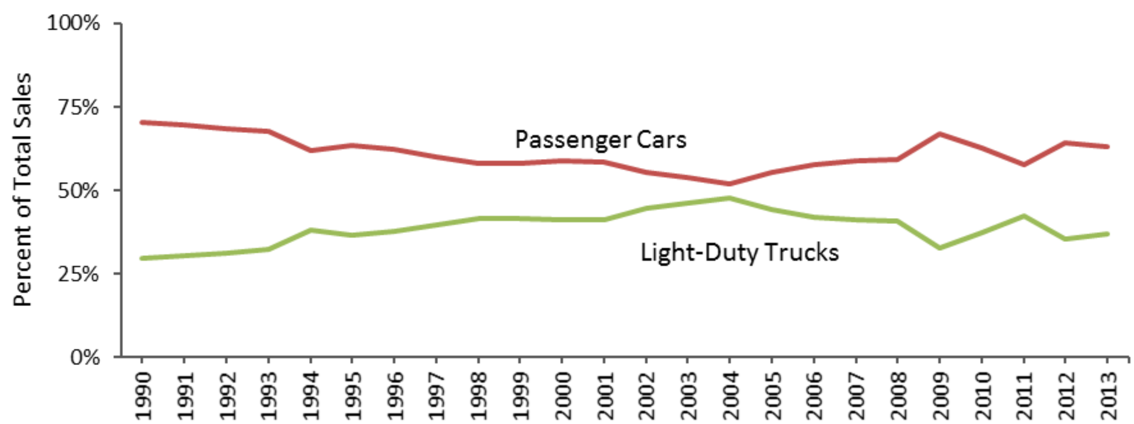
[21] Includes consumption of jet fuel and aviation gasoline. Does not include aircraft bunkers, which are not included in national emission totals, in line with IPCC methodological guidance and UNFCCC reporting obligations.

Figure 3-11: Sales-Weighted Fuel Economy of New Passenger Cars and Light-Duty Trucks, 1990–2013 (miles/gallon)



Source: EPA (2014)

Figure 3-12: Sales of New Passenger Cars and Light-Duty Trucks, 1990–2013 (percent)



Source: EPA (2014)

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

Fuel/Vehicle Type	1990	2005	2009[a]	2010	2011	2012	2013
Gasoline[c]	**983.5**	**1,183.9**	**1,101.7**	**1,092.7**	**1,069.0**	**1,064.9**	**1,065.8**
Passenger Cars	621.4	655.9	744.3	738.2	732.8	731.5	731.5
Light-Duty Trucks	309.1	477.2	296.9	295.0	280.4	277.4	277.7
Medium- and Heavy-Duty Trucks[b]	38.7	34.8	42.6	42.3	38.9	38.7	39.5
Buses	0.3	0.4	0.7	0.7	0.7	0.8	0.8
Motorcycles	1.7	1.6	4.1	3.6	3.6	4.1	3.9
Recreational Boats	12.2	14.1	13.0	12.7	12.6	12.5	12.4
Distillate Fuel Oil (Diesel)[c]	**262.9**	**458.1**	**409.0**	**425.5**	**433.7**	**431.3**	**437.6**
Passenger Cars	7.9	4.2	3.6	3.8	4.1	4.1	4.1
Light-Duty Trucks	11.5	25.8	12.1	12.6	13.1	13.0	13.0

Medium- and Heavy-Duty Trucks[b]	190.5	360.6	332.0	345.6	347.3	347.5	353.0
Buses	8.0	10.6	13.7	13.6	14.6	15.5	15.8
Rail	35.5	45.6	36.2	39.0	40.8	39.8	40.4
Recreational Boats	2.0	3.1	3.5	3.5	3.6	3.7	3.7
Ships and Other Boats	7.5	8.1	7.9	7.5	10.3	7.6	7.7
International Bunker Fuels[d]	*11.7*	*9.4*	*8.2*	*9.5*	*7.9*	*6.8*	*5.6*
Jet Fuel	**184.2**	**189.3**	**154.1**	**151.5**	**146.6**	**143.4**	**147.1**
Commercial Aircraft[e]	109.9	132.7	119.5	113.3	114.6	113.3	114.3
Military Aircraft	35.0	19.4	15.4	13.6	11.6	12.1	11.0
General Aviation Aircraft	39.4	37.3	19.2	24.6	20.4	18.0	21.8
International Bunker Fuels[d]	*38.0*	*60.1*	*52.8*	*61.0*	*64.8*	*64.5*	*65.7*
International Bunker Fuels from Commercial Aviation	*30.0*	*55.6*	*49.2*	*57.4*	*61.7*	*61.4*	*62.8*
Aviation Gasoline	**3.1**	**2.4**	**1.8**	**1.9**	**1.9**	**1.7**	**1.5**
General Aviation Aircraft	3.1	2.4	1.8	1.9	1.9	1.7	1.5
Residual Fuel Oil	**22.6**	**19.3**	**13.9**	**20.4**	**19.4**	**15.8**	**15.0**
Ships and Other Boats	22.6	19.3	13.9	20.4	19.4	15.8	15.0
International Bunker Fuels[d]	*53.7*	*43.6*	*45.4*	*46.5*	*38.9*	*34.5*	*28.5*
Natural Gas	**36.0**	**33.1**	**37.9**	**38.1**	**38.9**	**41.3**	**48.8**
Passenger Cars	+	+	+	+	+	+	+
Light-Duty Trucks	+	+	+	+	+	+	+
Buses	+	0.8	1.2	1.1	1.1	1.0	1.0
Pipeline[f]	36.0	32.2	36.7	37.1	37.8	40.3	47.7
LPG	**1.4**	**1.7**	**1.7**	**1.8**	**2.1**	**2.3**	**2.5**
Light-Duty Trucks	0.6	1.3	1.2	1.3	1.5	1.6	1.8
Medium- and Heavy-Duty Trucks[b]	0.8	0.4	0.5	0.6	0.6	0.7	0.7
Buses	+	+	+	+	+	+	+
Electricity	**3.0**	**4.7**	**4.5**	**4.5**	**4.3**	**3.9**	**4.0**
Rail	3.0	4.7	4.5	4.5	4.3	3.9	4.0
Ethanol[g]	***4.1***	***22.4***	***61.2***	***71.3***	***71.5***	***71.5***	***73.4***
Total	**1,496.8**	**1,892.5**	**1,724.8**	**1,736.5**	**1,715.8**	**1,704.6**	**1,722.4**
Total (Including Bunkers)[d]	**1,600.3**	**2,005.7**	**1,831.2**	**1,853.4**	**1,827.5**	**1,810.4**	**1,822.2**

Note: 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. In addition, this table does not include CO_2 emissions from U.S. Territories, since these are covered in a separate chapter of the Inventory.

[a] In 2011 FHWA changed its methods for estimating vehicle miles traveled (VMT) and related data. These methodological changes included how vehicles are classified, moving from a system based on body-type to one that is based on wheelbase. These changes were first incorporated for the 2010 Inventory and apply to the 2007-13 time period. This resulted in large changes in VMT and fuel consumption data by vehicle class, thus leading to a shift in emissions among on-road vehicle classes.

[b] Includes medium- and heavy-duty trucks over 8,500 lbs.

[c] Gasoline and diesel highway vehicle fuel consumption estimates are based on data from FHWA Highway Statistics Table VM-1 and MF-27.

[d] 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.

[e] Commercial aircraft, as modeled in FAA's AEDT, consists of passenger aircraft, cargo, and other chartered flights.

[f] Pipelines reflect CO_2 emissions from natural gas powered pipelines transporting natural gas.

[g] Ethanol estimates are presented for informational purposes only. See Section 3.10 of this chapter and the estimates in Land Use, Land-Use Change, and Forestry (see Chapter 6), in line with IPCC methodological guidance and UNFCCC reporting obligations, for more information on ethanol.

Note: Totals may not sum due to independent rounding.

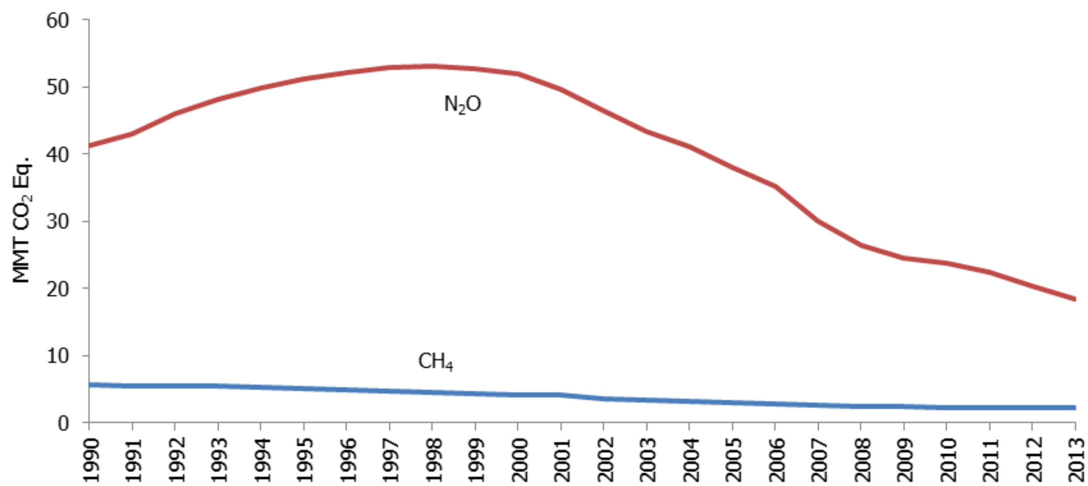
+ Less than 0.05 MMT CO_2 Eq.

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;[22] 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.).[23] Annex 3.2 includes a summary of all emissions from both transportation and mobile sources. Table 3-13 and Table 3-14 provide mobile fossil fuel CH_4 and N_2O emission estimates in MMT CO_2 Eq.[24]

Mobile combustion was responsible for a small portion of national CH_4 emissions (0.3 percent) but was the third largest source of U.S. N_2O emissions (5.2 percent). From 1990 to 2013, mobile source CH_4 emissions declined by 62 percent, to 2.1 MMT CO_2 Eq. (86 kt CH_4), 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 55 percent, to 18.4 MMT CO_2 Eq. (62 kt N_2O). Earlier generation control technologies initially resulted in higher N_2O emissions, causing a 28 percent increase in N_2O emissions from mobile sources between 1990 and 1997. Improvements in later-generation emission control technologies have reduced N_2O output, resulting in a 65 percent decrease in mobile source N_2O emissions from 1997 to 2013 (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 (MMT CO_2 Eq.)



Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values.

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22 Emissions of CH_4 from natural gas systems are reported separately. More information on the methodology used to calculate these emissions are included in this chapter and Annex 3.4.

23 See the methodology sub-sections of the CO_2 from Fossil Fuel Combustion and CH_4 and N_2O from Mobile Combustion sections of this chapter. Note that N_2O and CH_4 emissions are reported using different categories than CO_2. CO_2 emissions are reported by end-use sector (Transportation, Industrial, Commercial, Residential, U.S Territories), and generally adhere to a top-down approach to estimating emissions. CO_2 emissions from non-transportation sources (e.g., lawn and garden equipment, farm equipment, construction equipment) are allocated to their respective end-use sector (i.e., construction equipment CO_2 emissions are included in the Commercial end-use sector instead of the Transportation end-use sector). CH_4 and N_2O emissions are reported using the "Mobile Combustion" category, which includes non-transportation mobile sources. CH_4 and N_2O emissions estimates are bottom-up estimates, based on total activity (fuel use, VMT) and emissions factors by source and technology type. These reporting schemes are in accordance with IPCC guidance. For informational purposes only, CO_2 emissions from non-transportation mobile sources are presented separately from their overall end-use sector in Annex 3.2.

24 See Annex 3.2 for a complete time series of emission estimates for 1990 through 2013.

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

Fuel Type/Vehicle Type[a]	1990	2005	2009	2010	2011	2012	2013
Gasoline On-Road[b]	**5.2**	**2.4**	**1.7**	**1.7**	**1.6**	**1.5**	**1.5**
Passenger Cars	3.2	1.4	1.2	1.2	1.2	1.1	1.0
Light-Duty Trucks	1.7	0.9	0.4	0.4	0.4	0.3	0.3
Medium- and Heavy-Duty Trucks and Buses	0.3	0.1	0.1	0.1	0.1	0.1	0.1
Motorcycles	+	+	+	+	+	+	+
Diesel On-Road[b]	**+**	**+**	**+**	**+**	**+**	**+**	**+**
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**
Non-Road	**0.4**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.6**
Ships and Boats	+	+	+	+	+	+	+
Rail[f]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Aircraft	0.1	0.1	+	+	+	+	+
Agricultural Equipment[c]	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Construction/Mining Equipment[d]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other[e]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**5.6**	**3.0**	**2.3**	**2.3**	**2.3**	**2.2**	**2.1**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values. Totals may not sum due to independent rounding.
Note: In 2011, FHWA changed its methods for estimating vehicle miles traveled (VMT) and related data. These methodological changes included how vehicles are classified, moving from a system based on body-type to one that is based on wheelbase. These changes were first incorporated for the 1990-2010 Inventory and apply to the 2007 through 2013 time period. This resulted in large changes in VMT and fuel consumption data by vehicle class, thus leading to a shift in emissions among on-road vehicle classes.
[a] See Annex 3.2 for definitions of on-road vehicle types.
[b] Gasoline and diesel highway vehicle mileage are based on data from FHWA Highway Statistics Table VM-1.
[c] Includes equipment, such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.
[d] Includes equipment, such as cranes, dumpers, and excavators, as well as fuel consumption from trucks that are used off-road in construction.
[e] "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.
[f] Rail emissions do not include emissions from electric powered locomotives.
+ Less than 0.05 MMT CO_2 Eq.

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

Fuel Type/Vehicle Type[a]	1990	2005	2009	2010	2011	2012	2013
Gasoline On-Road[b]	**37.4**	**33.6**	**20.4**	**19.2**	**18.0**	**15.8**	**13.9**
Passenger Cars	24.1	18.0	13.8	12.9	12.3	10.7	9.3
Light-Duty Trucks	12.7	14.8	5.7	5.5	5.0	4.4	3.9
Medium- and Heavy-Duty Trucks and Buses	0.5	0.8	0.8	0.8	0.7	0.7	0.7
Motorcycles	+	+	+	+	+	+	+
Diesel On-Road[b]	**0.2**	**0.3**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Passenger Cars	+	+	+	+	+	+	+
Light-Duty Trucks	+	+	+	+	+	+	+
Medium- and Heavy-Duty Trucks and Buses	0.2	0.3	0.4	0.4	0.4	0.4	0.4

Alternative Fuel On-Road	**0.1**	**0.1**	**0.1**	**0.2**	**0.2**	**0.2**	**0.2**
Non-Road	**3.5**	**4.1**	**3.7**	**4.0**	**4.0**	**3.9**	**3.9**
Ships and Boats	0.6	0.6	0.5	0.8	0.8	0.7	0.7
Rail[f]	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Aircraft	1.7	1.8	1.4	1.4	1.4	1.3	1.4
Agricultural Equipment[c]	0.2	0.3	0.3	0.4	0.4	0.4	0.4
Construction/Mining Equipment[d]	0.3	0.5	0.5	0.5	0.6	0.6	0.6
Other[e]	0.4	0.6	0.6	0.6	0.6	0.6	0.6
Total	**41.2**	**38.1**	**24.6**	**23.7**	**22.5**	**20.2**	**18.4**

Note: Emissions values are presented in CO_2 equivalent mass units using IPCC AR4 GWP values. Totals may not sum due to independent rounding.

Note: In 2011, FHWA changed its methods for estimating vehicle miles traveled (VMT) and related data. These methodological changes included how vehicles are classified, moving from a system based on body type to one that is based on wheelbase. These changes were first incorporated for the 1990-2010 Inventory and apply to the 2007 through 2013 time period. This resulted in large changes in VMT and fuel consumption data by vehicle class, thus leading to a shift in emissions among on-road vehicle classes.

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

[b] Gasoline and diesel highway vehicle mileage are based on data from FHWA Highway Statistics Table VM-1.

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

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

[e] "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.

[f] Rail emissions do not include emissions from electric powered locomotives.

+ Less than 0.05 MMT 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).[25] The use of the most recently published calculation methodologies by the IPCC, as contained in the *2006 IPCC Guidelines*, is considered to improve the rigor and accuracy of this inventory and is fully in line with IPCC Good Practice Guidance. 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 EIA of the U.S. Department of Energy (DOE), primarily from the Monthly Energy Review and published supplemental tables on petroleum product detail (EIA 2015). The EIA does not include territories in its national energy statistics, so fuel consumption data for territories were collected separately from EIA's International Energy Statistics (EIA 2013) and Jacobs (2010).[26]

   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

[25] The IPCC Tier 3B methodology is used for estimating emissions from commercial aircraft.

[26] 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 32.1 MMT CO_2 Eq. in 2013.

production data (accounting for imports, exports, stock changes, and losses). The resulting quantities are referred to as "apparent consumption." The data collected in the United States by EIA on an annual basis and used in this inventory are predominantly from mid-stream or conversion energy consumers such as refiners and electric power generators. These annual surveys are supplemented with end-use energy consumption surveys, such as the Manufacturing Energy Consumption Survey, that are conducted on a periodic basis (every four years). These consumption data sets help inform the annual surveys to arrive at the national total and sectoral breakdowns for that total.[27]

Also, 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).[28]

2. *Subtract uses accounted for in the Industrial Processes and Product Use 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 and Product Use chapter, as they were consumed during non-energy related industrial activity. To make these adjustments, additional data were collected from AISI (2004 through 2013), Coffeyville (2014), U.S. Census Bureau (2011), EIA (2014c), USGS (1991 through 2011), USGS (1994 through 2011), USGS (1995, 1998, 2000 through 2002), USGS (2007), USGS (2009), USGS (2010), USGS (2011), USGS (1991 through 2010a), USGS (1991 through 2010b), USGS (2012a) and USGS (2012b).[29]

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.[30] 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.[31] 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 (2015), data for synthetic natural gas were collected from EIA (2014), and data for CO_2 exports were collected from the Eastman Gasification Services Company (2011), Dakota Gasification Company (2006), Fitzpatrick (2002), Erickson (2003), EIA (2008) 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 data from the Federal Highway Administration 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 to match the value obtained from the bottom-up analysis. As the total distillate and motor gasoline consumption estimate from EIA are considered to be accurate at the national level, the distillate and motor gasoline consumption totals for the residential, commercial, and industrial sectors were adjusted proportionately. The data sources used in the bottom-up analysis of transportation fuel consumption include AAR (2008 through 2013), Benson

[27] 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.

[28] 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.

[29] 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 and Product Use chapter.

[30] Energy statistics from EIA (2015) are already adjusted downward to account for ethanol added to motor gasoline, and biogas in natural gas.

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

(2002 through 2004), DOE (1993 through 2014), EIA (2007), EIA (1991 through 2014), EPA (2013b), and FHWA (1996 through 2014).[32]

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 (2015).

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).[33] The Office of the Under Secretary of Defense (Installations and Environment) and the Defense Logistics Agency Energy (DLA Energy) of the U.S. Department of Defense (DoD) (DLA Energy 2014) supplied data on military jet fuel and marine fuel use. Commercial jet fuel use was obtained from FAA (2015); residual and distillate fuel use for civilian marine bunkers was obtained from DOC (1991 through 2013) for 1990 through 2001 and 2007 through 2013, 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 GHGRP (EPA 2010). A discussion of the methodology used to develop the C content coefficients are presented in Annexes 2.1 and 2.2.

8. *Estimate 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

[32] The source of highway vehicle VMT and fuel consumption is FHWA's VM-1 table. In 2011, FHWA changed its methods for estimating data in the VM-1 table. These methodological changes included how vehicles are classified, moving from a system based on body type to one that is based on wheelbase. These changes were first incorporated for the 1990-2010 Inventory and apply to the 2007 to 2013 time period. This resulted in large changes in VMT and fuel consumption data by vehicle class, thus leading to a shift in emissions among on-road vehicle classes. For example, the category "Passenger Cars" has been replaced by "Light-duty Vehicles-Short Wheelbase" and "Other 2 axle-4 Tire Vehicles" has been replaced by "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.

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

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. Heat contents and densities were obtained from EIA (2015) and USAF (1998).[34]

- For on-road vehicles, annual estimates of combined motor gasoline and diesel fuel consumption by vehicle category were obtained from FHWA (1996 through 2014); for each vehicle category, the percent gasoline, diesel, and other (e.g., CNG, LPG) fuel consumption are estimated using data from DOE (1993 through 2013).
- For non-road vehicles, activity data were obtained from AAR (2008 through 2013), APTA (2007 through 2013), APTA (2006), BEA (1991 through 2013), Benson (2002 through 2004), DOE (1993 through 2014), DLA Energy (2014), DOC (1991 through 2013), DOT (1991 through 2013), EIA (2009a), EIA (2015), EIA (2002), EIA (1991 through 2014), EPA (2014c), and Gaffney (2007).
- For jet fuel used by aircraft, CO_2 emissions from commercial aircraft were developed by the U.S. Federal Aviation Administration (FAA) using a Tier 3B methodology, consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (see Annex 3.3). CO_2 emissions from other aircraft were calculated directly based on reported consumption of fuel as reported by EIA. Allocation to domestic military uses was made using DoD data (see Annex 3.8). General aviation jet fuel consumption is calculated as the remainder of total jet fuel use (as determined by EIA) nets all other jet fuel use as determined by FAA and DoD. For more information, see Annex 3.2.

Box 3-4: Uses of Greenhouse Gas Reporting Program Data and Improvements in Reporting Emissions from Industrial Sector Fossil Fuel Combustion

As described in the calculation methodology, total fossil fuel consumption for each year is based on aggregated end-use sector consumption published by the EIA. The availability of facility-level combustion emissions through EPA's Greenhouse Gas Reporting Program (GHGRP) has provided an opportunity to better characterize the industrial sector's energy consumption and emissions in the United States, through a disaggregation of EIA's industrial sector fuel consumption data from select industries.

For EPA's GHGRP 2010, 2011, 2012, and 2013 reporting years, facility-level fossil fuel combustion emissions reported through the GHGRP were categorized and distributed to specific industry types by utilizing facility-reported NAICS codes (as published by the U.S. Census Bureau), and associated data available from EIA's 2010 Manufacturing Energy Consumption Survey (MECS). As noted previously in this report, the definitions and provisions for reporting fuel types in EPA's GHGRP include some differences from the inventory's use of EIA national fuel statistics to meet the UNFCCC reporting guidelines. The IPCC has provided guidance on aligning facility-level reported fuels and fuel types published in national energy statistics, which guided this exercise.[35]

This year's effort represents an attempt to align, reconcile, and coordinate the facility-level reporting of fossil fuel combustion emissions under EPA's GHGRP with the national-level approach presented in this report. Consistent with recommendations for reporting the inventory to the UNFCCC, progress was made on certain fuel types for specific industries and has been included in the Common Reporting Format (CRF) tables that are submitted to the UNFCCC along with this report.[36] However, a full mapping was not completed this year due to fuel category differences between national statistics published by EIA and facility-level reported GHGRP data. Furthermore, given that calendar year 2010 was the first year in which emissions data were reported to EPA's GHGRP, the current inventory's examination only focused on 2010, 2011, 2012 and 2013. For the current exercise, the efforts in reconciling fuels focused on standard, common fuel types (e.g., natural gas, distillate fuel oil, etc.) where the fuels in EIA's national statistics aligned well with facility-level GHGRP data. For these reasons, the current information

[34] 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 3.8.

[35] See Section 4 "Use of Facility-Level Data in Good Practice National Greenhouse Gas Inventories" of the IPCC meeting report, and specifically the section on using facility-level data in conjunction with energy data, at <http://www.ipcc-nggip.iges.or.jp/meeting/pdffiles/1008_Model_and_Facility_Level_Data_Report.pdf>.

[36] See < http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html>.

presented in the CRF tables should be viewed as an initial attempt at this exercise. Additional efforts will be made for future inventory reports to improve the mapping of fuel types, and examine ways to reconcile and coordinate any differences between facility-level data and national statistics. Additionally, in order to expand this effort through the full time series presented in this report, further analyses will be conducted linking GHGRP facility-level reporting with the information published by EIA in its MECS data, other available MECS survey years , and any further informative sources of data. It is believed that the current analysis has led to improvements in the presentation of data in the Inventory, but further work will be conducted, and future improvements will be realized in subsequent Inventory reports.

Additionally, to assist in the disaggregation of industrial fuel consumption, EIA will now synthesize energy consumption data using the same procedure as is used for the last historical (benchmark) year of the Annual Energy Outlook (AEO). This procedure reorganizes the most recent data from the Manufacturing Energy Consumption Survey (MECS) (conducted every four years) into the nominal data submission year using the same energy-economy integrated model used to produce the AEO projections, the National Energy Modeling System (NEMS). EIA believes this "nowcasting" technique provides an appropriate estimate of energy consumption for the CRF.

To address gaps in the time series, EIA performs a NEMS model projection, using the MECS baseline sub-sector energy consumption. The NEMS model accounts for changes in factors that influence industrial sector energy consumption, and has access to data which may be more recent than MECS, such as industrial sub-sector macro industrial output (i.e., shipments) and fuel prices. By evaluating the impact of these factors on industrial subsector energy consumption, NEMS can anticipate changes to the energy shares occurring post-MECS and can provide a way to appropriately disaggregate the energy-related emissions data into the CRF.

While the fuel consumption values for the various manufacturing sub-sectors are not directly surveyed for all years, they represent EIA's best estimate of historical consumption values for non-MECS years. Moreover, as an integral part of each AEO publication, this synthetic data series is likely to be maintained consistent with all available EIA and non-EIA data sources even as the underlying data sources evolve for both manufacturing and non-manufacturing industries alike.

Other sectors' fuel consumption (commercial, residential, transportation) will be benchmarked with the latest aggregate values from the Monthly Energy Review.[37] EIA will work with EPA to back cast these values to 1990.

Box 3-5: 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 MMT CO_2 Eq./QBtu for natural gas to upwards of 95 MMT CO_2 Eq./QBtu for coal and petroleum coke.[38] 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

[37] See <http://www.eia.gov/totalenergy/data/monthly/>.

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

sector was closely related to the C content of petroleum products (e.g., motor gasoline and jet fuel, both around 70 MMT 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.

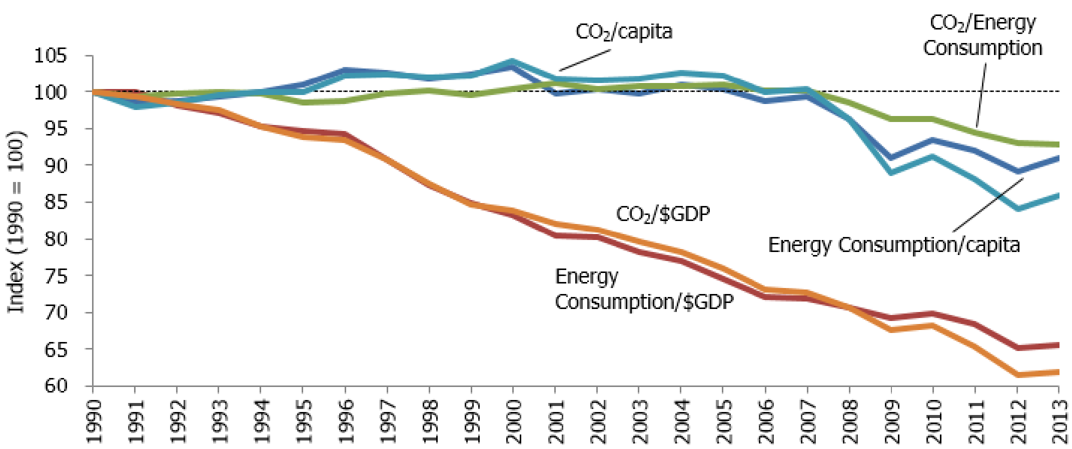
Table 3-15: Carbon Intensity from Direct Fossil Fuel Combustion by Sector (MMT CO_2 Eq./QBtu)

Sector	1990		2005		2009	2010	2011	2012	2013
Residential[a]	57.4		56.6		55.9	55.8	55.8	55.6	55.3
Commercial[a]	59.1		57.5		56.9	56.8	56.6	56.1	55.9
Industrial[a]	64.3		64.3		63.0	62.9	62.4	62.0	61.8
Transportation[a]	71.1		71.4		71.5	71.5	71.5	71.5	71.4
Electricity Generation[b]	87.3		85.8		83.7	83.6	82.9	79.9	81.3
U.S. Territories[c]	73.0		73.4		73.1	73.0	73.1	72.3	72.2
All Sectors[c]	**73.0**		**73.5**		**72.4**	**72.4**	**72.0**	**70.9**	**70.9**

[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-four-year period of 1990 through 2013, 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 2013 was approximately 9.0 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 2014).

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 (2015), EPA (2010a), and fossil fuel consumption data as discussed above and presented in Annex 2.1.

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. 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 Approach 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.[39] 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.[40]

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[39] 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.

[40] 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.

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).[41] For purposes of this uncertainty analysis, each input variable was simulated 10,000 times through Monte Carlo sampling.

The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 3-16. Fossil fuel combustion CO_2 emissions in 2013 were estimated to be between 5,051.0 and 5,403.7 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 2 percent below to 5 percent above the 2013 emission estimate of 5,157.7 MMT CO_2 Eq.

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

Fuel/Sector	2013 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Coal[b]	**1,658.1**	**1,600.7**	**1,814.7**	**-3%**	**9%**
Residential	NE	NE	NE	NE	NE
Commercial	3.9	3.7	4.5	-5%	15%
Industrial	75.8	72.2	87.7	-5%	16%
Transportation	NE	NE	NE	NE	NE
Electricity Generation	1,575.0	1,513.3	1,726.4	-4%	10%
U.S. Territories	3.4	3.0	4.1	-12%	19%
Natural Gas[b]	**1,389.5**	**1,374.4**	**1,453.5**	**-1%**	**5%**
Residential	267.2	259.6	285.9	-3%	7%
Commercial	178.2	173.2	190.8	-3%	7%
Industrial	450.8	437.3	483.2	-3%	7%
Transportation	48.8	47.4	52.2	-3%	7%
Electricity Generation	441.9	429.1	464.4	-3%	5%
U.S. Territories	2.6	2.3	3.1	-12%	17%
Petroleum[b]	**2,109.6**	**1,982.0**	**2,232.6**	**-6%**	**6%**
Residential	62.5	59.0	65.7	-6%	5%
Commercial	38.6	36.7	40.3	-5%	4%
Industrial	290.6	236.7	340.7	-19%	17%
Transportation	1,669.6	1,560.6	1,779.5	-7%	7%
Electric Utilities	22.4	21.2	24.4	-5%	9%
U.S. Territories	26.0	24.0	28.8	-8%	11%
Total (excluding Geothermal)[b]	**5,157.3**	**5,050.5**	**5,403.3**	**-2%**	**5%**
Geothermal	0.4	NE	NE	NE	NE
Total (including Geothermal)[b,c]	**5,157.7**	**5,051.0**	**5,403.7**	**-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.

[41] 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.

Methodological recalculations were applied to the entire time series to ensure time-series consistency from 1990 through 2013. 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 2015) updated energy consumption statistics across the time series relative to the previous Inventory. One such revision is the historical petroleum consumption in the residential sector in 2011 and 2012. These revisions primarily impacted the previous emission estimates from 2010 to 2012; however, additional revisions to industrial and transportation petroleum consumption as well as industrial natural gas and coal consumption impacted emission estimates across the time series. In addition, EIA revised the heat contents of motor gasoline, distillate fuel, and petroleum coke.

For motor gasoline, heating values were previously based on the relative volumes of conventional and reformulated gasoline in the total motor gasoline product supplied to the United States. The revised heating values (first occurring in the January 2015 publication of the Monthly Energy Review) incorporated inputs of ethanol, methyl tert-butyl ether (MTBE) through April 2006, other oxygenates through 2006, and a single national hydrocarbon gasoline blend-stock from 1993 through 2013. Under the previous MER approach, the heating values of conventional and reformulated gasoline were not adjusted for annual variation in the volumes of oxygenates, such as ethanol and MTBE, which have lower heating values than the hydrocarbon components used to produce gasoline. The calculation from the previous EIA Monthly Energy Review publication resulted in overestimated energy values of historic gasoline consumption since 2003, when ethanol use began to grow rapidly. The heating value revision resulted in an historical motor gasoline consumption decrease of approximately 1 percent per year between 1994 through 2012.

Changes to the heat content of distillate fuel resulted in an annual average decrease of approximately 0.1 percent between 1994 through 2012. This decrease was a result of EIA's heat content revision from a constant sulfur content across the time series, to a weighted sulfur content. Additionally, in 2009, EIA began subtracting inputs of renewable diesel fuel from petroleum consumption before converting to energy units. Also, new data from Oak Ridge National Laboratory's Transportation Energy Book (Edition 33) regarding the use of biodiesel in transit buses was incorporated and impacted the distribution of fuel consumption and emissions for on-road buses for the time series starting in 2006.

Petroleum coke consumption decreased by an annual average of approximately 0.1 percent from 2004 to 2012. This decrease was a result of a similar heat content revision in which the EIA recalculated the historically constant petroleum coke heat content to include weighted petroleum coke heat contents (by the two categories of petroleum coke, catalyst and marketable) starting in 2004.

Overall, these changes resulted in an average annual decrease of 9.6 MMT CO_2 Eq. (less than 0.2 percent) in CO_2 emissions from fossil fuel combustion for the period 1990 through 2012, relative to the previous report.

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 GHGRP will continue to 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, some facility-level fuel combustion emissions reported under the GHGRP may also include industrial process emissions.[42] In line with UNFCCC reporting guidelines, fuel combustion emissions are included in this chapter, while process emissions are included in the Industrial Processes and Product Use 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. Additional, analyses will be conducted to align reported facility-level fuel types and IPCC fuel types per the national energy statistics. Additional work will commence to ensure 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 continue to be relied upon.[43]

Another planned improvement is to 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 is currently being investigated.

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 the current Inventory report, 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 Monthly Energy Review (EIA 2015). Fuel consumption data for coal, natural gas, and fuel oil for the United States were also obtained from EIA's Monthly Energy Review and unpublished supplemental tables on petroleum product detail (EIA 2015). Because the United States does not include territories in its national energy statistics, fuel consumption data for territories were provided separately by EIA's International Energy Statistics (EIA 2013) and Jacobs (2010).[44] Fuel consumption for the industrial sector was adjusted to subtract out construction and agricultural use, which is reported under mobile sources.[45] Construction and agricultural fuel use

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

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

44 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.

45 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.

was obtained from EPA (2014). 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

The electric power sector now uses a Tier 2 emission estimation methodology as fuel consumption for the electricity generation sector by control-technology type was obtained from EPA's Acid Rain Program Dataset (EPA 2014a). This combustion technology- and fuel-use data was available by facility from 1996 to 2013 The Tier 2 emission factors used were taken from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006), which in turn are based on emission factors published by EPA.

Since there was a difference between the EPA (2014a) and EIA (2015) total energy consumption estimates, the remaining energy consumption from EIA (2015) was apportioned to each combustion technology type and fuel combination using a ratio of energy consumption by technology type from 1996 to 2013.

Energy consumption estimates were not available from 1990 to 1995 in the EPA (2014a) dataset, and as a result, consumption was calculated using total electric power consumption from EIA (2015) and the ratio of combustion technology and fuel types from EPA (2015). 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 (2014a) and EIA (2015) datasets. The higher wood biomass consumption from EIA (2015) 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 (2015).

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 Approach 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.[46] For these variables, the uncertainty

[46] 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

ranges were assigned to the input variables based on the data reported in SAIC/EIA (2001).[47] However, the CH_4 emission factors differ from those used by EIA. These factors and uncertainty ranges are based on IPCC default uncertainty estimates (IPCC 2006).

The results of the Approach 2 quantitative uncertainty analysis are summarized in Table 3-17. Stationary combustion CH_4 emissions in 2013 (*including* biomass) were estimated to be between 4.6 and 20.4 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 42 percent below to 157 percent above the 2013 emission estimate of 8.0 MMT CO_2 Eq.[48] Stationary combustion N_2O emissions in 2013 (*including* biomass) were estimated to be between 16.8 and 32.0 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 27 percent below to 40 percent above the 2013 emissions estimate of 22.9 MMT CO_2 Eq.

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

Source	Gas	2013 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Stationary Combustion	CH_4	8.0	4.6	20.4	-42%	+157%
Stationary Combustion	N_2O	22.9	16.8	32.0	-27%	+40%

[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 2013. 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

For the current Inventory, emission estimates have been revised to reflect the GWPs provided in the *IPCC Fourth Assessment Report* (AR4) (IPCC 2007). AR4 GWP values differ slightly from those presented in the *IPCC Second Assessment Report* (SAR) (IPCC 1996) (used in the previous Inventories) which results in time-series recalculations

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.

[47] 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.

[48] 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.

for most inventory sources. Under the most recent reporting guidelines (UNFCCC 2014), countries are required to report using the AR4 GWPs, which reflect an updated understanding of the atmospheric properties of each greenhouse gas. The GWPs of CH_4 and most fluorinated greenhouse gases have increased, leading to an overall increase in emissions from CH_4, HFCs, and PFCs. The GWPs of N_2O and SF_6 have decreased, leading to a decrease in emissions. The AR4 GWPs have been applied across the entire time series for consistency. For more information please see the Recalculations and Improvements Chapter.

Methane and N_2O emissions from stationary sources (excluding CO_2) across the entire time series were revised due revised data from EIA (2015) and EPA (2014a) relative to the previous Inventory. In addition, with the adoption of new GWPs, the entire time series from 1990 through 2012 decreased. The historical data changes resulted in an average annual decrease of 0.3 MMT CO_2 Eq. (4 percent) in CH_4 emissions from stationary combustion and an average annual increase of less than 0.2 MMT CO_2 Eq. (1 percent) in N_2O emissions from stationary combustion for the period 1990 through 2012.

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.

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.[49]

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) are based on VMT and emission factors by vehicle and fuel type.[50]

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

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

50 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.

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.[51]

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 2013 were obtained from the Federal Highway Administration's (FHWA) Highway Performance Monitoring System database as reported in Highway Statistics (FHWA 1996 through 2014).[52] 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 2014) and information on total motor vehicle fuel consumption by fuel type from FHWA (1996 through 2014). VMT for AFVs were estimated based on Browning (2003) and Browning (2015). The age distributions of the U.S. vehicle fleet were obtained from EPA (2013c, 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 (1994a, 1994b, 1998, 1999a) and IPCC (2006).

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).[53] Activity data were obtained from AAR (2008 through 2013), APTA (2007 through 2013), APTA (2006), BEA (1991 through 2013), Benson (2002 through 2004), DHS (2008), DLA Energy (2014), DOC (1991 through 2013), DOE (1993 through 2013), DOT (1991 through 2013), EIA (2002, 2008, 2007, 2014), EIA (2007 through 2015), EIA (1991 through 2014), EPA (2014d), Esser (2003 through 2004), FAA (2015), FHWA (1996 through 2014), Gaffney (2007), and Whorton (2006 through 2013). Emission factors for non-road modes were taken from IPCC (2006) and Browning (2009).

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

[52] The source of VMT is FHWA's VM-1 table. In 2011, FHWA changed its methods for estimating data in the VM-1 table. These methodological changes included how vehicles are classified, moving from a system based on body-type to one that is based on wheelbase. These changes were first incorporated for the 2010 Inventory and apply to the 2007-12 time period. This resulted in large changes in VMT by vehicle class, thus leading to a shift in emissions among on-road vehicle classes. For example, the category "Passenger Cars" has been replaced by "Light-duty Vehicles-Short Wheelbase" and "Other 2 axle-4 Tire Vehicles" has been replaced by "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.

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

Uncertainty and Time-Series Consistency

A quantitative uncertainty analysis was conducted for the mobile source sector using the IPCC-recommended Approach 2 uncertainty estimation methodology, Monte Carlo Stochastic Simulation technique, using @RISK software. The uncertainty analysis was performed on 2013 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) 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. For more information, see Section 3.8. However, a much higher level of uncertainty is associated with CH_4 and N_2O emission factors due to limited 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 2013 were estimated to be between 1.9 and 2.6 MMT CO_2 Eq. at a 95 percent confidence level. This indicates a range of 13 percent below to 21 percent above the corresponding 2013 emission estimate of 2.1 MMT CO_2 Eq. Also at a 95 percent confidence level, mobile combustion N_2O emissions from mobile sources in 2013 were estimated to be between 16.6 and 22.1 MMT CO_2 Eq., indicating a range of 10 percent below to 20 percent above the corresponding 2013 emission estimate of 18.4 MMT CO_2 Eq.

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

Source	Gas	2013 Emission Estimate[a] (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Mobile Sources	CH_4	2.1	1.9	2.6	-13%	+21%
Mobile Sources	N_2O	18.4	16.6	22.1	-10%	+20%

[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 Approach 2 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 2013. 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.