

# Executive Summary

An emissions inventory that identifies and quantifies a country's primary anthropogenic<sup>1</sup> 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.”<sup>2</sup>

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...”<sup>3</sup> 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 2014. 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.<sup>4</sup>

## 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 gross emissions total presented in this report for the United States excludes emissions and sinks from LULUCF. The net emissions total presented in this report for the United States includes emissions and sinks from LULUCF. All emissions and sinks are calculated using internationally-accepted methods provided by the

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<sup>1</sup> 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).

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

<sup>3</sup> 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>>.

<sup>4</sup> See <<http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf>>.

IPCC.<sup>5</sup> 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.<sup>6</sup> 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 from large greenhouse gas 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 carbon dioxide (CO<sub>2</sub>) underground for sequestration or other reasons.<sup>7</sup> 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.

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## ES.1. Background Information

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Greenhouse gases trap heat and make the planet warmer. The most important greenhouse gases directly emitted by humans include CO<sub>2</sub>, methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and several other fluorine-containing halogenated substances. Although the direct greenhouse gases CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O occur naturally in the atmosphere, human activities have changed their atmospheric concentrations. From the pre-industrial era (i.e., ending about 1750) to 2014, concentrations of these greenhouse gases have increased globally by 43, 160, and 21 percent, respectively (IPCC 2013 and NOAA/ESRL 2016). 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).<sup>8</sup> 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<sub>2</sub>, and therefore GWP-

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

<sup>6</sup> See <<http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf#page=2>>.

<sup>7</sup> See <<http://www.epa.gov/ghgreporting>> and <<http://ghgdata.epa.gov/ghgp/main.do>>.

<sup>8</sup> 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.

weighted emissions are measured in million metric tons of CO<sub>2</sub> equivalent (MMT CO<sub>2</sub> Eq.).<sup>9,10</sup> All gases in this Executive Summary are presented in units of MMT CO<sub>2</sub> Eq. Emissions by gas in unweighted mass tons are provided in the Trends chapter of this report.

UNFCCC reporting guidelines for national inventories require the use of GWP values from the *IPCC Fourth Assessment Report (AR4)* (IPCC 2007).<sup>11</sup> 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 *IPCC Second Assessment Report (SAR)* (IPCC 1996) GWP values in the Inventory. All estimates are provided throughout the report in both CO<sub>2</sub> equivalents and unweighted units. A comparison of emission values using the AR4 GWP values versus the SAR (IPCC 1996), 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.

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

Gas	GWP
CO <sub>2</sub>	1
CH <sub>4</sub> <sup>a</sup>	25
N <sub>2</sub> O	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 <sub>4</sub>	7,390
C <sub>2</sub> F <sub>6</sub>	12,200
C <sub>4</sub> F <sub>10</sub>	8,860
C <sub>6</sub> F <sub>14</sub>	9,300
SF <sub>6</sub>	22,800
NF <sub>3</sub>	17,200

Source: IPCC (2007)

<sup>a</sup> The CH<sub>4</sub> 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<sub>2</sub> is not included.

<sup>9</sup> Carbon comprises 12/44 of carbon dioxide by weight.

<sup>10</sup> One teragram is equal to 10<sup>12</sup> grams or one million metric tons.

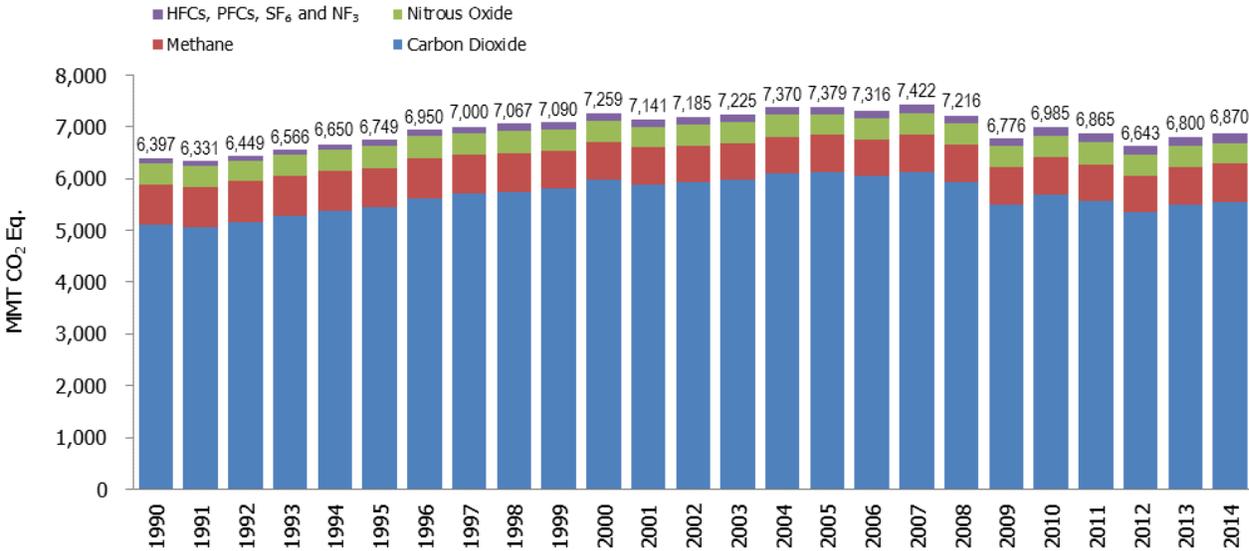
<sup>11</sup> See <<http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf>>.

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

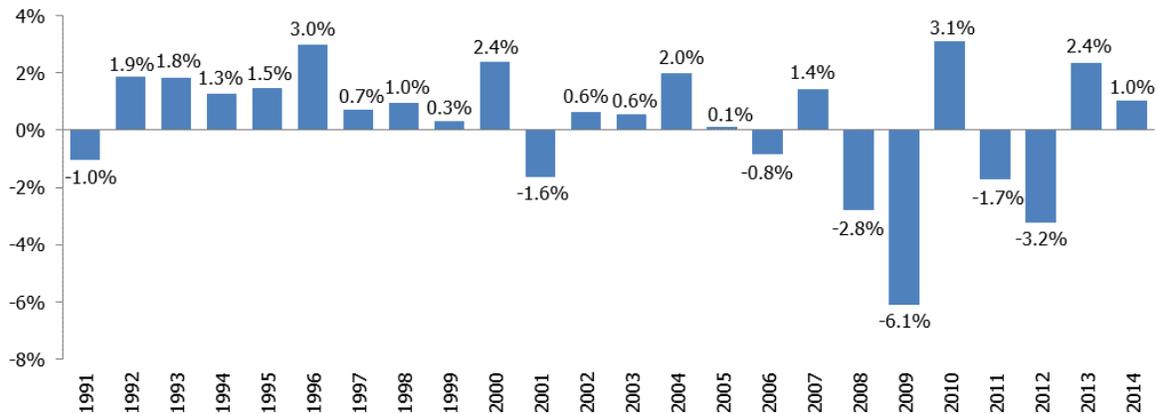
In 2014, total U.S. greenhouse gas emissions were 6,870.5 MMT or million metric tons CO<sub>2</sub> Eq. Total U.S. emissions have increased by 7.4 percent from 1990 to 2014, and emissions increased from 2013 to 2014 by 1.0 percent (70.5 MMT CO<sub>2</sub> Eq.). In 2014, relatively cool winter conditions led to an increase in fuels for the residential and commercial sectors for heating. Additionally, transportation emissions increased as a result of a small increase in vehicle miles traveled (VMT) and fuel use across on-road transportation modes. There also was an increase in industrial production across multiple sectors resulting in slight increases in industrial sector emissions. Lastly, 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. Overall, net emissions in 2014 were 8.6 percent below 2005 levels as shown in Table ES-2.

Table ES-2 provides a detailed summary of U.S. greenhouse gas emissions and sinks for 1990 through 2014.

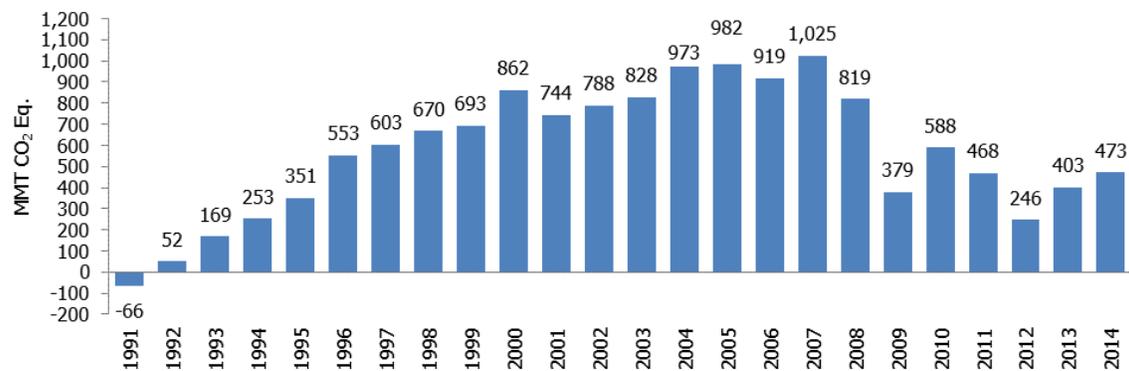
**Figure ES-1: U.S. Greenhouse Gas Emissions by Gas (MMT CO<sub>2</sub> Eq.)**



**Figure ES-2: Annual Percent Change in U.S. Greenhouse Gas Emissions Relative to the Previous Year**



**Figure ES-3: Cumulative Change in Annual U.S. Greenhouse Gas Emissions Relative to 1990 (1990=0, MMT CO<sub>2</sub> Eq.)**



**Table ES-2: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (MMT CO<sub>2</sub> Eq.)**

Gas/Source	1990	2005	2010	2011	2012	2013	2014
<b>CO<sub>2</sub></b>	<b>5,115.1</b>	<b>6,122.7</b>	<b>5,688.8</b>	<b>5,559.5</b>	<b>5,349.2</b>	<b>5,502.6</b>	<b>5,556.0</b>
Fossil Fuel Combustion	4,740.7	5,747.1	5,358.3	5,227.7	5,024.7	5,157.6	5,208.2
<i>Electricity Generation</i>	1,820.8	2,400.9	2,258.4	2,157.7	2,022.2	2,038.1	2,039.3
<i>Transportation</i>	1,493.8	1,887.0	1,728.3	1,707.6	1,696.8	1,713.0	1,737.6
<i>Industrial</i>	842.5	828.0	775.5	773.3	782.9	812.2	813.3
<i>Residential</i>	338.3	357.8	334.6	326.8	282.5	329.7	345.1
<i>Commercial</i>	217.4	223.5	220.1	220.7	196.7	221.0	231.9
<i>U.S. Territories</i>	27.9	49.9	41.4	41.5	43.6	43.5	41.0
Non-Energy Use of Fuels	118.1	138.9	114.1	108.5	105.6	121.7	114.3
Iron and Steel Production & Metallurgical Coke Production	99.7	66.5	55.7	59.9	54.2	52.2	55.4
Natural Gas Systems	37.7	30.1	32.4	35.7	35.2	38.5	42.4
Cement Production	33.3	45.9	31.3	32.0	35.1	36.1	38.8
Petrochemical Production	21.6	27.4	27.2	26.3	26.5	26.4	26.5
Lime Production	11.7	14.6	13.4	14.0	13.7	14.0	14.1

Other Process Uses of Carbonates	4.9	6.3	9.6	9.3	8.0	10.4	12.1
Ammonia Production	13.0	9.2	9.2	9.3	9.4	10.0	9.4
Incineration of Waste	8.0	12.5	11.0	10.5	10.4	9.4	9.4
Carbon Dioxide Consumption	1.5	1.4	4.4	4.1	4.0	4.2	4.5
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	4.7	4.0	4.4	4.2	4.0
Petroleum Systems	3.6	3.9	4.2	4.2	3.9	3.7	3.6
Aluminum Production	6.8	4.1	2.7	3.3	3.4	3.3	2.8
Soda Ash Production and Consumption	2.8	3.0	2.7	2.7	2.8	2.8	2.8
Ferroalloy Production	2.2	1.4	1.7	1.7	1.9	1.8	1.9
Titanium Dioxide Production	1.2	1.8	1.8	1.7	1.5	1.7	1.8
Glass Production	1.5	1.9	1.5	1.3	1.2	1.3	1.3
Phosphoric Acid Production	1.5	1.3	1.1	1.2	1.1	1.1	1.1
Zinc Production	0.6	1.0	1.2	1.3	1.5	1.4	1.0
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
Magnesium Production and Processing	+	+	+	+	+	+	+
Wood Biomass and Ethanol Consumption <sup>a</sup>	219.4	229.8	265.1	268.1	267.7	286.3	293.7
International Bunker Fuels <sup>b</sup>	103.5	113.1	117.0	111.7	105.8	99.8	103.2
<b>CH<sub>4</sub></b>	<b>773.9</b>	<b>717.4</b>	<b>722.4</b>	<b>717.4</b>	<b>714.4</b>	<b>721.5</b>	<b>730.8</b>
Natural Gas Systems	206.8	177.3	166.2	170.1	172.6	175.6	176.1
Enteric Fermentation	164.2	168.9	171.3	168.9	166.7	165.5	164.3
Landfills	179.6	154.0	142.1	144.4	142.3	144.3	148.0
Petroleum Systems	38.7	48.8	54.1	56.3	58.4	64.7	68.1
Coal Mining	96.5	64.1	82.3	71.2	66.5	64.6	67.6
Manure Management	37.2	56.3	60.9	61.5	63.7	61.4	61.2
Wastewater Treatment	15.7	15.9	15.5	15.3	15.0	14.8	14.7
Rice Cultivation	13.1	13.0	11.9	11.8	11.9	11.9	11.9
Stationary Combustion	8.5	7.4	7.1	7.1	6.6	8.0	8.1
Abandoned Underground Coal Mines	7.2	6.6	6.6	6.4	6.2	6.2	6.3
Composting	0.4	1.9	1.8	1.9	1.9	2.0	2.1
Mobile Combustion	5.6	2.7	2.3	2.2	2.2	2.1	2.0
Field Burning of Agricultural Residues	0.2	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	+	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels <sup>b</sup>	0.2	0.1	0.1	0.1	0.1	0.1	0.1
<b>N<sub>2</sub>O</b>	<b>406.2</b>	<b>397.6</b>	<b>410.3</b>	<b>416.5</b>	<b>409.3</b>	<b>403.4</b>	<b>403.5</b>
Agricultural Soil Management	303.3	297.2	320.7	323.1	323.1	318.6	318.4
Stationary Combustion	11.9	20.2	22.2	21.3	21.4	22.9	23.4
Manure Management	14.0	16.5	17.2	17.4	17.5	17.5	17.5
Mobile Combustion	41.2	34.4	23.6	22.4	20.0	18.2	16.3
Nitric Acid Production	12.1	11.3	11.5	10.9	10.5	10.7	10.9
Adipic Acid Production	15.2	7.1	4.2	10.2	5.5	4.0	5.4

Wastewater Treatment	3.4	4.3	4.5	4.7	4.8	4.8	4.8
N <sub>2</sub> O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Composting	0.3	1.7	1.6	1.7	1.7	1.8	1.8
Incineration of Waste	0.5	0.4	0.3	0.3	0.3	0.3	0.3
Semiconductor Manufacture	+	0.1	0.1	0.2	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
<i>International Bunker Fuels<sup>b</sup></i>	<i>0.9</i>	<i>1.0</i>	<i>1.0</i>	<i>1.0</i>	<i>0.9</i>	<i>0.9</i>	<i>0.9</i>
<b>HFCs</b>	<b>46.6</b>	<b>119.9</b>	<b>149.4</b>	<b>154.3</b>	<b>155.9</b>	<b>158.9</b>	<b>166.7</b>
Substitution of Ozone Depleting Substances <sup>c</sup>	0.3	99.7	141.2	145.3	150.2	154.6	161.2
HCFC-22 Production	46.1	20.0	8.0	8.8	5.5	4.1	5.0
Semiconductor Manufacture	0.2	0.2	0.2	0.2	0.2	0.2	0.3
Magnesium Production and Processing	0.0	0.0	+	+	+	0.1	0.1
<b>PFCs</b>	<b>24.3</b>	<b>6.7</b>	<b>4.5</b>	<b>7.0</b>	<b>6.0</b>	<b>5.8</b>	<b>5.6</b>
Semiconductor Manufacture	2.8	3.2	2.7	3.5	3.1	2.9	3.0
Aluminum Production	21.5	3.4	1.9	3.5	2.9	3.0	2.5
<b>SF<sub>6</sub></b>	<b>31.1</b>	<b>14.0</b>	<b>9.5</b>	<b>10.0</b>	<b>7.6</b>	<b>7.2</b>	<b>7.3</b>
Electrical Transmission and Distribution	25.4	10.6	7.0	6.8	5.6	5.4	5.6
Magnesium Production and Processing	5.2	2.7	2.1	2.8	1.6	1.5	1.0
Semiconductor Manufacture	0.5	0.7	0.4	0.4	0.4	0.4	0.7
<b>NF<sub>3</sub></b>	<b>+</b>	<b>0.5</b>	<b>0.6</b>	<b>0.7</b>	<b>0.6</b>	<b>0.6</b>	<b>0.5</b>
Semiconductor Manufacture	+	0.5	0.6	0.7	0.6	0.6	0.5
<b>Total Emissions</b>	<b>6,397.1</b>	<b>7,378.8</b>	<b>6,985.5</b>	<b>6,865.4</b>	<b>6,643.0</b>	<b>6,800.0</b>	<b>6,870.5</b>
<b>LULUCF Emissions<sup>d</sup></b>	<b>15.0</b>	<b>28.2</b>	<b>17.8</b>	<b>22.9</b>	<b>32.3</b>	<b>24.1</b>	<b>24.6</b>
<b>LULUCF Total Net Flux<sup>e</sup></b>	<b>(753.0)</b>	<b>(726.7)</b>	<b>(784.3)</b>	<b>(784.9)</b>	<b>(782.0)</b>	<b>(783.7)</b>	<b>(787.0)</b>
<b>LULUCF Sector Total<sup>f</sup></b>	<b>(738.0)</b>	<b>(698.5)</b>	<b>(766.4)</b>	<b>(762.0)</b>	<b>(749.7)</b>	<b>(759.6)</b>	<b>(762.5)</b>
<b>Net Emissions (Sources and Sinks)</b>	<b>5,659.2</b>	<b>6,680.3</b>	<b>6,219.0</b>	<b>6,103.4</b>	<b>5,893.3</b>	<b>6,040.4</b>	<b>6,108.0</b>

Notes: Total emissions presented without LULUCF. Net emissions presented with LULUCF.

+ Does not exceed 0.05 MMT CO<sub>2</sub> Eq.

<sup>a</sup> 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.

<sup>b</sup> Emissions from International Bunker Fuels are not included in totals.

<sup>c</sup> Small amounts of PFC emissions also result from this source.

<sup>d</sup> LULUCF emissions include the CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions reported for Non-CO<sub>2</sub> Emissions from Forest Fires, N<sub>2</sub>O Fluxes from Forest Soils, CO<sub>2</sub> Emissions from Agricultural Liming, CO<sub>2</sub> Emissions from Urea Fertilization, Peatlands Remaining Peatlands, and N<sub>2</sub>O Fluxes from Settlement Soils.

<sup>e</sup> Net CO<sub>2</sub> flux is the net C stock change from the following categories: *Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Settlements Remaining Settlements, and Other*. 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.

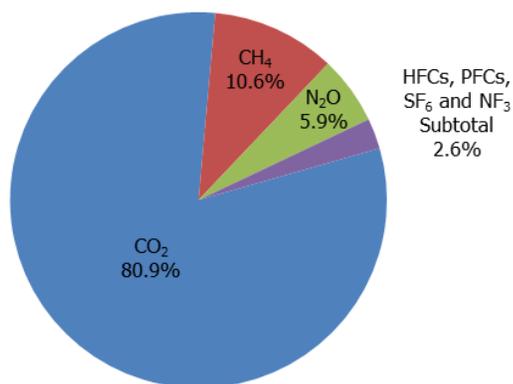
<sup>f</sup> The LULUCF Sector Total is the net sum of all emissions (i.e., sources) of greenhouse gases to the atmosphere plus removals of CO<sub>2</sub> (i.e., sinks or negative emissions) from the atmosphere.

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

Figure ES-4 illustrates the relative contribution of the direct greenhouse gases to total U.S. emissions in 2014. Note, unless otherwise stated, all tables and figures provide total emissions without LULUCF. The primary greenhouse gas emitted by human activities in the United States was CO<sub>2</sub>, representing approximately 80.9 percent of total greenhouse gas emissions. The largest source of CO<sub>2</sub>, and of overall greenhouse gas emissions, was fossil fuel combustion. CH<sub>4</sub> emissions, which have decreased by 5.6 percent since 1990, resulted primarily from decomposition of wastes in landfills, enteric fermentation associated with domestic livestock, and natural gas systems. Agricultural soil management, manure management, mobile source fuel combustion and stationary fuel

combustion were the major sources of N<sub>2</sub>O emissions. Ozone depleting substance substitute emissions and emissions of HFC-23 during the production of HCFC-22 were the primary contributors to aggregate hydrofluorocarbon (HFC) emissions. Perfluorocarbon (PFC) emissions resulted as a byproduct of primary aluminum production and from semiconductor manufacturing, electrical transmission and distribution systems accounted for most sulfur hexafluoride (SF<sub>6</sub>) emissions, and semiconductor manufacturing is the only source of nitrogen trifluoride (NF<sub>3</sub>) emissions.

**Figure ES-4: 2014 U.S. Greenhouse Gas Emissions by Gas (Percentages based on MMT CO<sub>2</sub> Eq.)**



Overall, from 1990 to 2014, total emissions of CO<sub>2</sub> increased by 440.9 MMT CO<sub>2</sub> Eq. (8.6 percent), while total emissions of CH<sub>4</sub> decreased by 43.0 MMT CO<sub>2</sub> Eq. (5.6 percent), and N<sub>2</sub>O decreased by 2.7 MMT CO<sub>2</sub> Eq. (0.7 percent). During the same period, aggregate weighted emissions of HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub> rose by 78.1 MMT CO<sub>2</sub> Eq. (76.6 percent). From 1990 to 2014, HFCs increased by 120.1 MMT CO<sub>2</sub> Eq. (257.9 percent), PFCs decreased by 18.7 MMT CO<sub>2</sub> Eq. (77.1 percent), SF<sub>6</sub> decreased by 23.7 MMT CO<sub>2</sub> Eq. (76.4 percent), and NF<sub>3</sub> increased by 0.4 MMT CO<sub>2</sub> Eq. (923.4 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub> are significant because many of these gases have extremely high global warming potentials and, in the cases of PFCs and SF<sub>6</sub>, long atmospheric lifetimes. Conversely, U.S. greenhouse gas emissions were partly offset by carbon (C) sequestration in forests, trees in urban areas, agricultural soils, and landfilled yard trimmings and food scraps, which, in aggregate, offset 11.5 percent of total emissions in 2014. The following sections describe each gas’s contribution to total U.S. greenhouse gas emissions in more detail.

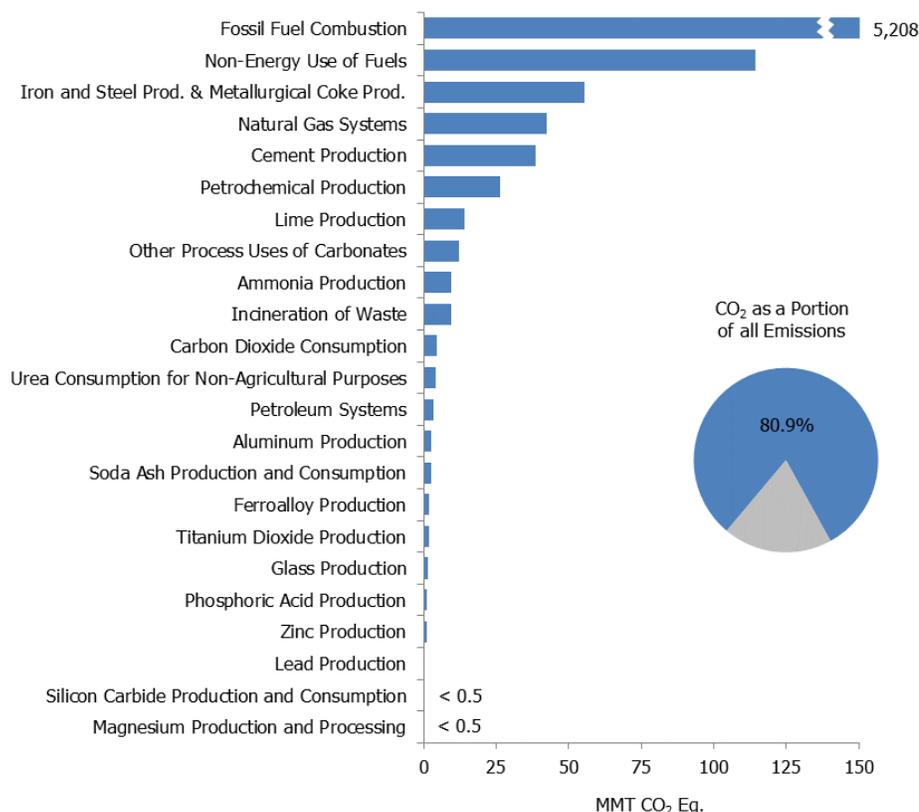
## Carbon Dioxide Emissions

The global carbon cycle is made up of large carbon flows and reservoirs. Billions of tons of carbon in the form of CO<sub>2</sub> 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.<sup>12</sup> Since the Industrial Revolution (i.e., about 1750), global atmospheric concentrations of CO<sub>2</sub> have risen approximately 43 percent (IPCC 2013 and NOAA/ESRL 2016), principally due to the combustion of fossil fuels. Within the United States, fossil fuel combustion accounted for 93.7 percent of CO<sub>2</sub> emissions in 2014. Globally,

<sup>12</sup> The term “flux” is used to describe the net emissions of greenhouse gases accounting for both the emissions of CO<sub>2</sub> to and the removals of CO<sub>2</sub> from the atmosphere. Removal of CO<sub>2</sub> from the atmosphere is also referred to as “carbon sequestration.”

approximately 32,190 MMT of CO<sub>2</sub> were added to the atmosphere through the combustion of fossil fuels in 2013, of which the United States accounted for approximately 16 percent.<sup>13</sup> Changes in land use and forestry practices can also emit CO<sub>2</sub> (e.g., through conversion of forest land to agricultural or urban use) or can act as a sink for CO<sub>2</sub> (e.g., through net additions to forest biomass). Although fossil fuel combustion is the greatest source of CO<sub>2</sub> emissions, there are 22 additional sources of CO<sub>2</sub> emissions (Figure ES-5).

**Figure ES-5: 2014 Sources of CO<sub>2</sub> Emissions (MMT CO<sub>2</sub> Eq.)**



Note: Fossil Fuel Combustion includes electricity generation, which also includes emissions of less than 0.05 MMT CO<sub>2</sub> Eq. from geothermal-based generation.

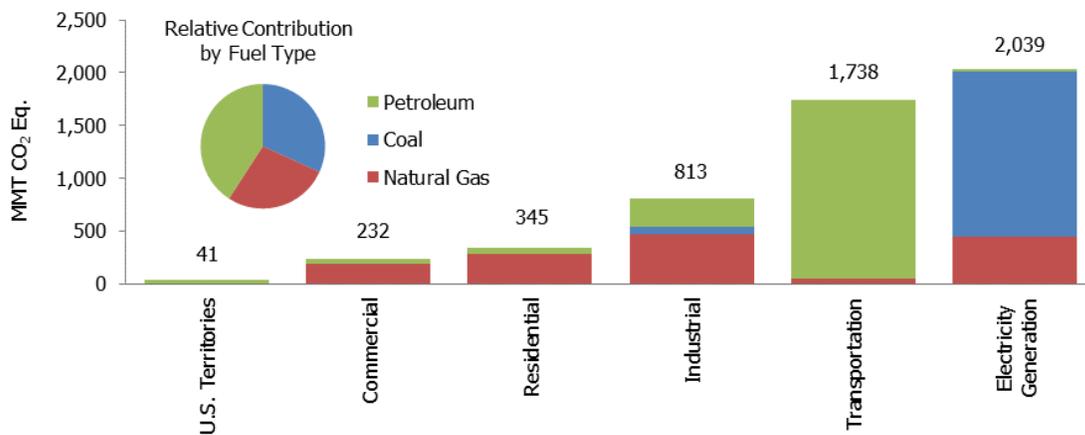
As the largest source of U.S. greenhouse gas emissions, CO<sub>2</sub> from fossil fuel combustion has accounted for approximately 76 percent of GWP-weighted emissions since 1990, and is approximately 76 percent of total GWP-weighted emissions in 2014. Emissions of CO<sub>2</sub> from fossil fuel combustion increased at an average annual rate of 0.4 percent from 1990 to 2014. The fundamental factors influencing this trend include (1) a generally growing domestic economy over the last 25 years, (2) an overall growth in emissions from electricity generation and transportation activities, and (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 2014, CO<sub>2</sub> emissions from fossil fuel combustion increased from 4,740.7 MMT CO<sub>2</sub> Eq. to 5,208.2 MMT CO<sub>2</sub> Eq., a 9.9 percent total increase over the twenty-five-year period. From 2013 to 2014, these emissions increased by 50.6 MMT CO<sub>2</sub> Eq. (1.0 percent).

Historically, changes in emissions from fossil fuel combustion have been the dominant factor affecting U.S. emission trends. Changes in CO<sub>2</sub> 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,

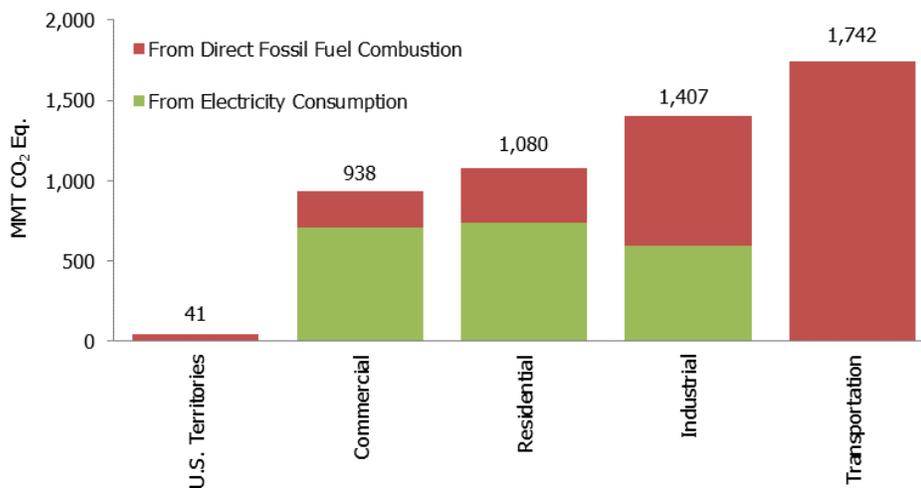
<sup>13</sup> Global CO<sub>2</sub> emissions from fossil fuel combustion were taken from International Energy Agency *CO<sub>2</sub> Emissions from Fossil Fuels Combustion – Highlights* (2015). See <<https://www.iea.org/publications/freepublications/publication/CO2EmissionsFromFuelCombustionHighlights2015.pdf>>.

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: 2014 CO<sub>2</sub> Emissions from Fossil Fuel Combustion by Sector and Fuel Type (MMT CO<sub>2</sub> Eq.)**



**Figure ES-7: 2014 End-Use Sector Emissions of CO<sub>2</sub> from Fossil Fuel Combustion (MMT CO<sub>2</sub> Eq.)**



The five major fuel consuming sectors contributing to CO<sub>2</sub> emissions from fossil fuel combustion are electricity generation, transportation, industrial, residential, and commercial. CO<sub>2</sub> 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<sub>2</sub> emissions from fossil fuel combustion by end-use sector.

**Table ES-3: CO<sub>2</sub> Emissions from Fossil Fuel Combustion by End-Use Sector (MMT CO<sub>2</sub> Eq.)**

End-Use Sector	1990	2005	2010	2011	2012	2013	2014
<b>Transportation</b>	<b>1,496.8</b>	<b>1,891.8</b>	<b>1,732.7</b>	<b>1,711.9</b>	<b>1,700.6</b>	<b>1,717.0</b>	<b>1,741.7</b>
Combustion	1,493.8	1,887.0	1,728.3	1,707.6	1,696.8	1,713.0	1,737.6
Electricity	3.0	4.7	4.5	4.3	3.9	4.0	4.1
<b>Industrial</b>	<b>1,529.2</b>	<b>1,564.6</b>	<b>1,416.5</b>	<b>1,398.0</b>	<b>1,375.7</b>	<b>1,407.0</b>	<b>1,406.8</b>
Combustion	842.5	828.0	775.5	773.3	782.9	812.2	813.3
Electricity	686.7	736.6	641.0	624.7	592.8	594.7	593.6
<b>Residential</b>	<b>931.4</b>	<b>1,214.1</b>	<b>1,174.6</b>	<b>1,117.5</b>	<b>1,007.8</b>	<b>1,064.6</b>	<b>1,080.3</b>
Combustion	338.3	357.8	334.6	326.8	282.5	329.7	345.1
Electricity	593.0	856.3	840.0	790.7	725.3	734.9	735.2
<b>Commercial</b>	<b>755.4</b>	<b>1,026.8</b>	<b>993.0</b>	<b>958.8</b>	<b>897.0</b>	<b>925.5</b>	<b>938.4</b>
Combustion	217.4	223.5	220.1	220.7	196.7	221.0	231.9
Electricity	538.0	803.3	772.9	738.0	700.3	704.5	706.5
<b>U.S. Territories<sup>a</sup></b>	<b>27.9</b>	<b>49.9</b>	<b>41.4</b>	<b>41.5</b>	<b>43.6</b>	<b>43.5</b>	<b>41.0</b>
<b>Total</b>	<b>4,740.7</b>	<b>5,747.1</b>	<b>5,358.3</b>	<b>5,227.7</b>	<b>5,024.7</b>	<b>5,157.6</b>	<b>5,208.2</b>
<b>Electricity Generation</b>	<b>1,820.8</b>	<b>2,400.9</b>	<b>2,258.4</b>	<b>2,157.7</b>	<b>2,022.2</b>	<b>2,038.1</b>	<b>2,039.3</b>

<sup>a</sup> 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.

Notes: Combustion-related emissions from electricity generation are allocated based on aggregate national electricity consumption by each end-use sector. Totals may not sum due to independent rounding.

*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<sub>2</sub> emissions from fossil fuel combustion in 2014. The largest sources of transportation CO<sub>2</sub> emissions in 2014 were passenger cars (42.4 percent), medium- and heavy-duty trucks (23.1 percent), light-duty trucks, which include sport utility vehicles, pickup trucks, and minivans (17.8 percent), commercial aircraft (6.6 percent), pipelines (2.7 percent), rail (2.6 percent), and ships and boats (1.6 percent). Annex 3.2 presents the total emissions from all transportation and mobile sources, including CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, and HFCs.

In terms of the overall trend, from 1990 to 2014, total transportation CO<sub>2</sub> emissions rose by 16 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 2014). The number of VMT by light-duty motor vehicles (i.e., passenger cars and light-duty trucks) increased 37 percent from 1990 to 2014, 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<sub>2</sub> 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<sub>2</sub> from fossil fuel combustion in 2014. 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<sub>2</sub> emissions from fossil fuel combustion in 2014. Both sectors relied heavily on electricity for meeting energy demands, with 68 and 75 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 16 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 39 percent of the CO<sub>2</sub> from fossil fuel combustion in 2014. 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 2014.<sup>14</sup> In addition, the coal used by electricity generators accounted for 93 percent of all coal consumed for energy in the United States in 2014.<sup>15</sup> 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 2014.<sup>16</sup> Across the time series, changes in electricity demand and the carbon intensity of fuels used for electricity generation have a significant impact on CO<sub>2</sub> emissions.

Other significant CO<sub>2</sub> trends included the following:

- Carbon dioxide emissions from non-energy use of fossil fuels decreased by 3.8 MMT CO<sub>2</sub> Eq. (3.2 percent) from 1990 through 2014. Emissions from non-energy uses of fossil fuels were 114.3 MMT CO<sub>2</sub> Eq. in 2014, which constituted 2.1 percent of total national CO<sub>2</sub> emissions, approximately the same proportion as in 1990.
- Carbon dioxide emissions from iron and steel production and metallurgical coke production have declined by 44.3 MMT CO<sub>2</sub> Eq. (44.5 percent) from 1990 through 2014, due to restructuring of the industry, technological improvements, and increased scrap steel utilization.
- Carbon dioxide emissions from ammonia production (9.4 MMT CO<sub>2</sub> Eq. in 2014) decreased by 3.6 MMT CO<sub>2</sub> Eq. (27.7 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.
- Total net flux from (i.e., net CO<sub>2</sub> removals) from Land Use, Land-Use Change, and Forestry increased by 34.1 MMT CO<sub>2</sub> Eq. (4.5 percent) from 1990 through 2014. This increase was primarily due to an increase in the rate of net C accumulation in forest and urban tree carbon stocks. 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.<sup>17</sup> 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 reviewed technical literature on CH<sub>4</sub> emissions and estimated CH<sub>4</sub> emissions

<sup>14</sup> See <[http://www.eia.gov/energyexplained/index.cfm?page=electricity\\_in\\_the\\_united\\_states](http://www.eia.gov/energyexplained/index.cfm?page=electricity_in_the_united_states)>.

<sup>15</sup> See Table 6.2 Coal Consumption by Sector of EIA 2016.

<sup>16</sup> See <[http://www.eia.gov/energyexplained/index.cfm?page=electricity\\_in\\_the\\_united\\_states](http://www.eia.gov/energyexplained/index.cfm?page=electricity_in_the_united_states)>.

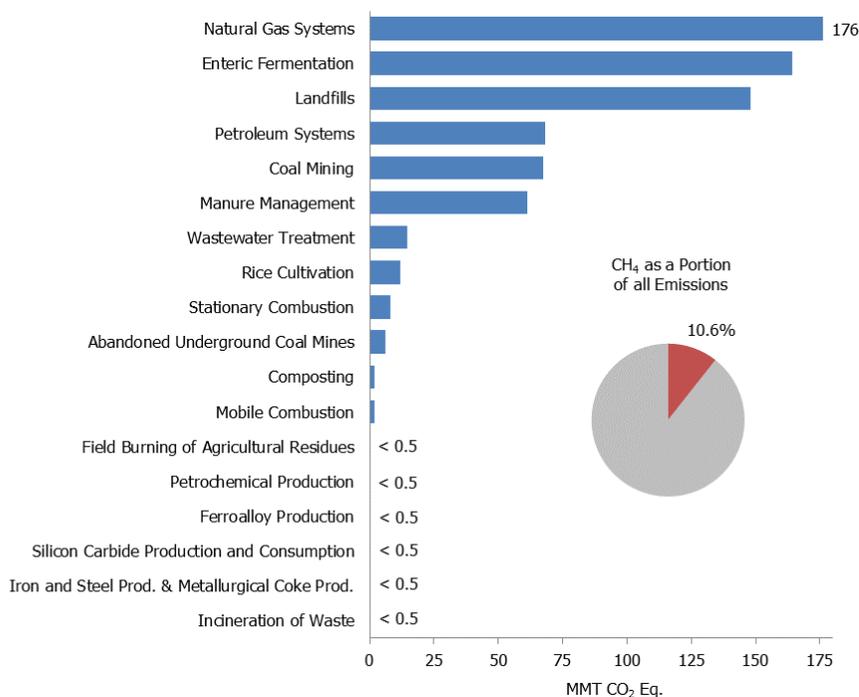
<sup>17</sup> See <<http://www.ipcc-nggip.iges.or.jp/public/index.html>>.

from all anthropogenic sources (e.g., livestock, oil and gas, waste emissions) to be greater than EPA’s estimate (Brandt et al. 2014). 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 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.<sup>18</sup>

## Methane Emissions

Methane (CH<sub>4</sub>) is 25 times as effective as CO<sub>2</sub> at trapping heat in the atmosphere (IPCC 2007). Over the last two hundred and fifty years, the concentration of CH<sub>4</sub> in the atmosphere increased by 160 percent (IPCC 2013 and CDIAC 2015). Anthropogenic sources of CH<sub>4</sub> 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: 2014 Sources of CH<sub>4</sub> Emissions (MMT CO<sub>2</sub> Eq.)**



Some significant trends in U.S. emissions of CH<sub>4</sub> include the following:

- Natural gas systems were the largest anthropogenic source category of CH<sub>4</sub> emissions in the United States in 2014 with 176.1 MMT CO<sub>2</sub> Eq. of CH<sub>4</sub> emitted into the atmosphere. Those emissions have decreased by 30.6 MMT CO<sub>2</sub> Eq. (14.8 percent) since 1990. The decrease in CH<sub>4</sub> emissions is largely due to the decrease in emissions from transmission, storage, and distribution. The decrease in transmission and storage

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

emissions is largely due to reduced compressor station emissions (including emissions from compressors and fugitives). The decrease in distribution emissions is largely attributed to increased use of plastic piping, which has lower emissions than other pipe materials, and station upgrades at metering and regulating (M&R) stations.

- Petroleum systems are the fourth anthropogenic source of CH<sub>4</sub> emissions in the United States (68.1 MMT CO<sub>2</sub> Eq.), accounting for 9.3 percent of total CH<sub>4</sub> emissions in 2014. From 1990 to 2014, CH<sub>4</sub> emissions from petroleum systems increased by 29.4 MMT CO<sub>2</sub> Eq. (or 76 percent). This increase is due primarily to increases in emissions from production equipment.
- Enteric fermentation is the second largest anthropogenic source of CH<sub>4</sub> emissions in the United States. In 2014, enteric fermentation CH<sub>4</sub> emissions were 164.3 MMT CO<sub>2</sub> Eq. (22.5 percent of total CH<sub>4</sub> emissions), which represents an increase of 0.1 MMT CO<sub>2</sub> Eq. (0.1 percent) since 1990. This increase in emissions from 1990 to 2014 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 2014 as beef cattle populations again decreased.
- Landfills are the third largest anthropogenic source of CH<sub>4</sub> emissions in the United States (148.0 MMT CO<sub>2</sub> Eq.), accounting for 20.2 percent of total CH<sub>4</sub> emissions in 2014. From 1990 to 2014, CH<sub>4</sub> emissions from landfills decreased by 31.6 MMT CO<sub>2</sub> Eq. (17.6 percent), with small increases occurring in some interim years. This downward trend in 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 2015b) and an increase in the amount of landfill gas collected and combusted (i.e., used for energy or flared),<sup>19</sup> which has more than offset the additional CH<sub>4</sub> emissions resulting from an increase in the amount of municipal solid waste landfilled.
- Methane emissions from manure management increased by 64.7 percent since 1990, from 37.2 MMT CO<sub>2</sub> Eq. in 1990 to 61.2 MMT CO<sub>2</sub> Eq. in 2014. 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<sub>4</sub> emissions. The increase in liquid systems is the combined result of a shift to larger facilities, and to facilities in the West and Southwest, all of which tend to use liquid systems. Also, new regulations limiting the application of manure nutrients have shifted manure management practices at smaller dairies from daily spread to manure managed and stored on site.

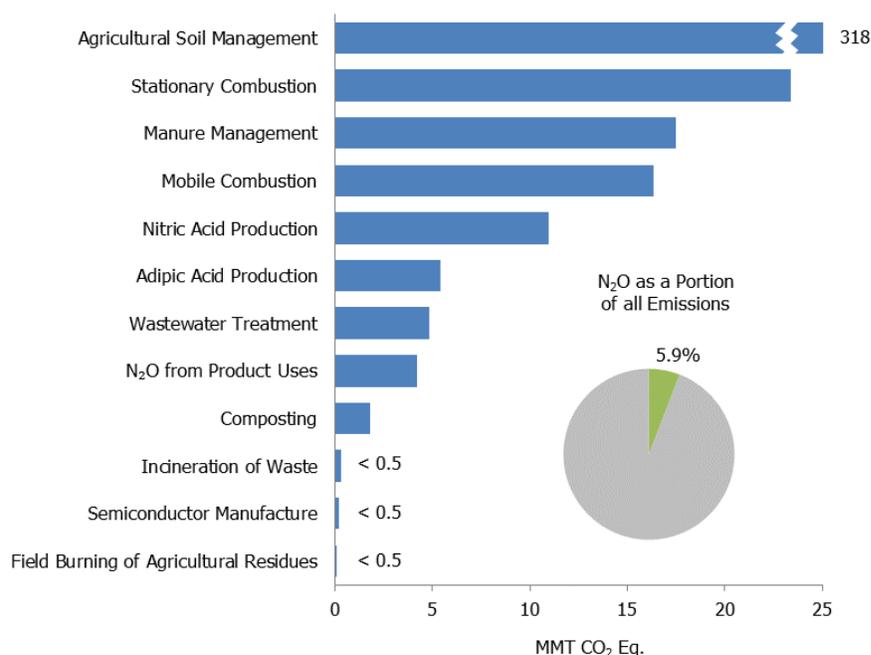
## Nitrous Oxide Emissions

Nitrous oxide (N<sub>2</sub>O) 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<sub>2</sub>O emissions are much lower than CO<sub>2</sub> emissions, N<sub>2</sub>O is approximately 300 times more powerful than CO<sub>2</sub> at trapping heat in the atmosphere (IPCC 2007). Since 1750, the global atmospheric concentration of N<sub>2</sub>O has risen by approximately 21 percent (IPCC 2013 and CDIAC 2015). The main anthropogenic activities producing N<sub>2</sub>O 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).

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<sup>19</sup> 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: 2014 Sources of N<sub>2</sub>O Emissions (MMT CO<sub>2</sub> Eq.)**



Some significant trends in U.S. emissions of N<sub>2</sub>O include the following:

- Agricultural soils accounted for approximately 78.9 percent of N<sub>2</sub>O emissions and 4.6 percent of total emissions in the United States in 2014. Estimated emissions from this source in 2014 were 318.4 MMT CO<sub>2</sub> Eq. Annual N<sub>2</sub>O emissions from agricultural soils fluctuated between 1990 and 2014, although overall emissions were 5.0 percent higher in 2014 than in 1990. Year-to-year fluctuations are largely a reflection of annual variation in weather patterns, synthetic fertilizer use, and crop production.
- Nitrous oxide emissions from stationary combustion increased 11.5 MMT CO<sub>2</sub> Eq. (96.4 percent) from 1990 through 2014. Nitrous oxide 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 2014, total N<sub>2</sub>O emissions from manure management were estimated to be 17.5 MMT CO<sub>2</sub> Eq.; emissions were 14.0 MMT CO<sub>2</sub> Eq. in 1990. These values include both direct and indirect N<sub>2</sub>O emissions from manure management. Nitrous oxide emissions have remained fairly steady since 1990. Small changes in N<sub>2</sub>O emissions from individual animal groups exhibit the same trends as the animal group populations, with the overall net effect that N<sub>2</sub>O emissions showed a 24.9 percent increase from 1990 to 2014 and a 0.1 percent decrease from 2013 through 2014. Overall shifts toward liquid systems have driven down the emissions per unit of nitrogen excreted.
- Nitrous oxide emissions from mobile combustion decreased 24.9 MMT CO<sub>2</sub> Eq. (60.4 percent) from 1990 through 2014, primarily as a result of N<sub>2</sub>O national emission control standards and emission control technologies for on-road vehicles.
- Nitrous oxide emissions from adipic acid production were 5.4 MMT CO<sub>2</sub> Eq. in 2014, 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 64.2 percent since 1990 and by 67.8 percent since a peak in 1995.

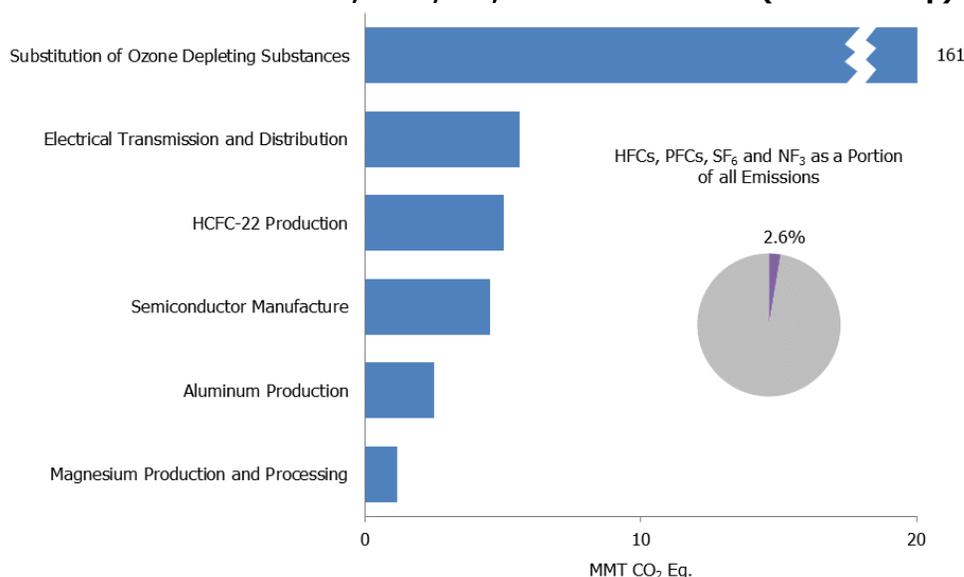
## HFC, PFC, SF<sub>6</sub>, and NF<sub>3</sub> Emissions

Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are families of synthetic chemicals that are used as alternatives to ozone depleting substances (ODS), which are being phased out under the Montreal Protocol and Clean Air Act Amendments of 1990. Hydrofluorocarbons and PFCs do not deplete the stratospheric ozone layer, and are therefore acceptable alternatives under the *Montreal Protocol on Substances that Deplete the Ozone Layer*.

These compounds, however, along with SF<sub>6</sub> and NF<sub>3</sub>, are potent greenhouse gases. In addition to having high global warming potentials, SF<sub>6</sub> 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: 2014 Sources of HFCs, PFCs, SF<sub>6</sub>, and NF<sub>3</sub> Emissions (MMT CO<sub>2</sub> Eq.)**



Some significant trends in U.S. HFC, PFC, SF<sub>6</sub>, and NF<sub>3</sub> emissions include the following:

- Emissions resulting from the substitution of ODS (e.g., chlorofluorocarbons [CFCs]) have been consistently increasing, from small amounts in 1990 to 161.2 MMT CO<sub>2</sub> Eq. in 2014. This increase was in large part the result of efforts to phase out CFCs and other ODS in the United States. In the short term, this trend is expected to continue, and will likely continue over the next decade as hydrochlorofluorocarbons (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<sub>6</sub>, and NF<sub>3</sub> emissions from semiconductor manufacture have increased by 27.4 percent from 1990 to 2014, due to industrial growth and the adoption of emission reduction technologies. Within that time span, emissions peaked in 1999, the initial year of EPA's PFC Reduction/Climate Partnership for the Semiconductor Industry, but have since declined to 4.5 MMT CO<sub>2</sub> Eq. in 2014 (a 49.8 percent decrease relative to 1999).
- Sulfur hexafluoride emissions from electric power transmission and distribution systems decreased by 77.9 percent (19.8 MMT CO<sub>2</sub> Eq.) from 1990 to 2014. There are two potential causes for this decrease: (1) a sharp increase in the price of SF<sub>6</sub> during the 1990s and (2) a growing awareness of the environmental

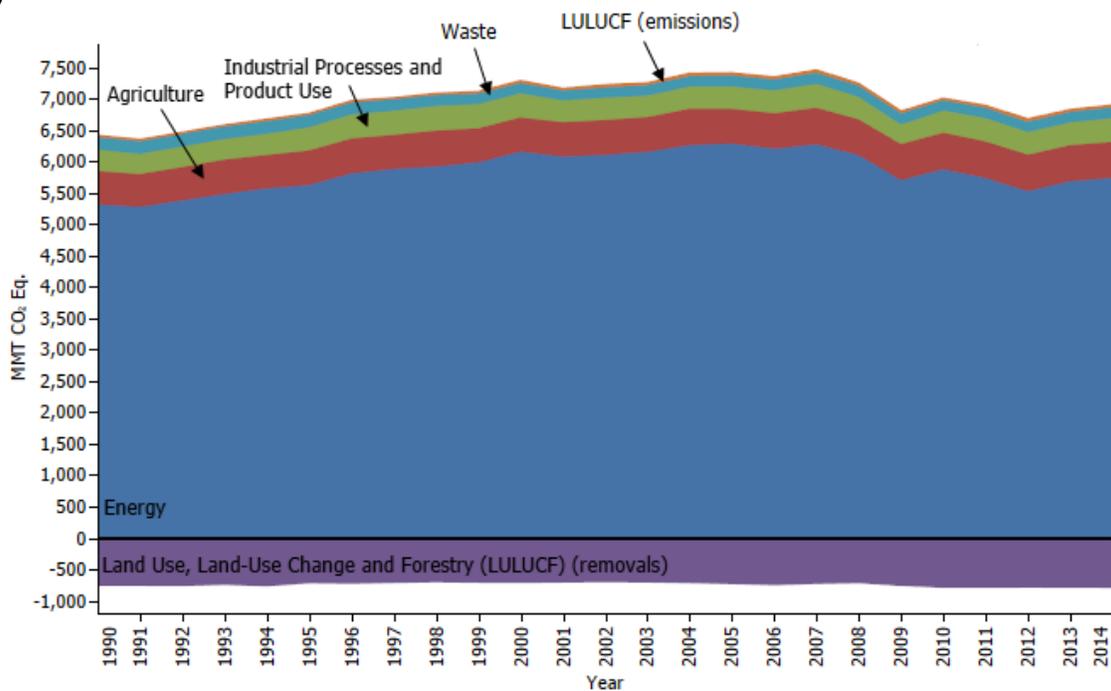
impact of SF<sub>6</sub> emissions through programs such as EPA’s SF<sub>6</sub> Emission Reduction Partnership for Electric Power Systems.

- Perfluorocarbon emissions from aluminum production decreased by 88.2 percent (18.9 MMT CO<sub>2</sub> Eq.) from 1990 to 2014. 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 the sectors defined by those guidelines. Over the twenty-five-year period of 1990 to 2014, total emissions in the Energy, Industrial Processes and Product Use, and Agriculture grew by 421.3 MMT CO<sub>2</sub> Eq. (7.9 percent), 38.3 MMT CO<sub>2</sub> Eq. (11.2 percent), and 41.6 MMT CO<sub>2</sub> Eq. (7.8 percent), respectively. Over the same period, total emissions in the Waste sector decreased by 27.9 MMT CO<sub>2</sub> Eq. (14.0 percent) and estimates of net C sequestration in the Land Use, Land-Use Change, and Forestry (LULUCF) sector (magnitude of emissions plus CO<sub>2</sub> removals from all LULUCF source categories) decreased by 24.5 MMT CO<sub>2</sub> Eq. (3.3 percent).

**Figure ES-11: U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (MMT CO<sub>2</sub> Eq.)**



**Table ES-4: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (MMT CO<sub>2</sub> Eq.)**

Chapter/IPCC Sector	1990	2005	2010	2011	2012	2013	2014
Energy	5,324.9	6,294.5	5,884.6	5,744.0	5,533.9	5,693.5	5,746.2
Fossil Fuel Combustion	4,740.7	5,747.1	5,358.3	5,227.7	5,024.7	5,157.6	5,208.2

Natural Gas Systems	244.5	207.4	198.6	205.7	207.8	214.0	218.5
Non-Energy Use of Fuels	118.1	138.9	114.1	108.5	105.6	121.7	114.3
Petroleum Systems	42.3	52.8	58.2	60.5	62.2	68.4	71.7
Coal Mining	96.5	64.1	82.3	71.2	66.5	64.6	67.6
Stationary Combustion	20.4	27.6	29.2	28.4	28.0	30.9	31.5
Mobile Combustion	46.9	37.1	25.9	24.7	22.2	20.3	18.4
Incineration of Waste	8.4	12.8	11.4	10.9	10.7	9.7	9.7
Abandoned Underground Coal Mines	7.2	6.6	6.6	6.4	6.2	6.2	6.3
<b>Industrial Processes and Product Use</b>	<b>340.9</b>	<b>354.3</b>	<b>353.0</b>	<b>370.5</b>	<b>360.1</b>	<b>363.5</b>	<b>379.2</b>
Substitution of Ozone Depleting Substances	0.3	99.7	141.2	145.3	150.2	154.6	161.2
Iron and Steel Production & Metallurgical Coke Production	99.7	66.6	55.7	59.9	54.2	52.2	55.4
Cement Production	33.3	45.9	31.3	32.0	35.1	36.1	38.8
Petrochemical Production	21.8	27.5	27.3	26.4	26.5	26.5	26.6
Lime Production	11.7	14.6	13.4	14.0	13.7	14.0	14.1
Other Process Uses of Carbonates	4.9	6.3	9.6	9.3	8.0	10.4	12.1
Nitric Acid Production	12.1	11.3	11.5	10.9	10.5	10.7	10.9
Ammonia Production	13.0	9.2	9.2	9.3	9.4	10.0	9.4
Electrical Transmission and Distribution	25.4	10.6	7.0	6.8	5.6	5.4	5.6
Adipic Acid Production	15.2	7.1	4.2	10.2	5.5	4.0	5.4
Aluminum Production	28.3	7.6	4.6	6.8	6.4	6.2	5.4
HCFC-22 Production	46.1	20.0	8.0	8.8	5.5	4.1	5.0
Semiconductor Manufacture	3.6	4.7	4.0	5.1	4.5	4.2	4.7
Carbon Dioxide Consumption	1.5	1.4	4.4	4.1	4.0	4.2	4.5
N <sub>2</sub> O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	4.7	4.0	4.4	4.2	4.0
Soda Ash Production and Consumption	2.8	3.0	2.7	2.7	2.8	2.8	2.8
Ferroalloy Production	2.2	1.4	1.7	1.7	1.9	1.8	1.9
Titanium Dioxide Production	1.2	1.8	1.8	1.7	1.5	1.7	1.8
Glass Production	1.5	1.9	1.5	1.3	1.2	1.3	1.3
Magnesium Production and Processing	5.2	2.7	2.1	2.8	1.7	1.5	1.2
Phosphoric Acid Production	1.5	1.3	1.1	1.2	1.1	1.1	1.1
Zinc Production	0.6	1.0	1.2	1.3	1.5	1.4	1.0
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
<b>Agriculture</b>	<b>532.0</b>	<b>552.2</b>	<b>582.3</b>	<b>583.1</b>	<b>583.3</b>	<b>575.3</b>	<b>573.6</b>
Agricultural Soil Management	303.3	297.2	320.7	323.1	323.1	318.6	318.4
Enteric Fermentation	164.2	168.9	171.3	168.9	166.7	165.5	164.3
Manure Management	51.1	72.9	78.1	78.9	81.2	78.9	78.7
Rice Cultivation	13.1	13.0	11.9	11.8	11.9	11.9	11.9
Field Burning of Agricultural Residues	0.3	0.3	0.4	0.4	0.4	0.4	0.4
<b>Waste</b>	<b>199.3</b>	<b>177.8</b>	<b>165.5</b>	<b>167.8</b>	<b>165.7</b>	<b>167.8</b>	<b>171.4</b>
Landfills	179.6	154.0	142.1	144.4	142.3	144.3	148.0
Wastewater Treatment	19.0	20.2	19.9	19.9	19.8	19.6	19.5
Composting	0.7	3.5	3.5	3.5	3.7	3.9	3.9
<b>Total Emissions<sup>a</sup></b>	<b>6,397.1</b>	<b>7,378.8</b>	<b>6,985.5</b>	<b>6,865.4</b>	<b>6,643.0</b>	<b>6,800.0</b>	<b>6,870.5</b>
<b>Land Use, Land-Use Change, and Forestry</b>	<b>(738.0)</b>	<b>(698.5)</b>	<b>(766.4)</b>	<b>(762.0)</b>	<b>(749.7)</b>	<b>(759.6)</b>	<b>(762.5)</b>
Forest Land	(718.7)	(675.8)	(736.5)	(725.6)	(717.4)	(726.8)	(730.0)
Cropland	38.5	25.9	34.0	17.1	21.1	21.1	22.3
Grassland	26.2	39.8	32.0	43.0	43.9	44.1	44.2

Wetlands	1.1	1.1	1.0	0.9	0.8	0.8	0.8
Settlements	(59.0)	(78.2)	(83.8)	(84.8)	(85.8)	(87.1)	(88.2)
Other	(26.0)	(11.4)	(13.2)	(12.7)	(12.2)	(11.7)	(11.6)
<b>Net Emissions (Sources and Sinks)<sup>b</sup></b>	<b>5,659.2</b>	<b>6,680.3</b>	<b>6,219.0</b>	<b>6,103.4</b>	<b>5,893.3</b>	<b>6,040.4</b>	<b>6,108.0</b>

Notes: Total emissions presented without LULUCF. Net emissions presented with LULUCF.

<sup>a</sup> Total emissions without LULUCF.

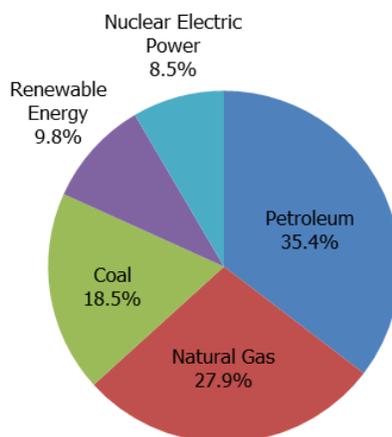
<sup>b</sup> Total emissions with LULUCF.

Notes: 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<sub>2</sub> emissions for the period of 1990 through 2014. In 2014, 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<sub>4</sub> and N<sub>2</sub>O emissions (45 percent and 10 percent of total U.S. emissions of each gas, respectively). Overall, emission sources in the Energy chapter account for a combined 83.6 percent of total U.S. greenhouse gas emissions in 2014.

**Figure ES-12: 2014 U.S. Energy Consumption by Energy Source (Percent)**



## 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.

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<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O. 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<sub>2</sub> consumption, silicon carbide production and consumption, aluminum production, petrochemical production, nitric acid production, adipic acid production, lead production, zinc production, and N<sub>2</sub>O from product uses. Industrial processes also release HFCs, PFCs, SF<sub>6</sub>, and

NF<sub>3</sub>. In addition to their use as ODS substitutes, HFCs, PFCs, SF<sub>6</sub>, NF<sub>3</sub>, 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 5.5 percent of U.S. greenhouse gas emissions in 2014.

## Agriculture

The Agriculture chapter contains anthropogenic emissions from agricultural activities (except fuel combustion, which is addressed in the Energy chapter, and agricultural CO<sub>2</sub> 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<sub>4</sub> and N<sub>2</sub>O were the primary greenhouse gases emitted by agricultural activities. CH<sub>4</sub> emissions from enteric fermentation and manure management represented 22.5 percent and 8.4 percent of total CH<sub>4</sub> emissions from anthropogenic activities, respectively, in 2014. Agricultural soil management activities such as fertilizer application and other cropping practices were the largest source of U.S. N<sub>2</sub>O emissions in 2014, accounting for 78.9 percent. In 2014, emission sources accounted for in the Agricultural chapters were responsible for 8.3 percent of total U.S. greenhouse gas emissions.

## Land Use, Land-Use Change, and Forestry

The Land Use, Land-Use Change, and Forestry chapter contains emissions of CH<sub>4</sub> and N<sub>2</sub>O, and emissions and removals of CO<sub>2</sub> 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<sub>2</sub> (C sequestration) in the United States. Forests (including vegetation, soils, and harvested wood) accounted for 87 percent of total 2014 CO<sub>2</sub> removals, urban trees accounted for 11 percent, landfilled yard trimmings and food scraps accounted for 1.4 percent, and mineral and organic soil C stock changes from *Cropland Remaining Cropland* accounted for 1.0 percent of the total CO<sub>2</sub> removals in 2014. The net forest sequestration is a result of net forest growth and increasing forest area, as well as a net accumulation of C 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 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.

LULUCF activities in 2014 resulted in a net increase in C stocks (i.e., net CO<sub>2</sub> removals) of 787.0 MMT CO<sub>2</sub> Eq. (Table ES-5).<sup>20</sup> This represents an offset of 11.5 percent of total (i.e., gross) greenhouse gas emissions in 2014. Emissions from land use, land-use change, and forestry activities in 2014 are 24.6 MMT CO<sub>2</sub> Eq. and represent 0.4 percent of total greenhouse gas emissions.<sup>21</sup> Between 1990 and 2014, total C sequestration in the LULUCF sector increased by 4.5 percent, primarily due to an increase in the rate of net C accumulation in forest and urban tree C stocks. 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.

Carbon dioxide removals are presented in Table ES-5 along with CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions for LULUCF source categories. Liming and urea fertilization in 2014 resulted in CO<sub>2</sub> emissions of 8.7 MMT CO<sub>2</sub> Eq. (8,653 kt). Lands

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<sup>20</sup> Net CO<sub>2</sub> flux is the net C stock change from the following categories: *Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Settlements Remaining Settlements, and Other.*

<sup>21</sup> LULUCF emissions include the CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions reported for Non-CO<sub>2</sub> Emissions from Forest Fires, N<sub>2</sub>O Fluxes from Forest Soils, CO<sub>2</sub> Emissions from Liming, CO<sub>2</sub> Emissions from Urea Fertilization, Peatlands Remaining Peatlands, and N<sub>2</sub>O Fluxes from Settlement Soils.

undergoing peat extraction (i.e., *Peatlands Remaining Peatlands*) resulted in CO<sub>2</sub> emissions of 0.8 MMT CO<sub>2</sub> Eq. (842 kt) and CH<sub>4</sub> and N<sub>2</sub>O emissions of less than 0.05 MMT CO<sub>2</sub> Eq. each. The application of synthetic fertilizers to forest soils in 2014 resulted in N<sub>2</sub>O emissions of 0.5 MMT CO<sub>2</sub> Eq. (2 kt). N<sub>2</sub>O 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<sub>2</sub>O emissions from fertilizer application to settlement soils in 2014 accounted for 2.4 MMT CO<sub>2</sub> Eq. (8 kt). This represents an increase of 78 percent since 1990. Forest fires in 2014 resulted in CH<sub>4</sub> emissions of 7.3 MMT CO<sub>2</sub> Eq. (294 kt), and in N<sub>2</sub>O emissions of 4.8 MMT CO<sub>2</sub> Eq. (16 kt).

**Table ES-5: U.S. Greenhouse Gas Emissions and Removals (Net Flux) from Land Use, Land-Use Change, and Forestry (MMT CO<sub>2</sub> Eq.)**

Gas/Land-Use Category	1990	2005	2010	2011	2012	2013	2014
<b>Net CO<sub>2</sub> Flux<sup>a</sup></b>	<b>(753.0)</b>	<b>(726.7)</b>	<b>(784.3)</b>	<b>(784.9)</b>	<b>(782.0)</b>	<b>(783.7)</b>	<b>(787.0)</b>
Forest Land Remaining Forest Land <sup>b</sup>	(723.5)	(691.9)	(742.0)	(736.7)	(735.8)	(739.1)	(742.3)
Land Converted to Forest Land	(0.7)	(0.8)	(0.4)	(0.4)	(0.4)	(0.3)	(0.3)
Cropland Remaining Cropland	(34.3)	(14.1)	1.8	(12.5)	(11.2)	(9.3)	(8.4)
Land Converted to Cropland	65.7	32.2	23.7	21.6	22.0	22.1	22.1
Grassland Remaining Grassland	(12.9)	(3.3)	(7.3)	3.1	3.6	3.8	3.8
Land Converted to Grassland	39.1	43.1	39.3	39.9	40.4	40.4	40.4
Settlements Remaining Settlements	(60.4)	(80.5)	(86.1)	(87.3)	(88.4)	(89.5)	(90.6)
Other: Landfilled Yard Trimmings and Food Scraps	(26.0)	(11.4)	(13.2)	(12.7)	(12.2)	(11.7)	(11.6)
<b>CO<sub>2</sub></b>	<b>8.1</b>	<b>9.0</b>	<b>9.6</b>	<b>8.9</b>	<b>11.0</b>	<b>9.0</b>	<b>9.5</b>
Cropland Remaining Cropland: CO <sub>2</sub> Emissions from Urea Fertilization	2.4	3.5	3.8	4.1	4.2	4.3	4.5
Cropland Remaining Cropland: CO <sub>2</sub> Emissions from Liming	4.7	4.3	4.8	3.9	6.0	3.9	4.1
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	1.1	1.1	1.0	0.9	0.8	0.8	0.8
<b>CH<sub>4</sub></b>	<b>3.3</b>	<b>9.9</b>	<b>3.3</b>	<b>6.6</b>	<b>11.1</b>	<b>7.3</b>	<b>7.4</b>
Forest Land Remaining Forest Land: Non-CO <sub>2</sub> Emissions from Forest Fires	3.3	9.9	3.3	6.6	11.1	7.3	7.3
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
<b>N<sub>2</sub>O</b>	<b>3.6</b>	<b>9.3</b>	<b>5.0</b>	<b>7.3</b>	<b>10.3</b>	<b>7.7</b>	<b>7.7</b>
Forest Land Remaining Forest Land: Non-CO <sub>2</sub> Emissions from Forest Fires	2.2	6.5	2.2	4.4	7.3	4.8	4.8
Settlements Remaining Settlements: N <sub>2</sub> O Fluxes from Settlement Soils <sup>c</sup>	1.4	2.3	2.4	2.5	2.5	2.4	2.4
Forest Land Remaining Forest Land: N <sub>2</sub> O Fluxes from Forest Soils <sup>d</sup>	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
<b>LULUCF Emissions<sup>e</sup></b>	<b>15.0</b>	<b>28.2</b>	<b>17.8</b>	<b>22.9</b>	<b>32.3</b>	<b>24.1</b>	<b>24.6</b>
<b>LULUCF Total Net Flux<sup>a</sup></b>	<b>(753.0)</b>	<b>(726.7)</b>	<b>(784.3)</b>	<b>(784.9)</b>	<b>(782.0)</b>	<b>(783.7)</b>	<b>(787.0)</b>
<b>LULUCF Sector Total<sup>f</sup></b>	<b>(738.0)</b>	<b>(698.5)</b>	<b>(766.4)</b>	<b>(762.0)</b>	<b>(749.7)</b>	<b>(759.6)</b>	<b>(762.5)</b>

+ Does not exceed 0.05 MMT CO<sub>2</sub> Eq.

<sup>a</sup> Net CO<sub>2</sub> flux is the net C stock change from the following categories: *Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Settlements Remaining Settlements, and Other.*

<sup>b</sup> Includes the effects of net additions to stocks of carbon stored in forest ecosystem pools and harvested wood products.

<sup>c</sup> Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements* and *Land Converted to Settlements*.

<sup>d</sup> Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

<sup>e</sup> LULUCF emissions include the CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions reported for Non-CO<sub>2</sub> Emissions from Forest Fires, N<sub>2</sub>O Fluxes from Forest Soils, CO<sub>2</sub> Emissions from Liming, CO<sub>2</sub> Emissions from Urea Fertilization, Peatlands Remaining Peatlands, and N<sub>2</sub>O Fluxes from Settlement Soils.

<sup>f</sup> The LULUCF Sector Total is the net sum of all emissions (i.e., sources) of greenhouse gases to the atmosphere plus removals of CO<sub>2</sub> (i.e., sinks or negative emissions) from the atmosphere.

Notes: Totals may not sum due to independent rounding. Parentheses indicate net 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 86.3 percent of this chapter's emissions, and 20.2 percent of total U.S. CH<sub>4</sub> emissions.<sup>22</sup> Additionally, wastewater treatment accounts for 11.4 percent of Waste emissions, 2.0 percent of U.S. CH<sub>4</sub> emissions, and 1.2 percent of U.S. N<sub>2</sub>O emissions. Emissions of CH<sub>4</sub> and N<sub>2</sub>O from composting are also accounted for in this chapter, generating emissions of 2.1 MMT CO<sub>2</sub> Eq. and 1.8 MMT CO<sub>2</sub> Eq., respectively. Overall, emission sources accounted for in the Waste chapter generated 2.5 percent of total U.S. greenhouse gas emissions in 2014.

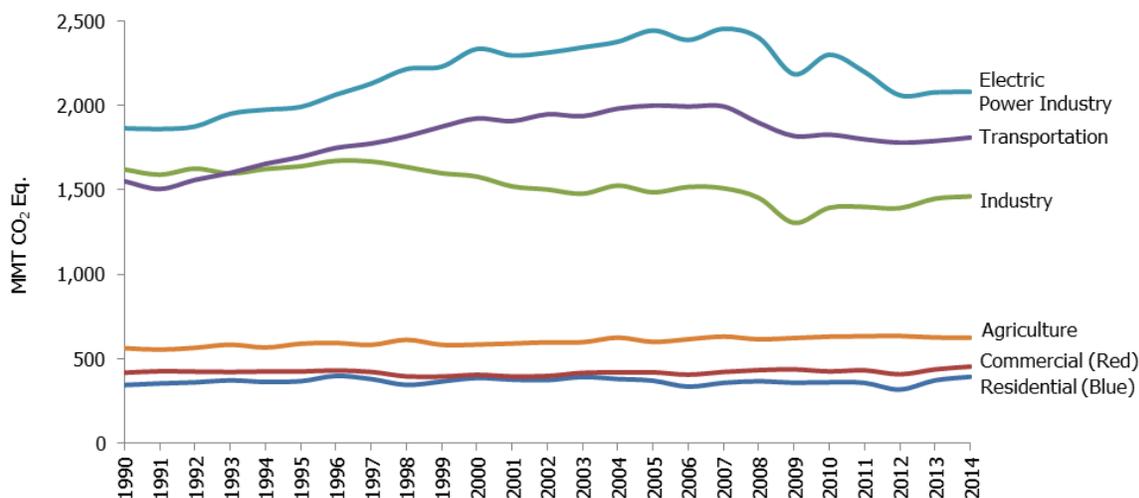
## ES.4. Other Information

### 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; LULUCF; 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 economic sectors, and Figure ES-13 shows the trend in emissions by sector from 1990 to 2014.

**Figure ES-13: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (MMT CO<sub>2</sub> Eq.)**



<sup>22</sup> 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.

**Table ES-6: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (MMT CO<sub>2</sub> Eq.)**

<b>Economic Sectors</b>	<b>1990</b>	<b>2005</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>
Electric Power Industry	1,864.8	2,443.9	2,300.5	2,198.1	2,060.7	2,078.0	2,080.7
Transportation	1,551.3	1,999.6	1,827.4	1,799.6	1,780.4	1,789.9	1,810.3
Industry <sup>1</sup>	1,620.9	1,486.2	1,394.5	1,399.0	1,392.1	1,448.2	1,461.7
Agriculture	563.4	600.2	631.1	633.7	635.4	626.3	625.4
Commercial	418.1	420.3	425.5	432.1	408.5	437.5	453.9
Residential	344.9	370.4	361.2	357.6	318.4	372.6	393.7
U.S. Territories	33.7	58.2	45.3	45.4	47.6	47.5	44.7
<b>Total Emissions</b>	<b>6,397.1</b>	<b>7,378.8</b>	<b>6,985.5</b>	<b>6,865.4</b>	<b>6,643.0</b>	<b>6,800.0</b>	<b>6,870.5</b>
<b>LULUCF Sector Total<sup>a</sup></b>	<b>(738.0)</b>	<b>(698.5)</b>	<b>(766.4)</b>	<b>(762.0)</b>	<b>(749.7)</b>	<b>(759.6)</b>	<b>(762.5)</b>
<b>Net Emissions (Sources and Sinks)</b>	<b>5,659.2</b>	<b>6,680.3</b>	<b>6,219.0</b>	<b>6,103.4</b>	<b>5,893.3</b>	<b>6,040.4</b>	<b>6,108.0</b>

Note: Total emissions presented without LULUCF. Total net emissions presented with LULUCF.

<sup>a</sup> The LULUCF Sector Total is the net sum of all emissions (i.e., sources) of greenhouse gases to the atmosphere plus removals of CO<sub>2</sub> (i.e., sinks or negative emissions) from the atmosphere.

Notes: 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 (30 percent) of U.S. greenhouse gas emissions in 2014. Transportation activities, in aggregate, accounted for the second largest portion (26 percent), while emissions from industry accounted for the third largest portion (21 percent) of U.S. greenhouse gas emissions in 2014. 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 22 percent of U.S. greenhouse gas emissions were contributed by, in order of magnitude, 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<sub>2</sub>O emissions from agricultural soil management and CH<sub>4</sub> emissions from enteric fermentation. The commercial and residential sectors accounted for 7 percent and 6 percent of emissions, respectively, and U.S. Territories accounted for 1 percent of emissions; emissions from these sectors primarily consisted of CO<sub>2</sub> emissions from fossil fuel combustion. CO<sub>2</sub> 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.<sup>23</sup> These source categories include CO<sub>2</sub> from fossil fuel combustion and the use of limestone and dolomite for flue gas desulfurization, CO<sub>2</sub> and N<sub>2</sub>O from incineration of waste, CH<sub>4</sub> and N<sub>2</sub>O from stationary sources, and SF<sub>6</sub> 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 26 percent, respectively) in 2014. The residential and commercial sectors contributed the next largest shares of total U.S. greenhouse gas emissions in 2014. 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). In all sectors except agriculture, CO<sub>2</sub> 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 2014.

<sup>23</sup> 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.

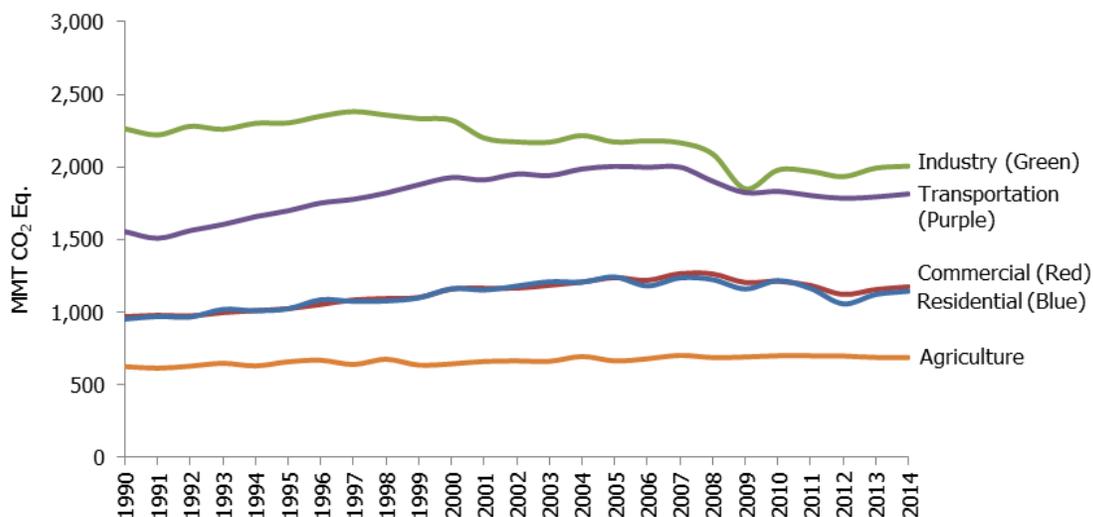
**Table ES-7: U.S. Greenhouse Gas Emissions by Economic Sector with Electricity-Related Emissions Distributed (MMT CO<sub>2</sub> Eq.)**

Implied Sectors	1990	2005	2010	2011	2012	2013	2014
Industry	2,262.9	2,171.9	1,979.1	1,970.0	1,934.0	1,992.5	2,005.7
Transportation	1,554.4	2,004.4	1,832.0	1,803.9	1,784.3	1,794.0	1,814.5
Commercial	969.1	1,238.0	1,212.8	1,183.9	1,122.1	1,155.8	1,174.7
Residential	952.2	1,242.1	1,216.9	1,163.1	1,057.5	1,121.9	1,143.8
Agriculture	624.8	664.2	699.5	699.1	697.5	688.3	687.0
U.S. Territories	33.7	58.2	45.3	45.4	47.6	47.5	44.7
<b>Total Emissions</b>	<b>6,397.1</b>	<b>7,378.8</b>	<b>6,985.5</b>	<b>6,865.4</b>	<b>6,643.0</b>	<b>6,800.0</b>	<b>6,870.5</b>
<b>LULUCF Sector Total<sup>a</sup></b>	<b>(738.0)</b>	<b>(698.5)</b>	<b>(766.4)</b>	<b>(762.0)</b>	<b>(749.7)</b>	<b>(759.6)</b>	<b>(762.5)</b>
<b>Net Emissions (Sources and Sinks)</b>	<b>5,659.2</b>	<b>6,680.3</b>	<b>6,219.0</b>	<b>6,103.4</b>	<b>5,893.3</b>	<b>6,040.4</b>	<b>6,108.0</b>

<sup>a</sup> The LULUCF Sector Total is the net sum of all emissions (i.e., sources) of greenhouse gases to the atmosphere plus removals of CO<sub>2</sub> (i.e., sinks or negative emissions) from the atmosphere.

Notes: Emissions from electricity generation are allocated based on aggregate electricity consumption in each end-use sector. Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

**Figure ES-14: U.S. Greenhouse Gas Emissions with Electricity-Related Emissions Distributed to Economic Sectors (MMT CO<sub>2</sub> Eq.)**



**Box ES-3: 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 2014; (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	2010	2011	2012	2013	2014	Avg. Annual Growth Rate
Greenhouse Gas Emissions <sup>a</sup>	100	115	109	107	104	106	107	0.3%
Energy Consumption <sup>b</sup>	100	118	116	115	112	116	117	0.7%
Fossil Fuel Consumption <sup>b</sup>	100	119	112	110	107	110	111	0.5%
Electricity Consumption <sup>b</sup>	100	134	137	137	135	136	138	1.4%
GDP <sup>c</sup>	100	159	165	168	171	174	178	2.5%
Population <sup>d</sup>	100	118	124	125	126	126	127	1.0%

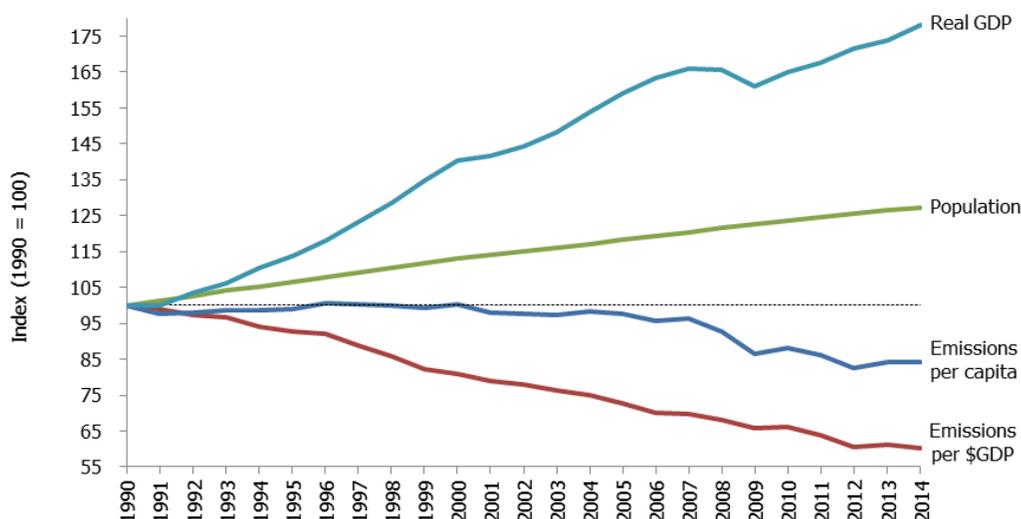
<sup>a</sup> GWP-weighted values

<sup>b</sup> Energy content-weighted values (EIA 2016)

<sup>c</sup> Gross Domestic Product in chained 2009 dollars (BEA 2016)

<sup>d</sup> U.S. Census Bureau (2015)

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



Source: BEA (2016), U.S. Census Bureau (2015), and emission estimates in this report.

## Key Categories

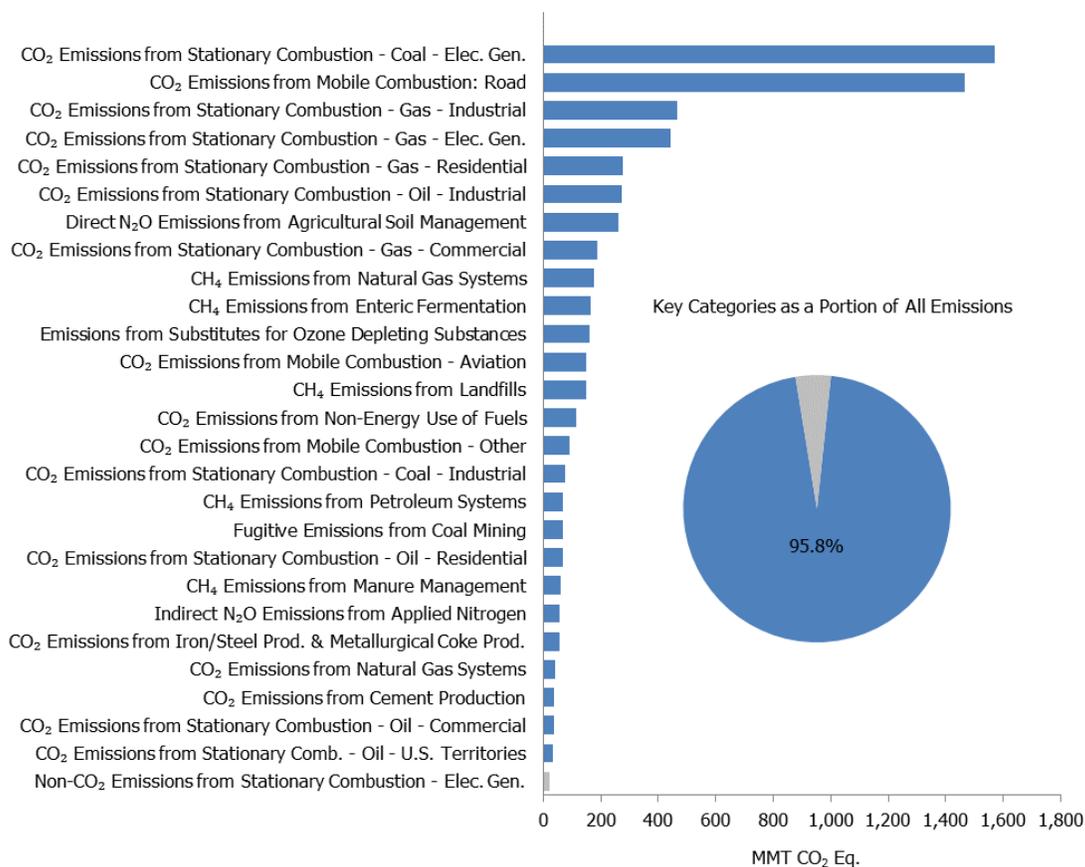
The 2006 IPCC Guidelines (IPCC 2006) defines a key category as a “[category] that is prioritized within the national inventory system because its estimate has a significant influence on a country’s total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals.”<sup>24</sup> 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

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

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 2014 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.

**Figure ES-16: 2014 Key Categories (MMT CO<sub>2</sub> Eq.)**



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 *Quality Assurance/Quality Control and Uncertainty Management Plan (QA/QC Management Plan)* for the Inventory and the UNFCCC reporting guidelines.

## Uncertainty Analysis of Emission Estimates

Uncertainty estimates are an essential element of a complete inventory of greenhouse gas emissions and removals. Some of the current estimates, such as those for CO<sub>2</sub> 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-4: 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.