Executive Summary

An emissions inventory that identifies and quantifies a country's 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 national sources and sinks of anthropogenic greenhouse gases, and (2) a common and consistent format 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]

As a signatory to the UNFCCC, consistent with Article 4[3] and decisions at the First, Second, Fifth, and Nineteenth Conference of Parties,[4] the United States is committed to submitting a national inventory of anthropogenic sources and sinks of greenhouse gases to the UNFCCC by April 15 of each year. The United States views this report, in conjunction with Common Reporting Format (CRF) reporting tables that accompany this report, as an opportunity to fulfill this annual commitment under the UNFCCC.

This executive summary provides the latest information on U.S. anthropogenic greenhouse gas emission trends from 1990 through 2019. The structure of this report is consistent with the UNFCCC guidelines for inventory reporting, as discussed in Box ES-1.[5]

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[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) and subsequent decisions by the Conference of the Parties elaborated the role of Annex I Parties in preparing national inventories. Article 4 states "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…" See <http://unfccc.int> for more information.

[4] See UNFCCC decisions 3/CP.1, 9/CP.2, 3/CP.5, and 24/CP.19 at <https://unfccc.int/documents>.

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

Box ES-1: Methodological Approach for Estimating and Reporting U.S. Emissions and Removals, including Relationship to EPA's Greenhouse Gas Reporting Program

In following the UNFCCC requirement under Article 4.1 and related decisions to develop and submit annual national greenhouse gas emission inventories, the emissions and removals presented in this report and this chapter are organized by source and sink categories and calculated using internationally-accepted methods provided by the IPCC in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines)* and where appropriate, its supplements and refinements. Additionally, the calculated emissions and removals 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 removals by all nations providing their inventories to the UNFCCC ensures that these reports are comparable. The presentation of emissions and removals provided in this Inventory does not preclude alternative examinations, but rather this Inventory presents emissions and removals 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 application of methods used to calculate emissions and removals.

EPA also collects greenhouse gas emissions data from individual facilities and suppliers of certain fossil fuels and industrial gases through its Greenhouse Gas Reporting Program (GHGRP).[6] The GHGRP applies to direct greenhouse gas emitters, fossil fuel suppliers, industrial gas suppliers, and facilities that inject carbon dioxide (CO_2) underground for sequestration or other reasons and requires reporting by over 8,000 sources or suppliers in 41 industrial categories.[7] Annual reporting is at the facility level, except for certain suppliers of fossil fuels and industrial greenhouse gases. In general, the threshold for reporting is 25,000 metric tons or more of CO_2 Eq. per year. Facilities in most source categories subject to GHGRP began reporting for the 2010 reporting year while additional types of industrial operations began reporting for reporting year 2011. While the GHGRP does not provide full coverage of total annual U.S. greenhouse gas emissions and sinks (e.g., the GHGRP excludes emissions from the agricultural, land use, and forestry sectors), it is an important input to the calculations of national-level emissions in the Inventory.

Data presented in this Inventory report and EPA's Greenhouse Gas Reporting Program (GHGRP) are complementary. The GHGRP dataset continues to be an important resource for the Inventory, providing not only annual emissions information, but also other annual information such as activity data and emission factors that can improve and refine national emission estimates and trends over time. Methodologies used in EPA's GHGRP are consistent with the *2006 IPCC Guidelines* (e.g., higher tier methods). GHGRP data also allow EPA to disaggregate national inventory estimates in new ways that can highlight differences across regions and sub-categories of emissions, along with enhancing application of QA/QC procedures and assessment of uncertainties. EPA uses annual GHGRP data in a number of categories to improve the national estimates presented in this Inventory consistent with IPCC methodological guidance. See Annex 9 for more information on specific uses of GHGRP data in the Inventory (e.g., natural gas systems).

[6] On October 30, 2009 the EPA promulgated a rule requiring annual reporting of greenhouse gas data from large greenhouse gas emissions sources in the United States. Implementation of the rule, codified at 40 CFR Part 98, is referred to as EPA's Greenhouse Gas Reporting Program (GHGRP).

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

ES.1 Background Information

Greenhouse gases absorb infrared radiation, thereby trapping heat in the atmosphere and making the planet warmer. The most important greenhouse gases directly emitted by humans include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and several fluorine-containing halogenated substances (HFCs, PFCs, SF_6 and NF_3). Although 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 2019, concentrations of these greenhouse gases have increased globally by 47, 167, and 23 percent, respectively (IPCC 2013; NOAA/ESRL 2021a, 2021b, 2021c). 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 a 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 accumulated radiative forcing within a specific time horizon caused by emitting 1 kilogram of the gas, relative to that of the reference gas CO_2 (IPCC 2013). Therefore GWP-weighted emissions are provided in million metric tons of CO_2 equivalent (MMT CO_2 Eq.).[9, 10] Estimates for all gases in this Executive Summary are presented in units of MMT CO_2 Eq. Emissions by gas in unweighted mass kilotons are provided in the Trends chapter of this report and in the Common Reporting Format (CRF) tables that are also part of the submission to the UNFCCC.

UNFCCC reporting guidelines for national inventories require the use of GWP values from the *IPCC Fourth Assessment Report* (AR4) (IPCC 2007).[11] 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), 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_2	1
CH_4[a]	25
N_2O	298
HFC-23	14,800
HFC-32	675
HFC-41	92
HFC-125	3,500

[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 of carbon dioxide by weight.

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

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

HFC-134a	1,430
HFC-143a	4,470
HFC-152a	124
HFC-227ea	3,220
HFC-236fa	9,810
HFC-43-10mee	1,640
HFC-245fa	1,030
HFC-365mfc	794
CF_4	7,390
C_2F_6	12,200
C_3F_8	8,830
c-C_5F_8	1.97
C_4F_{10}	8,860
c-C_4F_8	10,300
C_5F_{12}	9,160
C_6F_{14}	9,300
SF_6	22,800
NF_3	17,200
Other Fluorinated Gases	See Annex 6

[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 production of CO_2 is not included. See Annex 6 for additional information.
Source: IPCC (2007).

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

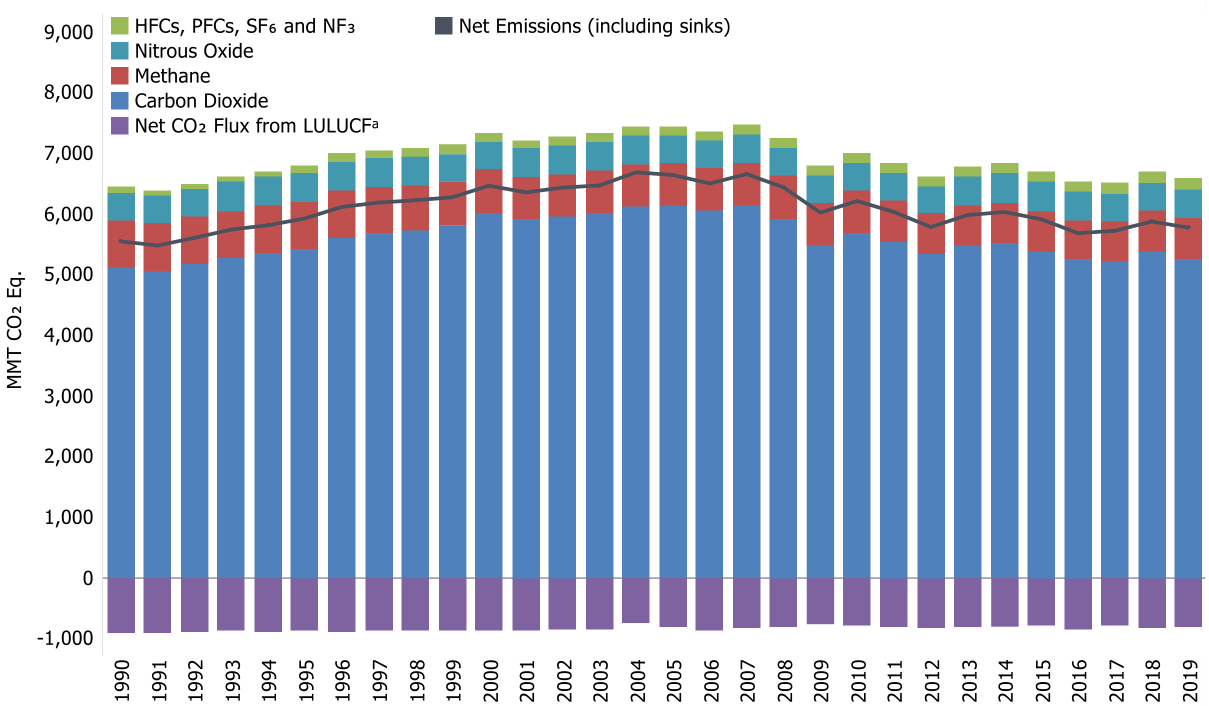
In 2019, total gross U.S. greenhouse gas emissions were 6,558.3 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq).[12] Total U.S. emissions have increased by 1.8 percent from 1990 to 2019, down from a high of 15.6 percent above 1990 levels in 2007. Emissions decreased from 2018 to 2019 by 1.7 percent (113.1 MMT CO_2 Eq.). Net emissions (including sinks) were 5,769.1 MMT CO_2 Eq. Overall, net emissions decreased 1.7 percent from 2018 to 2019 and decreased 13.0 percent from 2005 levels as shown in Table ES-2. The decline reflects the combined impacts of many long-term trends, including population, economic growth, energy market trends, technological changes including energy efficiency, and carbon intensity of energy fuel choices. Between 2018 and 2019, the decrease in total greenhouse gas emissions was largely driven by the decrease in CO_2 emissions from fossil fuel combustion. The decrease in CO_2 emissions from fossil fuel combustion was a result of a 1 percent decrease in total energy use and reflects a continued shift from coal to less carbon intensive natural gas and renewables in the electric power sector.

Figure ES-1 through Figure ES-3 illustrate the overall trends in total U.S. emissions by gas, annual percent changes, and relative change since 1990 for each year of the time series, and Table ES-2 provides information on trends in

[12] The gross emissions total presented in this report for the United States excludes emissions and removals from Land Use, Land-Use Change, and Forestry (LULUCF). The net emissions total presented in this report for the United States includes emissions and removals from LULUCF.

gross U.S. greenhouse gas emissions and sinks for 1990 through 2019. Unless otherwise stated, all tables and figures provide total gross emissions and exclude the greenhouse gas fluxes from the Land Use, Land-Use Change, and Forestry (LULUCF) sector. For more information about the LULUCF sector see Section ES.3 Overview of Sector Emissions and Trends.

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



[a] The term "flux" is used to describe the exchange of CO_2 to and from the atmosphere, with net flux being either positive or negative depending on the overall balance. Removal and long-term storage of CO_2 from the atmosphere is also referred to as "carbon sequestration."

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

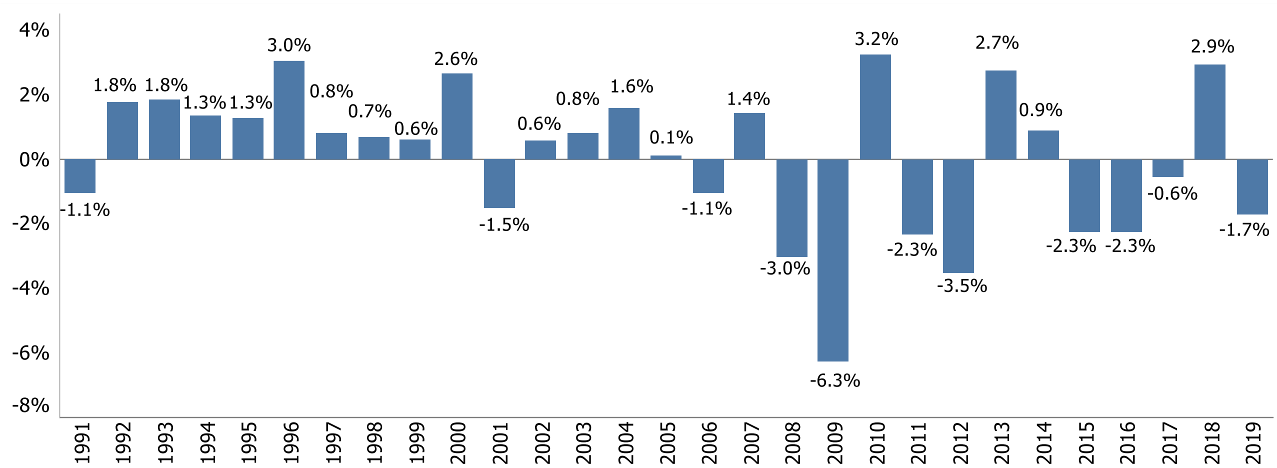
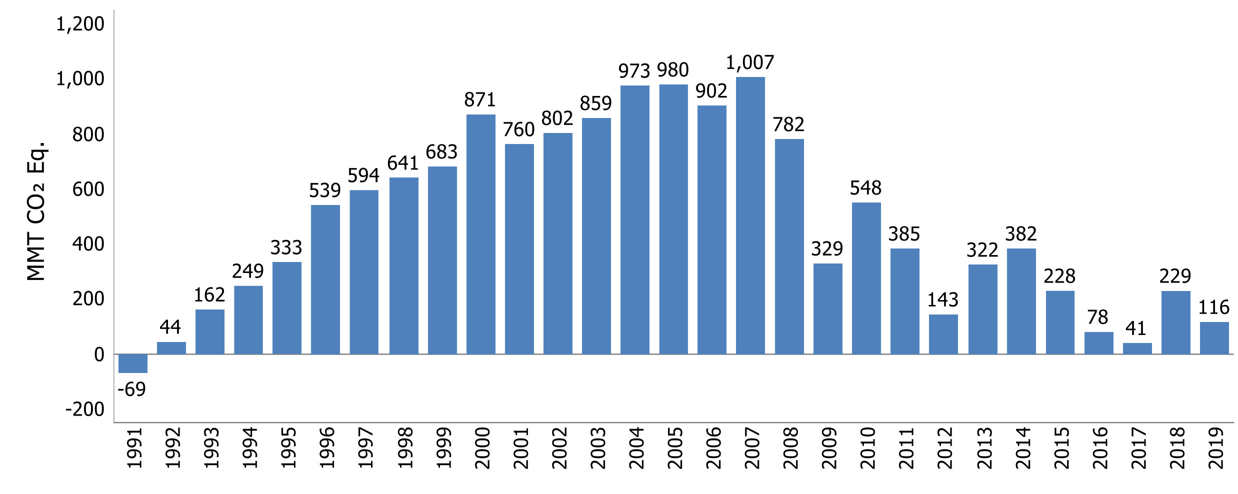


Figure ES-3: Change in Annual Gross U.S. Greenhouse Gas Emissions Relative to 1990 (1990=0)



Box ES-2: Improvements and Recalculations Relative to the Previous Inventory

Each year, some emission and sink estimates in the Inventory are recalculated and revised to incorporate improved methods and/or data. The most common reason for recalculating U.S. greenhouse gas emission estimates is to update recent historical data. Changes in historical data are generally the result of changes in data supplied by other U.S. government agencies or organizations, as they continue to make refinements and improvements. These improvements are implemented consistently across the previous Inventory's time series (i.e., 1990 to 2018) to ensure that the trend is accurate.

Below are categories with recalculations resulting in an average change over the time series of greater than 10 MMT CO_2 Eq.

- *Forest Land Remaining Forest Land: Changes in Forest Carbon Stocks (CO_2)*
- *Wastewater Treatment (N_2O)*
- *Land Converted to Forest Land: Changes in all Ecosystem Carbon Stocks (CO_2)*
- *Non-Energy Use of Fuels (CO_2)*

In each Inventory, the results of all methodological changes and historical data updates are summarized in the Recalculations and Improvements chapter (Chapter 9). For more detailed descriptions of each recalculation including references for data, please see the respective source or sink category description(s) within the relevant report chapter (i.e., Energy chapter (Chapter 3), the Industrial Process and Product Use (IPPU) chapter (Chapter 4) the Agriculture chapter (Chapter 5), the Land Use, Land Use Change and Forestry (LULUCF) chapter (Chapter 6), and the Waste chapter (Chapter 7)). In implementing improvements, 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."

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

Gas/Source	1990	2005	2015	2016	2017	2018	2019
CO_2	**5,113.5**	**6,134.5**	**5,371.8**	**5,248.0**	**5,207.8**	**5,375.5**	**5,255.8**
Fossil Fuel Combustion	4,731.5	5,753.5	5,008.3	4,911.5	4,854.5	4,991.4	4,856.7
Transportation	*1,469.1*	*1,858.6*	*1,719.2*	*1,759.9*	*1,782.4*	*1,816.6*	*1,817.2*
Electric Power	*1,820.0*	*2,400.1*	*1,900.6*	*1,808.9*	*1,732.0*	*1,752.9*	*1,606.0*
Industrial	*853.8*	*852.9*	*797.3*	*792.5*	*790.1*	*813.6*	*822.5*
Residential	*338.6*	*358.9*	*317.3*	*292.8*	*293.4*	*338.1*	*336.8*
Commercial	*228.3*	*227.1*	*244.6*	*231.6*	*232.0*	*245.7*	*249.7*
U.S. Territories	*21.7*	*55.9*	*29.2*	*26.0*	*24.6*	*24.6*	*24.6*
Non-Energy Use of Fuels	112.8	129.1	108.5	99.8	113.5	129.7	128.8
Petroleum Systems	9.7	12.1	32.4	21.8	25.0	37.1	47.3
Iron and Steel Production & Metallurgical Coke Production	104.7	70.1	47.9	43.6	40.6	42.6	41.3
Cement Production	33.5	46.2	39.9	39.4	40.3	39.0	40.9
Natural Gas Systems	32.0	25.2	29.1	30.1	31.2	33.9	37.2
Petrochemical Production	21.6	27.4	28.1	28.3	28.9	29.3	30.8
Ammonia Production	13.0	9.2	10.6	10.2	11.1	12.2	12.3
Lime Production	11.7	14.6	13.3	12.6	12.9	13.1	12.1
Incineration of Waste	8.1	12.7	11.5	11.5	11.5	11.5	11.5
Other Process Uses of Carbonates	6.3	7.6	12.2	11.0	9.9	7.5	7.5
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	4.6	5.1	5.0	5.9	6.2
Urea Fertilization	2.4	3.5	4.7	4.9	5.1	5.2	5.3
Carbon Dioxide Consumption	1.5	1.4	4.9	4.6	4.6	4.1	4.9
Liming	4.7	4.3	3.7	3.1	3.1	2.2	2.4
Aluminum Production	6.8	4.1	2.8	1.3	1.2	1.5	1.9
Soda Ash Production	1.4	1.7	1.7	1.7	1.8	1.7	1.8
Ferroalloy Production	2.2	1.4	2.0	1.8	2.0	2.1	1.6
Titanium Dioxide Production	1.2	1.8	1.6	1.7	1.7	1.5	1.5
Glass Production	1.5	1.9	1.3	1.2	1.3	1.3	1.3
Zinc Production	0.6	1.0	0.9	0.8	0.9	1.0	1.0
Phosphoric Acid Production	1.5	1.3	1.0	1.0	1.0	0.9	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.2	0.2
Abandoned Oil and Gas Wells	+	+	+	+	+	+	+
Magnesium Production and Processing	+	+	+	+	+	+	+
Wood Biomass, Ethanol, and Biodiesel Consumption[a]	*219.4*	*230.7*	*317.7*	*316.6*	*312.3*	*319.6*	*316.2*
International Bunker Fuels[b]	*103.5*	*113.2*	*110.9*	*116.6*	*120.1*	*122.1*	*116.1*
CH_4[c]	**776.9**	**686.1**	**651.5**	**642.4**	**648.4**	**655.9**	**659.7**
Enteric Fermentation	164.7	169.3	166.9	172.2	175.8	178.0	178.6
Natural Gas Systems	186.9	164.2	149.8	147.3	148.7	152.5	157.6
Landfills	176.6	131.4	111.4	108.0	109.4	112.1	114.5
Manure Management	37.1	51.6	57.9	59.6	59.9	61.7	62.4
Coal Mining	96.5	64.1	61.2	53.8	54.8	52.7	47.4
Petroleum Systems	48.9	39.5	41.5	39.2	39.3	37.3	39.1
Wastewater Treatment	20.2	20.1	18.8	18.7	18.5	18.4	18.4

Rice Cultivation	16.0	18.0	16.2	15.8	14.9	15.6	15.1
Stationary Combustion	8.6	7.8	8.5	7.9	7.6	8.5	8.7
Abandoned Oil and Gas Wells	6.8	7.2	7.4	7.4	7.2	7.3	6.6
Abandoned Underground Coal Mines	7.2	6.6	6.4	6.7	6.4	6.2	5.9
Mobile Combustion	6.4	4.0	2.6	2.5	2.5	2.4	2.4
Composting	0.4	1.9	2.1	2.3	2.4	2.3	2.3
Field Burning of Agricultural Residues	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Petrochemical Production	0.2	0.1	0.2	0.2	0.3	0.3	0.3
Anaerobic Digestion at Biogas Facilities	+	0.1	0.2	0.2	0.2	0.2	0.2
Ferroalloy Production	+	+	+	+	+	+	+
Carbide Production and Consumption	+	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O[c]	**452.7**	**455.8**	**468.2**	**450.8**	**446.3**	**459.2**	**457.1**
Agricultural Soil Management	315.9	313.4	348.5	330.1	327.6	338.2	344.6
Wastewater Treatment	18.7	23.0	25.4	25.9	26.4	26.1	26.4
Stationary Combustion	25.1	34.4	30.5	30.0	28.4	28.2	24.9
Manure Management	14.0	16.4	17.5	18.1	18.7	19.4	19.6
Mobile Combustion	44.7	41.6	21.7	20.8	19.8	18.8	18.0
Nitric Acid Production	12.1	11.3	11.6	10.1	9.3	9.6	10.0
Adipic Acid Production	15.2	7.1	4.3	7.0	7.4	10.3	5.3
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Composting	0.3	1.7	1.9	2.0	2.2	2.0	2.0
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.7	2.1	1.9	1.7	1.5	1.4	1.4
Incineration of Waste	0.5	0.4	0.3	0.3	0.3	0.3	0.3
Electronics Industry	+	0.1	0.2	0.2	0.3	0.3	0.2
Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Petroleum Systems	+	+	+	+	+	+	+
Natural Gas Systems	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.9*	*1.0*	*1.0*	*1.0*	*1.1*	*1.1*	*1.0*
HFCs	**46.5**	**127.5**	**168.3**	**168.1**	**170.3**	**169.8**	**174.6**
Substitution of Ozone Depleting Substances[d]	0.2	107.3	163.6	164.9	164.7	166.0	170.5
HCFC-22 Production	46.1	20.0	4.3	2.8	5.2	3.3	3.7
Electronics Industry	0.2	0.2	0.3	0.3	0.4	0.4	0.3
Magnesium Production and Processing	+	+	0.1	0.1	0.1	0.1	0.1
PFCs	**24.3**	**6.7**	**5.2**	**4.4**	**4.1**	**4.7**	**4.5**
Electronics Industry	2.8	3.3	3.1	2.9	2.9	3.0	2.7
Aluminum Production	21.5	3.4	2.1	1.4	1.1	1.6	1.8
Substitution of Ozone Depleting Substances	+	+	+	+	+	0.1	0.1
SF_6	**28.8**	**11.8**	**5.5**	**6.0**	**5.9**	**5.7**	**5.9**
Electrical Transmission and Distribution	23.2	8.4	3.8	4.1	4.2	3.9	4.2
Magnesium Production and Processing	5.2	2.7	1.0	1.1	1.0	1.0	0.9
Electronics Industry	0.5	0.7	0.7	0.8	0.7	0.8	0.8

NF_3	**+**	**0.5**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**
Electronics Industry	+	0.5	0.6	0.6	0.6	0.6	0.6
Unspecified Mix of HFCs, PFCs, SF_6, and NF_3	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Electronics Industry	+	+	+	+	+	+	+
Total Emissions (Sources)	**6,442.7**	**7,423.0**	**6,671.1**	**6,520.3**	**6,483.3**	**6,671.4**	**6,558.3**
LULUCF Emissions[c]	**7.9**	**16.8**	**27.8**	**13.2**	**26.0**	**23.4**	**23.5**
LULUCF CH_4 Emissions	5.0	9.3	16.6	7.7	15.3	13.8	13.8
LULUCF N_2O Emissions	3.0	7.5	11.3	5.5	10.6	9.7	9.7
LULUCF Carbon Stock Change[e]	**(908.7)**	**(804.8)**	**(791.7)**	**(856.0)**	**(792.0)**	**(824.9)**	**(812.7)**
LULUCF Sector Net Total[f]	**(900.8)**	**(788.1)**	**(763.8)**	**(842.8)**	**(766.1)**	**(801.4)**	**(789.2)**
Net Emissions (Sources and Sinks)	**5,541.9**	**6,635.0**	**5,907.3**	**5,677.5**	**5,717.2**	**5,870.0**	**5,769.1**

Notes: Total emissions presented without LULUCF. Net emissions presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Emissions from Wood Biomass, Ethanol, and Biodiesel 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.

[c] LULUCF emissions of CH_4 and N_2O are reported separately from gross emissions totals. LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils.

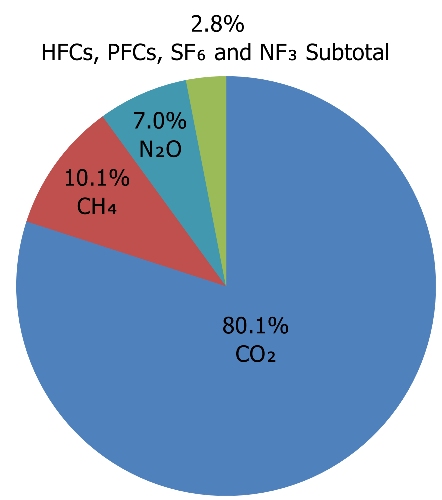
[d] Small amounts of PFC emissions also result from this source.

[e] LULUCF Carbon Stock Change 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, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements,* and *Land Converted to Settlements.*

[f] The LULUCF Sector Net Total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus net C stock changes.

Figure ES-4 illustrates the relative contribution of the greenhouse gases to total U.S. emissions in 2019, weighted by global warming potential. The primary greenhouse gas emitted by human activities in the United States was CO_2, representing approximately 80.1 percent of total greenhouse gas emissions. The largest source of CO_2, and of overall greenhouse gas emissions, was fossil fuel combustion primarily from transportation and power generation. Methane emissions (CH_4) account for approximately 10.1 percent of emissions. The major sources of methane include enteric fermentation associated with domestic livestock, natural gas systems, and decomposition of wastes in landfills. Agricultural soil management, wastewater treatment, stationary sources of fuel combustion, and manure management 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 hydrofluorocarbon (HFC) emissions. Perfluorocarbon (PFC) emissions were primarily attributable to electronics manufacturing and primary aluminum production. Electrical transmission and distribution systems accounted for most sulfur hexafluoride (SF_6) emissions. The electronics industry is the only source of nitrogen trifluoride (NF_3) emissions.

Figure ES-4: 2019 U.S. Greenhouse Gas Emissions by Gas (Percentages based on MMT CO_2 Eq.)



Overall, from 1990 to 2019, total emissions of CO_2 increased by 142.4 MMT CO_2 Eq. (2.8 percent), while total emissions of CH_4 decreased by 117.2 MMT CO_2 Eq. (15.1 percent) and emissions of N_2O increased by 4.5 MMT CO_2 Eq. (1.0 percent). During the same period, aggregate weighted emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) rose by 86.0 MMT CO_2 Eq. (86.3 percent). From 1990 to 2019, HFCs increased by 128.1 MMT CO_2 Eq. (275.4 percent), PFCs decreased by 19.8 MMT CO_2 Eq. (81.5 percent), SF_6 decreased by 22.9 MMT CO_2 Eq. (79.5 percent), and NF_3 increased by 0.6 MMT CO_2 Eq. (1,162.7 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 (C) sequestration in forests, trees in urban areas, agricultural soils, landfilled yard trimmings and food scraps, and coastal wetlands, which, in aggregate, offset 12.4 percent of total emissions in 2019 (as reflected in Figure ES-1). 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, global carbon fluxes among these various reservoirs are roughly balanced.[13]

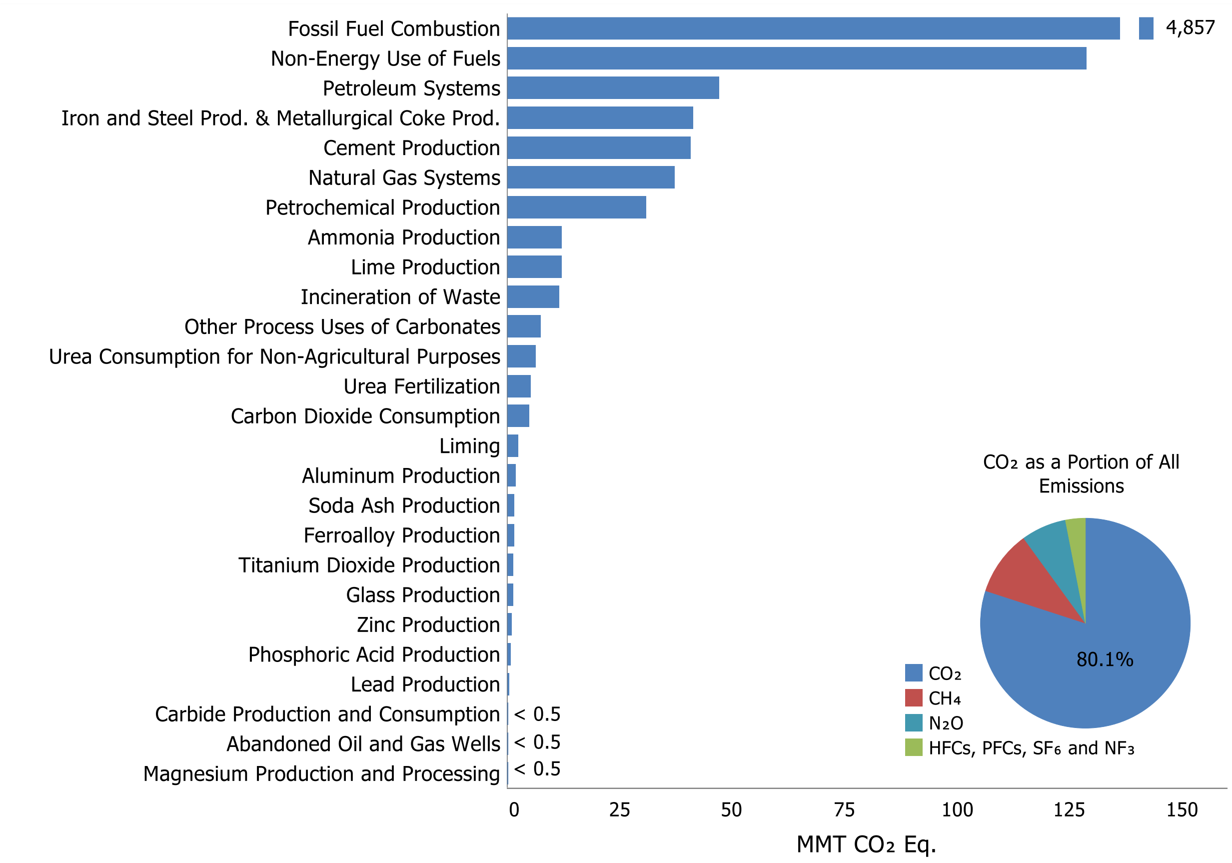
Since the Industrial Revolution (i.e., about 1750), global atmospheric concentrations of CO_2 have risen approximately 47 percent (IPCC 2013; NOAA/ESRL 2021a), principally due to the combustion of fossil fuels for

[13] The term "flux" is used to describe the exchange of CO_2 to and from the atmosphere, with net flux being either positive or negative depending on the overall balance. Removal and long-term storage of CO_2 from the atmosphere is also referred to as "carbon sequestration."

energy. Globally, an estimated 33,513 MMT of CO_2 were added to the atmosphere through the combustion of fossil fuels in 2018, of which the United States accounted for approximately 15 percent.[14]

Within the United States, fossil fuel combustion accounted for 92.4 percent of CO_2 emissions in 2019. Transportation was the largest emitter of CO_2 in 2019 followed by electric power generation. There are 25 additional sources of CO_2 emissions included in the Inventory (see Table ES-5). Although not illustrated in the Table ES-5, changes in land use and forestry practices can also lead to net CO_2 emissions (e.g., through conversion of forest land to agricultural or urban use) or to a net sink for CO_2 (e.g., through net additions to forest biomass). See more on these emissions and removals in Table ES-5.

Figure ES-5: 2019 Sources of CO_2 Emissions



As the largest source of U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion has accounted for approximately 76 percent of GWP-weighted total U.S. gross emissions across the time series. Between 1990 and 2019, CO_2 emissions from fossil fuel combustion increased from 4,731.5 MMT CO_2 Eq. to 4,856.7 MMT CO_2 Eq., a 2.6 percent total increase. Conversely, CO_2 emissions from fossil fuel combustion decreased by 896.8 MMT CO_2 Eq. from 2005 levels, a decrease of approximately 15.6 percent. From 2018 to 2019, these emissions decreased by 134.7 MMT CO_2 Eq. (2.7 percent).

Historically, changes in emissions from fossil fuel combustion have been the driving 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. Important drivers include: (1) changes in demand for energy; and (2) a general decline in the carbon

[14] Global CO_2 emissions from fossil fuel combustion were taken from International Energy Agency *CO_2 Emissions from Fossil Fuels Combustion Overview*. See <https://webstore.iea.org/co2-emissions-from-fuel-combustion-2020-highlights> (IEA 2020). The publication has not yet been updated to include complete global 2019 data.

intensity of fuels combusted for energy in recent years by non-transport sectors of the economy. Long-term factors affecting energy demand include population and economic trends, technological changes including energy efficiency, shifting energy fuel choices, and various policies at the national, state, and local level. In the short term, the overall consumption and mix of fossil fuels in the United States fluctuates primarily in response to changes in general economic conditions, overall energy prices, the relative price of different fuels, weather, and the availability of non-fossil alternatives.

The five major fuel-consuming economic sectors are transportation, electric power, industrial, residential, and commercial. Carbon dioxide emissions are produced by the electric power sector as fossil fuel is consumed to provide electricity to one of the other four sectors, or "end-use" sectors, see Figure ES-6. Note that this Figure reports emissions from U.S. Territories as their own end-use sector due to incomplete data for their individual end-use sectors. Fossil fuel combustion for electric power also includes emissions of less than 0.5 MMT CO_2 Eq. from geothermal-based generation.

Figure ES-6: 2019 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type

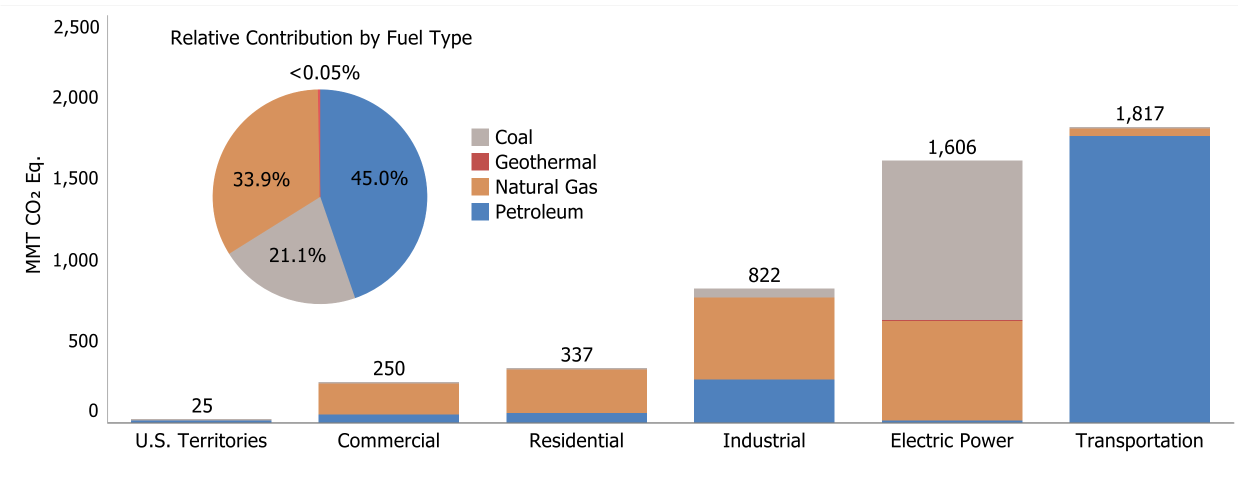


Figure ES-7 and Table ES-3 summarize CO_2 emissions from fossil fuel combustion by end-use sector including electric power emissions. For Figure ES-7 below, electric power emissions have been distributed to each end-use sector on the basis of each sector's share of aggregate electricity use (i.e., indirect fossil fuel combustion). This method of distributing emissions assumes that each end-use sector uses electricity that is generated from the national average mix of fuels according to their carbon intensity. Emissions from electric power are also addressed separately after the end-use sectors are discussed.

Figure ES-7: 2019 End-Use Sector Emissions of CO_2 from Fossil Fuel Combustion

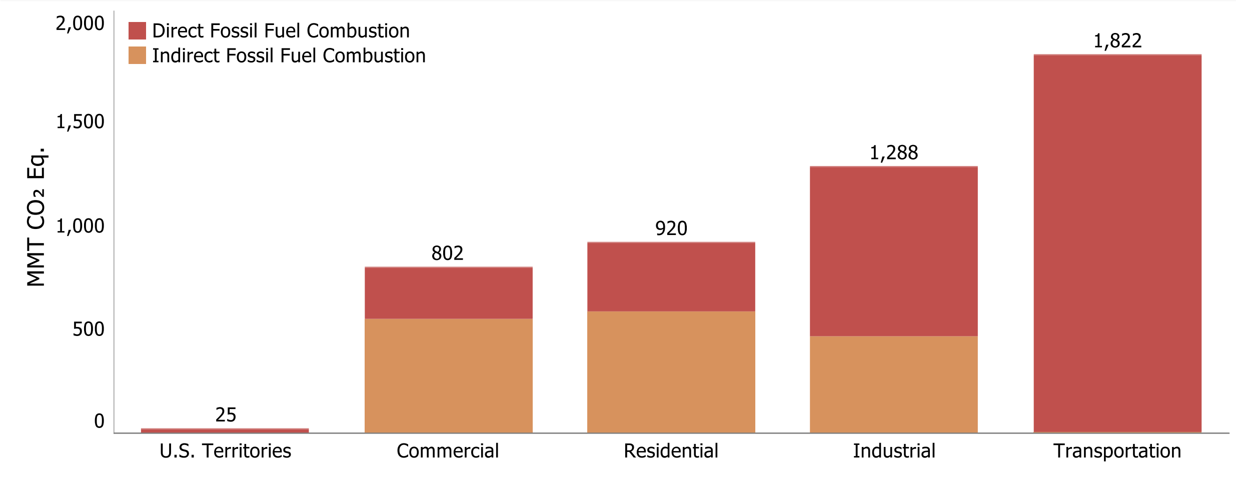


Table ES-3: CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector (MMT CO_2 Eq.)

End-Use Sector	1990	2005	2015	2016	2017	2018	2019
Transportation	**1,472.2**	**1,863.4**	**1,723.5**	**1,764.1**	**1,786.8**	**1,821.2**	**1,821.9**
Combustion	1,469.1	1,858.6	1,719.2	1,759.9	1,782.4	1,816.6	1,817.2
Electricity	3.0	4.7	4.3	4.2	4.3	4.7	4.7
Industrial	**1,540.2**	**1,589.2**	**1,346.8**	**1,310.1**	**1,294.5**	**1,314.9**	**1,287.8**
Combustion	853.8	852.9	797.3	792.5	790.1	813.6	822.5
Electricity	686.4	736.3	549.5	517.6	504.4	501.3	465.3
Residential	**931.3**	**1,214.9**	**1,001.1**	**946.2**	**910.5**	**980.2**	**920.3**
Combustion	338.6	358.9	317.3	292.8	293.4	338.1	336.8
Electricity	592.7	856.0	683.8	653.5	617.1	642.1	583.5
Commercial	**766.0**	**1,030.1**	**907.6**	**865.2**	**838.2**	**850.6**	**802.1**
Combustion	228.3	227.1	244.6	231.6	232.0	245.7	249.7
Electricity	537.7	803.0	663.0	633.6	606.2	604.8	552.4
U.S. Territories[a]	**21.7**	**55.9**	**29.2**	**26.0**	**24.6**	**24.6**	**24.6**
Total	**4,731.5**	**5,753.5**	**5,008.3**	**4,911.5**	**4,854.5**	**4,991.4**	**4,856.7**
Electric Power	**1,820.0**	**2,400.1**	**1,900.6**	**1,808.9**	**1,732.0**	**1,752.9**	**1,606.0**

Notes: Combustion-related emissions from electric power are allocated based on aggregate national electricity use by each end-use sector and represent indirect fossil fuel combustion for each end-use sector. Totals may not sum due to independent rounding.

[a] Fuel consumption by U.S. Territories (i.e., American Samoa, Guam, Puerto Rico, U.S. Virgin Islands, Wake Island, and other U.S. Pacific Islands) is included in this report.

Transportation End-Use Sector. Transportation activities accounted for 37.5 percent of U.S. CO_2 emissions from fossil fuel combustion in 2019. The largest sources of transportation CO_2 emissions in 2019 were passenger cars (40.5 percent); freight trucks (23.6 percent); light-duty trucks, which include sport utility vehicles, pickup trucks, and minivans (17.2 percent); commercial aircraft (7.2 percent); pipelines (2.9 percent); other aircraft (2.4 percent); rail (2.2 percent); and ships and boats (2.1 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 2019, total transportation CO_2 emissions increased due, in large part, to increased demand for travel. The number of vehicle miles traveled (VMT) by light-duty motor vehicles (i.e., passenger cars and light-duty trucks) increased 47.5 percent from 1990 to 2019,[15] 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. While an increased demand for travel has led to increasing CO_2 emissions since 1990, improvements in average new vehicle fuel economy since 2005 has slowed the rate of increase of CO_2 emissions. Petroleum-based products supplied 95.1 percent of the energy consumed for transportation, with 56.5 percent being related to gasoline consumption in automobiles and other highway vehicles. Diesel fuel for freight trucks and jet fuel for aircraft, accounted for 24.3 and 13.3 percent, respectively. The remaining 0.9 percent of petroleum-based energy consumed for transportation was supplied by natural gas, residual fuel, aviation gasoline, and liquefied petroleum gases. The remaining 4.9 percent of energy consumed for transportation is associated with renewable fuels (i.e., biofuels).

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 used by industry, accounted for 27 percent of CO_2 emissions from fossil fuel combustion in 2019. Approximately 64 percent of these emissions resulted from direct fossil fuel combustion to produce steam and/or heat for industrial processes. The remaining emissions resulted from the use of electricity for motors, electric furnaces, ovens, lighting, and other applications. Total direct and indirect emissions from the industrial sector have declined by 16.4 percent 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 19 and 17 percent, respectively, of CO_2 emissions from fossil fuel combustion in 2019. The residential and commercial sectors relied heavily on electricity for meeting energy demands, with 63 and 69 percent, respectively, of their emissions attributable to electricity use for lighting, heating, cooling, and operating appliances. The remaining emissions were due to the consumption of natural gas and petroleum for heating and cooking. Total direct and indirect emissions from the residential sector have decreased by 1 percent since 1990. Total direct and indirect emissions from the commercial sector have increased by 4.7 percent since 1990.

Electric Power. The United States relies on electricity to meet a significant portion of its energy demands. Electricity generators used 31 percent of U.S. energy from fossil fuels and emitted 33 percent of the CO_2 from fossil fuel combustion in 2019. The type of energy source used to generate electricity is the main factor influencing emissions.[16] For example, some electricity is generated through non-fossil fuel options such as nuclear, hydroelectric, wind, solar, or geothermal energy. The mix of fossil fuels used also impacts emissions. The electric power sector is the largest consumer of coal in the United States. The coal used by electricity generators accounted for 93 percent of all coal consumed for energy in the United States in 2019.[17] However, the amount of coal and the percent of total electricity generation from coal has been decreasing over time. Coal-fired electric generation (in kilowatt-hours [kWh]) decreased from 54 percent of generation in 1990 to 28 percent in 2019.[18] This corresponded with an increase in natural gas generation and renewable energy generation, largely from wind and solar energy. Natural gas generation (in kWh) represented 11 percent of electric power generation in 1990 and increased over the thirty-year period to represent 34 percent of electric power generation in 2019. Wind and

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[15] VMT estimates are based on data from FHWA Highway Statistics Table VM-1 (FHWA 1996 through 2019). In 2007 and 2008 light-duty VMT decreased 3.0 percent and 2.3 percent, respectively. Note that the decline in light-duty VMT from 2006 to 2007 is due at least in part to a change in FHWA's methods for estimating VMT. In 2011, FHWA changed its methods for estimating VMT by vehicle class, which led to a shift in VMT and emissions among on-road vehicle classes in the 2007 to 2019 time period. In absence of these method changes, light-duty VMT growth between 2006 and 2007 would likely have been higher.

[16] In line with the reporting requirements for inventories submitted under the UNFCCC, CO_2 emissions from biomass combustion have been estimated separately from fossil fuel CO_2 emissions and are not included in the electricity sector totals and trends discussed in this section. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for Land Use, Land-Use Change, and Forestry.

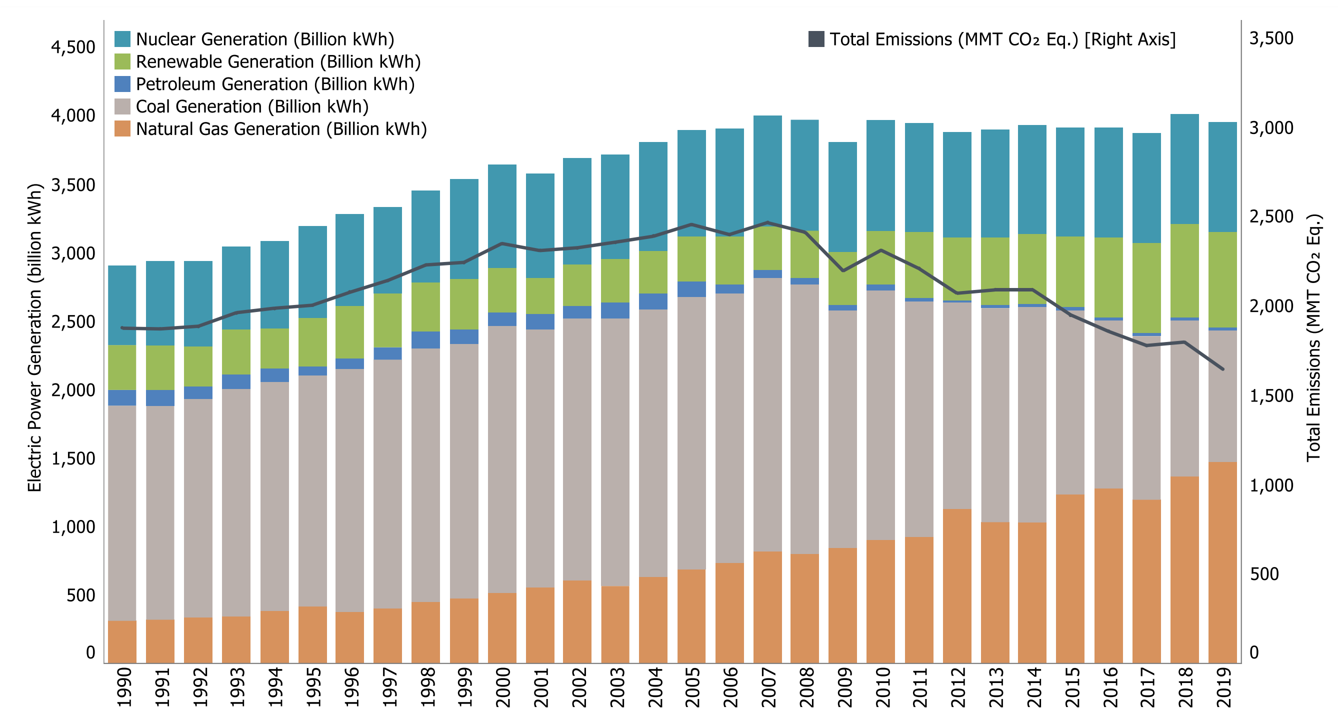
[17] See Table 6.2 Coal Consumption by Sector of EIA (2020a).

[18] Values represent electricity *net* generation from the electric power sector. See Table 7.2b Electricity Net Generation: Electric Power Sector of EIA (2020a).

solar generation (in kWh) represented 0.1 percent of electric power generation in 1990 and increased over the thirty-year period to represent 9 percent of electric power generation in 2019.

Across the time series, changes in electricity generation and the carbon intensity of fuels used for electric power have a significant impact on CO_2 emissions. While CO_2 emissions from the electric power sector have decreased by approximately 12 percent since 1990, the carbon intensity of the electric power sector, in terms of CO_2 Eq. per QBtu input, has significantly decreased– by 27 percent–during that same timeframe. This decoupling of the level of electric power generation and the resulting CO_2 emissions is shown in Figure ES-8.

Figure ES-8: Electric Power Generation and Emissions



Other significant CO_2 trends included the following:

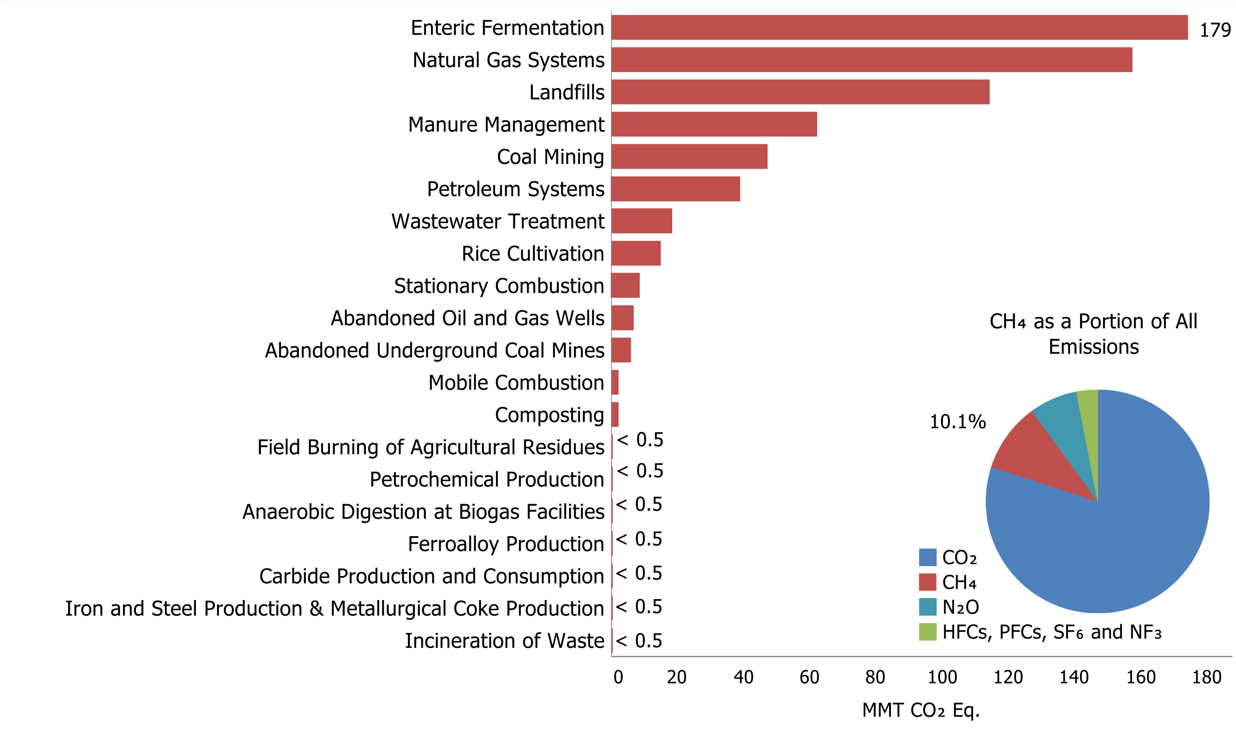
- Carbon dioxide emissions from natural gas and petroleum systems increased by 42.8 MMT CO_2 Eq. (102.4 percent) from 1990 to 2019. This increase is due primarily to increases in the production segment, where flaring emissions from associated gas flaring, tanks, and miscellaneous production flaring have increased over time.
- Carbon dioxide emissions from iron and steel production and metallurgical coke production have decreased by 63.4 MMT CO_2 Eq. (60.6 percent) from 1990 through 2019, due to restructuring of the industry, technological improvements, and increased scrap steel utilization.
- Total C stock change (i.e., net CO_2 removals) in the LULUCF sector decreased by approximately 10.6 percent between 1990 and 2019. This decrease was primarily due to a decrease in the rate of net C accumulation in forest C stocks and *Cropland Remaining Cropland,* as well as an increase in emissions from *Land Converted to Settlements*.

Methane Emissions

Methane (CH_4) is significantly more effective than CO_2 at trapping heat in the atmosphere–by a factor of 25 over a 100-year time frame based on the *IPCC Fourth Assessment Report* estimate (IPCC 2007). Over the last two hundred and fifty years, the concentration of CH_4 in the atmosphere increased by 167 percent (IPCC 2013; NOAA/ESRL

2021b). Within the United States, the main anthropogenic sources of CH_4 include enteric fermentation from domestic livestock, natural gas systems, landfills, domestic livestock manure management, coal mining, and petroleum systems (see Figure ES-9).

Figure ES-9: 2019 Sources of CH_4 Emissions



Note: Emissions of CH_4 from LULUCF are reported separately from gross emissions totals and are not included in Figure ES-9. Refer to Table ES-5 for a breakout of LULUCF emissions by gas.

Significant trends for the largest sources of U.S. CH_4 emissions include the following:

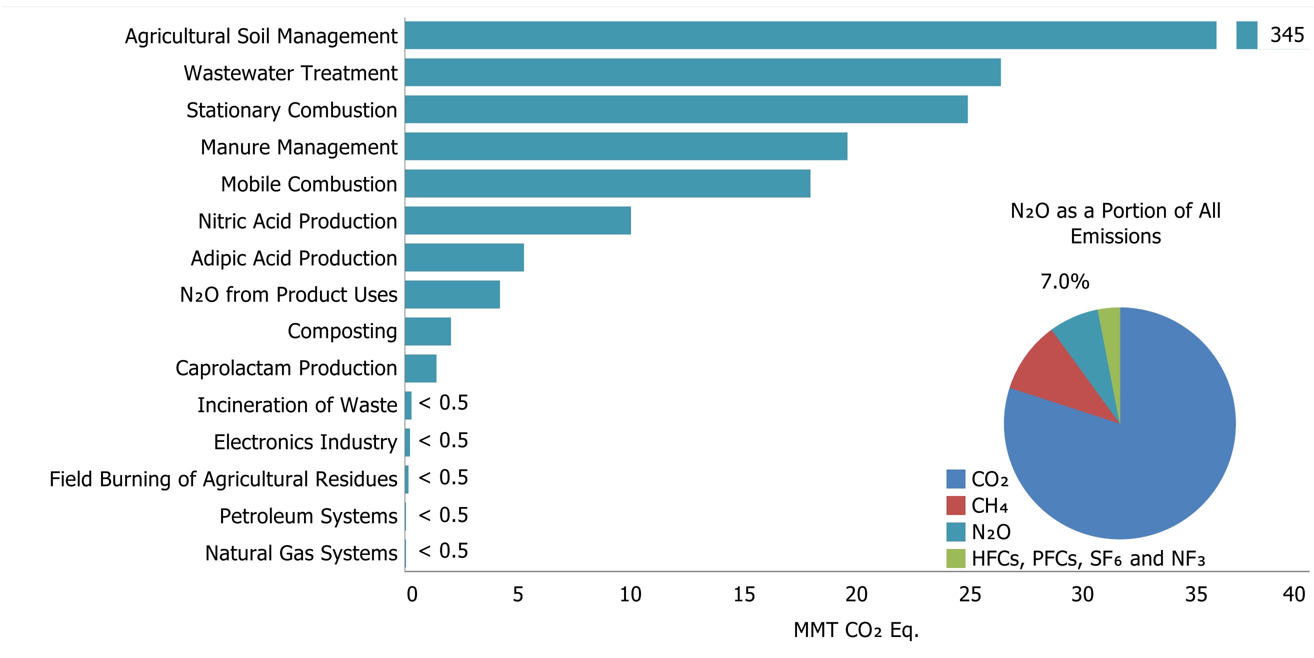
- Enteric fermentation was the largest anthropogenic source of CH_4 emissions in the United States. In 2019, enteric fermentation CH_4 emissions were 178.6 MMT CO_2 Eq. (27.1 percent of total CH_4 emissions), which represents an increase of 13.9 MMT CO_2 Eq. (8.4 percent) since 1990. This increase in emissions from 1990 to 2019 generally follows the increasing trends in cattle populations.
- Natural gas systems were the second largest anthropogenic source category of CH_4 emissions in the United States in 2019 with 157.6 MMT CO_2 Eq. of CH_4 emitted into the atmosphere. Those emissions have decreased by 29.3 MMT CO_2 Eq. (15.7 percent) since 1990. The decrease in CH_4 emissions is largely due to decreases in emissions from distribution, transmission, and storage. The decrease in distribution emissions is due to decreased emissions from pipelines and distribution station leaks, and the decrease in transmission and storage emissions is largely due to reduced compressor station emissions (including emissions from compressors and equipment leaks).
- Landfills were the third largest anthropogenic source of CH_4 emissions in the United States (114.5 MMT CO_2 Eq.), accounting for 17.4 percent of total CH_4 emissions in 2019. From 1990 to 2019, CH_4 emissions from landfills decreased by 62.1 MMT CO_2 Eq. (35.2 percent), with small year-to-year increases. This downward trend in emissions coincided with increased landfill gas collection and control systems, and a reduction of decomposable materials (i.e., paper and paperboard, food scraps, and yard trimmings)

discarded in MSW landfills over the time series.[19] While the amount of landfill gas collected and combusted continues to increase, the rate of increase in collection and combustion no longer exceeds the rate of additional CH_4 generation from the amount of organic MSW landfilled as the U.S. population grows.

Nitrous Oxide Emissions

Nitrous oxide (N_2O) is produced by biological processes that occur in soil and water and by a variety of anthropogenic activities in the agricultural, energy, industrial, and waste management fields. While total N_2O emissions are much lower than CO_2 emissions, N_2O is nearly 300 times more powerful than CO_2 at trapping heat in the atmosphere over a 100-year time frame (IPCC 2007). Since 1750, the global atmospheric concentration of N_2O has risen by approximately 23 percent (IPCC 2013; NOAA/ESRL 2021c). The main anthropogenic activities producing N_2O in the United States are agricultural soil management, wastewater treatment, stationary fuel combustion, manure management, fuel combustion in motor vehicles, and nitric acid production (see Figure ES-10).

Figure ES-10: 2019 Sources of N_2O Emissions



Note: Emissions of N_2O from LULUCF are reported separately from gross emissions totals and are not included in Figure ES-10. Refer to Table ES-5 for a breakout of LULUCF emissions by gas.

Significant trends for the largest sources of U.S. emissions of N_2O include the following:

- Agricultural soils accounted for 75.4 percent of N_2O emissions and 5.3 percent of total greenhouse gas emissions in the United States in 2019. Estimated emissions from this source in 2019 were 344.6 MMT CO_2 Eq. Annual N_2O emissions from agricultural soils fluctuated between 1990 and 2019, although overall emissions were 9.1 percent higher in 2019 than in 1990. Year-to-year fluctuations are largely a reflection of annual variation in weather patterns, synthetic fertilizer use, and crop production.

[19] Carbon dioxide emissions from landfills are not included specifically in summing waste sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs and decay of disposed wood products are accounted for in the estimates for LULUCF.

- Wastewater treatment, both domestic and industrial, accounted for 5.8 percent of N_2O emissions and 0.4 percent of total greenhouse gas emissions in the United States in 2019. Emissions from wastewater treatment increased by 41.0 percent (7.7 MMT CO_2 Eq.) since 1990. Nitrous oxide emissions from wastewater treatment processes gradually increased across the time series as a result of growing U.S. population and protein consumption. Nitrous oxide emissions from industrial wastewater treatment sources, included for the first time in the current (i.e., 1990 to 2019) Inventory, fluctuated throughout the time series with production changes associated with the treatment of wastewater from the pulp and paper manufacturing, meat and poultry processing, fruit and vegetable processing, starch-based ethanol production, petroleum refining, and brewery industries. Industrial wastewater emissions have increased since 2017.
- Nitrous oxide emissions from manure management accounted for 4.3 percent of N_2O emissions in 2019 and increased by 40.2 percent (5.6 MMT CO_2 Eq.) from 1990 to 2019. While the industry trend has been a shift toward liquid systems, driving down the emissions per unit of nitrogen excreted (dry manure handling systems have greater aerobic conditions that promote N_2O emissions), increases in specific animal populations have driven an increase in overall manure management N_2O emissions over the time series.
- Nitrous oxide emissions from mobile combustion decreased by 26.8 MMT CO_2 Eq. (59.8 percent) from 1990 to 2019, primarily as a result of national vehicle emissions standards and emission control technologies for on-road vehicles.

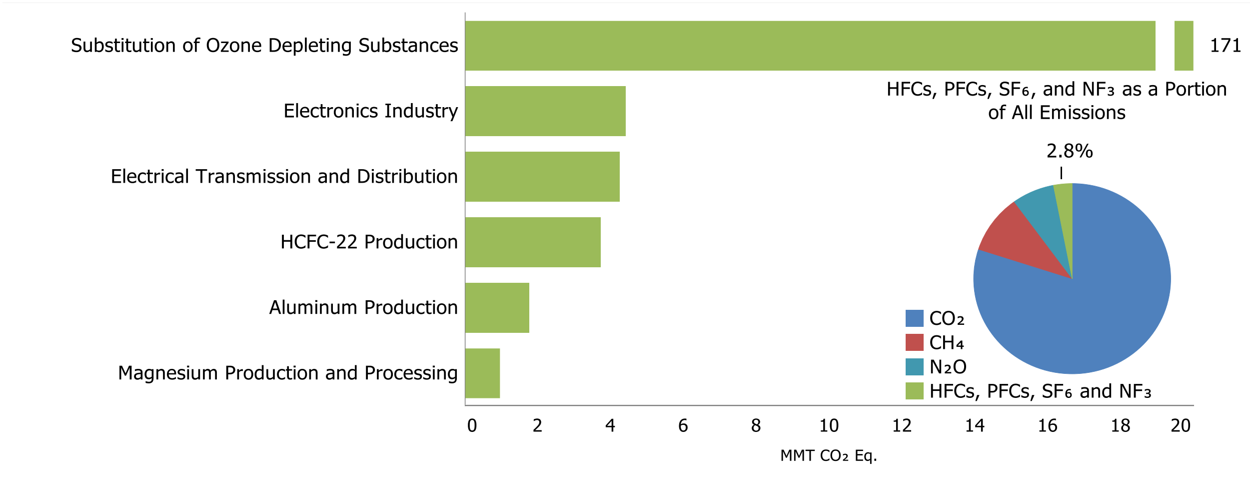
HFC, PFC, SF_6, and NF_3 Emissions

Hydrofluorocarbons (HFCs) are 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 do not deplete the stratospheric ozone layer and therefore have been used as alternatives under the Montreal Protocol on Substances that Deplete the Ozone Layer.

Perfluorocarbons (PFCs) are emitted from the production of electronics and aluminum and also (in smaller quantities) from their use as alternatives to ozone depleting substances. Sulfur hexafluoride (SF_6) is emitted from the production of electronics and magnesium and from the manufacturing and use of electrical transmission and distribution equipment. NF_3 is also emitted from electronics production. One HFC, HFC-23, is emitted during production of HCFC-22 and electronics (see Figure ES-11).

HFCs, PFCs, SF_6, and NF_3 are potent greenhouse gases. In addition to having very 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).

Figure ES-11: 2019 Sources of HFCs, PFCs, SF_6, and NF_3 Emissions



Some significant trends for the largest sources of U.S. HFC, PFC, SF_6, and NF_3 emissions include the following:

- Hydrofluorocarbon and perfluorocarbon emissions resulting from their use as substitutes for ODS (e.g., chlorofluorocarbons [CFCs]) are the largest share of fluorinated emissions (92 percent) and have been consistently increasing, from small amounts in 1990 to 170.6 MMT CO_2 Eq. in 2019. This increase was in large part the result of efforts to phase out CFCs and other ODS in the United States.
- Emissions from HCFC-22 production were 3.7 MMT CO_2 Eq. in 2019, a 92 percent decrease from 1990 emissions. The decrease from 1990 emissions was caused primarily by a reduction in the HFC-23 emission rate (kg HFC-23 emitted/kg HCFC-22 produced). The emission rate was lowered by optimizing the production process and capturing much of the remaining HFC-23 for use or destruction.
- GWP-weighted PFC, HFC, SF_6, and NF_3 emissions from the electronics industry have increased by 23.7 percent from 1990 to 2019, reflecting the competing influences of industrial growth and the adoption of emission reduction technologies. Within that time span, emissions peaked at 9.0 MMT CO_2 Eq. in 1999, the initial year of EPA's PFC Reduction/Climate Partnership for the Semiconductor Industry, but have since declined to 4.4 MMT CO_2 Eq. in 2019 (a 51.3 percent decrease relative to 1999).
- Sulfur hexafluoride emissions from electric power transmission and distribution systems decreased by 81.7 percent (18.9 MMT CO_2 Eq.) from 1990 to 2019. There are two factors contributing to 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.

ES.3 Overview of Sector Emissions and Trends

Figure ES-12 and Table ES-4 aggregate emissions and sinks by the sectors defined by the UNFCCC reporting guidelines to promote comparability across countries. Over the thirty-year period of 1990 to 2019, total emissions from the Energy, Industrial Processes and Product Use, and Agriculture sectors grew by 66.7 MMT CO_2 Eq. (1.3 percent), 28.2 MMT CO_2 Eq. (8.1 percent), and 73.3 MMT CO_2 Eq. (13.2 percent), respectively. Emissions from the Waste sector decreased by 52.4 MMT CO_2 Eq. (24.2 percent). Over the same period, net C sequestration in the LULUCF sector decreased by 96.0 MMT CO_2 (10.6 percent decrease in total net C sequestration), while emissions from the LULUCF sector (i.e., CH_4 and N_2O) increased by 15.5 MMT CO_2 Eq. (196.1 percent).

Figure ES-12: U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector

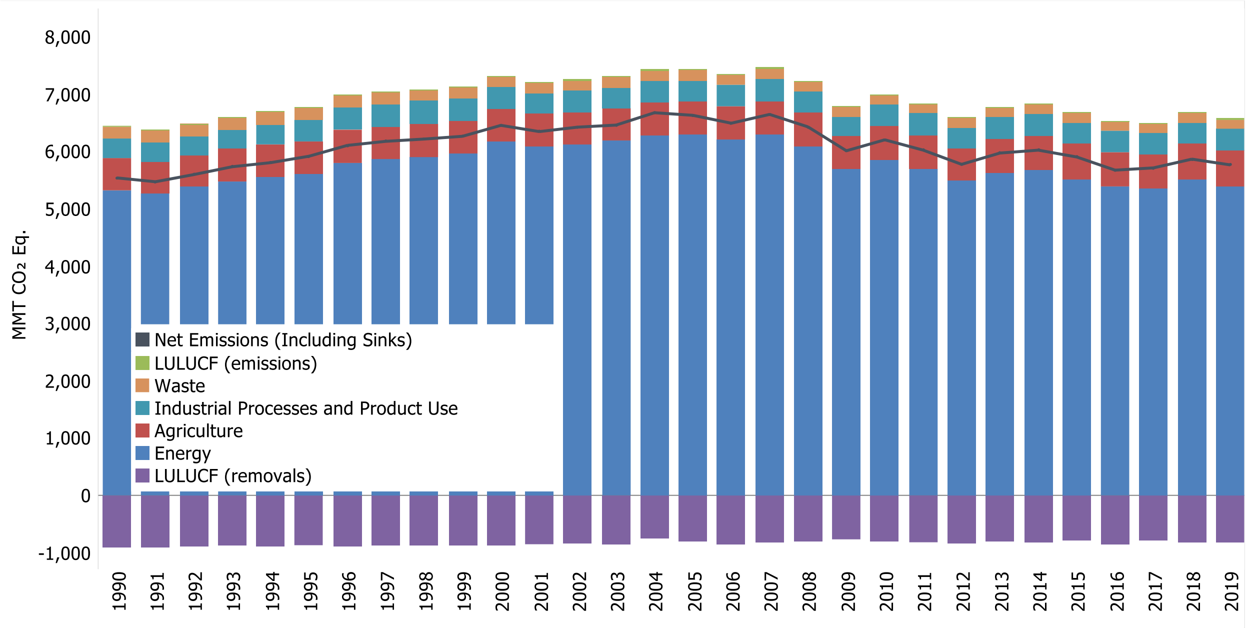


Table ES-4: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (MMT CO_2 Eq.)

Chapter/IPCC Sector	1990	2005	2015	2016	2017	2018	2019
Energy	**5,325.6**	**6,302.3**	**5,519.8**	**5,390.9**	**5,351.0**	**5,518.1**	**5,392.3**
Fossil Fuel Combustion	4,731.5	5,753.5	5,008.3	4,911.5	4,854.5	4,991.4	4,856.7
Natural Gas Systems	219.0	189.4	179.0	177.4	179.9	186.4	194.9
Non-Energy Use of Fuels	112.8	129.1	108.5	99.8	113.5	129.7	128.8
Petroleum Systems	58.6	51.5	73.9	61.1	64.4	74.5	86.4
Coal Mining	96.5	64.1	61.2	53.8	54.8	52.7	47.4
Stationary Combustion	33.7	42.2	39.0	37.9	36.1	36.8	33.5
Mobile Combustion	51.1	45.5	24.4	23.4	22.3	21.3	20.3
Incineration of Waste	8.5	13.1	11.8	11.8	11.8	11.9	11.8
Abandoned Oil and Gas Wells	6.8	7.2	7.4	7.4	7.2	7.3	6.6
Abandoned Underground Coal Mines	7.2	6.6	6.4	6.7	6.4	6.2	5.9
Industrial Processes and Product Use	**345.6**	**365.7**	**375.4**	**368.0**	**367.7**	**371.3**	**373.7**
Substitution of Ozone Depleting Substances	0.2	107.3	163.6	164.9	164.7	166.1	170.6
Iron and Steel Production & Metallurgical Coke Production	104.8	70.1	47.9	43.6	40.6	42.6	41.3
Cement Production	33.5	46.2	39.9	39.4	40.3	39.0	40.9
Petrochemical Production	21.8	27.5	28.2	28.6	29.2	29.6	31.1
Ammonia Production	13.0	9.2	10.6	10.2	11.1	12.2	12.3
Lime Production	11.7	14.6	13.3	12.6	12.9	13.1	12.1
Nitric Acid Production	12.1	11.3	11.6	10.1	9.3	9.6	10.0
Other Process Uses of Carbonates	6.3	7.6	12.2	11.0	9.9	7.5	7.5
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	4.6	5.1	5.0	5.9	6.2
Adipic Acid Production	15.2	7.1	4.3	7.0	7.4	10.3	5.3
Carbon Dioxide Consumption	1.5	1.4	4.9	4.6	4.6	4.1	4.9
Electronics Industry	3.6	4.8	5.0	5.0	4.9	5.1	4.6
Electrical Transmission and Distribution	23.2	8.4	3.8	4.1	4.2	3.9	4.2
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2

HCFC-22 Production	46.1	20.0	4.3	2.8	5.2	3.3	3.7
Aluminum Production	28.3	7.6	4.9	2.7	2.3	3.1	3.6
Soda Ash Production	1.4	1.7	1.7	1.7	1.8	1.7	1.8
Ferroalloy Production	2.2	1.4	2.0	1.8	2.0	2.1	1.6
Titanium Dioxide Production	1.2	1.8	1.6	1.7	1.7	1.5	1.5
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.7	2.1	1.9	1.7	1.5	1.4	1.4
Glass Production	1.5	1.9	1.3	1.2	1.3	1.3	1.3
Zinc Production	0.6	1.0	0.9	0.8	0.9	1.0	1.0
Magnesium Production and Processing	5.2	2.7	1.1	1.2	1.1	1.1	1.0
Phosphoric Acid Production	1.5	1.3	1.0	1.0	1.0	0.9	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.2	0.2
Agriculture	**555.3**	**577.1**	**616.1**	**604.4**	**605.5**	**621.0**	**628.6**
Agricultural Soil Management	315.9	313.4	348.5	330.1	327.6	338.2	344.6
Enteric Fermentation	164.7	169.3	166.9	172.2	175.8	178.0	178.6
Manure Management	51.1	67.9	75.4	77.7	78.5	81.1	82.0
Rice Cultivation	16.0	18.0	16.2	15.8	14.9	15.6	15.1
Urea Fertilization	2.4	3.5	4.7	4.9	5.1	5.2	5.3
Liming	4.7	4.3	3.7	3.1	3.1	2.2	2.4
Field Burning of Agricultural Residues	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Waste	**216.2**	**178.0**	**159.8**	**157.1**	**159.0**	**161.1**	**163.7**
Landfills	176.6	131.4	111.4	108.0	109.4	112.1	114.5
Wastewater Treatment	38.9	43.0	44.2	44.6	44.9	44.6	44.8
Composting	0.7	3.5	4.0	4.3	4.6	4.3	4.3
Anaerobic Digestion at Biogas Facilities	+	0.1	0.2	0.2	0.2	0.2	0.2
Total Emissions[a] (Sources)	**6,442.7**	**7,423.0**	**6,671.1**	**6,520.3**	**6,483.3**	**6,671.4**	**6,558.3**
LULUCF Sector Net Total[b]	**(900.8)**	**(788.1)**	**(763.8)**	**(842.8)**	**(766.1)**	**(801.4)**	**(789.2)**
Forest land	(884.1)	(751.4)	(749.5)	(814.7)	(740.0)	(781.4)	(774.6)
Cropland	28.6	23.2	43.2	31.7	32.3	37.7	39.7
Grassland	2.2	(29.4)	(10.1)	(13.7)	(12.5)	(11.9)	(8.0)
Wetlands	(2.8)	(1.9)	(3.9)	(3.9)	(3.8)	(3.9)	(3.9)
Settlements	(44.7)	(28.5)	(43.5)	(42.2)	(42.1)	(42.0)	(42.4)
Net Emission (Sources and Sinks)[c]	**5,541.9**	**6,635.0**	**5,907.3**	**5,677.5**	**5,717.2**	**5,870.0**	**5,769.1**

Notes: Total emissions presented without LULUCF. Net emissions presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

[a] Total emissions without LULUCF.

[b] The LULUCF Sector Net Total is the sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes in units of MMT CO_2 Eq.

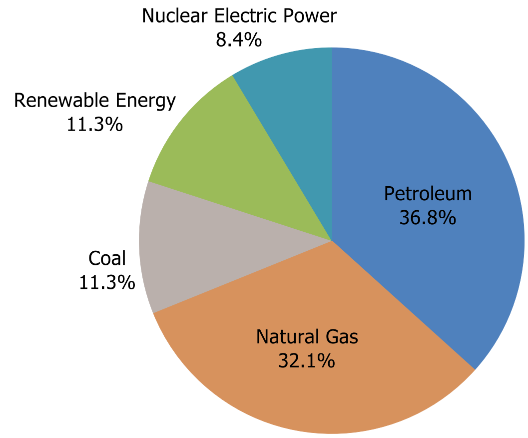
[c] Net emissions with LULUCF.

Energy

The Energy chapter contains emissions of all greenhouse gases resulting from stationary and mobile energy activities including fuel combustion and fugitive fuel emissions, and the use of fossil fuels for non-energy purposes. Energy-related activities, primarily fossil fuel combustion, accounted for the vast majority of U.S. CO_2 emissions for the period of 1990 through 2019. Energy-related activities are also responsible for CH_4 and N_2O emissions (40.6 percent and 9.5 percent of total U.S. emissions of each gas, respectively). Overall, emission sources in the Energy chapter account for a combined 82.2 percent of total U.S. greenhouse gas emissions in 2019.

In 2019, approximately 80 percent of the energy used in the United States (on a Btu basis) was produced through the combustion of fossil fuels. The remaining 20 percent came from other energy sources, such as hydropower, biomass, nuclear, wind, and solar energy (see Figure ES-13).

Figure ES-13: 2019 U.S. Energy Consumption by Energy Source (Percent)



Industrial Processes and Product Use

The Industrial Processes and Product Use (IPPU) chapter contains information on greenhouse gas emissions generated and emitted as the byproducts of non-energy-related industrial processes, which involve the chemical or physical transformation of raw materials and can release waste gases such as CO_2, CH_4, N_2O, and fluorinated gases (e.g., HFC-23). These processes include iron and steel production and metallurgical coke production, cement production, petrochemical production, lime production, ammonia production, nitric acid production, other process uses of carbonates (e.g., flue gas desulfurization), urea consumption for non-agricultural purposes, adipic acid production, HCFC-22 production, aluminum production, soda ash production and use, ferroalloy production, titanium dioxide production, caprolactam production, glass production, zinc production, phosphoric acid production, lead production, and silicon carbide production and consumption. Most of these industries also emit CO_2 from fossil fuel combustion which, in line with IPCC sectoral definitions, is included in the Energy Sector.

This chapter also contains information on the release of HFCs, PFCs, SF_6, and NF_3 and other fluorinated compounds used in industrial manufacturing processes and by end-consumers (e.g., residential and mobile air conditioning). These industries include electronics industry, electric power transmission and distribution, and magnesium metal production and processing. In addition, N_2O is used in and emitted by electronics industry and anesthetic and aerosol applications, and CO_2 is consumed and emitted through various end-use applications. In 2019, emissions resulting from use of the substitution of ODS (e.g., chlorofluorocarbons [CFCs]) by end-consumers was the largest source of IPPU emissions and accounted for 170.6 MMT CO_2 Eq, or 45.6 percent of total IPPU emissions.

IPPU activities are responsible for 3.2, 0.1, and 4.6 percent of total U.S. CO_2, CH_4, and N_2O emissions respectively as well as for all U.S. emissions of fluorinated gases such as HFCs, PFCs, SF_6 and NF_3. Overall, emission sources in the IPPU chapter accounted for 5.7 percent of U.S. greenhouse gas emissions in 2019.

Agriculture

The Agriculture chapter contains information on anthropogenic emissions from agricultural activities (except fuel combustion, which is addressed in the Energy chapter, and some agricultural CO_2, CH_4, and N_2O 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: agricultural soil management, enteric fermentation in domestic livestock, livestock manure management, rice cultivation, urea fertilization, liming, and field burning of agricultural residues.

In 2019, agricultural activities were responsible for emissions of 628.6 MMT CO_2 Eq., or 9.6 percent of total U.S. greenhouse gas emissions. Methane, N_2O, and CO_2 are greenhouse gases emitted by agricultural activities. Methane emissions from enteric fermentation and manure management represented approximately 27.1 percent and 9.5 percent of total CH_4 emissions from anthropogenic activities, respectively, in 2019. Agricultural soil management activities, such as application of synthetic and organic fertilizers, deposition of livestock manure, and growing N-fixing plants, were the largest contributors to U.S. N_2O emissions in 2019, accounting for 75.4 percent of total N_2O emissions. Carbon dioxide emissions from the application of crushed limestone and dolomite (i.e., soil liming) and urea fertilization represented 0.1 percent of total CO_2 emissions from anthropogenic activities.

Land Use, Land-Use Change, and Forestry

The LULUCF chapter contains emissions and removals of CO_2 and emissions of CH_4 and N_2O from managed lands in the United States. Consistent with the *2006 IPCC Guidelines*, emissions and removals from managed lands are considered to be anthropogenic, while emissions and removals from unmanaged lands are considered to be natural.[20] The share of managed land in the U.S. is approximately 95 percent of total land included in the Inventory.[21] More information on the definition of managed land used in the Inventory is provided in Chapter 6.

Overall, the Inventory results show that managed land is a net sink for CO_2 (C sequestration). The primary drivers of fluxes on managed lands include forest management practices, tree planting in urban areas, the management of agricultural soils, landfilling of yard trimmings and food scraps, and activities that cause changes in C stocks in coastal wetlands. The main drivers for forest C sequestration include forest growth and increasing forest area (i.e., afforestation), as well as a net accumulation of C stocks in harvested wood pools. The net sequestration in *Settlements Remaining Settlements,* which occurs predominantly from urban forests (i.e., Settlement Trees) and landfilled yard trimmings and food scraps, is a result of net tree growth and increased urban forest area, as well as long-term accumulation of yard trimmings and food scraps carbon in landfills.

The LULUCF sector in 2019 resulted in a net increase in C stocks (i.e., net CO_2 removals) of 812.7 MMT CO_2 Eq. (Table ES-5).[22] This represents an offset of 12.3 percent of total (i.e., gross) greenhouse gas emissions in 2019. Emissions of CH_4 and N_2O from LULUCF activities in 2019 were 23.5 MMT CO_2 Eq. and represent 0.4 percent of total greenhouse gas emissions.[23] Between 1990 and 2019, total C sequestration in the LULUCF sector decreased by 10.6 percent, primarily due to a decrease in the rate of net C accumulation in forests and *Cropland Remaining Cropland,* as well as an increase in CO_2 emissions from *Land Converted to Settlements*. The overall net flux from LULUCF (i.e., net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes in units of MMT CO_2 eq.) resulted in a removal of 789.2 MMT CO_2 Eq. in 2019.

Forest fires were the largest source of CH_4 emissions from the LULUCF sector in 2019, totaling 9.5 MMT CO_2 Eq. (379 kt of CH_4). *Coastal Wetlands Remaining Coastal Wetlands* resulted in CH_4 emissions of 3.8 MMT CO_2 Eq. (153 kt of CH_4). Grassland fires resulted in CH_4 emissions of 0.3 MMT CO_2 Eq. (12 kt of CH_4). *Land Converted to Wetlands* resulted in CH_4 emissions of 0.2 MMT CO_2 Eq (7 kt of CH_4). *Drained Organic Soils* and *Peatlands Remaining Peatlands* resulted in CH_4 emissions of less than 0.05 MMT CO_2 Eq. each.

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[20] See <http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_01_Ch1_Introduction.pdf>.

[21] The current land representation does not include land in U.S. Territories, but there are planned improvements to include these regions in future Inventories. U.S. Territories represent approximately 0.1 percent of the total land base for the United States. See Box 6-2 in Chapter 6 of this report.

[22] LULUCF Carbon Stock Change 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, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements,* and *Land Converted to Settlements.*

[23] LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils.

Forest fires were also the largest source of N_2O emissions from the LULUCF sector in 2019, totaling 6.2 MMT CO_2 Eq. (21 kt of N_2O). Nitrous oxide emissions from fertilizer application to settlement soils in 2019 totaled to 2.4 MMT CO_2 Eq. (8 kt of N_2O). Additionally, the application of synthetic fertilizers to forest soils in 2019 resulted in N_2O emissions of 0.5 MMT CO_2 Eq. (2 kt of N_2O). Grassland fires resulted in N_2O emissions of 0.3 MMT CO_2 Eq. (1 kt of N_2O). *Coastal Wetlands Remaining Coastal Wetlands* and *Drained Organic Soils* resulted in N_2O emissions of 0.1 MMT CO_2 Eq. each (less than 0.5 kt of N_2O). *Peatlands Remaining Peatlands* resulted in N_2O emissions of less than 0.05 MMT CO_2 Eq.

Carbon dioxide removals from C stock changes are presented in Table ES-5 along with CH_4 and N_2O emissions for LULUCF source categories.

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

Land-Use Category	1990	2005	2015	2016	2017	2018	2019
Forest Land Remaining Forest Land	**(785.9)**	**(652.8)**	**(650.6)**	**(715.7)**	**(640.9)**	**(682.4)**	**(675.5)**
Changes in Forest Carbon Stocks[a]	(787.6)	(661.5)	(671.4)	(721.9)	(659.7)	(698.6)	(691.8)
Non-CO_2 Emissions from Forest Fires[b]	1.5	8.2	20.3	5.6	18.3	15.7	15.7
N_2O Emissions from Forest Soils[c]	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Non-CO_2 Emissions from Drained Organic Soils[d]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Land Converted to Forest Land	**(98.2)**	**(98.7)**	**(98.9)**	**(99.0)**	**(99.1)**	**(99.1)**	**(99.1)**
Changes in Forest Carbon Stocks[e]	(98.2)	(98.7)	(98.9)	(99.0)	(99.1)	(99.1)	(99.1)
Cropland Remaining Cropland	**(23.2)**	**(29.0)**	**(12.8)**	**(22.7)**	**(22.3)**	**(16.6)**	**(14.5)**
Changes in Mineral and Organic Soil Carbon Stocks	(23.2)	(29.0)	(12.8)	(22.7)	(22.3)	(16.6)	(14.5)
Land Converted to Cropland	**51.8**	**52.2**	**56.1**	**54.4**	**54.6**	**54.3**	**54.2**
Changes in all Ecosystem Carbon Stocks[f]	51.8	52.2	56.1	54.4	54.6	54.3	54.2
Grassland Remaining Grassland	**8.5**	**10.7**	**13.8**	**10.4**	**11.9**	**12.3**	**15.1**
Changes in Mineral and Organic Soil Carbon Stocks	8.3	10.0	13.1	9.8	11.3	11.7	14.5
Non-CO_2 Emissions from Grassland Fires[g]	0.2	0.7	0.7	0.6	0.6	0.6	0.6
Land Converted to Grassland	**(6.2)**	**(40.1)**	**(23.9)**	**(24.0)**	**(24.4)**	**(24.1)**	**(23.2)**
Changes in all Ecosystem Carbon Stocks[f]	(6.2)	(40.1)	(23.9)	(24.0)	(24.4)	(24.1)	(23.2)
Wetlands Remaining Wetlands	**(3.5)**	**(2.6)**	**(4.1)**	**(4.1)**	**(4.0)**	**(4.0)**	**(4.0)**
Changes in Organic Soil Carbon Stocks in Peatlands	1.1	1.1	0.8	0.7	0.8	0.8	0.8
Changes in Biomass, DOM, and Soil Carbon Stocks in Coastal Wetlands	(8.5)	(7.6)	(8.8)	(8.8)	(8.8)	(8.8)	(8.8)
CH_4 Emissions from Coastal Wetlands Remaining Coastal Wetlands	3.7	3.8	3.8	3.8	3.8	3.8	3.8
N_2O Emissions from Coastal Wetlands Remaining Coastal Wetlands	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Non-CO_2 Emissions from Peatlands Remaining Peatlands	+	+	+	+	+	+	+
Land Converted to Wetlands	**0.7**	**0.7**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Changes in Biomass, DOM, and Soil Carbon Stocks	0.4	0.4	(0.1)	(+)	(+)	(+)	(+)
CH_4 Emissions from Land Converted to Coastal Wetlands	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Settlements Remaining Settlements	**(107.6)**	**(113.5)**	**(123.7)**	**(121.5)**	**(121.4)**	**(121.2)**	**(121.7)**
Changes in Organic Soil Carbon Stocks	11.3	12.2	15.7	16.0	16.0	15.9	15.9
Changes in Settlement Tree Carbon Stocks	(96.4)	(117.4)	(130.4)	(129.8)	(129.8)	(129.8)	(129.8)
Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills	(24.5)	(11.4)	(11.1)	(10.0)	(9.8)	(9.8)	(10.2)
N_2O Emissions from Settlement Soils[h]	2.0	3.1	2.2	2.2	2.3	2.4	2.4

Land Converted to Settlements	**62.9**		**85.0**		**80.1**	**79.4**	**79.3**	**79.3**	**79.2**
Changes in all Ecosystem Carbon Stocks[f]	62.9		85.0		80.1	79.4	79.3	79.3	79.2
LULUCF Carbon Stock Change[i]	**(908.7)**		**(804.8)**		**(791.7)**	**(856.0)**	**(792.0)**	**(824.9)**	**(812.7)**
LULUCF Emissions[j]	**7.9**		**16.8**		**27.8**	**13.2**	**26.0**	**23.4**	**23.5**
LULUCF CH_4 Emissions	5.0		9.3		16.6	7.7	15.3	13.8	13.8
LULUCF N_2O Emissions	3.0		7.5		11.3	5.5	10.6	9.7	9.7
LULUCF Sector Net Total[k]	**(900.8)**		**(788.1)**		**(763.8)**	**(842.8)**	**(766.1)**	**(801.4)**	**(789.2)**

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

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.

[a] Includes the net changes to carbon stocks stored in all forest ecosystem pools and harvested wood products.

[b] Estimates include emissions from fires on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land.*

[c] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

[d] Estimates include CH_4 and N_2O emissions from drained organic soils on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land.*

[e] Includes the net changes to carbon stocks stored in all forest ecosystem pools.

[f] Includes changes in mineral and organic soil carbon stocks for all land use conversions to cropland, grassland, and settlements, respectively. Also includes aboveground/belowground biomass, dead wood, and litter carbon stock changes for conversion of forest land to cropland, grassland, and settlements, respectively.

[g] Estimates include CH_4 and N_2O emissions from fires on both *Grassland Remaining Grassland* and *Land Converted to Grassland.*

[h] Estimates include N_2O emissions from N fertilizer additions on both *Settlements Remaining Settlements* and *Land Converted to Settlements* because it is not possible to separate the activity data at this time.

[i] LULUCF Carbon Stock Change includes any C stock gains and losses from all land use and land use conversion categories.

[j] LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils.

[k] The LULUCF Sector Net Total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes in units of MMT CO_2 Eq.

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 from waste management activities, generating 114.5 MMT CO_2 Eq. and accounting for 69.9 percent of total greenhouse gas emissions from waste management activities, and 17.4 percent of total U.S. CH_4 emissions.[24] Additionally, wastewater treatment generated emissions of 44.8 MMT CO_2 Eq. and accounted for 27.3 percent of total Waste sector greenhouse gas emissions, 2.8 percent of U.S. CH_4 emissions, and 5.8 percent of U.S. N_2O emissions in 2019. Emissions of CH_4 and N_2O from composting are also accounted for in this chapter, generating emissions of 2.3 MMT CO_2 Eq. and 2.0 MMT CO_2 Eq., respectively. Anaerobic digestion at biogas facilities generated CH_4 emissions of 0.2 MMT CO_2 Eq., accounting for 0.1 percent of emissions from the waste sector. Overall, emission sources accounted for in the Waste chapter generated 163.7 MMT CO_2 Eq., or 2.5 percent of total U.S. greenhouse gas emissions in 2019.

[24] 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.

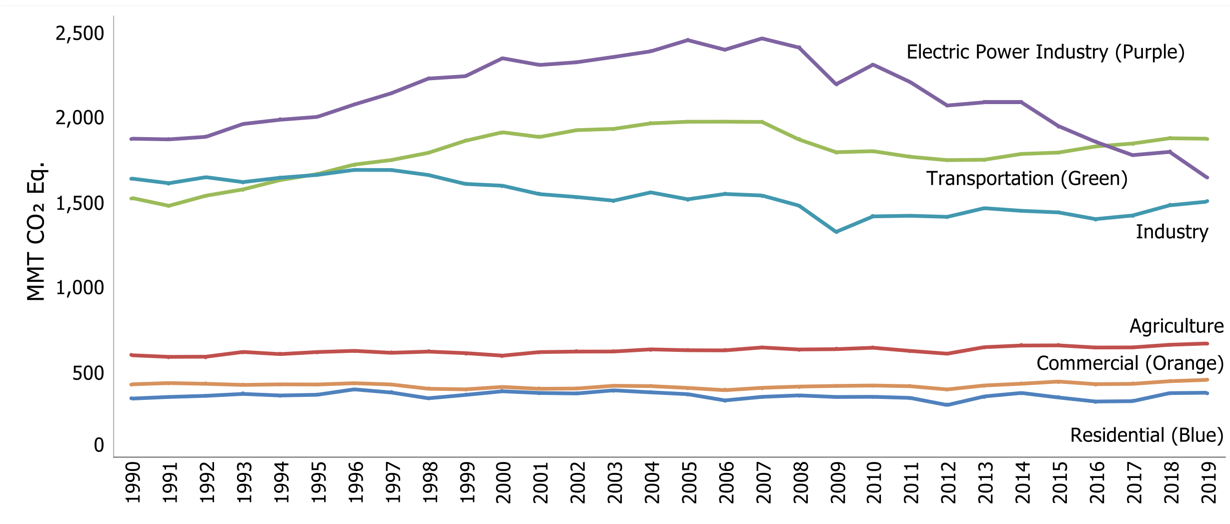
ES.4 Other Information

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; IPPU; Agriculture; LULUCF; and Waste. It is also useful to characterize emissions according to commonly used economic sector categories: residential, commercial, industry, transportation, electric power, and agriculture. Emissions from U.S. Territories are reported as their own end-use sector due to a lack of specific consumption data for the individual end-use sectors within U.S. Territories. For more information on trends in the Land use, Land Use Change and Forestry sector, see section ES.2 Recent Trends in U.S. Greenhouse Gas Emissions and Sinks.

Figure ES-14 shows the trend in emissions by economic sector from 1990 to 2019, and Table ES-6 summarizes emissions from each of these economic sectors.

Figure ES-14: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors



Note: Emissions and removals from Land Use, Land-Use Change, and Forestry are excluded from figure above. Excludes U.S. Territories.

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

Economic Sectors	1990	2005	2015	2016	2017	2018	2019
Transportation	1,526.6	1,975.6	1,794.1	1,830.0	1,847.3	1,878.2	1,875.7
Electric Power Industry	1,875.7	2,456.3	1,950.0	1,857.6	1,778.9	1,798.0	1,648.1
Industry	1,640.7	1,518.8	1,441.6	1,402.2	1,423.4	1,483.3	1,504.8
Agriculture	600.2	629.7	658.5	645.8	646.6	662.0	669.5
Commercial	429.2	407.9	445.4	430.1	431.9	447.3	455.3
Residential	345.1	371.0	351.5	327.8	329.9	377.3	379.5
U.S. Territories	25.2	63.7	30.0	26.8	25.4	25.4	25.4
Total Emissions (Sources)	**6,442.7**	**7,423.0**	**6,671.1**	**6,520.3**	**6,483.3**	**6,671.4**	**6,558.3**
LULUCF Sector Net Total[a]	**(900.8)**	**(788.1)**	**(763.8)**	**(842.8)**	**(766.1)**	**(801.4)**	**(789.2)**
Net Emissions (Sources and Sinks)	**5,541.9**	**6,635.0**	**5,907.3**	**5,677.5**	**5,717.2**	**5,870.0**	**5,769.1**

Notes: Total emissions presented without LULUCF. Total net emissions presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

[a] The LULUCF Sector Net Total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.

Using this categorization, emissions from transportation activities, in aggregate, accounted for the largest portion (28.6 percent) of total U.S. greenhouse gas emissions in 2019. Electric power accounted for the second largest portion (25.1 percent) of U.S. greenhouse gas emissions in 2019, while emissions from industry accounted for the third largest portion (22.9 percent). Emissions from industry have in general declined over the past decade, due to a number of factors, including 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 23.3 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 10.2 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. An increasing amount of carbon is stored in agricultural soils each year, but this CO_2 sequestration is assigned to the LULUCF sector rather than the agriculture economic sector. The commercial and residential sectors accounted for 6.9 percent and 5.8 percent of emissions, respectively, and U.S. Territories accounted for 0.4 percent of emissions; emissions from these sectors primarily consisted of CO_2 emissions from fossil fuel combustion. Carbon dioxide was also emitted and sequestered by a variety of activities related to forest management practices, tree planting in urban areas, the management of agricultural soils, landfilling of yard trimmings, and changes in C stocks in coastal wetlands.

Electricity is ultimately used in the economic sectors described above. Table ES-7 presents greenhouse gas emissions from economic sectors with emissions related to electric power distributed into end-use categories (i.e., emissions from electric power are allocated to the economic sectors in which the electricity is used). To distribute electricity emissions among end-use sectors, emissions from the source categories assigned to electric power were allocated to the residential, commercial, industry, transportation, and agriculture economic sectors according to retail sales of electricity for each end-use sector (EIA 2020a and Duffield 2006).[25] 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 use are distributed among these end-use sectors, industrial activities and transportation account for the largest shares of U.S. greenhouse gas emissions (29.7 percent and 28.7 percent, respectively) in 2019. The commercial and residential sectors contributed the next largest shares of total U.S. greenhouse gas emissions in 2019 (15.6 and 14.9 percent, respectively). Emissions from the commercial and residential sectors increase substantially when emissions from electricity use are included, due to their relatively large share of electricity use for energy (e.g., lighting, cooling, appliances). In all sectors except agriculture, CO_2 accounts for more than 79.0 percent of greenhouse gas emissions, primarily from the combustion of fossil fuels. Figure ES-15 shows the trend in these emissions by sector from 1990 to 2019.

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

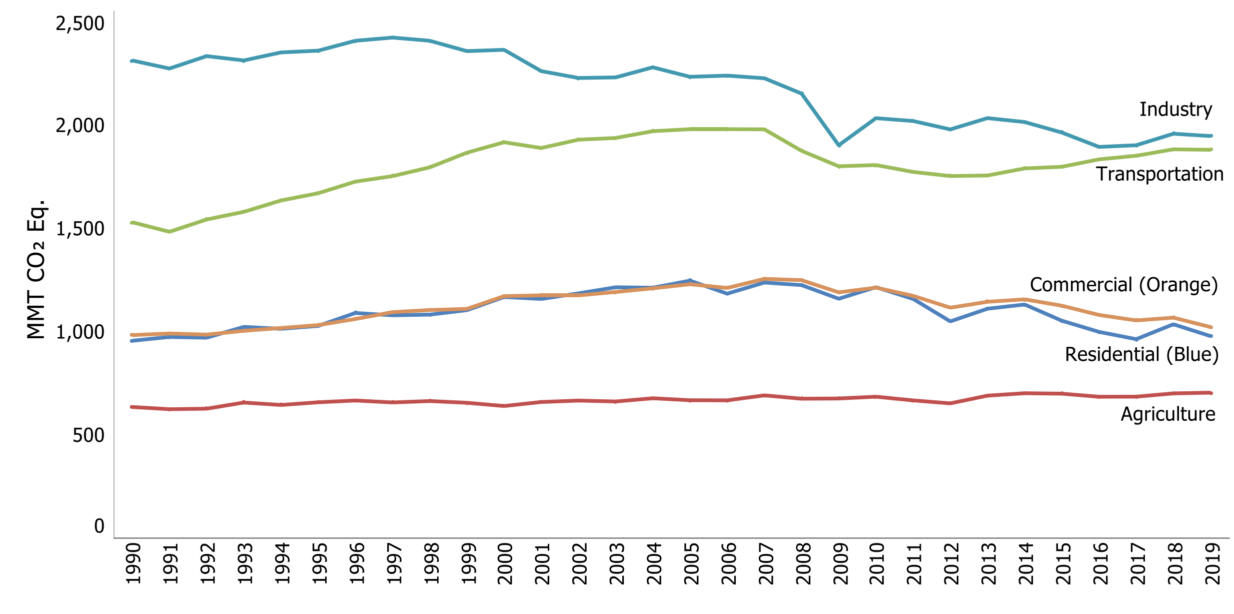
Economic Sectors	1990	2005	2015	2016	2017	2018	2019
Industry	2,313.1	2,234.1	1,964.2	1,894.6	1,902.7	1,958.3	1,947.2
Transportation	1,529.8	1,980.4	1,798.4	1,834.3	1,851.8	1,883.0	1,880.6
Commercial	983.4	1,229.8	1,125.7	1,080.8	1,054.5	1,067.8	1,022.3
Residential	956.0	1,247.1	1,053.1	998.9	963.7	1,035.9	978.3
Agriculture	635.3	668.0	699.7	684.9	685.3	701.1	704.6
U.S. Territories	25.2	63.7	30.0	26.8	25.4	25.4	25.4
Total Emissions (Sources)	**6,442.7**	**7,423.0**	**6,671.1**	**6,520.3**	**6,483.3**	**6,671.4**	**6,558.3**
LULUCF Sector Net Total[a]	**(900.8)**	**(788.1)**	**(763.8)**	**(842.8)**	**(766.1)**	**(801.4)**	**(789.2)**
Net Emissions (Sources and Sinks)	**5,541.9**	**6,635.0**	**5,907.3**	**5,677.5**	**5,717.2**	**5,870.0**	**5,769.1**

[25] U.S. Territories consumption data that are obtained from EIA are only available at the aggregate level and cannot be broken out by end-use sector. The distribution of emissions to each end-use sector for the 50 states does not apply to territories data.

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

[a] The LULUCF Sector Net Total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.

Figure ES-15: U.S. Greenhouse Gas Emissions with Electricity-Related Emissions Distributed to Economic Sectors



Note: Emissions and removals from Land Use, Land-Use Change, and Forestry are excluded from figure above. Excludes U.S. Territories.

Box ES-3: Trends in Various U.S. Greenhouse Gas Emissions-Related Data

Total greenhouse gas 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 use, 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 total gross domestic product as a measure of national economic activity; and (4) 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. These values represent the relative change in each statistic since 1990. Greenhouse gas emissions in the United States have grown at an average annual rate of 0.1 percent since 1990, although changes from year to year have been significantly larger. This growth rate is slightly slower than that for total energy use and fossil fuel consumption, and overall gross domestic product (GDP), and national population (see Figure ES-16). The direction of these trends started to change after 2005, when greenhouse gas emissions, total energy use and fossil fuel consumption began to peak. Greenhouse gas emissions in the United States have decreased at an average annual rate of 0.8percent since 2005. Fossil fuel consumption has also decreased at a slower rate than emissions since 2005, while total energy use, GDP, and national population continued to increase.

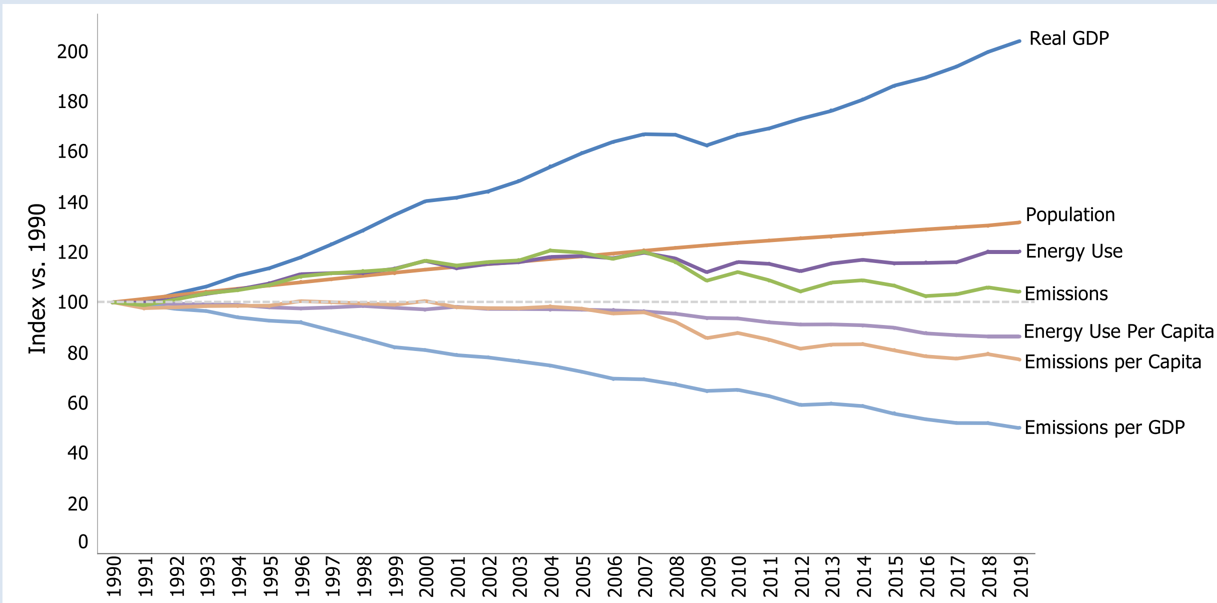
Table ES-8: Recent Trends in Various U.S. Data (Index 1990 = 100)

Variable	1990	2005	2015	2016	2017	2018	2019	Avg. Annual Growth Rate Since 1990[a]	Avg. Annual Growth Rate Since 2005[a]
Greenhouse Gas Emissions[b]	100	115	104	101	101	104	102	0.1%	-0.8%
Energy Use[c]	100	119	116	116	116	120	119	0.6%	0.0%
GDP[d]	100	159	186	189	194	200	204	2.5%	1.8%

Population[e]	100		118		128	129	130	131	132	1.0%	0.8%

[a] Average annual growth rate.
[b] GWP-weighted values.
[c] Energy content-weighted values (EIA 2020a).
[d] GDP in chained 2009 dollars (BEA 2020).
[e] U.S. Census Bureau (2020).

Figure ES-16: U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product (GDP)



Source: BEA (2019), U.S. Census Bureau (2020), and emission estimates in this report.

Key Categories

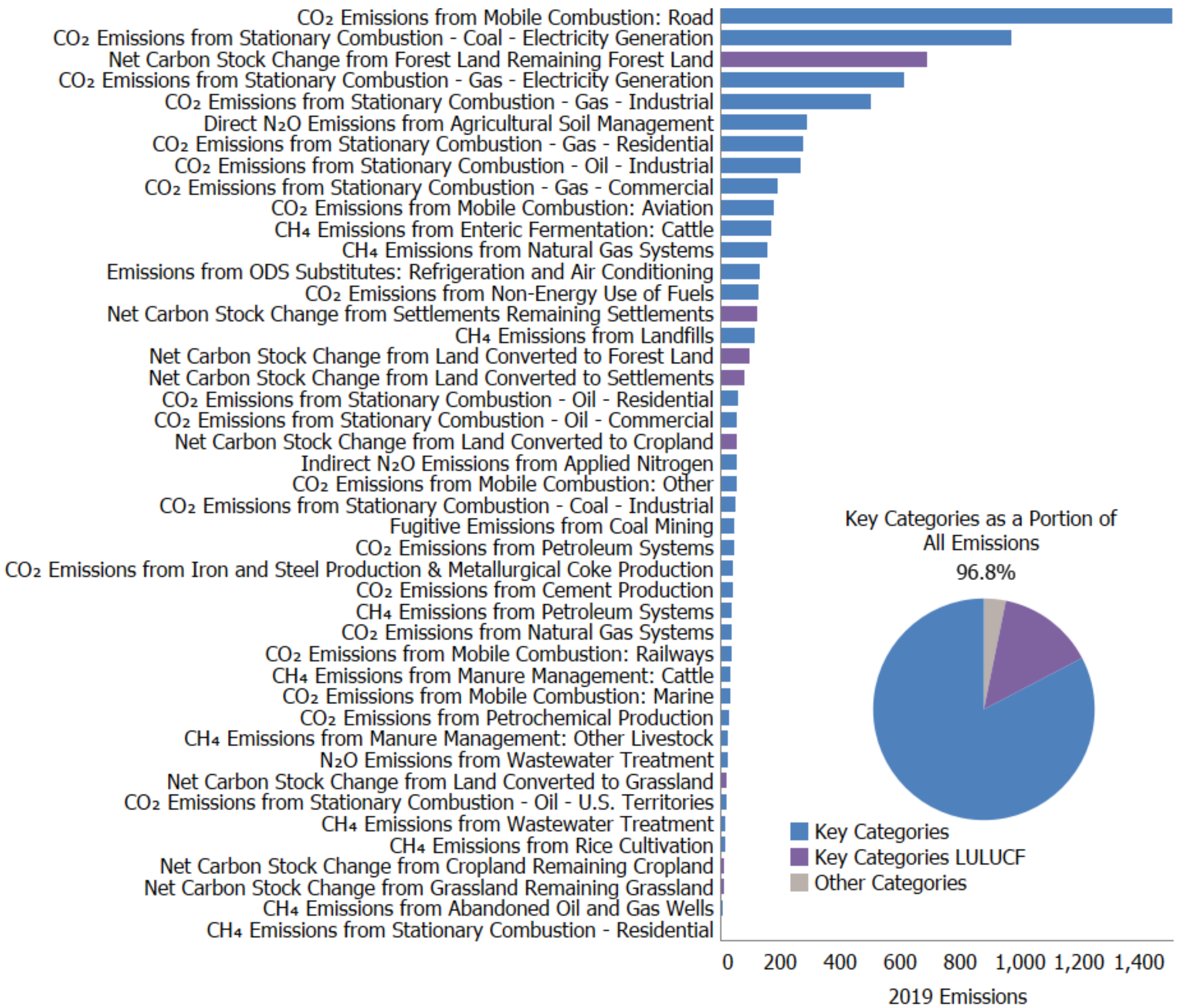
The *2006 IPCC Guidelines* (IPCC 2006) defines a key category as a "[category] that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals."[26] A key category analysis identifies priority source or sink categories for focusing efforts to improve overall Inventory quality. In addition, a qualitative review of key categories and non-key categories can also help identify additional source and sink categories to consider for improvement efforts, including reducing uncertainty.

Figure ES-17 presents the key categories identified by Approach 1 and Approach 2 level assessments including the LULUCF sector for 2019. A level assessment using Approach 1 identifies all source and sink categories that cumulatively account for 95 percent of total (i.e., gross) emissions in a given year when assessed in descending order of absolute magnitude. An Approach 2 level assessment incorporates the results of the uncertainty analysis for each category and identifies all sources and sink categories that cumulatively account for 90 percent of the sum of all level assessments when sorted in descending order of magnitude.

[26] 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>.

For a complete list of key categories and more information regarding the overall key category analysis, including approaches accounting for the influence of trends of individual source and sink categories, see the Introduction chapter, Section 1.5 – Key Categories and Annex 1.

Figure ES-17: 2019 Key Categories[a]



[a] For a complete list of key categories and detailed discussion of the underlying key category analysis, see Annex 1. Bars indicate key categories identified using Approach 1 and Approach 2 level assessment including the LULUCF sector.
[b] The absolute values of net CO_2 emissions from LULUCF are presented in this figure but reported separately from gross emissions totals. Refer to Table ES-5 for a breakout of emissions and removals for LULUCF by gas and source/sink category.

Quality Assurance and Quality Control (QA/QC)

The United States seeks to continually improve the quality, transparency, and usability 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. The procedures followed for the Inventory have been formalized in accordance with the U.S. Inventory QA/QC plan for the Inventory, and the UNFCCC reporting guidelines and *2006 IPCC Guidelines*. The QA process includes expert and public reviews for both the Inventory estimates and the Inventory report.

Box ES-4: 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.[27] Several recent studies have estimated emissions at the national or regional level with estimated results that sometimes differ from EPA's estimate of emissions. EPA has engaged with researchers on how remote sensing, ambient measurement, and inverse modeling techniques for estimating greenhouse gas emissions could assist in improving the understanding of inventory estimates. In working with the research community on ambient measurement and remote sensing techniques to improve national greenhouse gas inventories, EPA follows guidance from the IPCC on the use of measurements and modeling to validate emission inventories.[28] An area of particular interest in EPA's outreach efforts is how ambient measurement data can be used in a manner consistent with this Inventory report's transparency of 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 an effort to improve the ability to compare the national-level greenhouse gas inventory with measurement results that may be at other scales, a team at Harvard University along with EPA and other coauthors developed a gridded inventory of U.S. anthropogenic methane emissions with 0.1° x 0.1° spatial resolution, monthly temporal resolution, and detailed scale-dependent error characterization. The gridded inventory is designed to be consistent with the 1990 to 2014 U.S. EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks* estimates for the year 2012, which presents national totals for different source types.[29] This gridded inventory is consistent with the recommendations contained in two National Academies of Science reports examining greenhouse gas emissions data (National Research Council 2010; National Academies of Sciences, Engineering, and Medicine 2018).

Uncertainty Analysis of Emission Estimates

Uncertainty estimates are an essential element of a complete inventory of greenhouse gas emissions and removals because they help to inform and prioritize inventory improvements. Recognizing the benefit of conducting an uncertainty analysis, the UNFCCC reporting guidelines follow the recommendations of the *2006 IPCC Guidelines* (IPCC 2006), Volume 1, Chapter 3 and require that countries provide single estimates of uncertainty for source and sink categories. In addition to quantitative uncertainty assessments, a qualitative discussion of uncertainty is presented for each source and sink category identifying specific factors affecting the uncertainty surrounding the estimates provided in accordance with UNFCCC reporting guidelines. Some of the current estimates, such as those for CO_2 emissions from energy-related combustion activities, are considered to have low uncertainties. This is because the amount of CO_2 emitted from energy-related combustion activities is directly related to the amount of fuel consumed, the fraction of the fuel that is oxidized, and the carbon content of the fuel, and for the United States, the uncertainties associated with estimating those factors is believed to be relatively small. For some other categories of emissions, however, inherent variability or a lack of data increases the uncertainty or systematic error associated with the estimates presented. Finally, an analysis is conducted to assess uncertainties associated with the overall emissions, sinks and trends estimates. The overall uncertainty surrounding total net greenhouse gas emissions is estimated to be -6 to + 6 percent in 1990 and -5 to +5 percent in 2019. When the LULUCF sector is excluded from the analysis the uncertainty is estimated to be -2 to +5 percent in 1990 and -2 to +4 percent in 2019.

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

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

[29] See <https://www.epa.gov/ghgemissions/gridded-2012-methane-emissions>.