Executive Summary

This *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2023* (*Inventory*) identifies and quantifies the anthropogenic[1] emissions sources and removals (by sinks) of greenhouse gases in the U.S. It is an essential tool for understanding the relative magnitude of different sources and sinks across the U.S., as well as changes in these magnitudes over time. This Executive Summary provides the latest information on U.S. anthropogenic greenhouse gas emissions and removals trends from 1990 through 2023. Throughout this report, emission and sink estimates are grouped into five reporting sectors (i.e., chapters): Energy; Industrial Processes and Product Use (IPPU); Agriculture; Land Use, Land-Use Change, and Forestry (LULUCF); and Waste; and are calculated using methods that are consistent with the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (*2006 IPCC Guidelines)* and, where appropriate, its supplements and refinements. The structure of this report follows the common approach used by Parties to the United Nations Framework Convention on Climate Change (UNFCCC). The presentation of emissions and removals provided in this *Inventory* does not preclude alternative examinations (e.g., economic sectors). See Box ES-1 to understand the relationship to other greenhouse gas data collected and reported by the U.S. Environmental Protection Agency (U.S. EPA).

Box ES-1: Relationship to the U.S. EPA's Greenhouse Gas Reporting Program

The U.S. EPA also collects greenhouse gas data and other relevant information from individual facilities and suppliers of certain fossil fuels and industrial gases through its Greenhouse Gas Reporting Program (GHGRP), which is complementary to the U.S. Inventory.[2] The GHGRP applies to direct greenhouse gas emitters, fossil fuel suppliers, industrial greenhouse 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 46 industrial categories.[3] 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 (EPA, 2019). Methodologies used in the U.S. EPA's GHGRP are consistent with the *2006 IPCC Guidelines*. While the GHGRP does not provide full coverage of total

[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] On October 30, 2009, 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).

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

annual U.S. greenhouse gas emissions and removals (e.g., the GHGRP excludes emissions from the Agriculture and Land Use, Land-Use Change, and Forestry sectors), it is an important input to the calculations of national-level emissions in this *Inventory*.

The GHGRP dataset provides 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 over time. GHGRP data also allow the U.S. EPA to disaggregate national inventory estimates in new ways that can highlight differences across regions and subcategories of emissions, along with enhancing the application of quality assurance/quality control procedures and assessment of uncertainties. See Annex 9 for more information on specific uses of GHGRP data in the *Inventory*.

ES.1 Background Information

Greenhouse gases absorb infrared radiation, trapping heat in the atmosphere and making the planet warmer. The most important greenhouse gases directly emitted by human activities include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and several fluorine-containing halogenated substances (hydrofluorocarbons [HFCs], perfluorocarbons [PFCs], sulfur hexafluoride [SF_6] and nitrogen trifluoride [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 2023, concentrations of these greenhouse gases have increased globally by 50.4, 163.2, and 24.7 percent, respectively (IPCC 2013; NOAA/ESRL 2025a, 2025b, 2025c). This annual report estimates the total national greenhouse gas emissions and removals associated with human activities across the United States.

Global Warming Potentials

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. A GWP is a quantified measure of the warming impact of a unit of a specific greenhouse gas over a specific period of time relative to the same unit of CO_2. 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 2021); therefore, CO_2-equivalent emissions are provided in million metric tons of CO_2 equivalent (MMT CO_2 Eq.) for non-CO_2 greenhouse gases.[4,5] All estimates are provided throughout the main report in both CO_2 equivalents and unweighted units. 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 also provided in Chapter 2, *Trends* and individual sector chapters of this report.

Based on recent decisions under the UNFCCC[6] in 2024, Parties began using 100-year GWP values from the IPCC *Fifth Assessment Report* (AR5) for calculating CO_2-equivalents in their national greenhouse

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

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

[6] See paragraphs 1 and 2 of the decision on common metrics adopted at the 27th UNFCCC Conference of Parties (COP27), available online at https://unfccc.int/sites/default/files/resource/cp2022_10a01_E.pdf.

gas inventories (IPCC 2013). This change reflects updated science and ensures that national greenhouse gas inventories from all nations are comparable. A comparison of emission values with the IPCC *Sixth Assessment Report* (AR6) (IPCC 2021) values can be found in Annex 6.1 of this report. The 100-year 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]	28
N_2O	265
HFCs	up to 12,400
PFCs	up to 11,100
SF_6	23,500
NF_3	16,100
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 (2013).

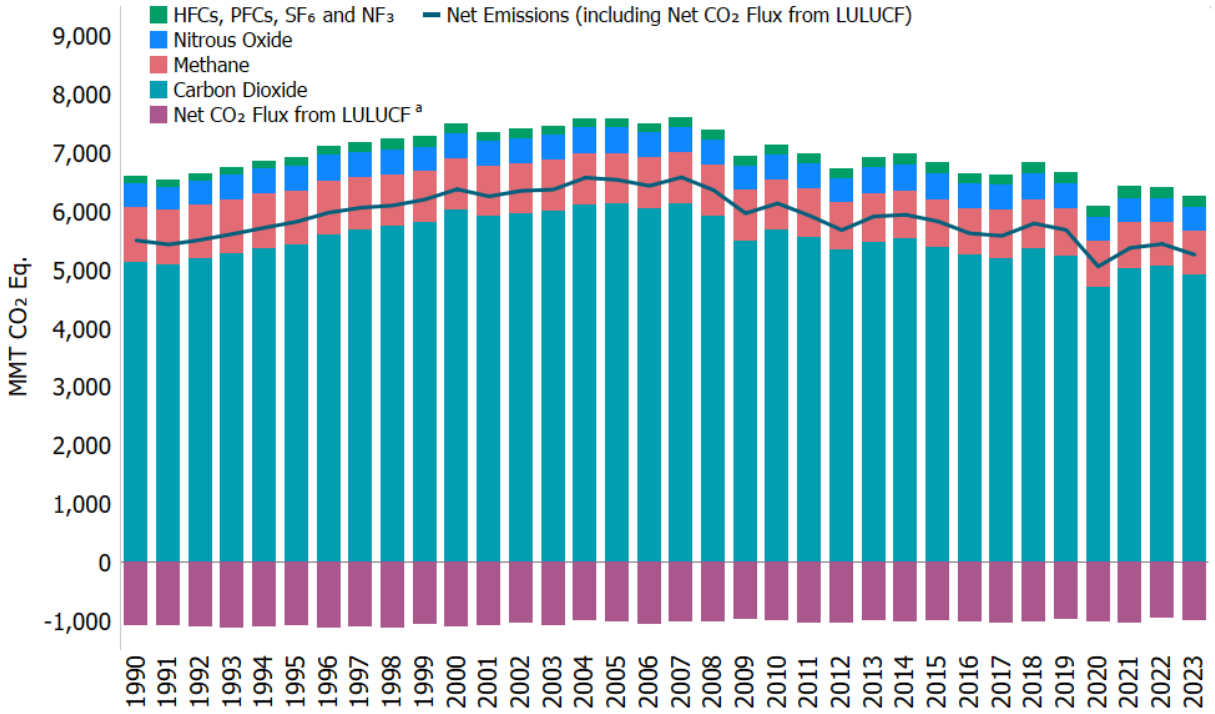
ES.2 Summary of Trends in U.S. Greenhouse Gas Emissions and Sinks

In 2023, total gross U.S. greenhouse gas emissions were 6,197.3 MMT CO_2 Eq. Total gross U.S. emissions, which exclude emissions and sinks from the LULUCF sector, decreased by 5.2 percent from 1990 to 2023, down from a high of 15.3 percent above 1990 levels in 2007. Gross emissions decreased from 2022 to 2023 by 2.3 percent (146.8 MMT CO_2 Eq.), driven largely by a decrease in CO_2 emissions from fossil fuel combustion. CO_2 emissions from fossil fuel combustion decreased by 3.0 percent in 2023 relative to 2022 and were 4.1 percent below 1990 emissions. Specifically, CO_2 emissions from coal consumption decreased by 18.3 percent (164.1 MMT CO_2 Eq.) from 2022 to 2023. CO_2 emissions from natural gas use increased by 1.0 percent (17.6 MMT CO_2 Eq.) and emissions from petroleum use increased by 0.2 percent (3.1 MMT CO_2 Eq.) from 2022 to 2023. The decrease in coal use and associated emissions from 2022 to 2023 is mainly due to reduced use in the electric power sector and is driving the overall reduction. The increase in natural gas consumption and associated emissions in 2023 is observed mostly in the electric power and industrial sectors, the increase in petroleum use is mainly in the transportation sector.

Net emissions, including emissions and sinks from the LULUCF sector, were 5,257.4 MMT CO_2 Eq. in 2023. Overall, net emissions decreased by 3.3 percent from 2022 to 2023. Over the last 20 years, net emissions decreased by nearly 20 percent. Trends in net emissions are illustrated in Table ES-2. Carbon sequestration from the LULUCF sector offset 16.1 percent of total gross emissions in 2023.

Figure ES-1 and Figure ES-2 illustrate the overall trend in total U.S. emissions and sinks since 1990, by gas and annual percent change relative to the previous year. Table ES-2 provides information on trends in gross and net U.S. greenhouse gas emissions and sinks for 1990 through 2023. Unless otherwise stated, all tables and figures provide total gross emissions and exclude the greenhouse gas fluxes from the LULUCF sector. For an overview of the LULUCF sector, see Section ES-3.

Figure ES-1: U.S. Greenhouse Gas Emissions and Sinks 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."
Notes: Gas totals exclude CH_4, and N_2O greenhouse gas fluxes from the LULUCF sector. Net emissions values include both CH_4 and N_2O emissions and the net carbon flux from the LULUCF sector.

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

Gas/Source	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
CO_2	5,131.8	6,126.9	5,235.9	4,690.0	5,020.1	5,055.4	4,918.4	-4.2%
CH_4 (excludes LULUCF sources) [a]	873.1	797.1	752.6	730.9	715.6	696.8	686.7	-21.4%
N_2O (excludes LULUCF sources) [a]	407.8	424.8	416.4	391.4	398.4	387.5	387.0	-5.1%
HFCs	47.8	125.0	175.8	177.8	184.3	189.5	191.0	299.8%
PFCs	39.7	10.3	7.3	6.6	6.3	6.5	5.8	-85.5%
SF_6	37.9	20.2	8.3	7.7	8.0	7.2	7.7	-79.6%
NF_3	0.2	1.0	1.1	1.3	1.1	1.1	0.8	335.8%
Total Gross Emissions (Sources) [a]	**6,538.3**	**7,505.3**	**6,597.4**	**6,005.7**	**6,333.8**	**6,344.1**	**6,197.3**	**-5.2%**

LULUCF Emissions [b]	**59.1**	**71.8**	**63.2**	**82.6**	**81.0**	**68.6**	**60.6**	**2.6%**
CH_4	54.4	60.9	56.1	69.0	67.8	59.6	54.7	0.5%
N_2O	4.7	10.9	7.0	13.7	13.1	9.0	5.9	26.7%
LULUCF Carbon Stock Change [c]	**(1,096.9)**	**(1,040.7)**	**(982.6)**	**(1,034.2)**	**(1,043.8)**	**(973.9)**	**(1,000.5)**	**-8.8%**
LULUCF Sector Net Total [d]	**(1,037.9)**	**(968.9)**	**(919.4)**	**(951.6)**	**(962.9)**	**(905.3)**	**(939.9)**	**-9.4%**
Net Emissions (Sources and Sinks)	**5,500.4**	**6,536.4**	**5,678.0**	**5,054.2**	**5,371.0**	**5,438.7**	**5,257.4**	**-4.4%**

[a] Gross emissions totals do not include CH_4 and N_2O emissions from Land Use, Land-Use Change, and Forestry (LULUCF). LULUCF CH_4 and N_2O emissions are included in net emission totals.

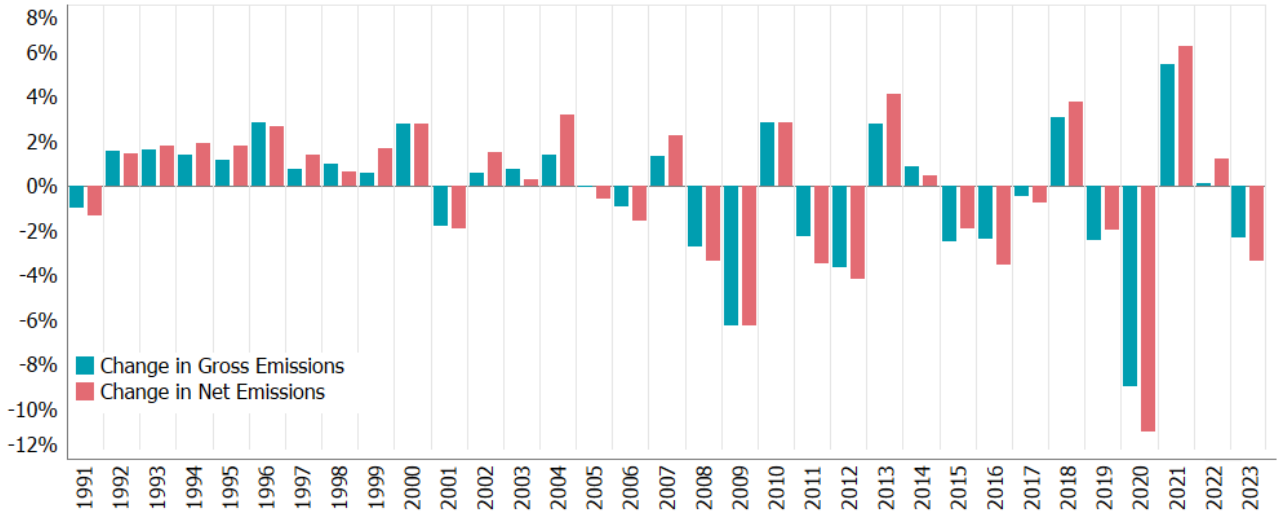
[b] LULUCF emissions subtotal of CH_4 and N_2O are reported separately from gross emissions totals. LULUCF emissions include the CH_4 and N_2O emissions reported for peatlands remaining peatlands, forest fires, drained organic soils, grassland fires, and coastal wetlands remaining coastal wetlands; CH_4 emissions from land converted to coastal wetlands, flooded land remaining flooded land, and land converted to flooded land; and N_2O emissions from forest soils and settlement soils.

[c] LULUCF carbon stock change is the net carbon 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.

[d] The LULUCF sector net total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus LULUCF net carbon stock changes.

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

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



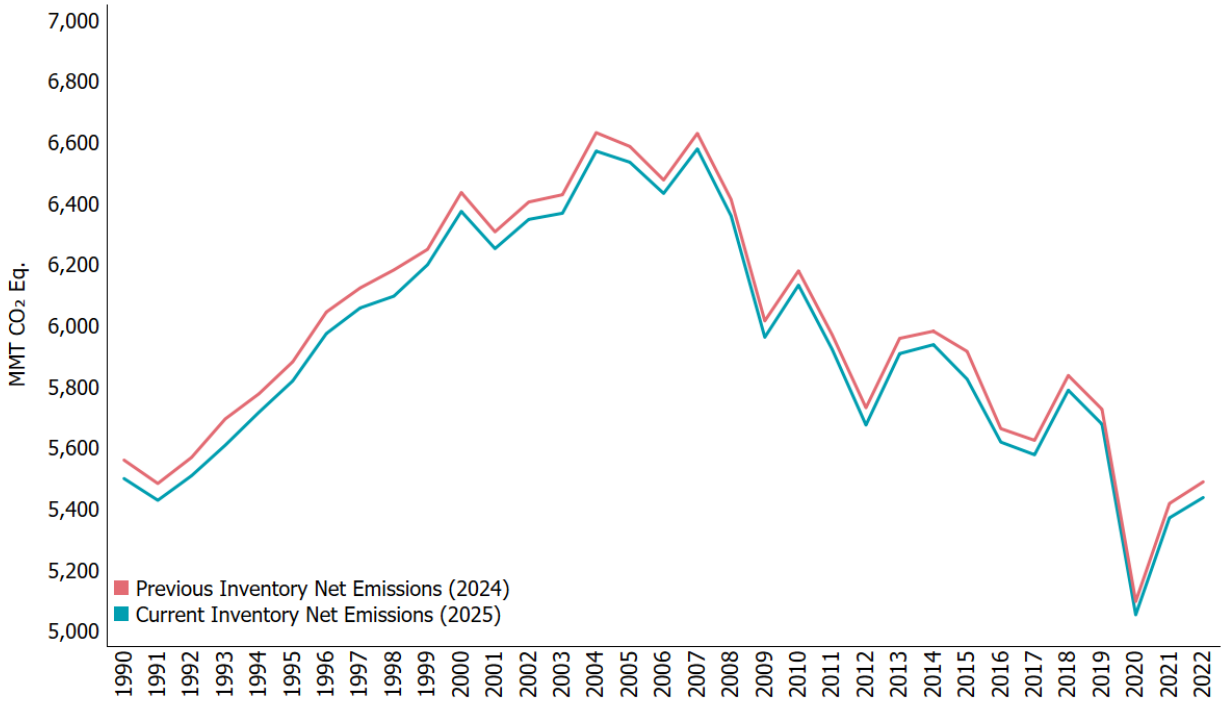
Improvements and Recalculations Relative to the Previous Inventory

Each year, some of the emission and removal 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, as necessary, (i.e., 1990 to 2022) to ensure that the trend is accurate.

Collectively, all methodological changes and historical data updates made in the current *Inventory* resulted in lower estimates of annual net emissions by an average of 56.0 MMT CO_2 Eq. (0.9 percent).

Figure ES-3: Impacts of Recalculations on Net Emissions



Below are categories with methodological and data-related recalculations resulting in an average annual change of greater than 2.0 MMT CO_2 Eq. over the time series, in descending order.

- Forest land remaining forest land: changes in forest carbon stocks (CO_2)
- Land converted to settlements: changes in all ecosystem carbon stocks (CO_2)
- Substitution of ozone depleting substances (HFCs)
- Land converted to grassland: changes in all ecosystem carbon stocks (CO_2)
- Land converted to forest land: changes in forest carbon stocks (CO_2)

In addition, the current *Inventory* includes the following new categories that were not a part of the previous *Inventory* that improve the completeness of the national estimates: CO_2 transport, injection and storage; and perennial woody biomass carbon stock changes and biomass carbon stock changes from croplands and lands converted to and from croplands (e.g., croplands converted to grasslands, grasslands converted to croplands). This *Inventory* also now includes additional gases (NF_3 and HFCs) within the SF_6 and PFCs from other product use category.

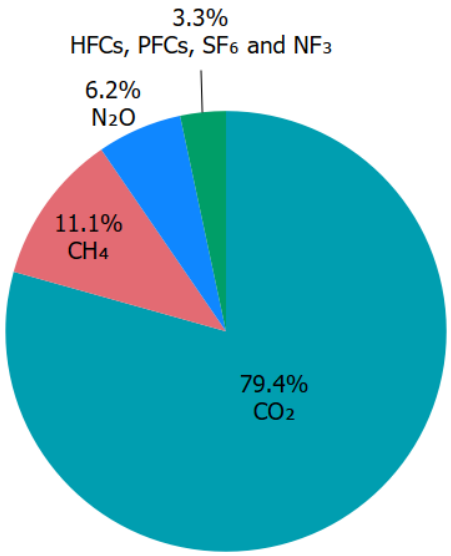
The results of all methodological changes and historical data updates and the inclusion of new sources and sink estimates are summarized in the Recalculations and Improvements chapter (Chapter 9 of this

Inventory). For more detailed descriptions of each recalculation, including references for data, please see the respective emission or sink category description(s) within the relevant chapter (Chapter 3, *Energy*; Chapter 4, *Industrial Processes and Product Use*; Chapter 5, *Agriculture*; Chapter 6, *Land Use, Land-Use Change, and Forestry*; and Chapter 7, *Waste*).

Emissions and Sinks Trends by Greenhouse Gas

Figure ES-4 illustrates the relative contribution of each gas to total gross U.S. emissions in 2023, in CO_2 equivalents (i.e., weighted by GWP). The primary greenhouse gas emitted by human activities in the United States is CO_2, representing 79.4 percent of total greenhouse gas emissions. The largest source of CO_2, and of overall greenhouse gas emissions, is fossil fuel combustion, primarily from transportation and power generation. CH_4 emissions account for 11.1 percent of emissions while N_2O accounts for an additional 6.2 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, mobile combustion and manure management are the major sources of N_2O emissions. Emissions of substitutes for ozone depleting substances are the primary contributor to aggregate HFC emissions. PFC emissions are primarily attributable to fluorochemical production, electronics manufacturing, and primary aluminum production. Electrical equipment systems account for most SF_6 emissions. The electronics industry and fluorochemical production are the only sources of NF_3 emissions. U.S. greenhouse gas emissions were partly offset by carbon sequestration in forests, trees in urban areas, agricultural soils, landfilled yard trimmings and food scraps, and coastal wetlands, which together offset 16.1 percent of total gross emissions in 2023 (as reflected in Figure ES-1). The following sections describe in more detail each gas's contribution to total U.S. greenhouse gas emissions.

Figure ES-4: 2023 Total Gross U.S. Greenhouse Gas Emissions by Gas (Percentages based on MMT CO_2 Eq.)

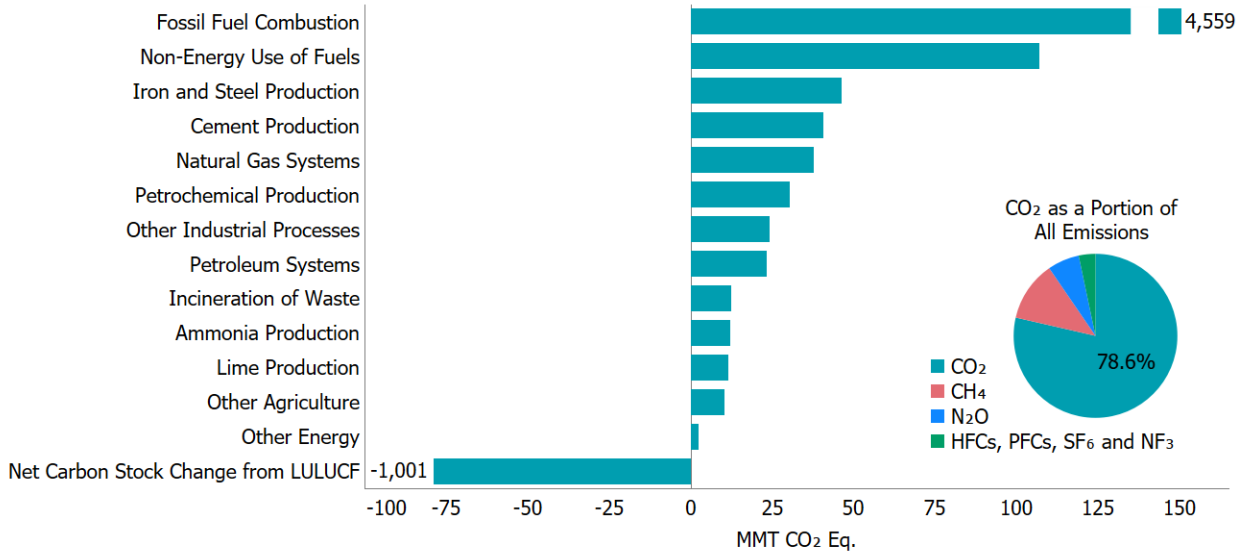


Note: Emissions and sinks from the Land Use, Land-Use Change, and Forestry sector are excluded from the figure above.

Carbon Dioxide Emissions

Overall, gross CO_2 emissions have decreased by 4.2 percent since 1990 and decreased by 2.7 percent since 2022, consistent with trends in fuel combustion emissions. In the United States, fossil fuel combustion accounted for 92.7 percent of gross CO_2 emissions in 2023. Nationally, within fossil fuel combustion, the transportation sector was the largest emitter of CO_2 in 2023, followed by electric power generation. There are 28 additional sources of CO_2 emissions included in the *Inventory* (see Table 2-1), including sources and sinks from the LULUCF sector. 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 LULUCF emissions and removals or sinks in Table ES-4 and a summarization of CO_2 sources in Figure ES-5.

Figure ES-5: 2023 Sources and Sinks of Carbon Dioxide Emissions



Note: "Other Industrial Processes" includes emissions from aluminum production, carbide production and consumption, non-EOR carbon dioxide utilization, ferroalloy production, glass production, lead production, magnesium production, other process uses of carbonates, phosphoric acid production, substitution of ozone depleting substances, soda ash production, titanium dioxide production, urea consumption for non-agricultural purposes, and zinc production. "Other Energy" includes emissions from abandoned oil and gas wells; CO_2 transport, injection, and storage; and coal mining.

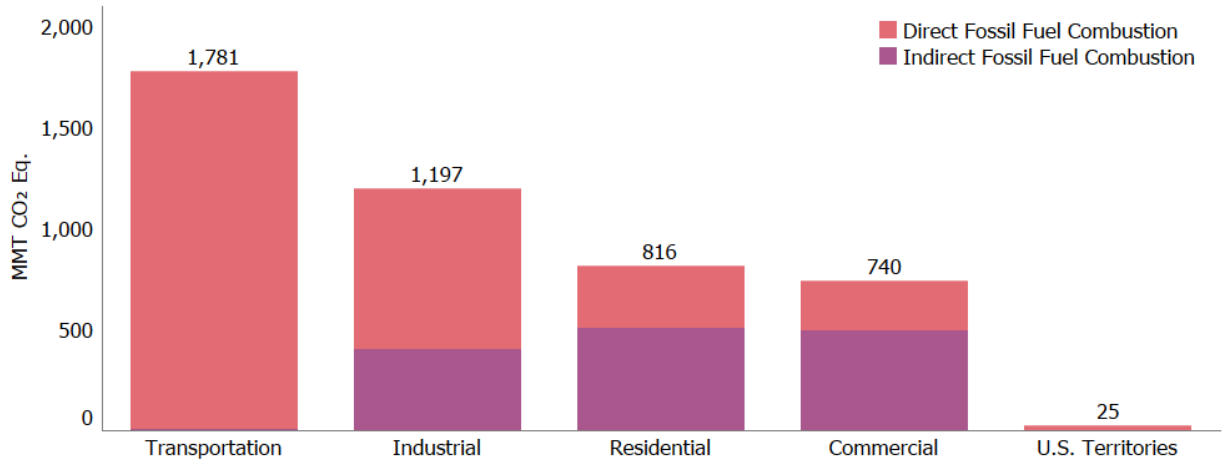
Fossil Fuel Combustion Trends

Historically, changes in emissions from fossil fuel combustion have been the driving factor affecting overall U.S. emission trends. Important drivers include changes in demand for energy and a general decline in the overall carbon intensity of fuels combusted for energy in recent years by non-transport sectors of the economy. Between 1990 and 2023, CO_2 emissions from fossil fuel combustion decreased by 4.1 percent; emissions decreased by 20.6 percent (1,184.8 MMT CO_2 Eq.) from 2005 level peak; and from 2022 to 2023, these emissions decreased by 3.0 percent (143.4 MMT CO_2 Eq.).

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 economic sectors, or "end-use" sectors. Greenhouse gas emissions from the commercial, residential, and industrial end-use sectors

increase substantially when indirect emissions from electric power end-use are distributed, due to the relatively large share of electricity use by buildings (e.g., heating, ventilation, and air conditioning; lighting; and appliances) and use of electricity for powering industrial machinery.

Figure ES-6: 2023 End-Use Sector Emissions of Carbon Dioxide from Fossil Fuel Combustion



- *Transportation End-Use Sector.* Transportation activities accounted for 39.1 percent of U.S. CO_2 emissions from fossil fuel combustion in 2023, with the largest contributors being light-duty trucks (39.7 percent), followed by medium- and heavy-duty trucks (23.4 percent) and passenger vehicles (16.6 percent). The overall trend from 1990 to 2023 shows that total transportation CO_2 emissions increased due largely to increased demand for travel, which was 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 generally increasing CO_2 emissions since 1990, improvements in average new vehicle fuel economy since 2005 have slowed the rate of increase of CO_2 emissions.
- *Industrial End-Use Sector.* Industrial CO_2 emissions, resulting both directly from the combustion of fossil fuels[7] and indirectly from the generation of electricity that is used by industry, accounted for 26.3 percent of CO_2 emissions from fossil fuel combustion in 2023. Approximately 66.2 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 23.4 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. From 2022 to 2023, total energy use in the industrial sector decreased by 1.2 percent due largely to a decrease in total coal consumption.
- *Residential and Commercial End-Use Sectors.* The residential and commercial end-use sectors accounted for 17.9 and 16.2 percent, respectively, of CO_2 emissions from fossil fuel combustion

[7] This does not include fossil fuels used as feedstocks and reductants, which are reported under IPPU emissions.

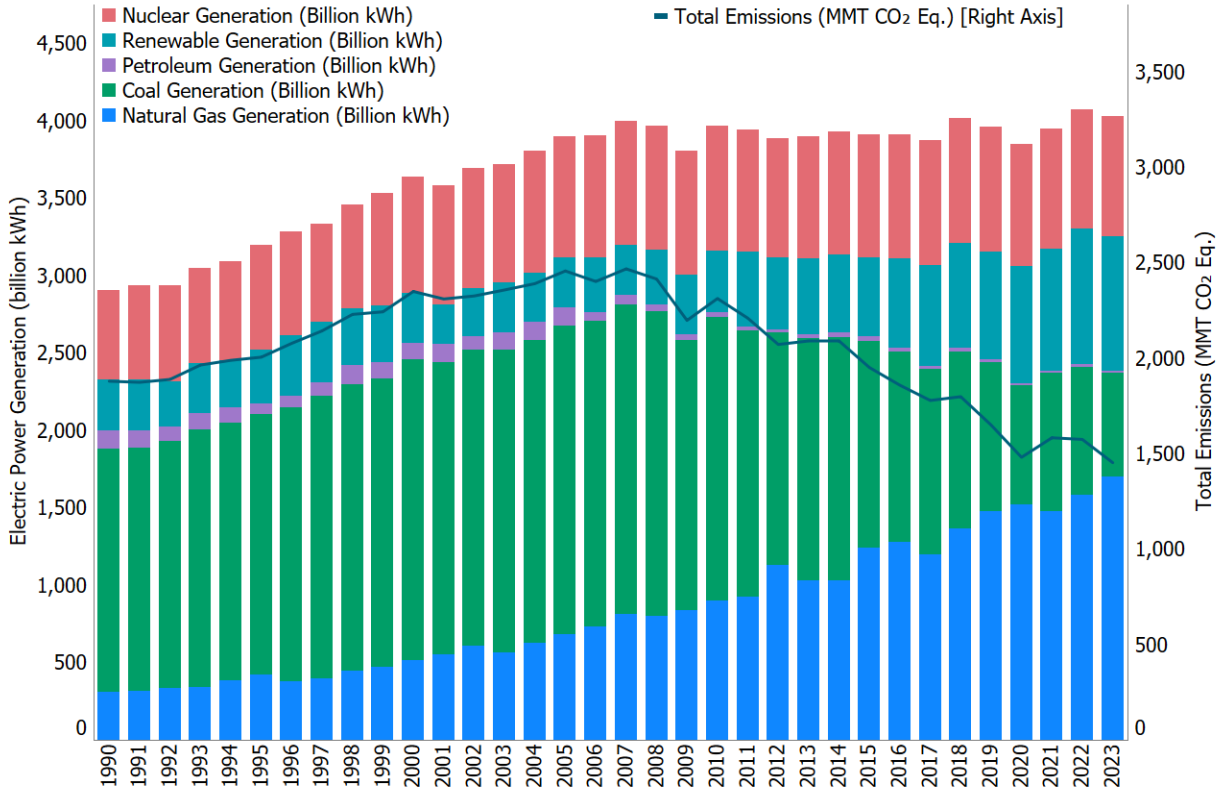
in 2023 including indirect emissions from electricity. The residential and commercial sectors relied heavily on electricity for meeting energy demands, with 62.3 and 67.0 percent, respectively, of their emissions attributable to electricity use for building-related activities such as lighting, heating, 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 12.4 percent since 1990, and total direct and indirect emissions from the commercial sector have decreased by 3.4 percent since 1990. From 2022 to 2023, a decrease in heating degree days (of 10.4 percent) decreased energy demand for heating in the residential and commercial sectors; also, a 5.2 percent decrease in cooling degree days compared to 2022 decreased demand for air conditioning in the residential and commercial sectors.

- *Electric Power Sector.* Electricity generators used 29.9 percent of U.S. energy from fossil fuels and emitted 31.0 percent of the CO_2 from fossil fuel combustion in 2023. Across the time series, the type of energy source used to generate electricity, its carbon intensity, and the mix of electric generation resources used to meet demand, are the main factors influencing emissions.[8] Coal-fired electric generation (in kilowatt-hours [kWh]) decreased from 54.1 percent of generation in 1990 to 16.6 percent in 2023.[9] This corresponded with an increase in natural gas generation and non-fossil fuel renewable energy generation, largely from wind and solar energy. Natural gas generation (in kWh) represented 10.7 percent of electric power generation in 1990 and increased over the 34-year period to represent 42.2 percent of electric power generation in 2023. Wind and solar generation (in kWh) represented 0.1 percent of electric power generation in 1990 and increased over the 34-year period to represent 14.5 percent of electric power generation in 2023. Between 2022 and 2023, coal electricity generation decreased by 17.9 percent, natural gas generation increased by 8.6 percent, and renewable energy generation increased by 0.7 percent. While CO_2 emissions from fossil fuel combustion in the electric power sector have decreased by 22.3 percent since 1990, the carbon intensity of the electric power sector, in CO_2 Eq. per QBtu input, decreased by 31.3 percent during that same timeframe. This trend is shown in Figure ES-7.

[8] In line with IPCC guidelines, CO_2 emissions from biomass combustion have been estimated separately from fossil fuel CO_2 emissions and are not included in the electric power sector totals and trends discussed in this section. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for the LULUCF sector.

[9] Values represent electricity *net* generation from the electric power sector. See Table 7.2b Electricity Net Generation: Electric Power Sector of EIA (2024).

Figure ES-7: Electric Power Generation and Emissions



Other significant CO_2 trends included:

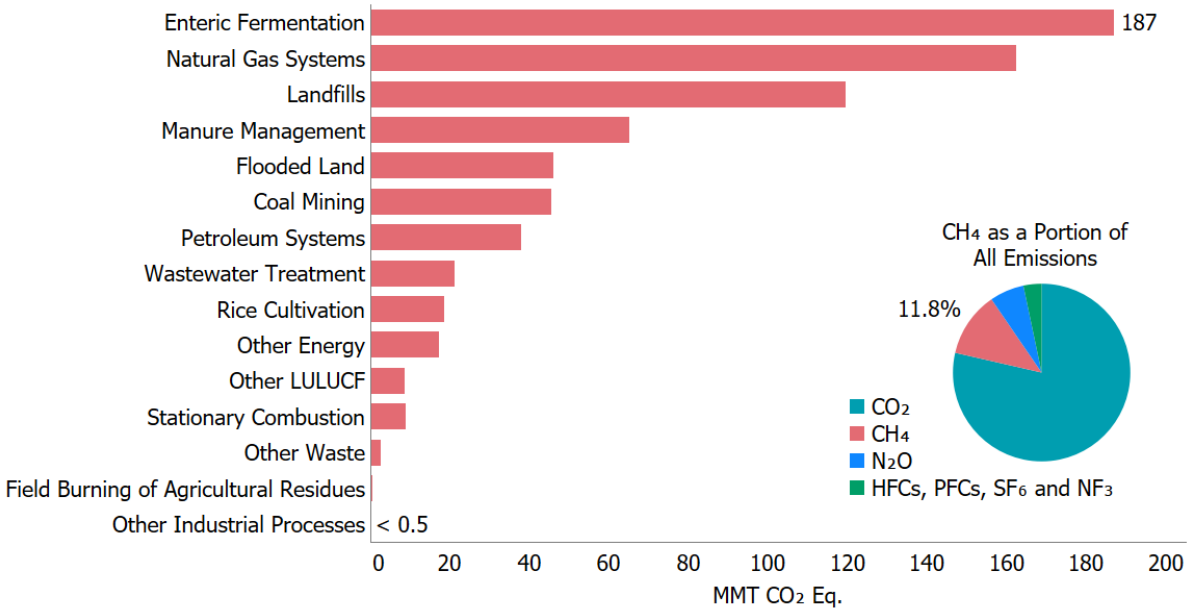
- CO_2 emissions from natural gas and petroleum systems combined accounted for 1.2percent of CO_2 emissions and 1.0 percent of total gross emissions in 2023. These emissions increased by 44.7 percent (18.8 MMT CO_2 Eq.) from 1990 to 2023. This increase is due primarily to increases in the production segment, where flaring emissions from associated gas flaring, tanks, and miscellaneous production flaring have increased over time.
- CO_2 emissions from iron, steel production and metallurgical coke production accounted for 0.9 percent of CO_2 and 0.7 percent of total gross emissions. Emissions decreased by 55.9 percent (58.5 MMT CO_2 Eq.) from 1990 through 2023. This decrease was primarily due to restructuring of the industry, technological improvements, and increased scrap steel utilization.
- Total carbon stock change (i.e., net CO_2 removals) in the LULUCF sector decreased by 8.8 percent between 1990 and 2023. This decrease was primarily due to a decrease in the rate of net carbon accumulation in forest carbon stocks as well as an increase in emissions from land converted to settlements. Disturbances on managed lands, particularly wildfire, are among the major influences that affect the annual net carbon flux by altering the amount of carbon stored in forest ecosystems.

Methane Emissions

CH_4 is significantly more effective than CO_2 at trapping heat in the atmosphere by a factor of 28 over a 100-year time frame based on the IPCC *Fifth Assessment Report* estimate (IPCC 2013). 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, flooded land, coal mining, and petroleum systems, as shown in Figure ES-8.

Figure ES-8: 2023 Sources of Methane Emissions



Note: "Other Energy" includes CH_4 emissions from abandoned oil and gas wells, abandoned underground coal mines, incineration of waste, and mobile combustion. "Other Waste" includes CH_4 emissions from anaerobic digestion at biogas facilities and composting. "Other Industrial Processes" includes CH_4 emissions from carbide production and consumption, ferroalloy production, iron and steel production and metallurgical coke production, and petrochemical production. "Other LULUCF" includes the CH_4 reported for peatlands remaining peatlands, forest fires, drained organic soils, grassland fires, coastal wetlands remaining coastal wetlands, and land converted to coastal wetlands.

Overall, CH_4 emissions in the United States in 2023, including LULUCF CH_4 emissions, accounted for 741.3 MMT CO_2 Eq., representing decreases of 20.1 percent (186.2 MMT CO_2 Eq.) since 1990 and 2.0 percent (15.1 MMT CO_2 Eq.) since 2022. Significant trends for the largest sources of anthropogenic CH_4 emissions include the following.

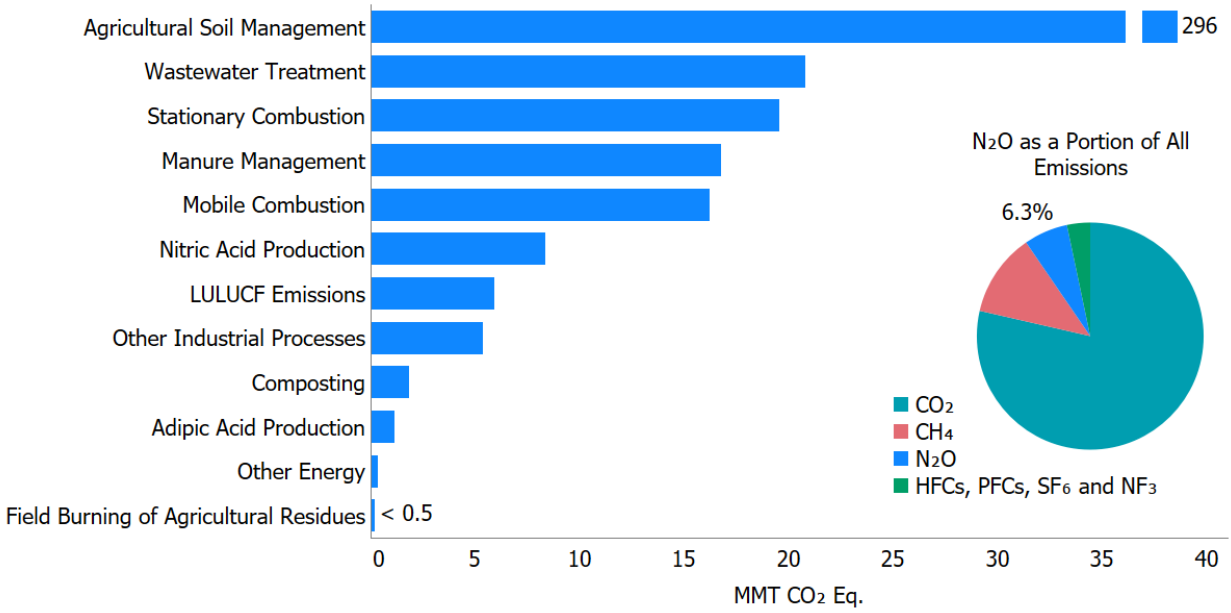
- Enteric fermentation emissions increased from 1990 to 2023, largely due to increasing cattle population. For example, emissions increased from 1990 to 1995 and then generally decreased from 1996 to 2004, mainly due to fluctuations in beef cattle populations and increased digestibility of feed for feedlot cattle. Emissions decreased again from 2008 to 2014 as beef cattle populations again decreased. Emissions increased from 2014 to 2023, consistent with an increase in beef cattle population over those same years. CH_4 emissions from enteric fermentation decreased by 2.9 percent (5.5 MMT CO_2 Eq.) from 2022 to 2023, however, largely driven by a decrease in beef cattle populations.
- Natural gas systems were the second largest anthropogenic source category of CH_4 emissions in the United States in 2023, accounting for 21.9 percent of total CH_4 emissions and 2.6 percent of total gross emissions. Emissions have decreased by 26.0 percent (57.1 MMT CO_2 Eq.) since 1990, largely due to decreases in emissions from distribution, transmission, and storage.

- Landfills were the third largest anthropogenic source of CH_4 emissions in the United States in 2023, accounting for 17.4 percent of total CH_4 emissions and 1.9 percent of total gross emissions and representing a decrease of 39.6 percent (78.3 MMT CO_2 Eq.) since 1990, 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.[10]

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 265 times more powerful than CO_2 at trapping heat in the atmosphere over a 100-year time frame (IPCC 2013). 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-9).

Figure ES-9: 2023 Sources of Nitrous Oxide Emissions



Note: "Other Industrial Processes" includes N_2O emissions from caprolactam, glyoxal, and glyoxylic acid production; the electronics industry; and product uses. "Other Energy" includes N_2O emissions from petroleum systems, natural gas systems, and incineration of waste. Land Use, Land-Use Change, and Forestry emissions include N_2O emissions reported for peatlands remaining peatlands, forest fires, drained organic soils, grassland fires, coastal wetlands remaining coastal wetlands, forest soils, and settlement soils.

[10] 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.

Overall, N_2O emissions in the United States in 2023, including LULUCF N_2O emissions, accounted for 392.9 MMT CO_2 Eq., representing a decrease of 4.8 percent (19.6 MMT CO_2 Eq.) since 1990 and a decrease of 0.9 percent (3.6 MMT CO_2 Eq.) since 2022. Significant trends for the largest sources of anthropogenic N_2O emissions include the following.

- Agricultural soils were the largest anthropogenic source of N_2O emissions in 2023, accounting for 75.4 percent of N_2O emissions and 4.8 percent of total gross greenhouse gas emissions in the United States. These emissions increased by 2.5 percent (7.2 MMT CO_2 Eq.) from 1990 to 2023 but fluctuated during that period due to annual variations in weather patterns, fertilizer use, and crop production.
- Wastewater treatment, both domestic and industrial, was the second largest anthropogenic source of N_2O emissions in 2023, accounting for 5.3 percent of N_2O emissions and 0.3 percent of total gross greenhouse gas emissions in the United States in 2023. Emissions from wastewater treatment increased by 41.0 percent (6.0 MMT CO_2 Eq.) since 1990 as a result of growing U.S. population and protein consumption.
- Stationary combustion was the third largest source of anthropogenic N_2O emissions in 2023, accounting for 5.0 percent of N_2O emissions and 0.3 percent of total gross U.S. greenhouse gas emissions in 2023. Stationary combustion emissions peaked in 2007 and steadily declined until 2020. Emissions increased from 2021 to 2022 but decreased again in 2023. Stationary combustion emissions have decreased by 12.4 percent (2.8 MMT CO_2 Eq.) since 1990.

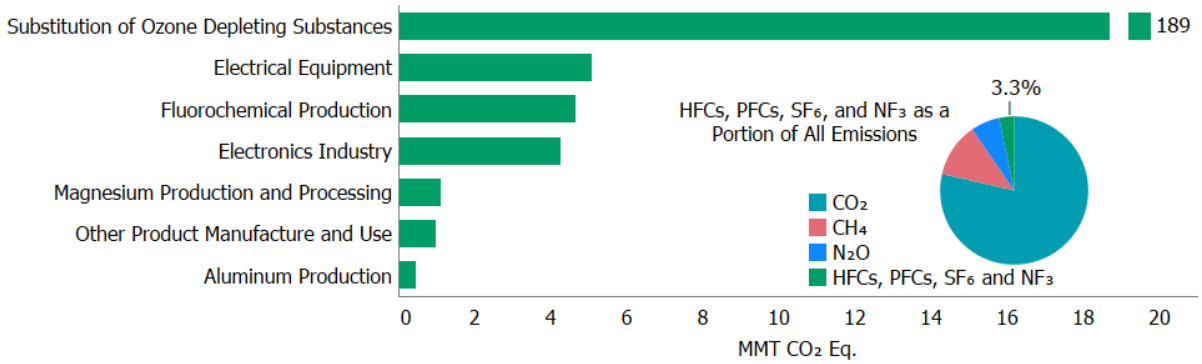
Hydrofluorocarbon, Perfluorocarbon, Sulfur Hexafluoride, and Nitrogen Trifluoride Emissions

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. HFCs do not deplete the stratospheric ozone layer and have been used as alternatives under the Montreal Protocol.

PFCs are emitted from the production of electronics and aluminum and also (in smaller quantities) from their use as alternatives to ODS. SF_6 is emitted from the manufacturing and use of electrical equipment as well as the production of electronics and magnesium. NF_3 is emitted from electronics production. HFCs are also emitted during production of HCFC-22 and electronics (see Figure ES-10).

HFCs, PFCs, SF_6, and NF_3 are potent greenhouse gases. In addition to having very high GWPs, PFCs, SF_6, and NF_3 have extremely long atmospheric lifetimes, resulting in their essentially irreversible accumulation in the atmosphere once emitted. SF_6 is the most potent greenhouse gas that the IPCC has evaluated (IPCC 2021).

Figure ES-10: 2023 Sources of Hydrofluorocarbon, Perfluorocarbon, Sulfur Hexafluoride, and Nitrogen Trifluoride Emissions



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

- HFC and PFC emissions resulting from their use as substitutes for ODS (e.g., chlorofluorocarbons [CFCs]) are the largest share of fluorinated emissions (92.1 percent) in 2023 and have been consistently increasing from small amounts since 1990. This increase over the time series was largely the result of efforts to phase out CFCs and other ODS in the United States.
- SF_6 emissions from electrical equipment decreased by 79.4 percent (19.6 MMT CO_2 Eq.) from 1990 to 2023. 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.
- HFC, PFC, SF_6, and NF_3 emissions from fluorochemical production decreased by 93.4 percent (66.4 MMT CO_2 Eq.) from 1990 to 2023 due to a reduction in the HFC-23 emission rate from HCFC-22 production (kg HFC-23 emitted/kg HCFC-22 produced), the imposition of emissions controls at production facilities, and a decrease in SF_6 production (due to the cessation of production at the major SF_6 production facility in 2010).
- PFC emissions from aluminum production decreased by 97.6 percent (18.8 MMT CO_2 Eq.) from 1990 to 2023, due to both industry emission reduction efforts and lower domestic aluminum production.
- HFC, PFC, SF_6, and NF_3 emissions from use in electronics increased 27.2 percent (0.9 MMT CO_2 Eq.) from 1990 to 2023. Industrial growth, increasing chip complexity, and the adoption of emissions reductions technologies contributed to the fluctuation in electronics industry emissions.

ES.3 Overview of Sector Emissions and Trends

In addition to understanding trends by GHG, this section provides an overview of the trends by inventory sectors. Figure ES-11 illustrates that over the 34-year period of 1990 to 2023, total emissions from the Energy and Waste sectors decreased by 6.2 percent (331.6 MMT CO_2 Eq.) and 29.7 percent (70.1 MMT CO_2 Eq.) respectively. Emissions from the IPPU and Agriculture sectors grew by 4.6 percent (16.8 MMT CO_2 Eq.), and 8.0 percent (43.9 MMT CO_2 Eq.), respectively. Over the same period, the overall net flux from LULUCF (i.e., the net sum of all CH_4 and N_2O emissions to the atmosphere plus LULUCF net carbon stock changes in units of MMT CO_2 Eq.) decreased by 9.4 percent (97.9 MMT CO_2 Eq.) and resulted in a removal of 939.9 MMT CO_2 Eq. in 2023.

Figure ES-11: U.S. Greenhouse Gas Emissions and Sinks by Inventory Sector

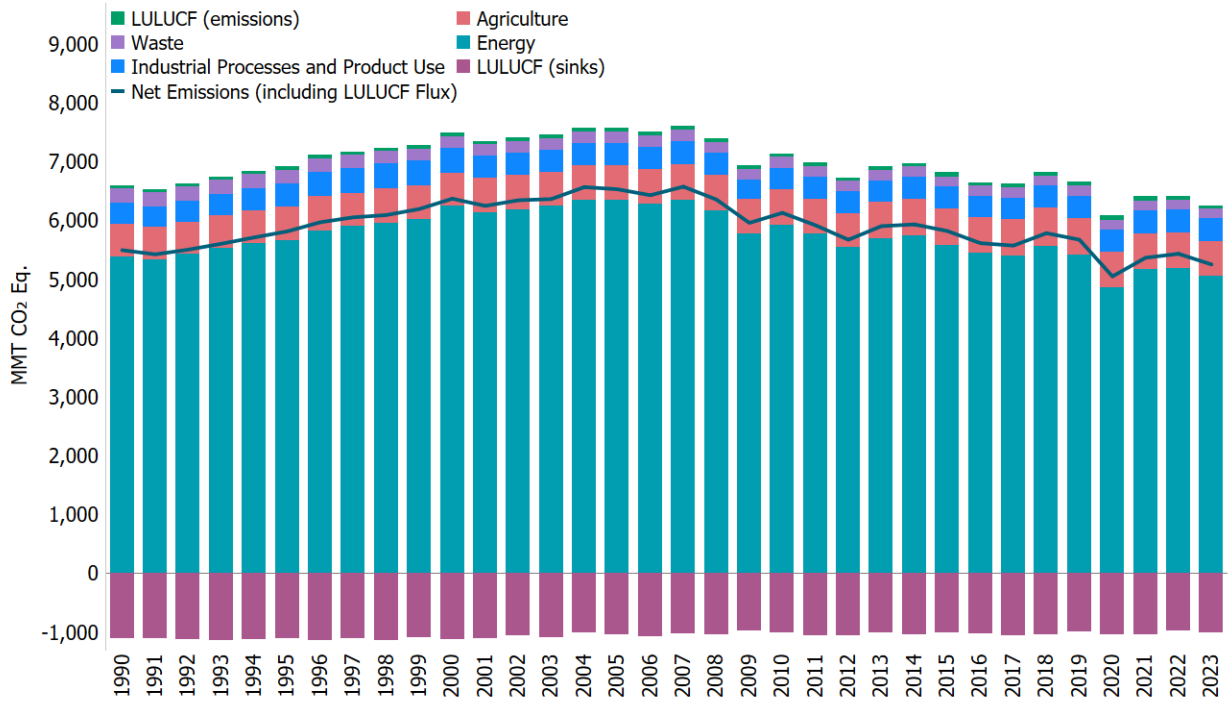


Table ES-3: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Inventory Sector (MMT CO_2 Eq.)

Inventory Sector	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
Energy	5,381.9	6,356.2	5,420.9	4,860.2	5,170.1	5,196.2	5,050.4	-6.2%
Industrial Processes and Product Use	368.9	374.7	380.8	375.3	390.9	389.6	385.7	4.6%
Agriculture	551.5	582.5	620.8	600.4	605.8	593.3	595.4	8.0%

Waste	235.9	192.0	174.8	169.7	167.0	165.1	165.8	-29.7%
Total Gross Emissions [a] (Sources)	**6,538.3**	**7,505.3**	**6,597.4**	**6,005.7**	**6,333.8**	**6,344.1**	**6,197.3**	**-5.2%**
LULUCF Sector Net Total [b]	**(1,037.9)**	**(968.9)**	**(919.4)**	**(951.6)**	**(962.9)**	**(905.3)**	**(939.9)**	**-9.4%**
Net Emissions (Sources and Sinks) [c]	**5,500.4**	**6,536.4**	**5,678.0**	**5,054.2**	**5,371.0**	**5,438.7**	**5,257.4**	**-4.4%**

[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 LULUCF net carbon stock changes in units of MMT CO_2 Eq.

[c] Net emissions with LULUCF.

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

Box ES-2: Inventory Reporting Sectors

Inventory reporting sectors are standardized to promote comparability for greenhouse gas inventories across countries. These sectors include Energy (chapter 3), Industrial Processes and Product Use (IPPU) (chapter 4), Agriculture (chapter 5), Land Use, Land-Use Change (chapter 6), and Forestry (LULUCF), and Waste (chapter 7). These categories facilitate consistent reporting and comparison of greenhouse gas emissions data.

In contrast, the economic sectors used in this report are aligned with more commonly used categories within the United States, but which may differ from country to country. These sectors include residential, commercial, industry, transportation, electric power, and agriculture. Emissions from the electric power industry can be distributed to each economic sector to reflect their use of electricity. This categorization helps to identify and analyze the sources of greenhouse gas emissions within the U.S. economy.

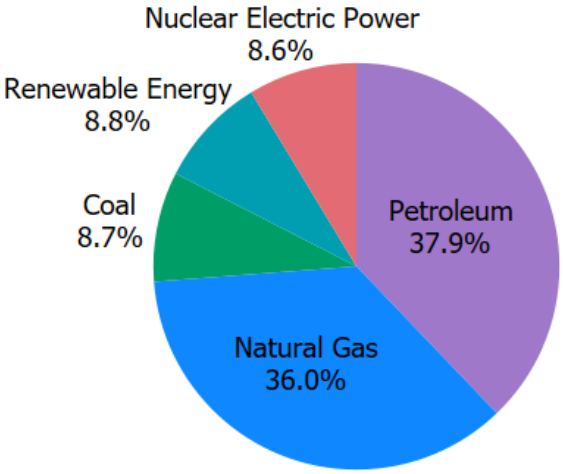
Energy

Chapter 3, *Energy*, 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 2023. Energy-related activities are also responsible for CH_4 and N_2O emissions (39.6 percent and 9.3 percent of total U.S. emissions of each gas, respectively).[11] Overall, emission sources in the Energy sector account for a combined 81.5 percent of total gross U.S. greenhouse gas emissions in 2023. Emissions from energy decreased by 2.8 percent (145.8 MMT CO_2 Eq.) since 2022 and 6.2 percent (331.6 MMT CO_2 Eq.) since 1990.

In 2023, 82.6 percent of the energy used in the United States (in Btus) was produced through the combustion of fossil fuels. The remaining 17.4 percent came from other energy sources, such as hydropower, biomass, nuclear, wind, and solar energy (see Figure ES-12).

[11] The contribution of energy non-CO_2 emissions is based on gross totals and excludes LULUCF methane (CH_4) and nitrous oxide (N_2O) emissions. The contribution of energy-related CH_4 and N_2O including LULUCF non-CO_2 emissions is 36.3 percent and 7.9 percent respectively.

Figure ES-12: 2023 U.S. Energy Consumption by Energy Source (Percent)



Industrial Processes and Product Use

Chapter 4, *Industrial Processes and Product Use*, chapter contains 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, ammonia production, lime production, other process uses of carbonates (e.g., other uses of carbonates, other uses of soda ash not associated with glass manufacturing, ceramics production, and non-metallurgical magnesia production), nitric acid production, adipic acid production, urea consumption for non-agricultural purposes, aluminum production, HCFC-22 production, other fluorochemical production, glass production, soda ash production, ferroalloy production, titanium dioxide production, caprolactam 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 sectoral definitions for national inventory reporting, is included in the Energy sector.

Chapter 4 also contains emissions resulting from the release of HFCs, PFCs, SF_6, and NF_3 and other human-made compounds used in industrial manufacturing processes and by end-consumers (e.g., residential and mobile air conditioning). These industries include electronics manufacturing, 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, PFCs and SF_6 are emitted in other product use, and CO_2 is consumed and emitted through various end-use applications. In 2023, emissions resulting from the use of ODS substitutes (e.g., HFCs, chlorofluorocarbons [CFCs]) by end-consumers was the largest source of IPPU emissions and accounted for 49.0 percent of total IPPU emissions.

Of total U.S. CO_2, CH_4, and N_2O emissions, IPPU activities are responsible for 3.4, less than 0.5, and 3.8 percent respectively, as well as for all U.S. emissions of fluorinated gases including HFCs, PFCs, SF_6 and NF_3. Overall, emission sources from the IPPU sector accounted for 6.2 percent of U.S. greenhouse gas emissions in 2023. Between 1990 and 2023, IPPU emissions increased by 4.6 percent (16.8 MMT CO_2

Eq.), primarily due to growth in the use of HFCs as substitutes for ozone depleting substances. IPPU emissions have decreased by 1.0 percent (3.8 MMT CO_2 Eq.) since 2022 largely due to decreased production of fluorochemicals and decreased consumption of other process uses of carbonates.

Agriculture

Chapter 5, *Agriculture*, contains information on anthropogenic emissions from agricultural activities (except fuel combustion, which is addressed in Chapter 3, *Energy*, and some agricultural CO_2, CH_4, and N_2O fluxes, which are addressed in Chapter 6, *Land Use, Land-Use Change, and Forestry*).

Several agricultural activities contribute directly to emissions of greenhouse gases, including agricultural soil management, enteric fermentation from domestic livestock production, livestock manure management, rice cultivation, urea fertilization, liming, and field burning of agricultural residues.

In 2023, agricultural activities were responsible for 9.6 percent of total gross U.S. greenhouse gas emissions. Agriculture sector emissions increased by 2.1 MMT CO_2 Eq. (0.4 percent) since 2022 and have increased by 43.9 MMT CO_2 Eq. (8.0 percent) since 1990, mostly from trends in enteric fermentation and manure management. CH_4, N_2O, and CO_2 are the greenhouse gases emitted by agricultural activities. CH_4 emissions from enteric fermentation and manure management represented 25.2 percent of total CH_4 emissions from anthropogenic activities in 2023. Agricultural soil management activities, such as application of synthetic and organic fertilizers, deposition of livestock manure, and growing N-fixing plants, were the largest contributor to U.S. N_2O emissions in 2023, accounting for 76.6 percent of total N_2O emissions. CO_2 emissions from the application of crushed limestone and dolomite (i.e., soil liming) and urea fertilization represented 0.2 percent of total CO_2 emissions from anthropogenic activities.

Land Use, Land-Use Change, and Forestry

Chapter 6, *Land Use, Land-Use Change, and Forestry*, 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 and therefore not included in this report.[12] The share of managed land in the United States is approximately 95 percent of total land included in the *Inventory*.[13] 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 (i.e., carbon sequestration). The primary drivers of fluxes on managed lands include forest management practices, tree planting in urban areas, the management of agricultural soils, lands remaining and lands converted to reservoirs and other constructed waterbodies, landfilling of yard trimmings and food scraps, and activities that cause changes in carbon stocks in coastal wetlands. The main drivers for forest carbon sequestration

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

[13] 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.

include forest growth and increasing forest area (i.e., afforestation), as well as a net accumulation of carbon 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 carbon from yard trimmings and food scraps in landfills.

The LULUCF sector in 2023 resulted in a net increase in carbon stocks (i.e., net CO_2 removals) of 1,000.5 CO_2 Eq.[14] The removals of carbon offset 16.1 percent of total gross greenhouse gas emissions in 2023. Emissions of CH_4 and N_2O from LULUCF activities in 2023 represented 1.2 percent of net greenhouse gas emissions.[15] Carbon dioxide removals from carbon stock changes are presented in Table ES-4 along with CH_4 and N_2O emissions for LULUCF source categories.

Table ES-4: 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	2019	2020	2021	2022	2023
Forest Land Remaining Forest Land [a]	(1049.3)	(932.8)	(867.4)	(898.0)	(881.0)	(827.6)	(873.3)
Settlements Remaining Settlements [b]	(109.1)	(115.2)	(131.4)	(131.7)	(132.1)	(132.1)	(131.7)
Land Converted to Forest Land [c]	(103.6)	(103.6)	(103.9)	(103.8)	(103.8)	(103.8)	(103.8)
Cropland Remaining Cropland	1.0	(31.0)	(19.3)	(8.7)	(31.9)	(31.6)	(30.5)
Land Converted to Wetlands [d]	6.8	1.9	0.7	0.7	0.7	0.7	0.6
Land Converted to Grassland [e]	35.6	21.9	20.9	24.1	19.9	20.9	20.9
Grassland Remaining Grassland [f]	24.2	24.5	28.5	16.8	11.2	13.7	22.7
Land Converted to Cropland [e]	48.5	35.5	31.4	29.2	34.9	35.0	35.6
Wetlands Remaining Wetlands [d]	38.5	40.9	39.7	39.7	39.7	39.7	39.7
Land Converted to Settlements [e]	69.5	89.0	81.4	80.3	79.7	79.8	79.8
LULUCF Carbon Stock Change [g]	**(1,096.9)**	**(1,040.7)**	**(982.6)**	**(1,034.2)**	**(1,043.8)**	**(973.9)**	**(1,000.5)**
LULUCF Emissions [h]	**59.1**	**71.8**	**63.2**	**82.6**	**81.0**	**68.6**	**60.6**
CH_4	54.4	60.9	56.1	69.0	67.8	59.6	54.7
N_2O	4.7	10.9	7.0	13.7	13.1	9.0	5.9
LULUCF Sector Net Total [i]	**(1,037.9)**	**(968.9)**	**(919.4)**	**(951.6)**	**(962.9)**	**(905.3)**	**(939.9)**

[a] Includes the net changes to carbon stocks stored in all forest ecosystem pools and harvested wood products, emissions from fires on both forest land remaining forest land and land converted to forest land, emissions from N fertilizer additions on both forest land remaining forest land and land converted to forest land, and CH_4 and N_2O emissions from drained organic soils on both forest land remaining forest land and land converted to forest land.

[b] 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.

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

[d] Estimates include CH_4 emissions from flooded land remaining flooded land and land converted to flooded land.

[14] 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.

[15] 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.

[e] 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.
[f] Estimates include CH_4 and N_2O emissions from fires on both grassland remaining grassland and land converted to grassland.
[g] LULUCF carbon stock change includes any carbon stock gains and losses from all land use and land use conversion categories.
[h] LULUCF emissions subtotal includes 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, flooded land remaining flooded land, and land converted to flooded land; and N_2O emissions from forest soils and settlement soils. Emissions values are included in land-use category rows.
[i] The LULUCF sector net total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus LULUCF net carbon stock changes in units of MMT CO_2 Eq.
Notes: Totals may not sum due to independent rounding.

Between 1990 and 2023, total carbon sequestration in the LULUCF sector decreased by 8.8 percent, primarily due to a decrease in the rate of net carbon accumulation in forests and in 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 LULUCF net carbon stock changes in units of MMT CO_2 Eq.) resulted in a removal of 939.9 MMT CO_2 Eq. in 2023.

Flooded lands were the largest source of CH_4 emissions from the LULUCF sector and the fifth largest source of overall net CH_4 emissions in 2023. Coastal wetlands remaining coastal wetlands were the second largest source of CH_4 emissions, followed by forest fires. Settlement soils were the largest source of N_2O emissions from the LULUCF sector in 2023.

Waste

Chapter 7, *Waste*, contains emissions from waste management activities (except the incineration of waste, which is addressed in Chapter 3, *Energy*). Landfills were the largest source of anthropogenic greenhouse gas emissions from waste management activities, accounting for 72.0 percent of total greenhouse gas emissions from waste management activities, and 17.4 percent of total U.S. CH_4 emissions.[16] Additionally, wastewater treatment accounted for 25.3 percent of total Waste sector greenhouse gas emissions, 3.1 percent of U.S. CH_4 emissions, and 5.4 percent of U.S. N_2O emissions in 2023. Emissions of CH_4 and N_2O from commercial composting are also included in this chapter, accounting for 1.6 percent (2.6 MMT CO_2 Eq.) and 1.1 percent (1.8 MMT CO_2 Eq.) of overall waste sector emissions, respectively. Anaerobic digestion at biogas facilities generated CH_4 emissions, accounting for less than 0.05 percent of emissions from the Waste sector. Overall, emission sources in Chapter 7, *Waste*, accounted for 2.7 percent of total gross U.S. greenhouse gas emissions in 2023. Waste sector emissions decreased by 0.5 percent (0.7 MMT CO_2 Eq.) since 2022 and by 29.7 percent (70.1 MMT CO_2 Eq.) since 1990.

[16] Landfills also store carbon, due to incomplete degradation of organic materials such as harvest wood products, yard trimmings, and food scraps, as described in Chapter 6, *Land Use, Land-Use Change, and Forestry*. Also, the estimated total methane emissions used to estimate contribution excludes methane emissions from the LULUCF sector.

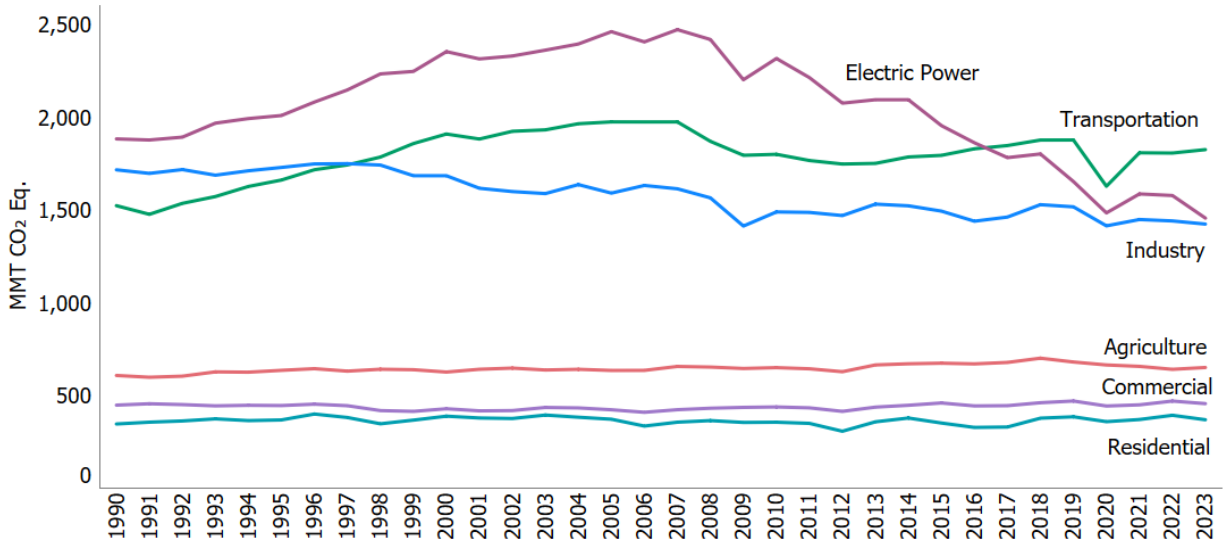
ES.4 Other Information

Emissions and Sinks by Economic Sector

This report also characterizes emissions according to commonly used economic sector categories: residential, commercial, industry, transportation, electric power, and agriculture.[17] All emissions from U.S. Territories are reported together as their own end-use sector in this characterization due to a lack of specific consumption data for the individual end-use sectors. For more information on trends in the Land Use, Land-Use Change, and Forestry sector, see Section 6.

Figure ES-13 shows the trend in emissions by economic sector from 1990 to 2023, and Table ES-5summarizes emissions from each of these economic sectors.

Figure ES-13: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors



Note: This figure excludes emissions and removals from Land Use, Land-Use Change, and Forestry and U.S. Territories.

Table ES-5: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (MMT CO_2 Eq.)

Economic Sectors	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
Transportation	1,520.8	1,971.8	1,874.2	1,625.3	1,805.5	1,804.0	1,822.5	19.8%
Electric Power	1,880.2	2,457.4	1,650.7	1,481.8	1,584.0	1,575.5	1,453.7	-22.7%
Industry	1,714.5	1,589.4	1,514.8	1,412.3	1,446.0	1,439.8	1,423.0	-17.0%
Agriculture	606.8	633.7	679.2	663.3	655.7	639.8	649.6	7.1%

[17] The agriculture economic sector includes emissions from fossil fuel combustion and electricity use within the Agriculture sector.

Commercial	447.0	422.1	469.2	442.3	448.6	469.0	455.1	1.8%
Residential	345.6	371.2	384.2	358.0	369.6	392.4	368.3	6.6%
U.S. Territories	23.4	59.7	25.1	22.6	24.4	23.7	25.1	6.9%
Total Gross Emissions (Sources)	**6,538.3**	**7,505.3**	**6,597.4**	**6,005.7**	**6,333.8**	**6,344.1**	**6,197.3**	**-5.2%**
LULUCF Sector Net Total [a]	**(1,037.9)**	**(968.9)**	**(919.4)**	**(951.6)**	**(962.9)**	**(905.3)**	**(939.9)**	**-9.4%**
Net Emissions (Sources and Sinks)	**5,500.4**	**6,536.4**	**5,678.0**	**5,054.2**	**5,371.0**	**5,438.7**	**5,257.4**	**-4.4%**

[a] The Land Use, Land-Use Change, and Forestry (LULUCF) sector net total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus LULUCF net carbon stock changes.
Notes: Total gross emissions are presented without LULUCF. Total net emissions are presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Using this categorization, emissions from transportation activities accounted for the largest portion (29.4 percent) of total gross greenhouse gas emissions in 2023. Electric power accounted for the second largest portion (23.5 percent) of greenhouse gas emissions in 2023, while emissions from industry accounted for the third largest portion (23.0 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 24.2 percent of total gross 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 10.5 percent of 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 7.3 percent and 5.9 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 carbon stocks in coastal wetlands.

Electric power is ultimately used in the other economic sectors. Table ES-6 presents greenhouse gas emissions from economic sectors with emissions related to electric power distributed into end-use categories (i.e., emissions from electric power generation 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 2025).[18] 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 equipment systems.

[18] 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.

When emissions from electric power use are distributed among these end-use sectors, transportation and industrial account for the largest shares of U.S. greenhouse gas emissions (29.5 percent and 29.2 percent, respectively) in 2023. The commercial and residential sectors contributed the next largest shares of total gross greenhouse gas emissions in 2023 (15.6 and 14.4 percent, respectively). Emissions from the commercial and residential sectors increase substantially when emissions from electric power use are included due to the relatively large share of electricity these sectors use for energy (e.g., lighting, cooling, appliances). Table ES-6 shows the trends in these emissions by sector from 1990 to 2023.

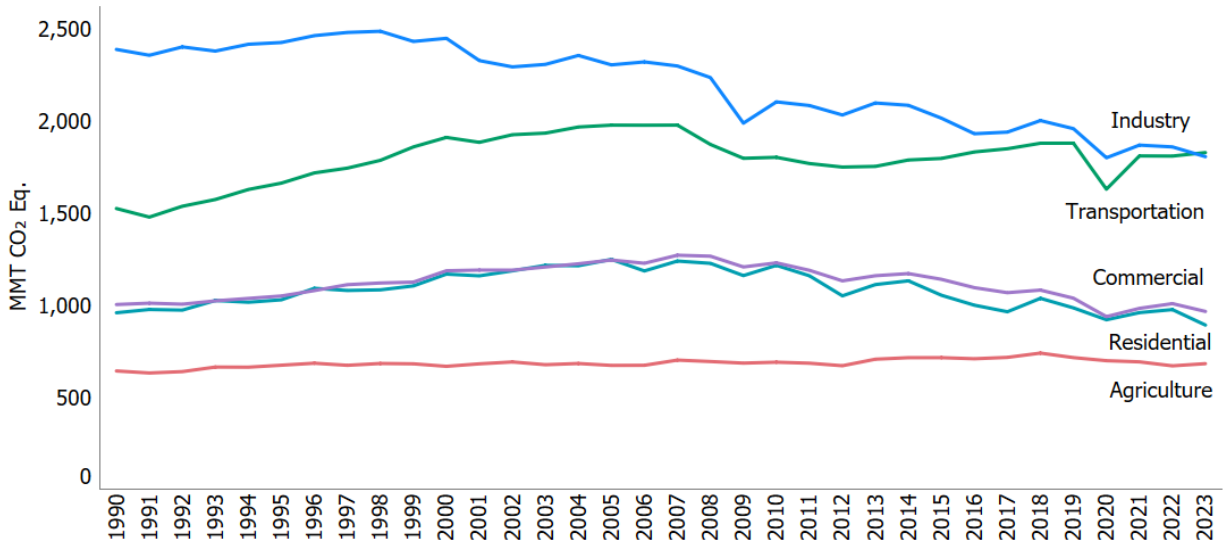
Table ES-6: U.S. Greenhouse Gas Emissions with Electricity-Related Emissions Distributed by Economic Sector (MMT CO_2 Eq.)

Economic Sectors	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
Transportation	1,523.9	1,976.6	1,878.5	1,628.9	1,809.5	1,808.6	1,827.7	19.9%
Industry	2,388.5	2,305.0	1,957.8	1,799.7	1,868.0	1,859.6	1,806.9	-24.4%
Commercial	1,002.5	1,244.3	1,037.1	936.9	981.8	1,007.5	965.1	-3.7%
Residential	957.9	1,247.7	984.4	919.9	958.7	975.0	891.1	-7.0%
Agriculture	641.9	672.0	714.4	697.7	691.4	669.6	681.5	6.2%
U.S. Territories	23.4	59.7	25.1	22.6	24.4	23.7	25.1	6.9%
Total Gross Emissions (Sources)	**6,538.3**	**7,505.3**	**6,597.4**	**6,005.7**	**6,333.8**	**6,344.1**	**6,197.3**	**-5.2%**
LULUCF Sector Net Total [a]	**(1,037.9)**	**(968.9)**	**(919.4)**	**(951.6)**	**(962.9)**	**(905.3)**	**(939.9)**	**-9.4%**
Net Emissions (Sources and Sinks)	**5,500.4**	**6,536.4**	**5,678.0**	**5,054.2**	**5,371.0**	**5,438.7**	**5,257.4**	**-4.4%**

[a] The Land Use and Land-Use Change and Forestry (LULUCF) sector net total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus LULUCF net carbon stock changes.

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.

Figure ES-14: U.S. Greenhouse Gas Emissions with Electricity-Related Emissions Distributed to Economic Sectors



Note: This figure excludes emissions and removals from Land Use, Land-Use Change, and Forestry and U.S. Territories.

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

Total gross greenhouse gas emissions can be compared to other economic and social indices to highlight changes over time. These comparisons include: (1) aggregate energy use, because energy-related activities are the largest sources of emissions; (2) energy use per capita as a measure of efficiency; (3) emissions per unit of total gross domestic product as a measure of national economic activity; and (4) emissions per capita.

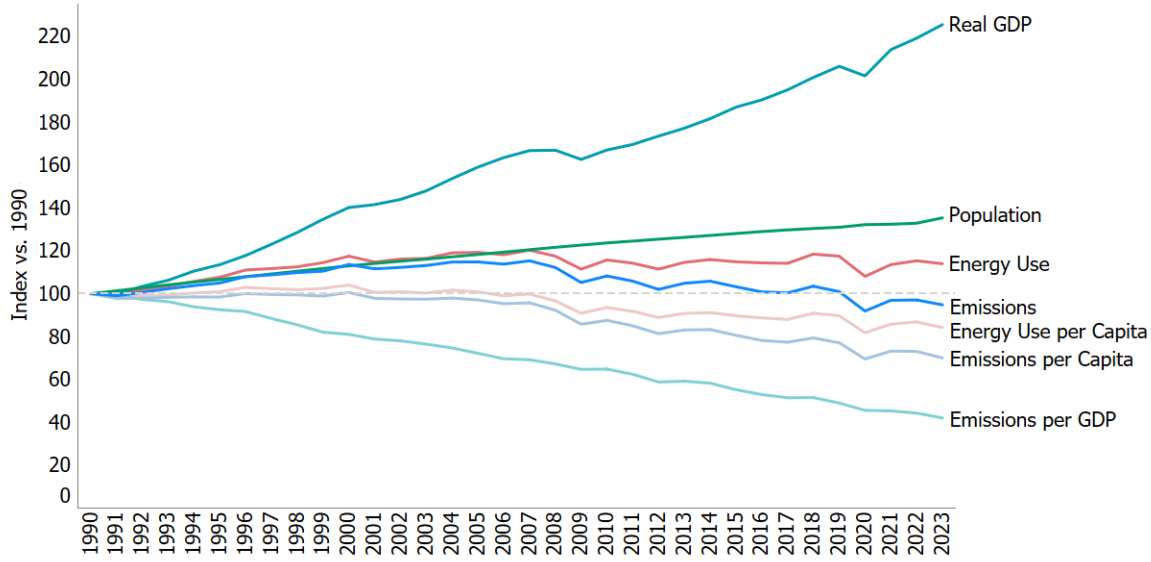
Table ES-7 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. These values represent the relative change in each statistic since 1990. Greenhouse gas emissions in the United States have declined at an average annual rate of 0.01 percent 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-15). 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 1.0 percent since 2005. Since 2005, GDP and national population, generally, continued to increase while energy has decreased slightly noting 2020 was impacted by the COVID-19 pandemic.

Table ES-7: Recent Trends in Various U.S. Data (Index 1990 = 100)

Variable	1990	2005	2019	2020	2021	2022	2023	Avg. Annual Growth Rate Since 1990 [a]	Avg. Annual Growth Rate Since 2005 [a]
Greenhouse Gas Emissions [b]	100	115	101	92	97	97	95	-0.1%	-1.0%
Energy Use [c]	100	119	117	107	113	115	113	0.4%	-0.2%
GDP [d]	100	159	206	202	214	219	225	2.5%	2.0%
Population [e]	100	118	131	132	132	133	135	0.9%	0.8%

+ Absolute value does not exceed 0.05 percent.
[a] Average annual growth rate.
[b] Total gross GWP-weighted values.
[c] Energy content-weighted values (EIA 2025).
[d] GDP in chained 2017 dollars (BEA 2024).
[e] U.S. Census Bureau (2025).

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



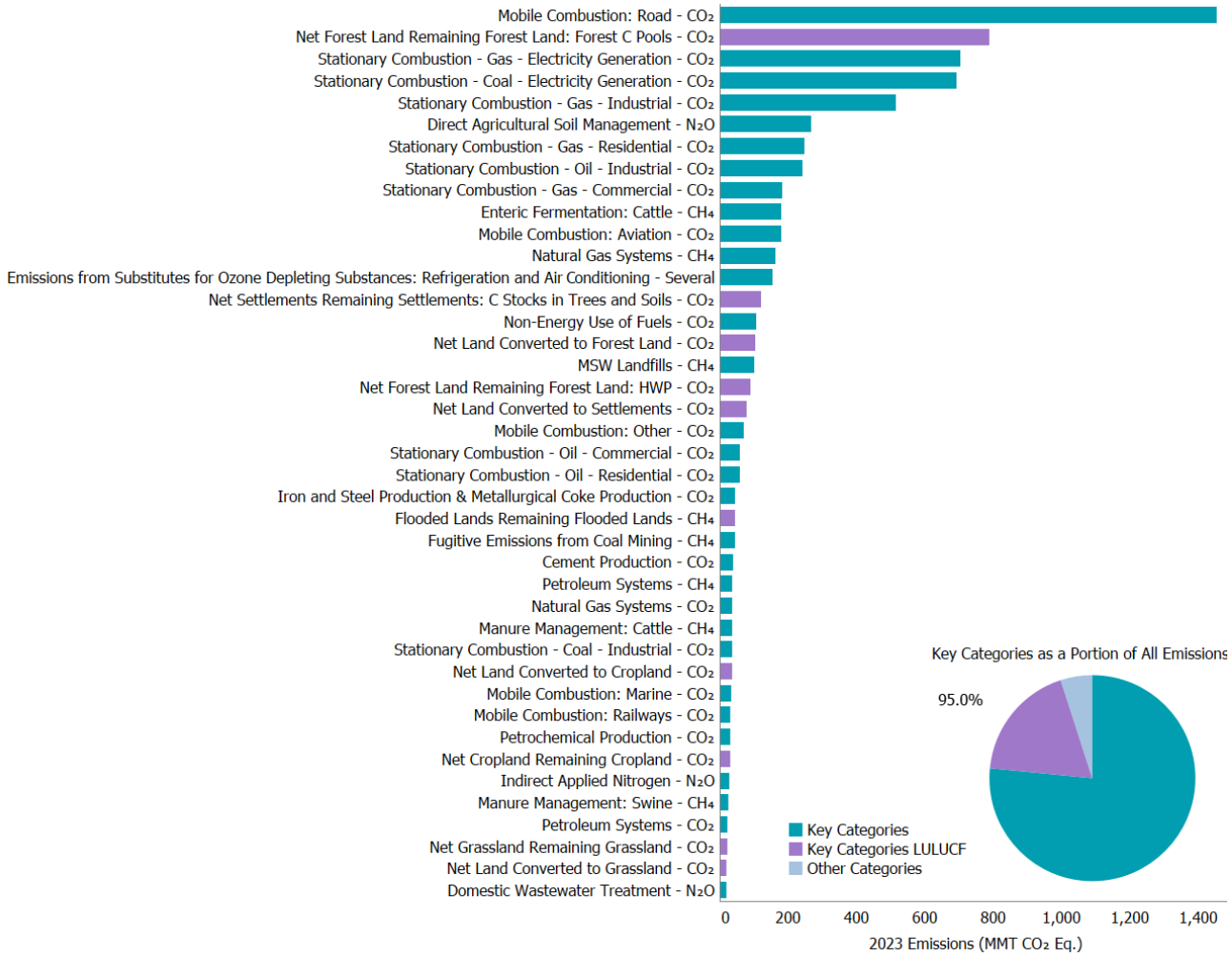
Source: BEA (2024), U.S. Census Bureau (2025), and net emissions in this report.

Key Categories

Key categories are "inventory categories which individually, or as a group of categories (for which a common method, emission factor and activity data are applied) are prioritized within the national inventory system because their estimates have a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the level of uncertainty in emissions or removals" (IPCC 2006; IPCC 2019). 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-16 presents the 2023 key categories identified by the Approach 1 level assessment, including the LULUCF sector. 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.

Figure ES-16: 2023 Key Categories (Approach 1 including LULUCF)



Note: 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 level assessment, including the Land Use, Land-Use Change, and Forestry (LULUCF) sector. 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-4 for a breakout of emissions and removals for LULUCF by source/sink category.

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

Quality Assurance and Quality Control

The EPA seeks continuous improvements to the quality, transparency, and usability of the *Inventory*. To assist in these efforts, the United States implemented a U.S. Inventory QA/QC plan, which includes

expert and public reviews for the emissions estimates and this report, along with other verification techniques, such as use of ambient measurements as described in Box ES-4.

Box ES-4: Use of Ambient Measurements Systems for Validation of Emission Inventories

Several recent studies have estimated emissions at the national or regional level with estimated results that sometimes differ from the results in this report and in previous reports. 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 to improve national greenhouse gas inventories, EPA follows guidance from the IPCC on the use of measurements and modeling to validate emission inventories.[19] An area of particular interest in EPA's outreach efforts is how ambient measurement data can be used to assess estimates or potentially be incorporated into the *Inventory* in a manner consistent with this *Inventory's* transparency in calculation methodologies, and the ability of inverse modeling techniques to attribute emissions and removals from remote sensing to anthropogenic sources, as defined by the IPCC, versus natural sources and sinks.

The *2019 Refinement* (IPCC 2019) Volume 1 General Guidance and Reporting, Chapter 6: *Quality Assurance, Quality Control and Verification*, notes that emission estimates derived from atmospheric concentration measurements can provide independent data sets as a basis for comparison with inventory estimates. The *2019 Refinement* provides guidance on conducting such comparisons (as summarized in Table 6.2 of IPCC [2019] Volume 1, Chapter 6) and provides guidance on using such comparisons to identify areas of improvement in national inventories (as summarized in Box 6.5 of IPCC [2019] Volume 1, Chapter 6). Further, it identified fluorinated gases as particularly suitable for such comparisons due to their limited natural sources, generally long atmospheric lifetimes, and well-understood loss mechanisms, which makes it relatively more straightforward to model their emission fluxes from observed mass quantities. Unlike emissions of CO_2, CH_4, and N_2O, emissions of fluorinated greenhouse gases are almost exclusively anthropogenic, meaning that the fluorinated greenhouse gas emission sources included in this *Inventory* account for the majority of the total U.S. emissions of these gases detectable in the atmosphere. This evaluation approach is also useful for gases and sources with larger uncertainties in available bottom-up inventory methods and data, such as emissions of CH_4, which are primarily from uncertain biological (e.g., enteric fermentation) and fugitive (e.g., natural gas production) activities.

In this *Inventory*, EPA includes the results from current and previous comparisons between fluorinated gas emissions inferred from atmospheric measurements and fluorinated gas emissions estimated based on bottom-up measurements and modeling. These comparisons, performed for HFCs and SF_6 respectively, are described under the QA/QC and Verification discussions in Chapter 4, Section 4.25, *Substitution of Ozone Depleting Substances*, and Section 4.26, *Electrical Equipment*.

Consistent with the *2019 Refinement*, a key element to facilitate such comparisons is a spatially explicit or gridded inventory as an input to inverse modeling. To improve the ability to compare methane emissions from the national-level greenhouse gas inventory with observation-based estimates, a team of researchers from U.S. EPA, SRON Netherlands Institute for Space Research, Harvard University, and

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

Lawrence Berkely National Laboratory and other coauthors developed a time series of anthropogenic methane emissions maps with 0.1° x 0.1° (10 kilometer (km) x 10 km) spatial resolution and monthly temporal resolution for the contiguous United States.[20] The gridded methane inventory is designed to be consistent with the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks* estimates, which presents national totals for different source types.[21] The development of 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).

Finally, in addition to the use of atmospheric concentration measurement data for comparison with Inventory data, information from top-down studies is directly incorporated in the natural gas systems calculations to quantify emissions from certain well blowout events.

Uncertainty Analysis of Emission and Sink Estimates

The *2006 IPCC Guidelines* (IPCC 2006), Volume 1, Chapter 3, describe the benefits of conducting an uncertainty analysis, which include informing and prioritizing inventory improvements. This report provides single estimates of uncertainty for all source and sink categories, and qualitative discussion of specific factors affecting the uncertainty estimate. 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 are relatively small. For some other categories of emissions and sinks, 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 +5 percent in 1990 and -5 to +6 percent in 2023. When the LULUCF sector is excluded from the analysis, the uncertainty is estimated to be -2 to +4 percent in 1990 and -2 to +4 percent in 2023.

[20] See https://www.epa.gov/ghgemissions/us-gridded-methane-emissions.
[21] See https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.