Executive Summary

An inventory that identifies and quantifies a country's anthropogenic[1] sources and sinks of greenhouse gas emissions and removals 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 Paris Agreement and United Nations Framework Convention on Climate Change (UNFCCC) to compare the relative contribution of different greenhouse gases emissions and removals to climate change.

The United States is party to both the 1992 UNFCCC and the 2015 Paris Agreement. The Paris Agreement set a global temperature goal – holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the increase to 1.5°C – that articulates with greater precision States' views on what is necessary to meet the UNFCCC's objective of "stabiliz[ing] … greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.[2]

The United States is committed to submitting a national inventory of anthropogenic emission sources and removals by sinks of greenhouse gases by April 15 of each year. The United States has prepared this report, in conjunction with Common Reporting Tables (CRTs) that accompany this report, consistent with its obligations under those agreements.

This Executive Summary provides the latest information on U.S. anthropogenic greenhouse gas emission trends from 1990 through 2022. The structure of this report is consistent with requirements under the Paris Agreement and the UNFCCC on national greenhouse gas inventory reporting, as discussed in Box ES-1. Throughout this report, emission and sink estimates are grouped into five reporting sectors (i.e., chapters): Energy, IPPU, Agriculture, Land Use, Land-Use Change, and Forestry (LULUCF), and waste. In describing trends (Chapter 2), emissions and sinks are also summarized according to commonly used economic sector categories: residential, commercial, industry, transportation, electric power, and agriculture. See Box 2-1 for more information on how economic sectors are defined.

[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] See Paris Agreement, Article 2.1(a); UNFCCC, Article 2.

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

Consistent with Article 13.7(a) of the Paris Agreement and Article 4.1(a) of the UNFCCC as well as relevant decisions under those agreements, the emissions and removals presented in this report and this chapter are organized by source and sink categories and calculated using internationally accepted methods 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 reporting guidelines for the reporting of inventories under the Paris Agreement and the UNFCCC. The Parties' use of consistent methods to calculate emissions and removals for their inventories helps to ensure that these reports are comparable. The presentation of emissions and removals provided in this Inventory does not preclude alternative examinations. Rather, this Inventory presents emissions and removals in a common format consistent with how Parties are to report their national inventories under the Paris Agreement and the UNFCCC. The report itself, and this chapter, follows this common 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), which is complementary to the U.S. Inventory.[3] 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 41 industrial categories.[4] 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. Methodologies used in EPA's GHGRP are consistent with the 2006 IPCC Guidelines. While the GHGRP does not provide full coverage of total annual U.S. greenhouse gas emissions and removals (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 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 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 QA/QC procedures and assessment of uncertainties. See Annex 9 for more information on specific uses of GHGRP data in the Inventory (e.g., use of Subpart W data in compiling estimates for natural gas systems).

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 (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

[3] 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).

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

concentrations. From the pre-industrial era (i.e., ending about 1750) to 2022, concentrations of these greenhouse gases have increased globally by 49.5, 173.1, and 24.3 percent, respectively (IPCC 2013; NOAA/ESRL 2024a, 2024b, 2024c). 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. 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, CO_2-equivalent emissions are provided in million metric tons of CO_2 equivalent (MMT CO_2 Eq.) for non-CO_2 greenhouse gases.[5,6] All estimates are provided throughout the main report in both CO_2 equivalents and unweighted units, while 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 the Trends chapter and individual sector chapters of this report, and in the CRTs that are included in the submission to the UNFCCC.

Recent decisions under the Paris Agreement[7] and the UNFCCC[8] require Parties to use 100-year GWP values from the IPCC *Fifth Assessment Report* (AR5) for calculating CO_2-equivalents in their national reporting (IPCC 2013) by the end of 2024. This reflects updated science and ensures that national greenhouse gas inventories reported by all nations are comparable. This report reflects CO_2-equivalent greenhouse gas emission totals using 100-year AR5 GWP values. A comparison of emission values with the previously used 100-year GWP values from the IPCC *Fourth Assessment Report* (AR4) (IPCC 2007), and 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).

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

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

[7] See Annex to decision 18/CMA.1, available online at https://unfccc.int/sites/default/files/resource/CMA2018_03a02E.pdf.

[8] 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_adv.pdf.

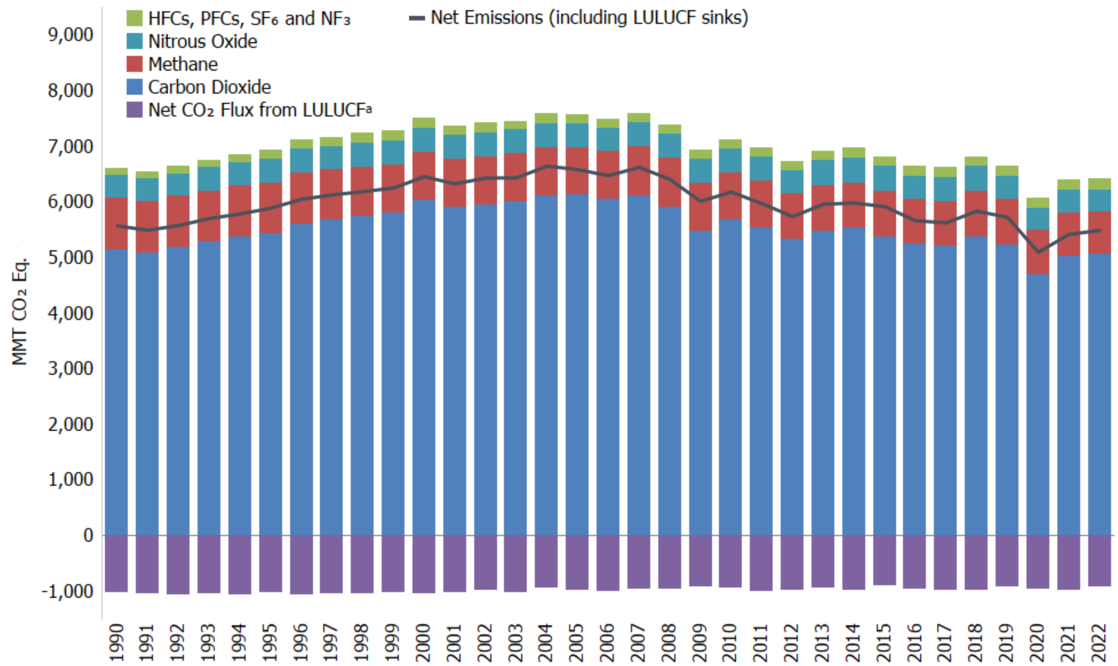
ES.2 Recent Trends in U.S. Greenhouse Gas Emissions and Sinks

In 2022, total gross U.S. greenhouse gas emissions were 6,341.2 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.).[9] Total gross U.S. emissions decreased by 3.1 percent from 1990 to 2022, down from a high of 15.0 percent above 1990 levels in 2007. Gross emissions increased from 2021 to 2022 by 0.3 percent (16.4 MMT CO_2 Eq.). Net emissions (including sinks) were 5,487.3 MMT CO_2 Eq. in 2022. Overall, net emissions increased by 1.3 percent from 2021 to 2022 and decreased by 16.6 percent from 2005 levels as shown in Table ES-2. Between 2021 and 2022, the increase in total greenhouse gas emissions was driven largely by an increase in CO_2 emissions from fossil fuel combustion across most end-use sectors due in part to increased energy use from the continued rebound of economic activity after the height of the COVID-19 pandemic. In 2022, CO_2 emissions from fossil fuel combustion increased by 1.0 percent relative to the previous year and was 16 percent below emissions in 1990. Carbon dioxide emissions from natural gas use increased by 5.4 percent (87.0 MMT CO_2 Eq.) from 2021, while CO_2 emissions from coal consumption decreased by 6.2 percent (59.0 MMT CO_2 Eq.) from 2021 to 2022. The increase in natural gas consumption and associated emissions in 2022 is observed across all sectors, while the coal decrease is due to reduced use in the electric power sector. Emissions from petroleum use also increased by 0.9 percent (19.2 MMT CO_2 Eq.) from 2021 to 2022, driving a 1.6 percent increase in transportation emissions. Carbon sequestration from the Land Use, Land-Use Change, and Forestry (LULUCF) sector offset 14.5 percent of total emissions in 2022.

Figure ES-1 and Figure ES-2 illustrate the overall trends in total U.S. emissions by gas and annual percent changes, and Table ES-2 provides information on trends in gross U.S. greenhouse gas emissions and sinks for 1990 through 2022. Unless otherwise stated, all tables and figures provide total gross emissions and exclude the greenhouse gas fluxes from the LULUCF sector. For more information about the LULUCF sector, see Section ES.3 Overview of Sector Emissions and TrendsES.3 Overview of Sector Emissions and Trends.

[9] 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.

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."

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

Gas/Source	1990	2005	2018	2019	2020	2021	2022	Percent Change Since 1990
CO_2	5,132.3	6,123.8	5,360.3	5,232.3	4,686.7	5,014.8	5,056.7	-1.5%
CH_4 (excludes LULUCF sources)[a]	871.6	795.4	771.5	754.3	735.3	720.6	702.5	-19.4%
N_2O (excludes LULUCF sources)[a]	408.1	419.2	439.4	416.4	391.1	398.1	386.5	-5.3%
HFCs	48.2	121.2	162.9	167.3	169.6	176.3	181.4	276.3%
PFCs	47.1	7.8	5.8	5.9	5.5	5.4	5.4	-88.5%
SF_6	35.9	20.0	7.7	8.4	8.1	8.5	7.6	-78.9%
NF_3	0.7	0.8	0.7	1.1	1.3	1.2	1.1	53.6%
Total Gross Emissions (Sources)[a]	**6,544.0**	**7,488.2**	**6,748.2**	**6,585.6**	**5,997.6**	**6,324.9**	**6,341.2**	**-3.1%**
LULUCF Emissions[b]	57.9	68.9	62.8	58.0	68.4	72.9	67.5	16.5%
CH_4	53.1	58.6	55.6	52.5	59.3	62.2	58.4	9.9%
N_2O	4.8	10.4	7.2	5.5	9.1	10.8	9.1	89.3%
LULUCF Carbon Stock Change[c]	(1,034.7)	(976.6)	(978.3)	(921.6)	(972.8)	(983.4)	(921.8)	-10.9%
LULUCF Sector Net Total[d]	(976.7)	(907.6)	(915.5)	(863.6)	(904.4)	(910.5)	(854.3)	-12.5%
Net Emissions (Sources and Sinks)	**5,567.3**	**6,580.5**	**5,832.7**	**5,722.0**	**5,093.2**	**5,414.4**	**5,487.0**	**-1.4%**

[a] Gross emissions totals do not include CH_4 and N_2O emissions from LULUCF. LULUCF CH_4 and N_2O emissions are included in net emission totals.

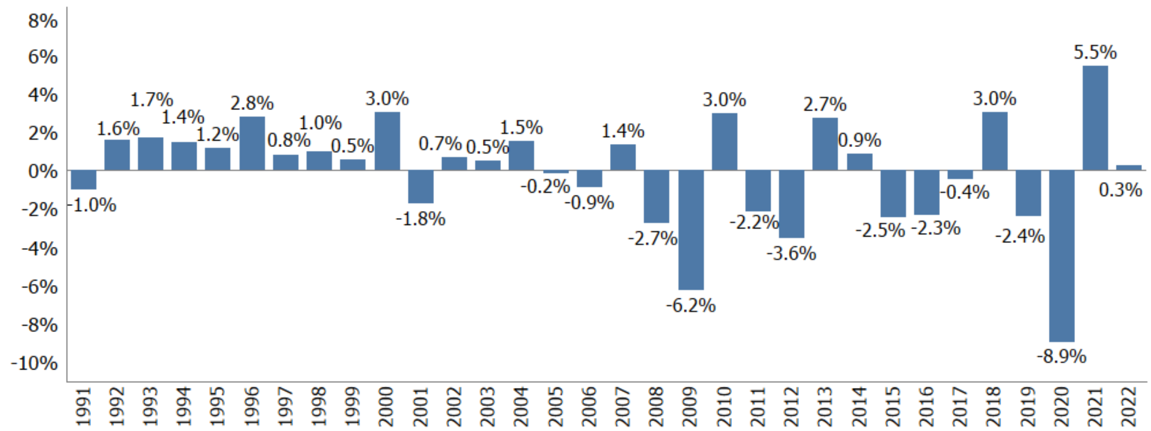
[b] LULUCF emissions subtotal of CH_4 and N_2O are reported separately from gross emissions totals. LULUCF emissions include the CH_4 and N_2O emissions reported for peatlands remaining peatlands, forest fires, drained organic soils, grassland fires, and coastal wetlands remaining coastal wetlands; CH_4 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) 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 Gross U.S. Greenhouse Gas Emissions and Sinks Relative to the Previous Year

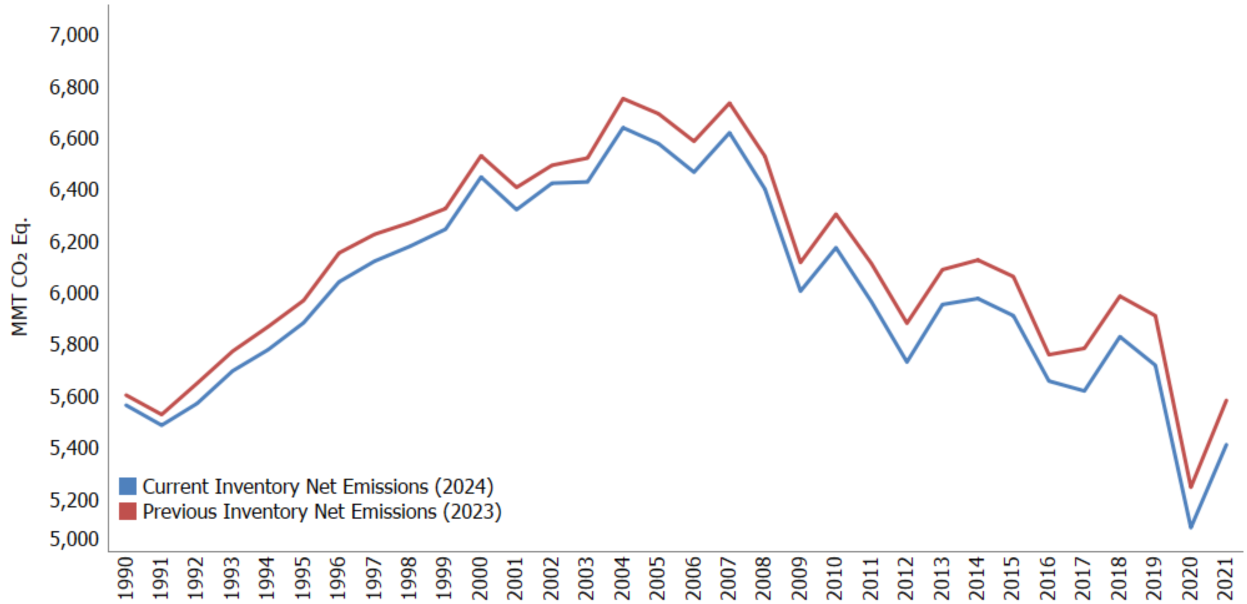


Improvements and Recalculations Relative to the Previous Inventory

Each year, some 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 2021) to ensure that the trend is accurate.

Collectively, all methodological changes and historical data updates made in the current *Inventory* resulted in an annual average decrease of 113.6 MMT CO_2 Eq. (1.9 percent) for net emissions.

Figure ES-3: Impacts of Recalculations on Net Emissions



Below are categories with methodological and data-related recalculations resulting in an average change of greater than 2.5 MMT CO_2 Eq. over the time series.

- Forest land remaining forest land: changes in forest carbon stocks (CO_2)
- Land converted to grassland: changes in all ecosystem carbon stocks (CO_2)
- Land converted to cropland: changes in all ecosystem carbon stocks (CO_2)
- Grassland remaining grassland: changes in all ecosystem carbon stocks (CO_2)
- Land converted to settlements: changes in all ecosystem carbon stocks (CO_2)
- Fluorochemical production (HFCs)
- Non-energy use of fuels (CO_2)
- Cropland remaining cropland: changes in all ecosystem carbon stocks (CO_2)
- Agricultural Soil Management (N_2O)
- Petroleum Systems (CH_4)

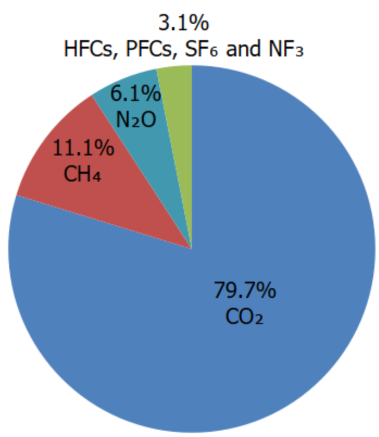
In addition, the current *Inventory* includes new categories not included in the previous *Inventory* that improve completeness of the national estimates: CO_2 emissions from ceramics production and non-metallurgical magnesia within other process use of carbonates category; fluorinated gases from fluorochemical production other than HCFC-22 within the fluorochemical production category; and SF_6 and PFCs from product uses.

In each *Inventory*, 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). 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 (the Energy chapter [Chapter 3], the Industrial Processes 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]).

Emissions and Sinks by Greenhouse Gas

Figure ES-4 illustrates the relative contribution of the greenhouse gases to total gross U.S. emissions in 2022, weighted by GWP. The primary greenhouse gas emitted by human activities in the United States is CO_2, representing 79.7 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. Methane (CH_4) emissions account for 11.1 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 are the major sources of N_2O emissions. Emissions of substitutes for ozone depleting substances are the primary contributor to aggregate hydrofluorocarbon (HFC) emissions. Perfluorocarbon (PFC) emissions are primarily attributable to electronics manufacturing, fluorochemical production, and primary aluminum production. Electrical equipment systems account for most sulfur hexafluoride (SF_6) emissions. The electronics industry is the only source of nitrogen trifluoride (NF_3) emissions. 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 together offset 14.5 percent of gross total emissions in 2022 (as reflected in Figure ES-1). The following sections describe each gas's contribution to total U.S. greenhouse gas emissions in more detail.

Figure ES-4: 2022 Total Gross U.S. Greenhouse Gas Emissions by Gas (Percentages based on MMT CO_2 Eq.)



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

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.[10]

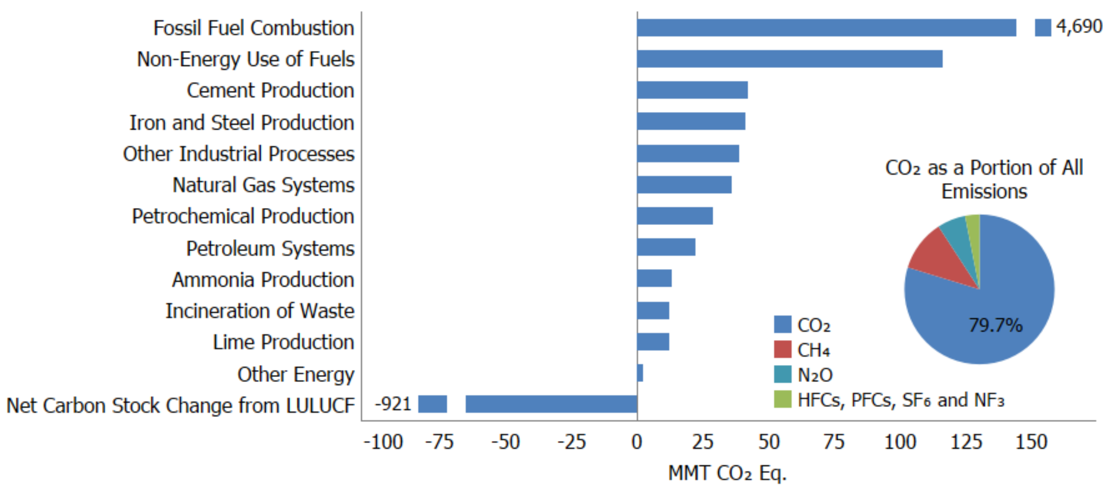
Since the Industrial Revolution (i.e., about 1750), global atmospheric concentrations of CO_2 have risen 49.5 percent (IPCC 2013; NOAA/ESRL 2024a), principally due to the combustion of fossil fuels for energy. Globally, an estimated

[10] 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."

33,000 MMT of CO_2 were added to the atmosphere through the combustion of fossil fuels in 2021, of which the United States accounted for approximately 14.2 percent.[11]

Overall CO_2 emissions have decreased by 1.5 percent since 1990 and increased by 0.8 percent since 2021, consistent with increases in fuel combustion as noted above. Within the United States, fossil fuel combustion accounted for 92.7 percent of CO_2 gross emissions in 2022. Nationally, the transportation was the largest emitter of CO_2 in 2022 followed by electric power generation. There are 27 additional sources of CO_2 emissions included in the Inventory (see [Table 2-1 in Trends]). Although not illustrated in Table ES-4, 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-4.

Figure ES-5: 2022 Sources of CO_2 Emissions



Note: "Other Industrial Processes" includes emissions from aluminum production, carbide production and consumption, carbon dioxide consumption, 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 and coal mining.

As the largest source of U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion has accounted for an average of 74.6 percent of CO_2-equivalent total gross U.S. greenhouse gas emissions across the time series. Between 1990 and 2022, CO_2 emissions from fossil fuel combustion decreased from 4,746.9 MMT CO_2 Eq. to 4,689.9 MMT CO_2 Eq., a 1.2 percent total decrease. Carbon dioxide emissions from fossil fuel combustion decreased by 18.3 percent (1,049.7 MMT CO_2 Eq.) from 2005 levels. From 2021 to 2022, these emissions increased by 1.0 percent (47.2 MMT CO_2 Eq.) .

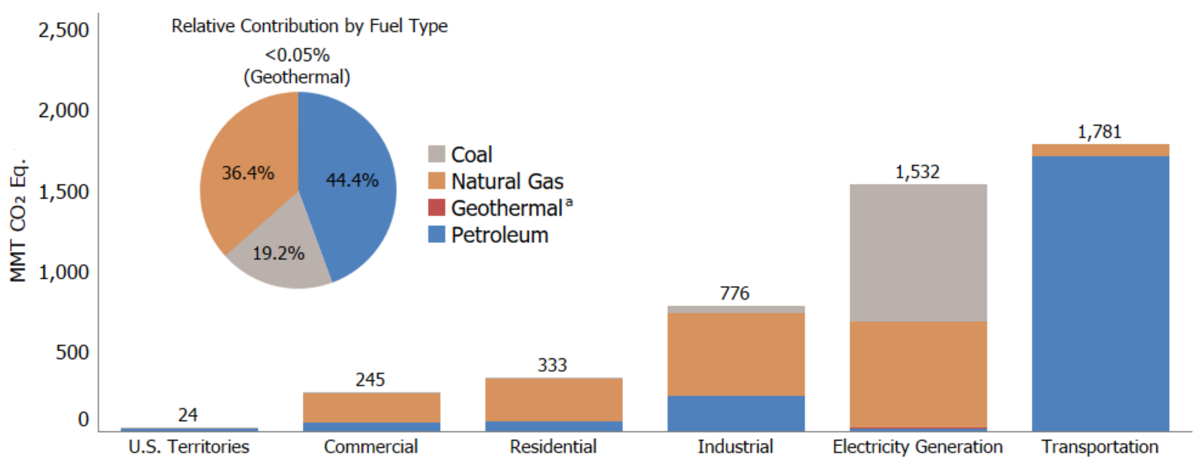
Historically, changes in emissions from fossil fuel combustion have been the driving factor affecting U.S. emission trends. Changes in CO_2 emissions from fossil fuel combustion are influenced by many long- and short-term factors. Important drivers include changes in demand for energy and a general decline in the overall carbon intensity of fuels combusted for energy in recent years by non-transport sectors of the economy. Long-term factors affecting energy demand include population and economic trends, technological changes (including energy efficiency), shifting energy fuel choices, and a variety of policies at the national, state, and local levels. In the short term, the

[11] Global CO_2 emissions from fossil fuel combustion were taken from International Energy Agency *Global energy-related CO_2 emissions, 1990-2021 – Charts.* Available at: https://www.iea.org/data-and-statistics/charts/global-energy-related-co2-emissions-1990-2021 (IEA 2022).

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. For example, between 2019 and 2021, changes in economic activity and travel due to the COVID-19 pandemic and the subsequent recovery had significant impacts on energy use and fossil fuel combustion emissions.

The five major fuel-consuming economic sectors are transportation, electric power, industrial, residential, and commercial and are described below. 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, 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.

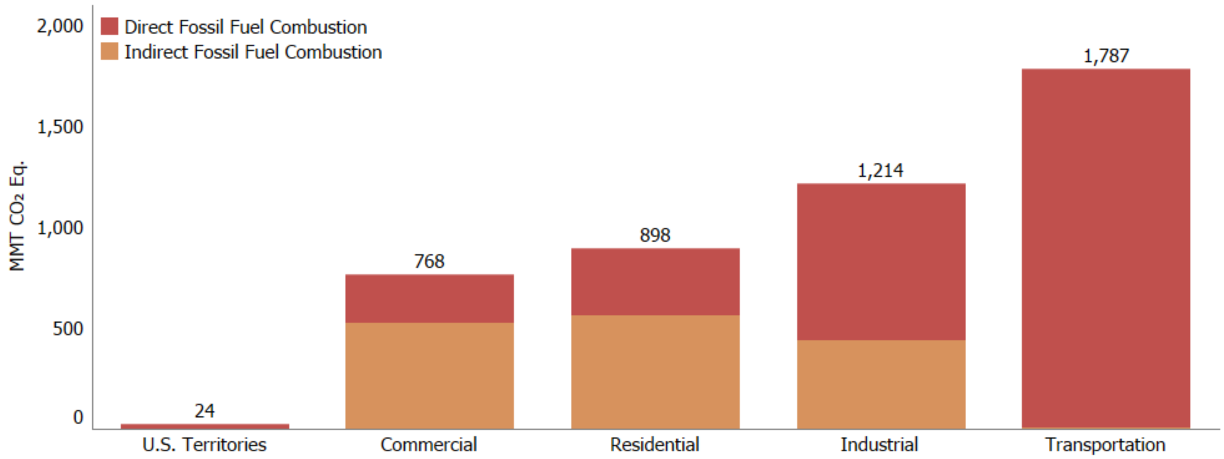
Figure ES-6: 2022 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type



[a] Although not technically a fossil fuel, geothermal energy-related CO_2 emissions are included for reporting purposes. The source of CO_2 is non-condensable gases in subterranean heated water.

Table ES-6 summarizes CO_2 emissions from fossil fuel combustion by end-use sector including electric power emissions. For Figure ES-7, 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: 2022 End-Use Sector Emissions of CO_2 from Fossil Fuel Combustion



Transportation End-Use Sector. Transportation activities accounted for 38.1 percent of U.S. CO_2 emissions from fossil fuel combustion in 2022, with the largest contributors being light-duty trucks (37.0 percent), followed by freight trucks (22.9 percent) and passenger vehicles (20.7 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 2022, 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. From 2021 to 2022, transportation CO_2 emissions, excluding emissions from international bunker fuels, increased 1.6 percent largely reflective of a continued rebound in travel activity since the COVID-19 pandemic. 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. In 2022, petroleum-based products supplied 94.4 percent of the energy consumed for transportation, primarily from gasoline consumption in automobiles and other highway vehicles (52.3 percent), diesel fuel for freight trucks (23.5 percent), jet fuel for aircraft (11.5 percent), and natural gas, residual fuel, aviation gasoline, and liquefied petroleum gases (7.1 percent). The remaining 5.6 percent 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[12] and indirectly from the generation of electricity that is used by industry, accounted for 25.9 percent of CO_2 emissions from fossil fuel combustion in 2022. Approximately 63.9 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 22.1 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 2021 to 2022, total energy use in the industrial sector increased by 2.1 percent due to an increase in total industrial production and manufacturing output.

Residential and Commercial End-Use Sectors. The residential and commercial end-use sectors accounted for 19.1 and 16.4 percent, respectively, of CO_2 emissions from fossil fuel combustion in 2022 including indirect emissions from electricity. The residential and commercial sectors relied heavily on electricity for meeting energy demands, with 62.9 and 68.1 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

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

by 3.6 percent since 1990, and total direct and indirect emissions from the commercial sector have increased by 0.2 percent since 1990. From 2021 to 2022, an increase in heating degree days (7.9 percent) increased energy demand for heating in the residential and commercial sectors; also, a 4.4 percent increase in cooling degree days compared to 2021increased demand for air conditioning in the residential and commercial sectors. Combined, this resulted in a 2.5 percent increase in residential sector energy use. From 2021 to 2022, energy use in the commercial sector increased by 4.7 percent.

Electric Power. The United States relies on electricity to meet a significant portion of its energy demands. Electricity generators used 30.6 percent of U.S. energy from fossil fuels and emitted 32.7 percent of the CO_2 from fossil fuel combustion in 2022. The type of energy source used to generate electricity, and the mix of electric generation resources used to meet demand, are the main factors influencing emissions.[13]electric power sector is the largest consumer of coal in the United States. The coal used by electricity generators accounted for 91.7 percent of all coal consumed for energy in the United States in 2022.[14] However, the amount of coal and the percentage of total electricity generation from coal has been decreasing over time. Coal-fired electric generation (in kilowatt-hours [kWh]) decreased from 54.1 percent of generation in 1990 to 20.3 percent in 2022.[15] 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 33-year period to represent 38.8 percent of electric power generation in 2022. Wind and solar generation (in kWh) represented 0.1 percent of electric power generation in 1990 and increased over the 33-year period to represent 14.2 percent of electric power generation in 2022. Between 2021 and 2022, coal electricity generation decreased by 10.2 percent, natural gas generation increased by 4.0 percent, and renewable energy generation increased by 7.6 percent.

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 fossil fuel combustion in the electric power sector have decreased by 15.8 percent since 1990, the carbon intensity of the electric power sector, in terms of CO_2 Eq. per QBtu input, decreased by 27.6 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.

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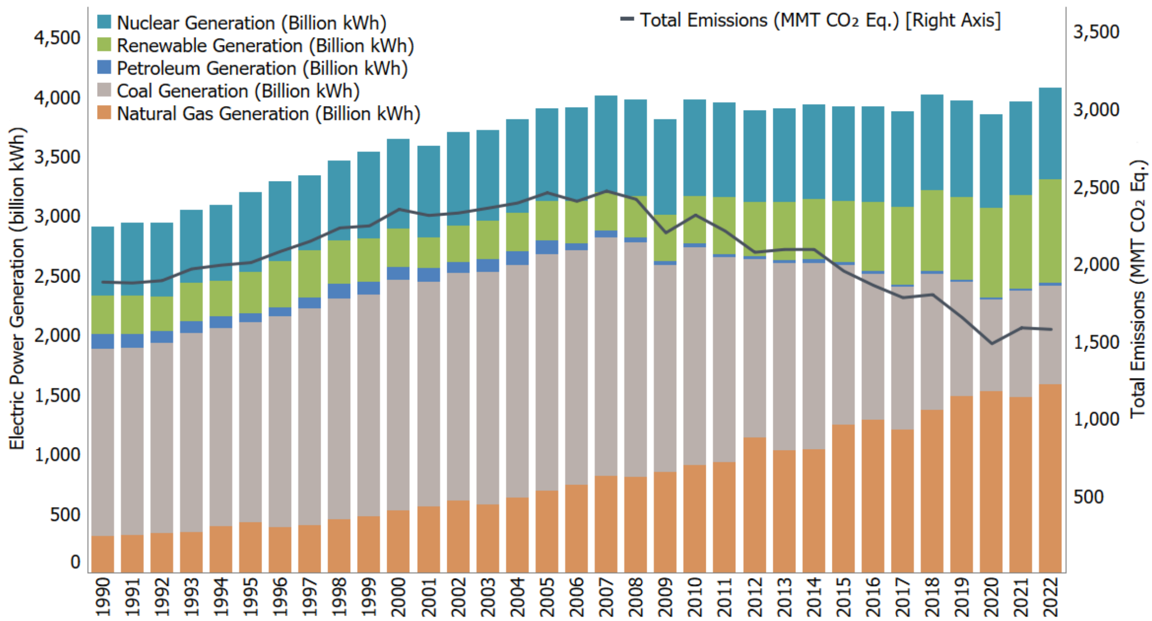
[13] In line with the reporting requirements for inventories submitted under the UNFCCC, CO_2 emissions from biomass combustion have been estimated separately from fossil fuel CO_2 emissions and are not included in the electricity sector totals and trends discussed in this section. Net carbon fluxes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

[14] See Table 6.2 Coal Consumption by Sector of EIA (2023).

[15] Values represent electricity *net* generation from the electric power sector. See Table 7.2b Electricity Net Generation: Electric Power Sector of EIA (2023).

Figure ES-8: Electric Power Generation and Emissions



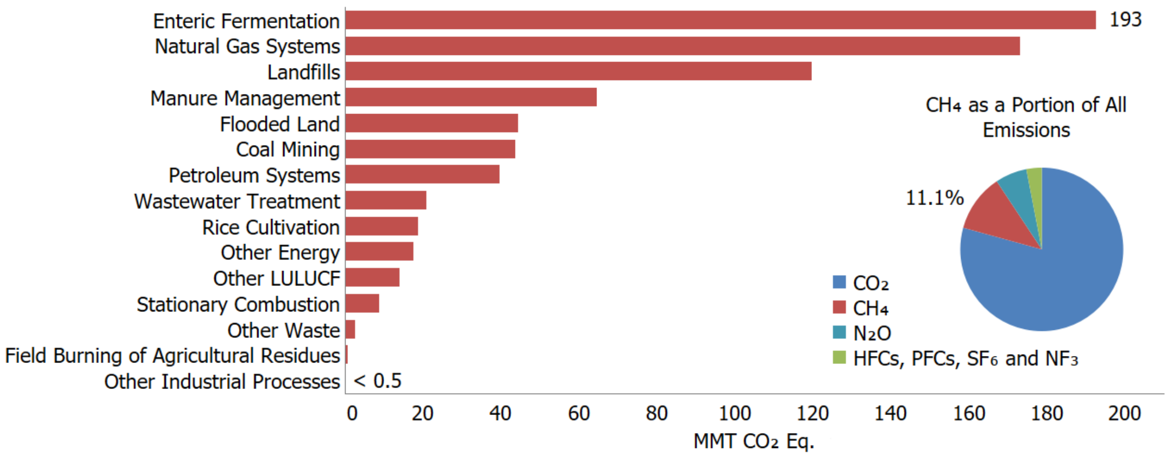
Other significant CO_2 trends included the following:

- Carbon dioxide emissions from natural gas and petroleum systems were 36.5 and 22.0 MMT CO_2 Eq., respectively, and combined accounted for 1.2 percent of CO_2 emissions and 0.9 percent of total gross emissions in 2022. These emissions increased by 39.0 percent (16.4 MMT CO_2 Eq.) from 1990 to 2022. 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 were 40.7 MMT CO_2 Eq. in 2022 and accounted for 0.8 percent of CO_2 and 0.6 percent of total gross emissions. Emissions decreased by 61.2 percent (64.1 MMT CO_2 Eq.) from 1990 through 2022. 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 10.9 percent between 1990 and 2022. This decrease was primarily due to a decrease in the rate of net carbon accumulation in forest carbon 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 28 over a 100-year time frame based on the IPCC *Fifth Assessment Report* estimate (IPCC 2013). Over the last 250 years, the concentration of CH_4 in the atmosphere increased by 173.1 percent (IPCC 2013; NOAA/ESRL 2024b). 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 (see Figure ES-9).

Figure ES-9: 2022 Sources of CH_4 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 2022, including LULUCF CH_4 emissions, accounted for 702.5 MMT CO_2 Eq., representing a decrease of 19.4 percent (169.1 MMT CO_2 Eq.) since 1990 and 2.5 percent (18.0 MMT CO_2 Eq.) since 2021. Significant trends for the largest sources of anthropogenic CH_4 emissions include the following:

- Enteric fermentation was the largest anthropogenic source of CH_4 emissions in the United States in 2022, accounting for 192.6 MMT CO_2 Eq. of CH_4 (27.4 percent of total CH_4 emissions and 3.0 percent of total gross emissions). Emissions have increased by 5.2 percent (9.5 MMT CO_2 Eq.) since 1990. This increase in emissions from 1990 to 2022 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 2022, accounting for 173.1 MMT CO_2 Eq. of CH_4 (24.6 percent of total CH_4 emissions and 2.7 percent of total gross emissions). Emissions have decreased by 20.9 percent (45.7 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 2022, accounting for 119.8 MMT CO_2 Eq. (17.0 percent of total CH_4 emissions and 1.9 percent of total gross emissions) and representing a decrease of 39.4 percent (78.0 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.[16]

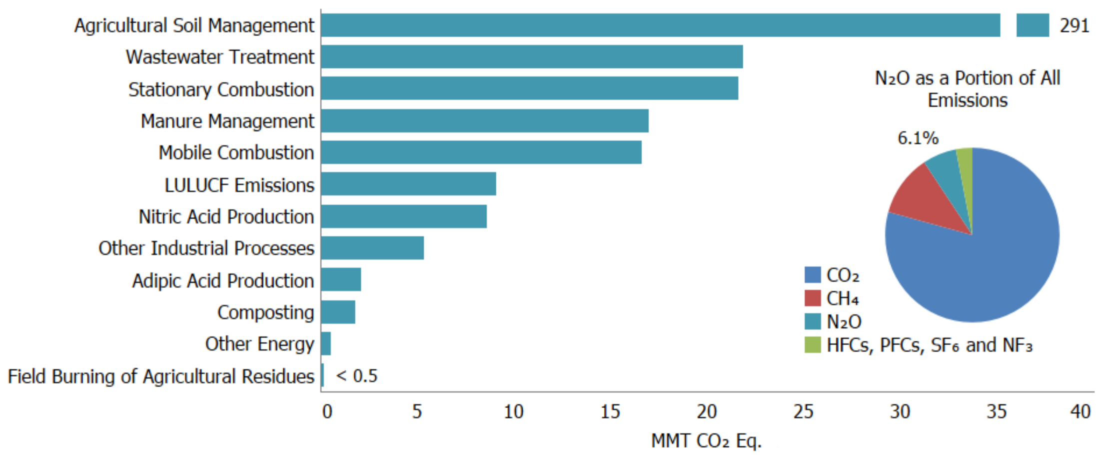
Nitrous Oxide Emissions

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). Since 1750, the global atmospheric concentration of N_2O has

[16] 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.

risen by 24.3 percent (IPCC 2013; NOAA/ESRL 2024c). 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: 2022 Sources of N_2O 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. LULUCF 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.

Overall, N_2O emissions in the United States in 2022, including LULUCF N_2O emissions, accounted for 386.5 MMT CO_2 Eq., representing a decrease of 5.3 percent (21.6 MMT CO_2 Eq.) since 1990 and a decrease of 2.9 percent (11.6 MMT CO_2 Eq.) since 2021. 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 2022, accounting for 290.8 MMT CO_2 Eq., 75.2 percent of N_2O emissions and 4.6 percent of total gross greenhouse gas emissions in the United States. These emissions increased by 0.7 percent (2.0 MMT CO_2 Eq.) from 1990 to 2022 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 2022, accounting for 21.9 MMT CO_2 Eq., 5.7 percent of N_2O emissions and 0.3 percent of total gross greenhouse gas emissions in the United States in 2022. Emissions from wastewater treatment increased by 48.2 percent (7.1 MMT CO_2 Eq.) since 1990 as a result of growing U.S. population and protein consumption. Nitrous oxide emissions from industrial wastewater treatment sources 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.
- Stationary combustion was the third largest source of anthropogenic N_2O emissions in 2022, accounting for 21.6 MMT CO_2 Eq. (5.6 percent of N_2O emissions and 0.3 percent of total gross U.S. greenhouse gas emissions) in 2022. Stationary combustion emissions peaked in 2007 and have steadily decreased since then.
- Nitrous oxide emissions from manure management accounted for 17.0 MMT CO_2 Eq., 4.4 percent of N_2O emissions and 0.3 percent of total gross greenhouse gas emissions in the United States in 2022. These emissions increased by 27.2 percent (3.6 MMT CO_2 Eq.) from 1990 to 2022. 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, the fifth largest anthropogenic source of N_2O emissions in 2022, decreased by 56.8 percent (21.8 MMT CO_2 Eq.) from 1990 to 2022, primarily as a result of national vehicle emissions standards and emission control technologies for on-road vehicles.

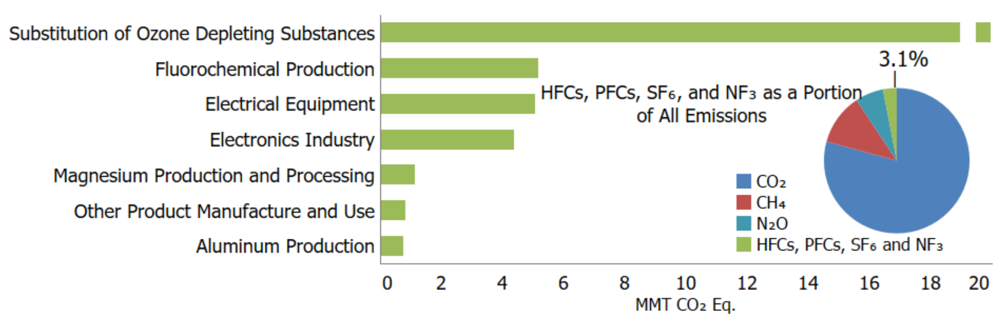
HFC, PFC, SF_6, and NF_3 Emissions

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.

Perfluorocarbons (PFCs) are emitted from the production of electronics and aluminum and also (in smaller quantities) from their use as alternatives to ODS. Sulfur hexafluoride (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-11).

HFCs, PFCs, SF_6, and NF_3 are potent greenhouse gases. In addition to having very high GWPs, SF_6, NF_3, 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 2021).

Figure ES-11: 2022 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 (91.1 percent) in 2022 and have been consistently increasing, from small amounts in 1990 to 178.1 MMT CO_2 Eq. in 2022. This increase was largely the result of efforts to phase out CFCs and other ODS in the United States.
- Sulfur hexafluoride emissions from electrical equipment decreased by 79.4 percent (19.6 MMT CO_2 Eq.) from 1990 to 2022. 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 93.3 percent (72.3 MMT CO_2 Eq.) from 1990 to 2022 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 96.1 percent (18.5 MMT CO_2 Eq.) from 1990 to 2022, due to both industry emission reduction efforts and lower domestic aluminum production.

ES.3 Overview of Sector Emissions and Trends

Figure ES-12 and Table ES-3 aggregate emissions and sinks by the sectors defined by the UNFCCC and Paris Agreement reporting guidelines and methodological framework in the IPCC guidelines to promote comparability across countries. Over the 33-year period of 1990 to 2022, total emissions from the Energy and Waste sectors decreased by 3.3 percent (179.6 MMT CO_2 Eq.) and 29.3 percent (69.1 MMT CO_2 Eq.) respectively. Emissions from the Industrial Processes and Product Use and Agriculture sectors grew by 1.0 percent (3.6 MMT CO_2 Eq.), and 7.7 percent (42.2 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 12.5 percent (122.9 MMT CO_2 Eq.) and resulted in a removal of 854.3 MMT CO_2 Eq. in 2022.

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

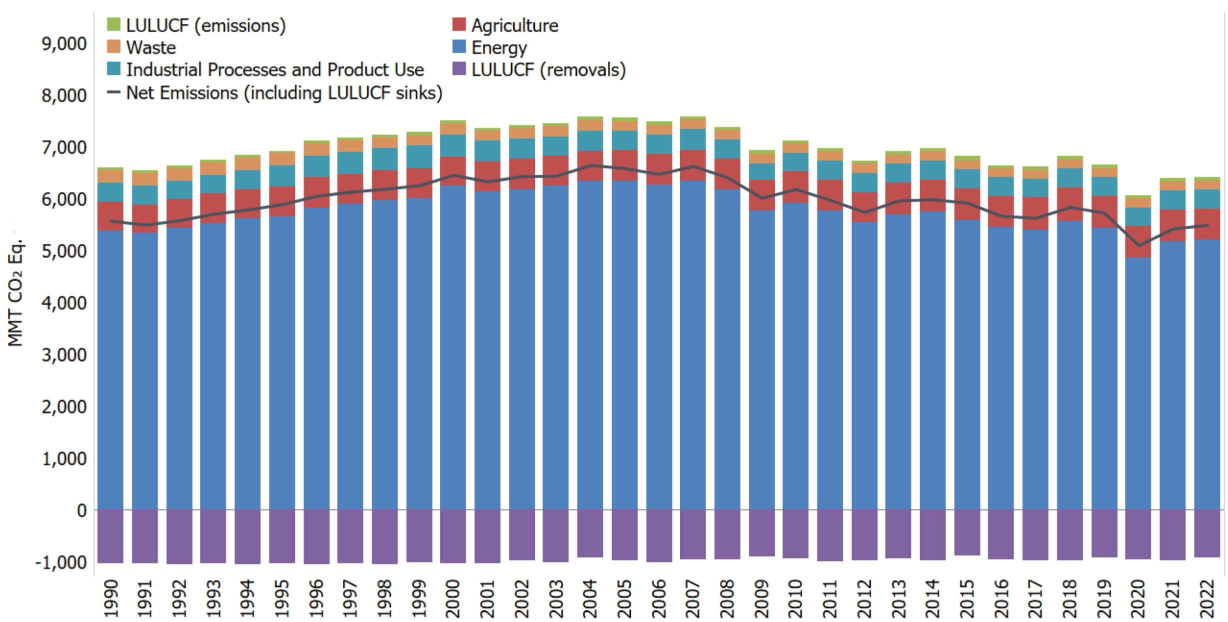


Table ES-3: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by UNFCCC/IPCC Sector (MMT CO_2 Eq.)

UNFCCC/IPCC Sector	1990	2005	2018	2019	2020	2021	2022	Percent Change Since 1990
Energy	5,380.1	6,345.9	5,568.1	5,420.2	4,860.2	5,171.0	5,200.5	-3.3%
Industrial Processes and Product Use	376.9	368.5	364.6	369.6	366.1	380.0	380.5	1.0%
Agriculture	551.1	581.8	642.4	620.0	599.6	604.8	593.4	7.7%
Waste	235.9	192.0	173.2	175.8	171.7	169.2	166.9	-29.3%
Total Gross Emissions[a] (Sources)	**6,544.0**	**7,488.2**	**6,748.2**	**6,585.6**	**5,997.6**	**6,324.9**	**6,341.2**	**-3.1%**
LULUCF Sector Net Total[b]	(976.7)	(907.6)	(915.5)	(863.6)	(904.4)	(910.5)	(854.3)	-12.5%
Net Emissions (Sources and Sinks)[c]	**5,567.3**	**6,580.5**	**5,832.7**	**5,722.0**	**5,093.2**	**5,414.4**	**5,487.0**	**-1.4%**

[a] Total emissions without LULUCF.

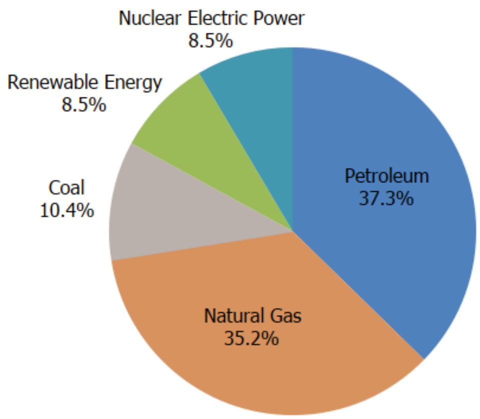
[b] The LULUCF sector net total is the sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus LULUCF net carbon stock changes in units of MMT CO_2 Eq.
[c] Net emissions with LULUCF.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

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 2022. Energy-related activities are also responsible for CH_4 and N_2O emissions (40.2 percent and 10.0 percent of total U.S. emissions of each gas, respectively).[17] Overall, emission sources in the Energy chapter account for a combined 82.0 percent of total gross U.S. greenhouse gas emissions in 2022. Emissions from energy increased by 0.6 percent (29.5 MMT CO_2 Eq.) since 2021, but they have decreased by 3.3 percent (179.6 MMT CO_2 Eq.) since 1990.

In 2022, 83.0 percent of the energy used in the United States (on a Btu basis) was produced through the combustion of fossil fuels. The remaining 17.0 percent came from other energy sources, such as hydropower, biomass, nuclear, wind, and solar energy (see Figure ES-13).

Figure ES-13: 2022 U.S. Energy Consumption by Energy Source (Percent)



Industrial Processes and Product Use

The Industrial Processes and Product Use (IPPU) 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

[17] 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 37.1 percent and 9.8 percent respectively.

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 IPCC sectoral definitions, is included in the Energy sector.

This chapter also contains emissions resulting from the release of HFCs, PFCs, SF_6, and NF_3 and other man-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 2022, 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 46.8 percent of total IPPU emissions.

IPPU activities are responsible for 3.3, less than 0.05, and 4.2 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 including HFCs, PFCs, SF_6 and NF_3. Overall, emission sources in the IPPU chapter accounted for 6.0 percent of U.S. greenhouse gas emissions in 2022. IPPU emissions have increased by 0.1 percent (0.6 MMT CO_2 Eq.) since 2021 and by 1.0 percent (3.6 MMT CO_2 Eq.) since 1990, mostly due to increased use of ODS substitutes (e.g., HFCs).

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).

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

In 2022, agricultural activities were responsible for9.4 percent of total gross U.S. greenhouse gas emissions. Agriculture sector emissions decreased by 11.4 MMT CO_2 Eq. (1.9 percent) since 2021 and have increased by 42.2 MMT CO_2 Eq. (7.7 percent) since 1990, mostly from trends in enteric fermentation and manure management. Methane, N_2O, and CO_2 are greenhouse gases emitted by agricultural activities. Methane emissions from enteric fermentation and manure management represented 36.6 percent of total CH_4 emissions from anthropogenic activities in 2022. 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 2022, accounting for 75.2 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 0.2 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.[18] The share of managed land in the United States is approximately 95 percent of total land included in the Inventory.[19] 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, 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 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 2022 resulted in a net increase in carbon stocks (i.e., net CO_2 removals) of 921.8 CO_2 Eq.[20] The removals of carbon offset 14.5 percent of total gross greenhouse gas emissions in 2022. Emissions of CH_4 and N_2O from LULUCF activities in 2022 represented 1.2 percent of net greenhouse gas emissions.[21] 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.

Between 1990 and 2022, total carbon sequestration in the LULUCF sector decreased by 10.9 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 854.3 MMT CO_2 Eq. in 2022.

Flooded lands were the largest source of CH_4 emissions from the LULUCF sector and the fifth largest source overall net CH_4 emissions in 2022. Forest fires were the second largest source of CH_4 emissions, followed by coastal wetlands remaining coastal wetlands. Forest fires were the largest source of N_2O emissions from the LULUCF sector in 2022.

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	2018	2019	2020	2021	2022
Forest Land Remaining Forest Land[a]	(968.8)	(860.0)	(863.3)	(807.0)	(846.3)	(823.8)	(771.7)
Land Converted to Forest Land[b]	(100.2)	(100.2)	(100.4)	(100.3)	(100.3)	(100.3)	(100.3)
Cropland Remaining Cropland	(5.0)	(31.6)	(17.8)	(19.4)	(8.8)	(32.0)	(31.7)
Land Converted to Cropland[c]	45.4	34.5	31.9	31.4	29.3	34.9	35.1
Grassland Remaining Grassland[d]	24.6	24.9	29.7	28.9	17.1	11.5	14.0
Land Converted to Grassland[c]	35.3	21.8	25.2	25.4	28.7	24.5	25.6
Wetlands Remaining Wetlands[e]	36.8	39.4	38.2	38.1	38.1	38.1	38.1
Land Converted to Wetlands[e]	7.2	1.8	0.7	0.7	0.7	0.7	0.7

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

[19] 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.

[20] 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.

[21] 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.

Settlements Remaining Settlements[f]	(109.1)	(115.2)	(131.0)	(131.5)	(131.8)	(132.3)	(132.3)
Land Converted to Settlements[c]	57.2	77.1	71.4	70.2	68.8	68.2	68.2
LULUCF Carbon Stock Change[g]	**(1,034.7)**	**(976.6)**	**(978.3)**	**(921.6)**	**(972.8)**	**(983.4)**	**(921.8)**
LULUCF Emissions[h]	**57.9**	**68.9**	**62.8**	**58.0**	**68.4**	**72.9**	**67.5**
CH_4	53.1	58.6	55.6	52.5	59.3	62.2	58.4
N_2O	4.8	10.4	7.2	5.5	9.1	10.8	9.1
LULUCF Sector Net Total[i]	**(976.7)**	**(907.6)**	**(915.5)**	**(863.6)**	**(904.4)**	**(910.5)**	**(854.3)**

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

[c] 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.

[d] Estimates include CH_4 and N_2O emissions from fires on both grassland remaining grassland and land converted to grassland.

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

[f] 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.

[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. Parentheses indicate net sequestration.

Waste

The Waste chapter contains emissions from waste management activities (except the incineration of waste, which is addressed in the Energy chapter). Landfills were the largest source of anthropogenic greenhouse gas emissions from waste management activities, accounting for 71.8 percent of total greenhouse gas emissions from waste management activities, and 17.0 percent of total U.S. CH_4 emissions.[22] Additionally, wastewater treatment accounted for 25.6 percent of total Waste sector greenhouse gas emissions, 3.0 percent of U.S. CH_4 emissions, and 5.7 percent of U.S. N_2O emissions in 2022. Emissions of CH_4 and N_2O from commercial composting are also included in this chapter, accounting for 2.6 percent 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 the Waste chapter accounted for 2.6 percent of total gross U.S. greenhouse gas emissions in 2022. Waste sector emissions decreased by 1.4 percent (2.3 MMT CO_2 Eq.) since 2021 and by 30.3 percent (69.1 MMT CO_2 Eq.) since 1990.

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

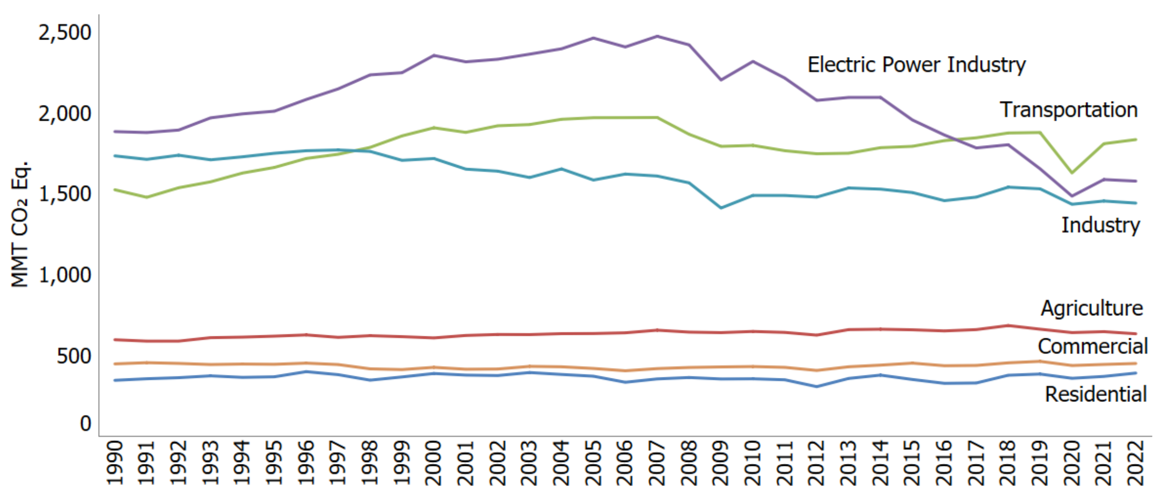
ES.4 Other Information

Emissions and Sinks by Economic Sector

In addition to the Paris Agreement and UNFCCC sectors and methods defined by the IPCC, this report also characterizes emissions according to commonly used economic sector categories: residential, commercial, industry, transportation, electric power, and agriculture.[23] 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 SinksES.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 2022, and Table ES-5 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-5: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (MMT CO_2 Eq.)

Economic Sectors	1990	2005	2018	2019	2020	2021	2022	Change from 1990
Transportation	1,521.4	1,965.9	1,871.6	1,874.6	1,625.3	1,805.5	1,830.9	20.3%
Electric Power Industry	1,880.2	2,457.4	1,799.2	1,650.8	1,482.2	1,584.4	1,574.7	-16.2%
Industry	1,730.4	1,581.2	1,537.3	1,527.3	1,431.8	1,451.9	1,439.1	-16.8%
Agriculture	595.9	634.3	683.5	661.0	640.0	645.9	632.7	6.2%
Commercial	447.0	418.7	453.5	462.6	436.9	443.7	449.6	0.6%
Residential	345.6	370.9	376.8	384.2	358.0	369.6	390.3	12.9%
U.S. Territories	23.4	59.7	26.3	25.1	23.4	23.9	23.9	2.0%

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

Total Gross Emissions (Sources)	**6,544.0**	**7,488.2**	**6,748.2**	**6,585.6**	**5,997.6**	**6,324.9**	**6,341.2**	**-3.1%**
LULUCF Sector Net Total[a]	(976.7)	(907.6)	(915.5)	(863.6)	(904.4)	(910.5)	(854.3)	-12.5%
Net Emissions (Sources and Sinks)	**5,567.3**	**6,580.5**	**5,832.7**	**5,722.0**	**5,093.2**	**5,414.4**	**5,487.0**	**-1.4%**

[a] 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 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 (28.9 percent) of total gross U.S. greenhouse gas emissions in 2022. Electric power accounted for the second largest portion (24.8 percent) of U.S. greenhouse gas emissions in 2022, while emissions from industry accounted for the third largest portion (22.7 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 23.6 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 10.0 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 7.1 percent and 6.2 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.

Electricity is ultimately used in the economic sectors described above. 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 2023).[24] 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.

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 (29.3 percent and 29.0 percent, respectively) in 2022. The commercial and residential sectors contributed the next largest shares of total gross U.S. greenhouse gas emissions in 2022 (15.6 and 15.3 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). Figure ES-15 shows the trends in these emissions by sector from 1990 to 2022.

[24] 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.

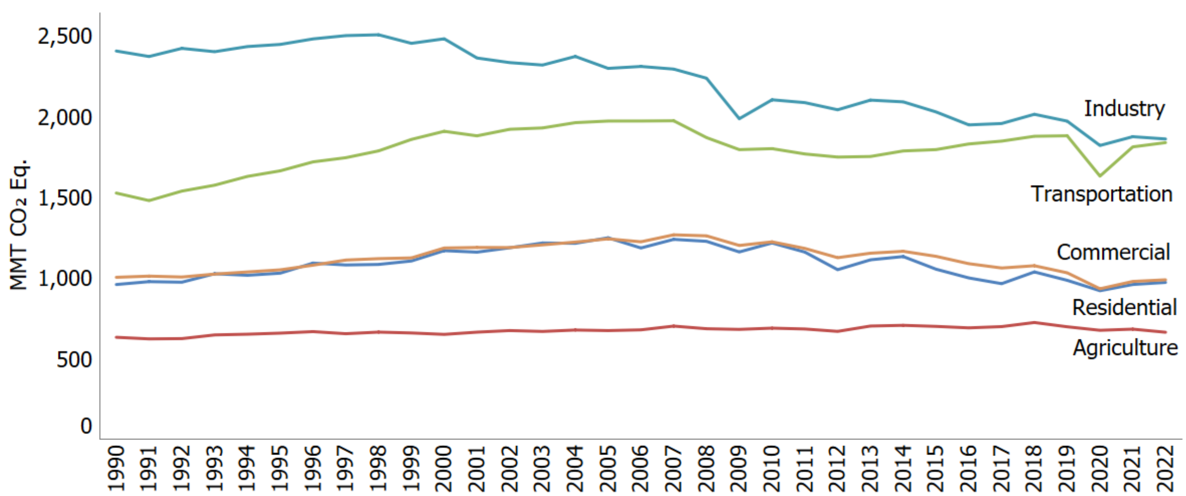
Table ES-6: U.S. Greenhouse Gas Emissions with Electricity-Related Emissions Distributed by Economic Sector (MMT CO_2 Eq.)

Economic Sectors	1990	2005	2018	2019	2020	2021	2022	Change from 1990
Industry	2,404.4	2,296.8	2,012.6	1,970.3	1,819.3	1,873.8	1,859.7	-22.7%
Transportation	1,524.6	1,970.8	1,876.5	1,879.5	1,629.5	1,810.7	1,837.2	20.5%
Commercial	1,002.5	1,240.9	1,074.3	1,030.5	931.5	976.9	987.1	-1.5%
Residential	958.0	1,247.4	1,035.9	984.0	919.5	958.0	971.0	1.4%
Agriculture	631.1	672.6	722.7	696.2	674.4	681.6	662.3	4.9%
U.S. Territories	23.4	59.7	26.3	25.1	23.4	23.9	23.9	2.0%
Total Gross Emissions (Sources)	**6,544.0**	**7,488.2**	**6,748.2**	**6,585.6**	**5,997.6**	**6,324.9**	**6,341.2**	**-3.1%**
LULUCF Sector Net Total[a]	(976.7)	(907.6)	(915.5)	(863.6)	(904.4)	(910.5)	(854.3)	-12.5%
Net Emissions (Sources and Sinks)	**5,567.3**	**6,580.5**	**5,832.7**	**5,722.0**	**5,093.2**	**5,414.4**	**5,487.0**	**1.4%**

[a] 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: 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-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-2: 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-16).

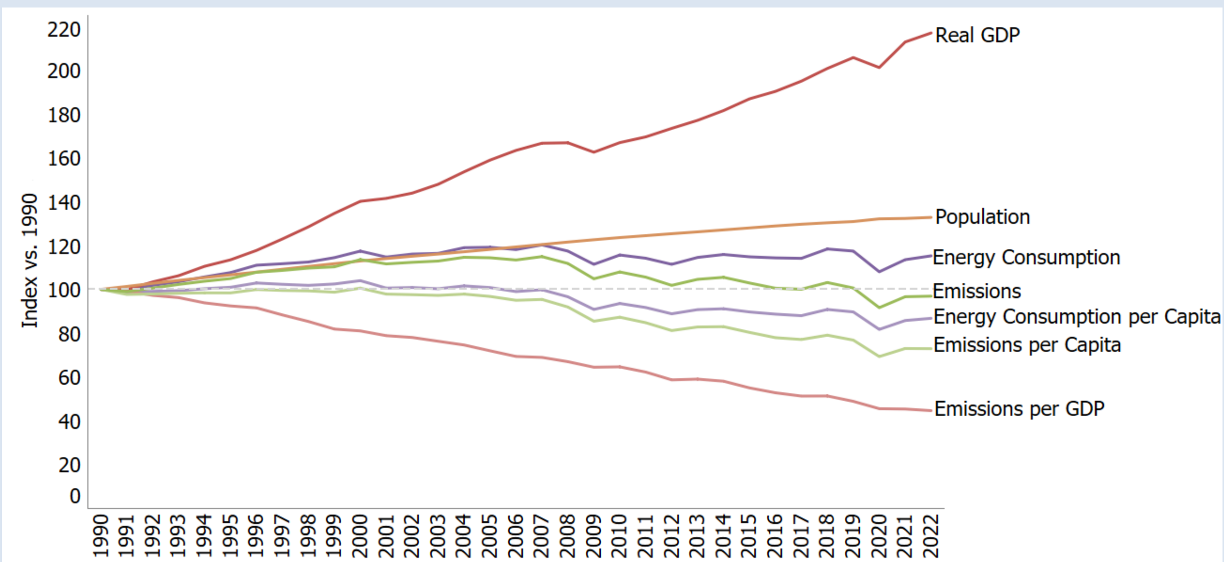
The direction of these trends started to change after 2005, when greenhouse gas emissions, total energy use, and fossil fuel consumption began to peak. Greenhouse gas emissions in the United States have decreased at an average annual rate of 0.9 percent since 2005. Since 2005, GDP and national population, generally, continued to increase while energy has decreased slightly— noting 2020 was impacted by COVID-19 pandemic.

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

Variable	1990	2005	2018	2019	2020	2021	2022	Avg. Annual Growth Rate Since 1990[a]	Avg. Annual Growth Rate Since 2005[a]
Greenhouse Gas Emissions[b]	100	114	103	101	92	97	97	-0.1%	-0.9%
Energy Use[c]	100	119	118	117	107	113	115	0.5%	-0.2%
GDP[d]	100	159	201	206	201	213	217	2.5%	1.9%
Population[e]	100	118	130	131	132	132	133	0.9%	0.7%

+ Absolute value does not exceed 0.05 percent.
[a] Average annual growth rate.
[b] Gross total GWP-weighted values.
[c] Energy content-weighted values (EIA 2023).
[d] GDP in chained 2012 dollars (BEA 2023).
[e] U.S. Census Bureau (2023).

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



Source: BEA (2023), U.S. Census Bureau (2023), and emission estimates in this report.

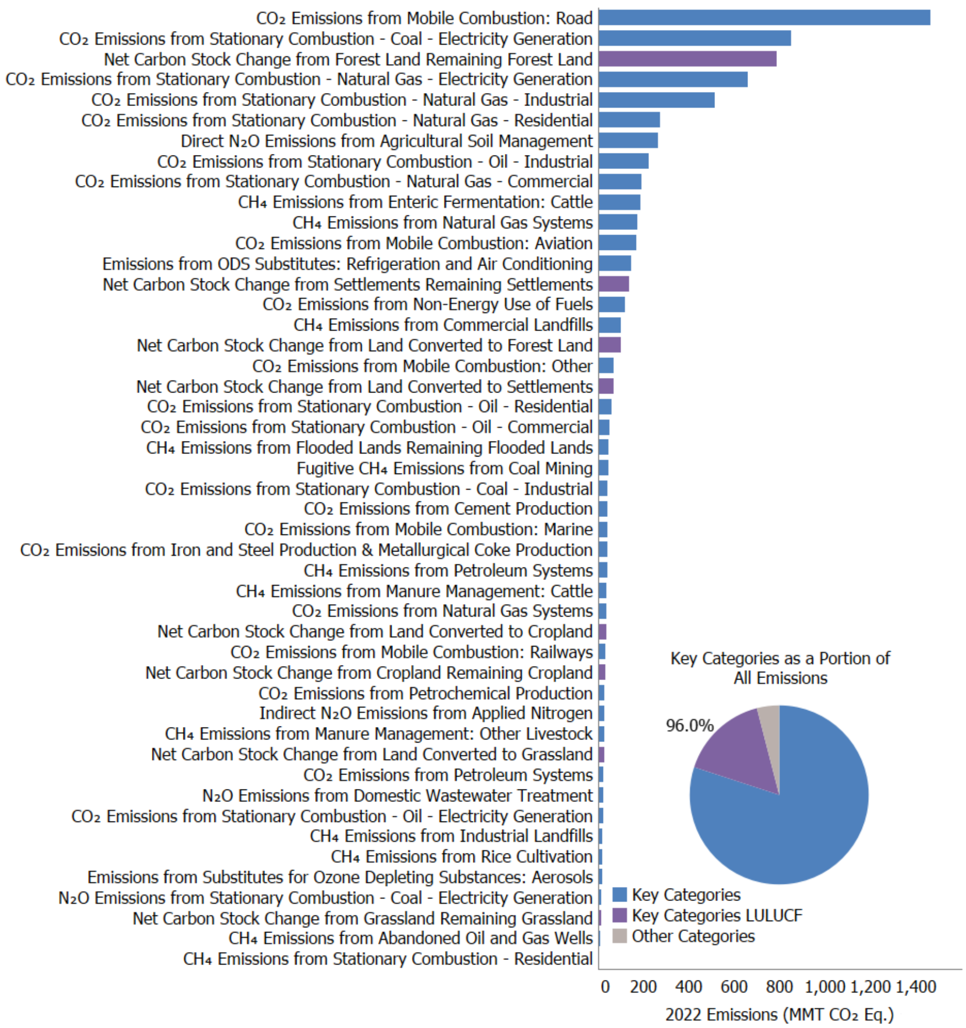
Key Categories

The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) and *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019) defines key categories as “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."[25] 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 2022 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.

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 the Introduction chapter, Section 1.5 – Key Categories, and Annex 1.

Figure ES-17: 2022 Key Categories (Approach 1 including LULUCF)[a]



[25] See Chapter 4 "Methodological Choice and Identification of Key Categories" in IPCC (2006) and IPCC (2019). See http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html and https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/1_Volume1/19R_V1_Ch04_MethodChoice.pdf.

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 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.

Quality Assurance and Quality Control (QA/QC)

The United States seeks continuous improvements to 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, and the UNFCCC reporting guidelines and *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. The QA process includes expert and public reviews for the Inventory estimates and this report.

Box ES-3: Use of Ambient Measurements Systems for Validation of Emission Inventories

In following Article 13.7(a) of the Paris Agreement and Article 4.1(a) of the UNFCCC, as well as relevant decisions under those agreements 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 in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines) and, where appropriate, its supplements and refinements.[26] 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 to improve national greenhouse gas inventories, EPA follows guidance from the IPCC on the use of measurements and modeling to validate emission inventories.[27] 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* report's transparency of its 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 for this report, versus natural sources and sinks.

The *2019 Refinement to the IPCC 2006 Guidelines for National Greenhouse Gas Inventories* (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 their limited natural sources, their 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-

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

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

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, Sections 4.25 Substitution of Ozone Depleting Substances and 4.26 Electrical Equipment, in the IPPU chapter of this report.

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 Lawrence Berkely National Laboratory and other coauthors developed a time series of anthropogenic methane emissions maps with 0.1° x 0.1° (10 km x 10 km) spatial resolution and monthly temporal resolution for the contiguous United States.[28] The gridded methane inventory is designed to be consistent with the U.S. EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks* estimates, which presents national totals for different source types.[29] 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 – TO BE UPDATED FOR FINAL REPORT

Uncertainty assessment is an essential element of a complete inventory of greenhouse gas emissions and removals because it helps 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 for National Greenhouse Gas Inventories* (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 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 -5 to +6 percent in 1990 and -4 to +6 percent in 2022. When the LULUCF sector is excluded from the analysis the uncertainty is estimated to be -2 to +5 percent in 1990 and -2 to +6 percent in 2022.

[28] See https://www.epa.gov/ghgemissions/us-gridded-methane-emissions.

[29] See https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.