1. Introduction

This report presents an inventory of U.S. anthropogenic greenhouse gas emissions and sinks for the years 1990 through 2021 compiled by the United States government. A summary of these estimates is provided in Table 2-1 and Table 2-2 by gas and source category in the Trends in Greenhouse Gas Emissions chapter. The emission and sink estimates in these tables are presented on both a full mass basis and on a global warming potential (GWP)-weighted basis[1] in order to show the relative contribution of each gas to global average radiative forcing. This report also discusses the methods and data used to calculate the emission and sink estimates.

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

As a signatory to the UNFCCC, consistent with Article 4[4] and decisions at the First, Second, Fifth, and Nineteenth Conference of Parties,[5] the U.S. is committed to submitting a national inventory of anthropogenic sources and sinks of greenhouse gases to the UNFCCC by April 15 of each year. This Inventory provides a national estimate of sources and sinks for the United States, including all states, the District of Columbia and U.S. Territories.[6] The United States views this report, in conjunction with Common Reporting Format (CRF) reporting tables that accompany this report, as an opportunity to fulfill this annual commitment under the UNFCCC. Overall, this

---

[1] More information provided in the Global Warming Potentials section of this chapter on the use of IPCC *Fifth Assessment Report* (AR5) GWP values.

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

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

[4] Article 4(1)(a) of the United Nations Framework Convention on Climate Change (also identified in Article 12) and subsequent decisions by the Conference of the Parties elaborated the role of Annex I Parties in preparing national inventories. Article 4 states "Parties to the Convention, by ratifying, shall develop, periodically update, publish and make available…national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies…" See http://unfccc.int for more information.

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

[6] U.S. Territories include American Samoa, Guam, Commonwealth of the Northern Mariana Islands, Puerto Rico, U.S. Virgin Islands, and other outlying U.S. Pacific Islands which are not permanently inhabited such as Wake Island. See https://www.usgs.gov/faqs/how-are-us-states-territories-and-commonwealths-designated-geographic-names-information-system?qt-news_science_products=0#qt-news_science_products. See more information on completeness in Section 1.8.

Inventory of anthropogenic greenhouse gas emissions and sinks provides a common and consistent mechanism through which Parties to the UNFCCC can compare the relative contribution of individual sources, gases, and nations to climate change. The structure of this report is consistent with the current UNFCCC Guidelines on Annual Inventories (UNFCCC 2014) for Parties included in Annex I of the Convention.

In 1988, preceding the creation of the UNFCCC, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) jointly established the Intergovernmental Panel on Climate Change (IPCC). The role of the IPCC is to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation (IPCC 2021). Under Working Group 1 of the IPCC, nearly 140 scientists and national experts from more than thirty countries collaborated in the creation of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) to ensure that the emission inventories submitted to the UNFCCC are consistent and comparable between nations. The *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* and the *IPCC Good Practice Guidance for Land Use, Land-Use Change, and Forestry* further expanded upon the methodologies in the *Revised 1996 IPCC Guidelines*. In 2006, the IPCC accepted the *2006 Guidelines for National Greenhouse Gas Inventories* at its Twenty-Fifth Session (Mauritius, April 2006). The *2006 IPCC Guidelines* built upon the previous bodies of work and include new sources and gases, "…as well as updates to the previously published methods whenever scientific and technical knowledge have improved since the previous guidelines were issued." The UNFCCC adopted the *2006 IPCC Guidelines* as the standard methodological approach for Annex I countries and encouraged countries to gain experience in using the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* at the Nineteenth Conference of the Parties (Warsaw, November 11-23, 2013). The IPCC has recently released the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* to clarify and elaborate on the existing guidance in the *2006 IPCC Guidelines*, along with providing updates to default values of emission factors and other parameters based on updated science. This report applies both the *2013 Supplement* and updated guidance in the *2019 Refinement* to improve accuracy and completeness of the Inventory. For more information on specific uses see Section 1.4 of this chapter on Methodology and Data Sources.

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

In following the UNFCCC requirement under Article 4.1 and decision 24/CP.19 to develop and submit annual national greenhouse gas emission inventories, the emissions and removals presented in this report and this chapter are organized by source and sink categories and calculated using internationally-accepted methods provided by the IPCC in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines)* and where appropriate, its supplements and refinements. Additionally, the calculated emissions and removals in a given year for the United States are presented in a common format in line with the UNFCCC reporting guidelines for the reporting of inventories under this international agreement. The use of consistent methods to calculate emissions and removals by all nations reporting their inventories to the UNFCCC ensures that the estimates are comparable. The presentation of emissions and removals provided in this Inventory does not preclude alternative examinations, but rather this Inventory presents emissions and removals in a common format consistent with how countries are to report Inventories under the UNFCCC. The report itself, and this chapter, follows this standardized format, and provides an explanation of the application of methods used to calculate emissions and removals.

EPA also collects greenhouse gas emissions data from individual facilities and suppliers of certain fossil fuels and industrial gases through its Greenhouse Gas Reporting Program (GHGRP).[7] The GHGRP applies to direct greenhouse gas emitters, fossil fuel suppliers, industrial gas suppliers, and facilities that inject carbon dioxide

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

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

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

1.1 Background Information

Science

For over the past 200 years, the burning of fossil fuels such as coal and oil, along with deforestation, land-use changes, and other activities have caused the concentrations of heat-trapping "greenhouse gases" to increase significantly in our atmosphere (IPCC 2021). These gases in the atmosphere absorb some of the energy being radiated from the surface of the Earth that would otherwise be lost to space, essentially acting like a blanket that makes the Earth's surface warmer than it would be otherwise.

Greenhouse gases are necessary to life as we know it. Without greenhouse gases to create the natural heat-trapping properties of the atmosphere, the planet's surface would be about 60 degrees Fahrenheit cooler than present (USGCRP 2017). Carbon dioxide is also necessary for plant growth. With emissions from biological and geological sources, there is a natural level of greenhouse gases that is maintained in the atmosphere. Human emissions of greenhouse gases and subsequent changes in atmospheric concentrations alter the balance of energy transfers between space and the earth system (IPCC 2021). A gauge of these changes is called radiative forcing, which is a measure of a substance's total net effect on the global energy balance for which a positive number represents a warming effect, and a negative number represents a cooling effect (IPCC 2021). IPCC concluded in its most recent scientific assessment report that it is "unequivocal that human influence has warmed the atmosphere, ocean and land" (IPCC 2021).

As concentrations of greenhouse gases continue to increase in from man-made sources, the Earth's temperature is climbing above past levels. The Earth's average land and ocean surface temperature has increased by about 2.0 degrees Fahrenheit from the 1850 to 1900 period to the decade of 2011 to 2020 (IPCC 2021). The last four decades have each been the warmest decade successively at the Earth's surface since at least 1850 (IPCC 2021). Other aspects of the climate are also changing, such as rainfall patterns, snow and ice cover, and sea level. If greenhouse gas concentrations continue to increase, climate models predict that the average temperature at the Earth's

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

surface is likely to increase by up to 8.3 degrees Fahrenheit above 2011 to 2020 levels by the end of this century, depending on future emissions and the responsiveness of the climate system (IPCC 2021), though the lowest emission scenario would limit future warming to an additional 0.5 degrees (best estimate).

For further information on greenhouse gases, radiative forcing, and implications for climate change, see the recent scientific assessment reports from the IPCC,[9] the U.S. Global Change Research Program (USGCRP),[10] and the National Academies of Sciences, Engineering, and Medicine (NAS).[11]

Greenhouse Gases

Although the Earth's atmosphere consists mainly of oxygen and nitrogen, neither plays a significant role in enhancing the greenhouse effect because both are essentially transparent to terrestrial radiation. The greenhouse effect is primarily a function of the concentration of water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the Earth (IPCC 2021).

Naturally occurring greenhouse gases include water vapor, CO_2, CH_4, N_2O, and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as bromofluorocarbons (i.e., halons). As stratospheric ozone depleting substances, CFCs, HCFCs, and halons are covered under the Montreal Protocol on Substances that Deplete the Ozone Layer. The UNFCCC defers to this earlier international treaty. Consequently, Parties to the UNFCCC are not required to include these gases in national greenhouse gas inventories.[12] Some other fluorine-containing halogenated substances—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)—do not deplete stratospheric ozone but are potent greenhouse gases. These latter substances are addressed by the UNFCCC and accounted for in national greenhouse gas inventories.

There are also several other substances that influence the global radiation budget but are short-lived and therefore not well-mixed, leading to spatially variable radiative forcing effects. These substances include carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and tropospheric (ground level) ozone (O_3). Tropospheric ozone is formed from chemical reactions in the atmosphere of precursor pollutants, which include volatile organic compounds (VOCs, including CH_4) and nitrogen oxides (NO_x), in the presence of ultraviolet light (sunlight).

Aerosols are extremely small particles or liquid droplets suspended in the Earth's atmosphere that are often composed of sulfur compounds, carbonaceous combustion products (e.g., black carbon), crustal materials (e.g., dust) and other human-induced pollutants. They can affect the absorptive characteristics of the atmosphere (e.g., scattering incoming sunlight away from the Earth's surface, or, in the case of black carbon, absorb sunlight) and can play a role in affecting cloud formation and lifetime, as well as the radiative forcing of clouds and precipitation patterns.

Carbon dioxide, CH_4, and N_2O are continuously emitted to and removed from the atmosphere by natural processes on Earth. Anthropogenic activities (such as fossil fuel combustion, cement production, land-use, land-use change, and forestry, agriculture, or waste management), however, can cause additional quantities of these and other greenhouse gases to be emitted or sequestered, thereby changing their global average atmospheric concentrations. Natural activities such as respiration by plants or animals and seasonal cycles of plant growth and

[9] See https://www.ipcc.ch/report/ar6/wg1/.

[10] See https://nca2018.globalchange.gov/.

[11] See https://www.nationalacademies.org/topics/climate.

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

decay are examples of processes that only cycle carbon or nitrogen between the atmosphere and organic biomass. Such processes, except when directly or indirectly perturbed out of equilibrium by anthropogenic activities, generally do not alter average atmospheric greenhouse gas concentrations over decadal timeframes. Climatic changes resulting from anthropogenic activities, however, could have positive or negative feedback effects on these natural systems. Atmospheric concentrations of these gases, along with their rates of growth and atmospheric lifetimes, are presented in Table 1-1.

Table 1-1: Global Atmospheric Concentration, Rate of Concentration Change, and Atmospheric Lifetime of Selected Greenhouse Gases

Atmospheric Variable	CO_2	CH_4	N_2O	SF_6	CF_4
Pre-industrial atmospheric concentration	280 ppm	0.730 ppm	0.270 ppm	0 ppt	40 ppt
Atmospheric concentration	419 ppm[a]	1.895 ppm[b]	0.334 ppm[c]	11.08 ppt[d]	85.5 ppt[e]
Rate of concentration change	2.38 ppm/yr[f]	18.21 ppb/yr[f,g]	1.29 ppb/yr[f]	0.39 ppt/yr[f]	0.81 ppt/yr[f]
Atmospheric lifetime (years)	See footnote[h]	11.8	109[i]	About 1,000[j]	50,000

[a] The atmospheric CO_2 concentration is the 2021 annual average at the Mauna Loa, HI station (NOAA/ESRL 2023a). The global atmospheric CO_2 concentration, computed using an average of sampling sites across the world, was 415 ppm in 2021.
[b] The values presented are global 2022 annual average mole fractions (NOAA/ESRL 2023b).
[c] The values presented are global 2022 annual average mole fractions (NOAA/ESRL 2023c).
[d] The values presented are global 2022 annual average mole fractions (NOAA/ESRL 2023d).
[e] The 2019 CF_4 global mean atmospheric concentration is from the Advanced Global Atmospheric Gases Experiment (IPCC 2021).
[f] The rate of concentration change for CO_2 is an average of the rates from 2007 through 2021 and has fluctuated between 1.5 to 3.0 ppm per year over this period (NOAA/ESRL 2023a). The rate of concentration change for CH_4, N_2O, and SF_6, is the average rate of change between 2007 and 2021 (NOAA/ESRL 2023b; NOAA/ESRL 2023c; NOAA/ESRL 2023d). The rate of concentration change for CF_4 is the average rate of change between 2011 and 2019 (IPCC 2021).
[g] The growth rate for atmospheric CH_4 decreased from over 10 ppb/year in the 1980s to nearly zero in the early 2000s; recently, the growth rate has been about 18.21 ppb/year (NOAA/ESRL 2023b).
[h] For a given amount of CO_2 emitted, some fraction of the atmospheric increase in concentration is quickly absorbed by the oceans and terrestrial vegetation, some fraction of the atmospheric increase will only slowly decrease over a number of years, and a small portion of the increase will remain for many centuries or more.
[i] This lifetime has been defined as an “adjustment time” that takes into account the indirect effect of the gas on its own residence time.
[j] The lifetime for SF_6 was revised from 3,200 years to about 1,000 years based on recent studies (IPCC 2021).
Source: Pre-industrial atmospheric concentrations and atmospheric lifetimes for CH_4, N_2O, SF_6, and CF_4 are from IPCC (2021).

A brief description of each greenhouse gas, its sources, and its role in the atmosphere is given below. The following section then explains the concept of GWPs, which are assigned to individual gases as a measure of their relative average global radiative forcing effect.

Water Vapor (H_2O). Water vapor is the largest contributor to the natural greenhouse effect. Water vapor is fundamentally different from other greenhouse gases in that it can condense and rain out when it reaches high concentrations, and the total amount of water vapor in the atmosphere is in part a function of the Earth’s temperature. While some human activities such as evaporation from irrigated crops or power plant cooling release water vapor into the air, these activities have been determined to have a negligible effect on global climate (IPCC 2021). The lifetime of water vapor in the troposphere is on the order of 10 days. Water vapor can also contribute to cloud formation, and clouds can have both warming and cooling effects by either trapping or reflecting heat. Because of the relationship between water vapor levels and temperature, water vapor and clouds serve as a feedback to climate change, such that for any given increase in other greenhouse gases, the total warming is greater than would happen in the absence of water vapor. Aircraft emissions of water vapor can create contrails, which may also develop into contrail-induced cirrus clouds, with complex regional and temporal net radiative forcing effects that currently have a low level of scientific certainty (IPCC 2021).

Carbon Dioxide (CO_2). In nature, carbon is cycled between various atmospheric, oceanic, land biotic, marine biotic, and mineral reservoirs. The largest fluxes occur between the atmosphere and terrestrial biota, and between the atmosphere and surface water of the oceans. In the atmosphere, carbon predominantly exists in its oxidized form as CO_2. Atmospheric CO_2 is part of this global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. Carbon dioxide concentrations in the atmosphere increased from approximately 280 parts per million by volume (ppmv) in pre-industrial times to 415 ppmv in 2021, a 48 percent increase (IPCC 2021; NOAA/ESRL 2023a).[13,14] The IPCC states that "Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally caused by human activities" (IPCC 2021). The predominant source of anthropogenic CO_2 emissions is the combustion of fossil fuels. Forest clearing, other biomass burning, and some non-energy production processes (e.g., cement production) also emit notable quantities of CO_2. In its *Sixth Assessment Report*, the IPCC determined that of the 2.0 degrees of observed warming, the best estimate is that 1.9 degrees of that are due to human influence, with elevated CO_2 concentrations being the most important contributor to that warming (IPCC 2021).

Methane (CH_4). Methane is primarily produced through anaerobic decomposition of organic matter in biological systems. Agricultural processes such as wetland rice cultivation, enteric fermentation in animals, and the decomposition of animal wastes emit CH_4, as does the decomposition of municipal solid wastes and treatment of wastewater. Methane is also emitted during the production and distribution of natural gas and petroleum, and is released as a byproduct of coal mining and incomplete fossil fuel combustion. Atmospheric concentrations of CH_4 have increased by about 162 percent since 1750, from a pre-industrial value of about 730 ppb to 1,895 ppb in 2021[15] although the rate of increase decreased to near zero in the early 2000s, and has recently increased again to about 18.12 ppb/year. The IPCC has estimated that about half of the current CH_4 flux to the atmosphere (and the entirety of the increase in concentration) is anthropogenic, from human activities such as agriculture, fossil fuel production and use, and waste disposal (IPCC 2021).

Methane is primarily removed from the atmosphere through a reaction with the hydroxyl radical (OH) and is ultimately converted to CO_2. Minor removal processes also include reaction with chlorine in the marine boundary layer, a soil sink, and stratospheric reactions. Increasing emissions of CH_4 reduce the concentration of OH, a feedback that increases the atmospheric lifetime of CH_4 (IPCC 2021). Methane's reactions in the atmosphere also lead to production of tropospheric ozone and stratospheric water vapor, both of which also contribute to climate change. Tropospheric ozone also has negative effects on human health and plant productivity.

Nitrous Oxide (N_2O). Anthropogenic sources of N_2O emissions include agricultural soils, especially production of nitrogen-fixing crops and forages, the use of synthetic and manure fertilizers, and manure deposition by livestock; fossil fuel combustion, especially from mobile combustion; adipic (nylon) and nitric acid production; wastewater treatment and waste incineration; and biomass burning. The atmospheric concentration of N_2O has increased by 24 percent since 1750, from a pre-industrial value of about 270 ppb to 334 ppb in 2021,[16] a concentration that has not been exceeded during at least the last 800 thousand years. Nitrous oxide is primarily removed from the atmosphere by the photolytic action of sunlight in the stratosphere (IPCC 2021).

Ozone (O_3). Ozone is present in both the upper stratosphere,[17] where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,[18] where it is the main component of anthropogenic photochemical "smog." During the last two decades, emissions of anthropogenic chlorine and bromine-containing halocarbons, such as CFCs, have depleted stratospheric ozone concentrations. This loss of

---

[13] The pre-industrial period is considered as the time preceding the year 1750 (IPCC 2013).

[14] Carbon dioxide concentrations during the last 1,000 years of the pre-industrial period (i.e., 750 to 1750), a time of relative climate stability, fluctuated by about $\pm$10 ppmv around 280 ppmv (IPCC 2013).

[15] This value is the global 2021 annual average mole fraction (NOAA/ESRL 2023b).

[16] This value is the global 2021 annual average (NOAA/ESRL 2023c).

[17] The stratosphere is the layer from the troposphere up to roughly 50 kilometers. In the lower regions the temperature is nearly constant but in the upper layer the temperature increases rapidly because of sunlight absorption by the ozone layer. The ozone-layer is the part of the stratosphere from 19 kilometers up to 48 kilometers where the concentration of ozone reaches up to 10 parts per million.

[18] The troposphere is the layer from the ground up to 11 kilometers near the poles and up to 16 kilometers in equatorial regions (i.e., the lowest layer of the atmosphere where people live). It contains roughly 80 percent of the mass of all gases in the atmosphere and is the site for most weather processes, including most of the water vapor and clouds.

ozone in the stratosphere has resulted in negative radiative forcing, representing an indirect effect of anthropogenic emissions of chlorine and bromine compounds (IPCC 2021). The depletion of stratospheric ozone and its radiative forcing remained relatively unchanged since 2000 for the last two decades and is starting to decline; recovery is expected to occur shortly after the middle of the twenty-first century (WMO/UNEP 2018).

The past increase in tropospheric ozone, which is also a greenhouse gas, is estimated to provide the third largest increase in direct radiative forcing since the pre-industrial era, behind CO_2 and CH_4. Tropospheric ozone is produced from complex chemical reactions of volatile organic compounds (including CH_4) mixing with NO_x in the presence of sunlight. The tropospheric concentrations of ozone and these other pollutants are short-lived and, therefore, spatially variable (IPCC 2021).

Halocarbons, Sulfur Hexafluoride, and Nitrogen Trifluoride. Halocarbons are, for the most part, man-made chemicals that have direct radiative forcing effects and could also have an indirect effect. Halocarbons that contain chlorine (CFCs, HCFCs, methyl chloroform, and carbon tetrachloride) and bromine (halons, methyl bromide, and hydrobromofluorocarbons) result in stratospheric ozone depletion and are therefore controlled under the Montreal Protocol on Substances that Deplete the Ozone Layer. Although most CFCs and HCFCs are potent global warming gases, their net radiative forcing effect on the atmosphere is reduced because they cause stratospheric ozone depletion, which itself is a greenhouse gas but which also shields the Earth from harmful levels of ultraviolet radiation. Under the Montreal Protocol, the United States phased out the production and importation of halons by 1994 and of CFCs by 1996. Under the Copenhagen Amendments to the Protocol, a cap was placed on the production and importation of HCFCs by non-Article 5 countries, including the United States,[19] beginning in 1996, and then followed by intermediate requirements and a complete phase-out by the year 2030. While ozone depleting gases covered under the Montreal Protocol and its Amendments are not covered by the UNFCCC, they are reported in this Inventory under Annex 6.2 for informational purposes.

Hydrofluorocarbons, PFCs, SF_6, and NF_3 are not ozone depleting substances. The most common HFCs are, however, powerful greenhouse gases. Hydrofluorocarbons are primarily used as replacements for ozone depleting substances but also emitted as a byproduct of the HCFC-22 (chlorodifluoromethane) manufacturing process. Currently, they have a small aggregate radiative forcing impact, but it is anticipated that without further controls their contribution to overall radiative forcing will increase, the ERF (effective radiative forcing) of halogenated gases increased by 3.5 percent between 2011 and 2019 primarily due to a decrease in atmospheric mixing-ratios of CFCs and an increase in their replacements (IPCC 2021). On December 27, 2020, the American Innovation and Manufacturing (AIM) Act was enacted by Congress and which gives EPA authority to phase down HFC production and consumption (i.e., production plus import, minus export), through an allowance allocation program, promulgate certain regulations for purposes of maximizing reclamation and minimizing releases of HFCs and their substitutes from equipment, and facilitating the transition to next-generation technologies through sector-based restrictions, which will lead to lower HFC emissions over time. Perfluorocarbons, SF_6, and NF_3 are predominantly emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. Currently, the radiative forcing impact of PFCs, SF_6, and NF_3 is also small, but they have a significant growth rate, extremely long atmospheric lifetimes, and are strong absorbers of infrared radiation, and therefore have the potential to influence climate far into the future (IPCC 2021).

Carbon Monoxide (CO). Carbon monoxide has an indirect radiative forcing effect by elevating concentrations of CH_4 and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g., the hydroxyl radical, OH) that would otherwise assist in destroying CH_4 and tropospheric ozone. Carbon monoxide is created when carbon-containing fuels are burned incompletely. Through natural processes in the atmosphere, it is eventually oxidized to CO_2. Carbon monoxide concentrations are both short-lived in the atmosphere and spatially variable.

[19] Article 5 of the Montreal Protocol covers several groups of countries, especially developing countries, with low consumption rates of ozone depleting substances. Developing countries with per capita consumption of less than 0.3 kg of certain ozone depleting substances (weighted by their ozone depleting potential) receive financial assistance and a grace period of ten additional years in the phase-out of ozone depleting substances.

Nitrogen Oxides (NO_x). The primary climate change effects of nitrogen oxides (i.e., NO and NO_2) are indirect. Warming effects can occur due to reactions leading to the formation of ozone in the troposphere, but cooling effects can occur due to the role of NO_x as a precursor to nitrate particles (i.e., aerosols) and due to destruction of stratospheric ozone when emitted from very high-altitude aircraft.[20] Additionally, NO_x emissions are also likely to decrease CH_4 concentrations, thus having a negative radiative forcing effect (IPCC 2021). Nitrogen oxides are created from lightning, soil microbial activity, biomass burning (both natural and anthropogenic fires) fuel combustion, and, in the stratosphere, from the photo-degradation of N_2O. Concentrations of NO_x are both relatively short-lived in the atmosphere and spatially variable.

Non-methane Volatile Organic Compounds (NMVOCs). Non-methane volatile organic compounds include substances such as propane, butane, and ethane. These compounds participate, along with NO_x, in the formation of tropospheric ozone and other photochemical oxidants. NMVOCs are emitted primarily from transportation and industrial processes, as well as biomass burning and non-industrial consumption of organic solvents. Concentrations of NMVOCs tend to be both short-lived in the atmosphere and spatially variable.

Aerosols. Aerosols are extremely small particles or liquid droplets found in the atmosphere that are either directly emitted into or are created through chemical reactions in the Earth's atmosphere. Aerosols or their chemical precursors can be emitted by natural events such as dust storms, biogenic or volcanic activity, or by anthropogenic processes such as transportation, coal combustion, cement manufacturing, waste incineration, or biomass burning. Various categories of aerosols exist from both natural and anthropogenic sources, such as soil dust, sea salt, biogenic aerosols, sulfates, nitrates, volcanic aerosols, industrial dust, and carbonaceous[21] aerosols (e.g., black carbon, organic carbon). Aerosols can be removed from the atmosphere relatively rapidly by precipitation or through more complex processes under dry conditions.

Aerosols affect radiative forcing differently than greenhouse gases. Their radiative effects occur through direct and indirect mechanisms: directly by scattering and absorbing solar radiation (and to a lesser extent scattering, absorption, and emission of terrestrial radiation); and indirectly by increasing cloud droplets and ice crystals that modify the formation, precipitation efficiency, and radiative properties of clouds (IPCC 2021). Despite advances in understanding of cloud-aerosol interactions, the contribution of aerosols to radiative forcing are difficult to quantify because aerosols generally have short atmospheric lifetimes, and have number concentrations, size distributions, and compositions that vary regionally, spatially, and temporally (IPCC 2021).

The net effect of aerosols on the Earth's radiative forcing is believed to be negative (i.e., net cooling effect on the climate). In fact, aerosols contributed a cooling influence of up to 1.4 degrees, offsetting a substantial portion of greenhouse gas warming (IPCC 2021). Because aerosols remain in the atmosphere for only days to weeks, their concentrations respond rapidly to changes in emissions.[22] Not all aerosols have a cooling effect. Current research suggests that another constituent of aerosols, black carbon, has a positive radiative forcing by heating the Earth's atmosphere and causing surface warming when deposited on ice and snow (IPCC 2021). Black carbon also influences cloud development, but the direction and magnitude of this forcing is an area of active research.

Global Warming Potentials

A global warming potential (GWP) is a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas (see Table 1-2). It is defined as the accumulated radiative forcing within a specific time horizon caused by emitting 1 kilogram (kg) of the gas, relative to that of the reference gas CO_2 (IPCC 2021). Direct radiative effects occur when the gas itself absorbs radiation. Indirect radiative forcing occurs when

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

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

[22] Volcanic activity can inject significant quantities of aerosol producing sulfur dioxide and other sulfur compounds into the stratosphere, which can result in a longer lasting negative forcing effect (i.e., a few years) (IPCC 2013).

chemical transformations involving the original gas produce a gas or gases that are greenhouse gases, or when a gas influences other radiatively important processes such as the atmospheric lifetimes of other gases. The reference gas used is CO_2, and therefore GWP-weighted emissions are measured in million metric tons of CO_2 equivalent (MMT CO_2 Eq.).[23] The relationship between kilotons (kt) of a gas and MMT CO_2 Eq. can be expressed as follows:

Equation 1-1: Calculating CO_2 Equivalent Emissions

$$\text{MMT CO}_2\text{ Eq.} = (\text{kt of gas}) \times (\text{GWP}) \times \left(\frac{\text{MMT}}{1{,}000\text{ kt}}\right)$$

where,

MMT CO_2 Eq.	= Million metric tons of CO_2 equivalent
kt	= kilotons (equivalent to a thousand metric tons)
GWP	= Global warming potential
MMT	= Million metric tons

GWP values allow for a comparison of the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of ±40 percent.

All estimates are provided throughout the report in both MMT CO_2 equivalents and unweighted units. Recent decisions under the UNFCCC[24] require Parties to use 100-year GWP values from the IPCC *Fifth Assessment Report* (AR5) for calculating CO_2-equivalence in their national reporting (IPCC 2013) by the end of 2024.

> *…Decides that, until it adopts a further decision on the matter, the global warming potential values used by Parties in their reporting under the Convention to calculate the carbon dioxide equivalence of anthropogenic greenhouse gas emissions by sources and removals by sinks shall be based on the effects of greenhouse gases over a 100-year time horizon as listed in table 8.A.1 in appendix 8.A to the contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,[25] excluding the value for fossil methane*; .[26]

This reflects updated science and ensures that national GHG inventories reported by all nations are comparable. In preparation for upcoming UNFCCC requirement,[27] this report reflects CO_2-equivalent greenhouse gas totals using 100-year AR5 GWP values. A comparison of emission values with the previously used 100-year GWP values from 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 1-2.

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. The short-lived gases such as water vapor, carbon monoxide, tropospheric ozone, ozone precursors (e.g., NO_x, and NMVOCs), and tropospheric aerosols (e.g., SO_2 products and carbonaceous particles), however, vary regionally, and consequently it is difficult to quantify their global radiative forcing impacts. Parties to the UNFCCC have not agreed upon GWP values for these gases that are short-lived and spatially inhomogeneous in the atmosphere.

---

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

[24] 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/sbsta2022_L25a01E.pdf. The UNFCCC reporting guidelines require use of the 100-year GWPs listed in table 8.A.1 in Annex 8.A of Chapter 8 of the *Fifth Assessment Report* (AR5) of the Intergovernmental Panel on Climate Change, excluding the value for fossil methane.

[25] Intergovernmental Panel on Climate Change. 2013. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the *Fifth Assessment Report* of the Intergovernmental Panel on Climate Change. TF Stocker, D Qin, G-K Plattner, et al. (eds.). Cambridge and New York: Cambridge University Press. Available at http://www.ipcc.ch/report/ar5/wg1.

[26] United Nations Framework Convention on Climate Change, see https://unfccc.int/sites/default/files/resource/sbsta2022_L25a01E.pdf.

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

Table 1-2: Global Warming Potentials and Atmospheric Lifetimes (Years) Used in this Report

Gas	Atmospheric Lifetime	GWP[a]
CO_2	See footnote[b]	1
CH_4[c]	12.4	28
N_2O	121	265
HFC-23	222	12,400
HFC-32	5.2	677
HFC-41[d]	2.8	116
HFC-125	28.2	3,170
HFC-134a	13.4	1,300
HFC-143a	47.1	4,800
HFC-152a	1.5	138
HFC-227ea	38.9	3,350
HFC-236fa	242	8,060
CF_4	50,000	6,630
C_2F_6	10,000	11,100
C_3F_8	2,600	8,900
c-C_4F_8	3,200	9,540
SF_6	3,200	23,500
NF_3	500	16,100
Other Fluorinated Gases		See Annex 6

[a] 100-year time horizon.
[b] For a given amount of CO_2 emitted, some fraction of the atmospheric increase in concentration is quickly absorbed by the oceans and terrestrial vegetation, some fraction of the atmospheric increase will only slowly decrease over a number of years, and a small portion of the increase will remain for many centuries or more.
[c] The GWP of CH_4 includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.
[d] See Table A-1 of 40 CFR Part 98
Source: IPCC (2013).

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

In 2021, the IPCC published its *Sixth Assessment Report* (AR6), which updated its comprehensive scientific assessment of climate change. Within the AR6 report, the GWP values of gases were revised relative to previous IPCC reports, namely the IPCC *Second Assessment Report* (SAR) (IPCC 1996), the IPCC *Third Assessment Report* (TAR) (IPCC 2001), the IPCC *Fourth Assessment Report* (AR4) (IPCC 2007), and the IPCC *Fifth Assessment Report* (AR5) (IPCC 2014). Although the AR5 GWP values are used throughout this report, consistent with UNFCCC reporting requirements, it is straight-forward to review the changes to the GWP values and their impact on estimates of the total GWP-weighted emissions of the United States. In the AR6, the IPCC used more recent estimates of the atmospheric lifetimes and radiative efficiencies of some gases and updated background concentrations. The AR6 now includes climate-carbon feedback effects for non-CO_2 gases, improving the consistency between treatment of CO_2 and non-CO_2 gases. Indirect effects of gases on other atmospheric constituents (such as the effect of methane on ozone) have also been updated to match more recent science.

Table 1-3 presents the new GWP values, relative to those presented in the AR4 and AR5, using the 100-year time horizon common to UNFCCC reporting. For consistency with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using AR4 100-year GWP values, as required by the 2013 revision to the UNFCCC reporting guidelines for national inventories.[28] Updated reporting guidelines under the Paris Agreement which require the United States and other countries to shift to use of the IPCC *Fifth Assessment Report* (AR5) (IPCC 2013) 100-year GWP values (without feedbacks) take effect for national inventory reporting in 2024.[29] All estimates provided throughout this report are also presented in unweighted units. For informational purposes, emission estimates that use 100-year GWPs from other recent IPCC Assessment Reports are presented in detail in Annex 6.1 of this report.

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

	100-Year GWP Values				Comparisons to AR5		
Gas	AR4	AR5[a]	AR5 with feedbacks[b]	AR6[c]	AR4	AR5 with feedbacks[b]	AR6[c]
CO_2	1	1	1	1	NC	NC	NC
CH_4[d]	25	28	34	27	(3)	6	1
N_2O	298	265	298	273	33	33	8
HFC-23	14,800	12,400	13,856	14,600	2,400	1,456	2,200
HFC-32	675	677	817	771	(2)	140	94
HFC-41	92	116	141	135	(24)	25	19
HFC-125	3,500	3,170	3,691	3,740	330	521	570
HFC-134a	1,430	1,300	1,549	1,530	130	249	230
HFC-143a	4,470	4,800	5,508	5,810	(330)	708	1,010
HFC-152a	124	138	167	164	(14)	29	26
HFC-227ea	3,220	3,350	3,860	3,600	(130)	510	250
HFC-236fa	9,810	8,060	8,998	8,690	1,750	938	630
CF_4	7,390	6,630	7,349	7,380	760	719	750
C_2F_6	12,200	11,100	12,340	12,400	1,100	1,240	1,300
C_3F_8	8,830	8,900	9,878	9,290	(70)	978	390
c-C_4F_8	10,300	9,540	10,592	10,200	(760)	1,052	660
SF_6	22,800	23,500	26,087	24,300	700	2,587	800
NF_3	17,200	16,100	17,885	17,400	(1,100)	1,785	1,300

NC (No Change)
[a] The GWP values in this column reflect values used in this report from AR5 excluding climate-carbon feedbacks and the value for fossil methane.
[b] The GWP values in this column are from the AR5 report but include climate-carbon feedbacks for the non-CO_2 gases in order to be consistent with the approach used in calculating the CO_2 lifetime.
[c] The GWP values in this column are from the AR6 report.
[d] The GWP of CH_4 includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. Including the indirect effect due to the production of CO_2 resulting from methane oxidation would lead to an increase in AR5 methane GWP values by 2 for fossil methane and is not shown in this table.
Note: Parentheses indicate negative values.
Sources: IPCC (2021), IPCC (2013), IPCC (2007), IPCC (2001), IPCC (1996).

1.2 National Inventory Arrangements

The U.S. Environmental Protection Agency (EPA), in cooperation with other U.S. government agencies, prepares the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. A wide range of agencies and individuals are involved in supplying data to, planning methodological approaches and improvements, reviewing, or preparing portions of the

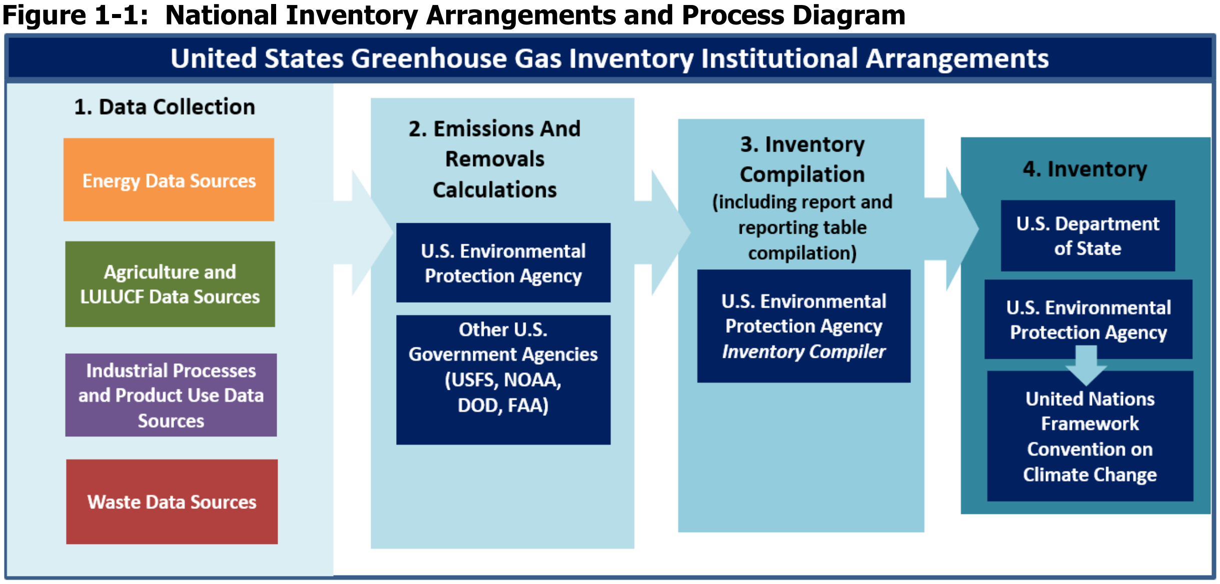
[28] See http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf.
[29] See https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-paris-agreement.

Inventory—including federal and state government authorities, research and academic institutions, industry associations, and private consultants.

Within EPA, the Office of Atmospheric Protection (OAP) is the lead office responsible for the emission and removal calculations provided in the Inventory, as well as the completion of the National Inventory Report and the Common Reporting Format (CRF) tables. EPA's Office of Transportation and Air Quality (OTAQ) and Office of Research and Development (ORD) are also involved in calculating emissions and removals for the Inventory. The U.S. Department of State (DOS) serves as the overall national focal point to the UNFCCC, and EPA's OAP serves as the National Inventory Focal Point for this report, including responding to technical questions and comments on the U.S. Inventory. EPA staff coordinate the annual methodological choice, activity data collection, emission and removal calculations, uncertainty assessment, QA/QC processes, and improvement planning at the individual source and sink category level. EPA, the inventory coordinator, compiles the entire Inventory into the proper reporting format for submission to the UNFCCC, and is responsible for the synthesis of information and for the consistent application of cross-cutting IPCC good practice across the Inventory.

Several other government agencies contribute to the collection and analysis of the underlying activity data used in the Inventory calculations via formal (e.g., interagency agreements) and informal relationships, in addition to the calculation of estimates integrated in the report (e.g., U.S. Department of Agriculture's U.S. Forest Service and Agricultural Service, National Oceanic and Atmospheric Administration, Federal Aviation Administration, and Department of Defense). Other U.S. agencies provide official data for use in the Inventory. The U.S. Department of Energy's Energy Information Administration provides national fuel consumption data and the U.S. Department of Defense provides data on military fuel consumption and use of bunker fuels. Other U.S. agencies providing activity data for use in EPA's emission calculations include: the U.S. Department of Agriculture, National Oceanic and Atmospheric Administration, the U.S. Geological Survey, the Federal Highway Administration, the Department of Transportation, the Bureau of Transportation Statistics, the Department of Commerce, and the Federal Aviation Administration. Academic and research centers also provide activity data and calculations to EPA, as well as individual companies participating in voluntary outreach efforts with EPA. Finally, EPA as the National Inventory Focal Point, in coordination with the U.S. Department of State, officially submits the Inventory to the UNFCCC each April.

Figure 1-1: National Inventory Arrangements and Process Diagram



Overview of Inventory Data Sources by Source and Sink Category

Energy	Agriculture and LULUCF	IPPU	Waste
U.S. Energy Information Administration	USDA U.S. Forest Service Forest Inventory and Analysis Program (FIA)	EPA Greenhouse Gas Reporting Program (GHGRP)	EPA Greenhouse Gas Reporting Program (GHGRP)
U.S. Department of Commerce – Bureau of the Census	USDA Natural Resource Conservation Service (NRCS)	U.S. Geological Survey (USGS) National Minerals Information Center	EPA Office of Land and Emergency Management (OLEM)
U.S. Department of Defense – Defense Logistics Agency	USDA National Agricultural Statistics Service (NASS) and Agricultural Research Service (ARS)	American Chemistry Council (ACC)	EPA Clean Watershed Needs Survey (CWNS)
U.S. Department of Homeland Security	EPA Office of Research and Development (ORD)	American Iron and Steel Institute (AISI)	American Housing Survey
U.S. Department of Transportation - Federal Highway Administration	U.S. Fish and Wildlife Service	U.S. International Trade Commission (USITC)	Data from research studies, trade publications, and industry associations
U.S. Department of Transportation - Federal Aviation Administration	U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS)	Air-Conditioning, Heating, and Refrigeration Institute	
U.S. Department of Transportation & Bureau of Transportation Statistics	Association of American Plant Food Control Officials (AAPFCO)	Data from other U.S. government agencies, research studies, trade publications, and industry association	
U.S. Department of Labor – Mine Safety and Health Administration	National Oceanic and Atmospheric Administration (NOAA)	UNEP Technology and Economic Assessment Panel	
U.S. Department of Energy and its National Laboratories	EPA Office of Land and Emergency Management (OLEM)		
EPA Acid Rain Program	USDA Farm Service Agency		
EPA MOVES Model	U.S. Geological Survey (USGS)		
EPA Greenhouse Gas Reporting Program (GHGRP)	U.S. Department of the Interior (DOI), Bureau of Land Management (BLM)		
U.S. Department of Labor – Mine Safety and Health Administration	EPA Office of Land and Emergency Management (OLEM)		
American Association of Railroads	Alaska Department of Natural Resources		
American Public Transportation Association	U.S. Census Bureau		
Data from research studies, trade publications, and industry associations	Data from research studies, trade publications, and industry associations		

Note: This table is not an exhaustive list of all data sources.

1.3 Inventory Process

This section describes EPA's approach to preparing the annual U.S. Inventory, which consists of the National Inventory Report (NIR) and Common Reporting Format (CRF) tables. The inventory coordinator at EPA, with support from the cross-cutting compilation staff, is responsible for aggregating all emission and removal estimates, conducting the overall uncertainty analysis of Inventory emissions and trends over time, and ensuring consistency and quality throughout the NIR and CRF tables. Emission and removal calculations, including associated uncertainty analysis for individual sources and/or sink categories are the responsibility of individual source and sink category leads, who are most familiar with each category, underlying data, and the unique national circumstances relevant to its emissions or removals profile. Using IPCC good practice guidance, the individual leads determine the most appropriate methodology and collect the best activity data to use in the emission and removal calculations, based upon their expertise in the source or sink category, as well as coordinating with researchers and expert consultants familiar with the sources and sinks. Each year, the coordinator oversees a multi-stage process for collecting information from each individual source and sink category lead to compile all information and data for the Inventory.

Methodology Development, Data Collection, and Emissions and Sink Estimation

Source and sink category leads at EPA collect input data and, as necessary, evaluate or develop the estimation methodology for the individual source and/or sink categories. Because EPA has been preparing the Inventory for many years, for most source and sink categories, the methodology for the previous year is applied to the new "current" year of the Inventory, and inventory analysts collect any new data or update data that have changed from the previous year. If estimates for a new source or sink category are being developed for the first time, or if the methodology is changing for an existing category (e.g., the United States is implementing improvement efforts to apply a higher tiered approach for that category), then the source and/or sink category lead will develop and implement the new or refined methodology, gather the most appropriate activity data and emission factors (or in some cases direct emission measurements) for the entire time series, and conduct any further category-specific review with involvement of relevant experts from industry, government, and universities (see Chapter 9 and Box ES-3 on EPA's approach to recalculations).

Once the methodology is in place and the data are collected, the individual source and sink category leads calculate emission and removal estimates. The individual leads then update or create the relevant report text and accompanying annexes for the Inventory. Source and sink category leads are also responsible for completing the relevant sectoral background tables of the CRF, conducting quality control (QC) checks, preparing relevant category materials for QA, or expert reviews, category-level uncertainty assessments, and reviewing data for publication in EPA's GHG Data Explorer.

The treatment of confidential business information (CBI) in the Inventory is based on EPA internal guidelines, as well as regulations[30] applicable to the data used. EPA has specific procedures in place to safeguard CBI during the inventory compilation process. When information derived from CBI data is used for development of inventory calculations, EPA procedures ensure that these confidential data are sufficiently aggregated to protect confidentiality while still providing useful information for analysis. For example, within the Energy and Industrial Processes and Product Use (IPPU) sectors, EPA has used aggregated facility-level data from the Greenhouse Gas Reporting Program (GHGRP) to develop, inform, and/or quality-assure U.S. emission estimates. In 2014, EPA's GHGRP, with industry engagement, compiled criteria that would be used for aggregating its confidential data to shield the underlying CBI from public disclosure.[31] In the Inventory, EPA is publishing only data values that meet the GHGRP aggregation criteria.[32] Specific uses of aggregated facility-level data are described in the respective

[30] 40 CFR part 2, Subpart B titled "Confidentiality of Business Information" which is the regulation establishing rules governing handling of data entitled to confidentiality treatment. See https://www.ecfr.gov/cgi-bin/text-idx?SID=a764235c9eadf9afe05fe04c07a28939&mc=true&node=sp40.1.2.b&rgn=div6.

[31] Federal Register Notice on "Greenhouse Gas Reporting Program: Publication of Aggregated Greenhouse Gas Data." See pp. 79 and 110 of notice at https://www.gpo.gov/fdsys/pkg/FR-2014-06-09/pdf/2014-13425.pdf.

[32] U.S. EPA Greenhouse Gas Reporting Program. Developments on Publication of Aggregated Greenhouse Gas Data, November 25, 2014. See http://www.epa.gov/ghgreporting/confidential-business-information-ghg-reporting.

methodological sections within those chapters. In addition, EPA uses historical data reported voluntarily to EPA via various voluntary initiatives with U.S. industry (e.g., EPA Voluntary Aluminum Industrial Partnership (VAIP)) and follows guidelines established under the voluntary programs for managing CBI.

Data Compilation and Archiving

The inventory coordinator at EPA with support from the data/document manager collects the source and sink categories' descriptive text and annexes, and also aggregates the emission and removal estimates into a summary data file that links the individual source and sink category data files together. This summary data file contains all of the essential data in one central location, in formats commonly used in the Inventory document. In addition to the data from each source and sink category, other national trend and related data are also gathered in the summary sheet for use in the Executive Summary, Introduction, and Trends sections of the Inventory report (e.g., GDP, population, energy use). Similarly, the recalculation analysis and key category analysis are completed in a separate data file based on output from the summary data file. The uncertainty estimates for each source and sink category are also aggregated into uncertainty summary data files that are used to conduct the overall Inventory uncertainty analysis (see Section 1.7). Microsoft SharePoint, kept on a central server at EPA under the jurisdiction of the inventory coordinator, provides a platform for facilitating collaboration during each compilation phase, but also the efficient storage and archiving of electronic files each annual cycle. Previous final published inventories are also maintained on a report archive page on EPA's Greenhouse Gas website.[33]

National Inventory Report (NIR) Preparation

The NIR is compiled from the sections developed by each individual source or sink category lead. In addition, the inventory coordinator prepares a brief overview of each chapter that summarizes the emissions and removals from all sources and sinks discussed in the chapters. Also at this time, the Executive Summary, Introduction, , Trends in Greenhouse Gas Emissions and Removals, and Recalculations and Improvements chapters are drafted, to reflect the trends and impact from improvements for the time series of the current Inventory. The analysis of trends necessitates gathering supplemental data, including weather and temperature conditions, economic activity and gross domestic product, population, atmospheric conditions, and the annual consumption of electricity, energy, and fossil fuels. Changes in these data are used to explain the trends observed in greenhouse gas emissions in the United States. Furthermore, specific factors that affect individual sectors are researched and discussed. Many of the factors that affect emissions are included in the Inventory document as separate analyses or side discussions in boxes within the text. Finally, the uncertainty analysis and key category analysis are compiled and updated in the report as part of final analysis steps. Throughout the report text boxes are also created to provide additional documentation (e.g., definitions) and/or examine the data aggregated in different ways than in the remainder of the document, such as a focus on transportation activities or emissions from electricity generation. The document is prepared to align with the specification of the UNFCCC reporting guidelines for National Inventory Reports while also reflecting national circumstances.

Common Reporting Format Table (CRF) Compilation

The CRF tables are compiled from individual time series input data sheets completed by each individual source or sink category lead, which contain emissions and/or removals and activity data, estimates, methodological and completeness notations and associated explanations. The inventory coordinator and cross-cutting compilation staff import the category data into the UNFCCC's "CRF Reporter" for the United States, assuring consistency and completeness across all sectoral tables. The summary reports for emissions and removals, methods, and emission factors used, the summary tables indicating completeness of estimates (i.e., notation key NE/IE tables), the recalculation tables, and the emission and removal trends tables automatically compiled by the CRF Reporter and reviewed by the inventory coordinator with support from the cross-cutting compilation staff. Internal automated

[33] See https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-archive.

quality checks within the CRF Reporter, as well as reviews by the cross-cutting and category leads, are completed for the entire time series of CRF tables before submission.

QA/QC and Uncertainty

Quality assurance and quality control (QA/QC) and uncertainty analyses are guided by the QA/QC and Inventory coordinators, who help maintain the QA/QC plan and the overall uncertainty analysis procedures (see sections on QA/QC and Uncertainty, below) in collaboration with the broader inventory compilation team. The QA/QC coordinator works closely with the Inventory coordinator and source and sink category leads to ensure that a consistent QA/QC plan is implemented across all inventory categories. Similarly, the Inventory coordinator ensures the uncertainty analysis is implemented consistently across all categories. The inventory QA/QC plan, outlined in Section 1.7 and Annex 8, is consistent with the quality assurance procedures outlined by EPA and IPCC good practices. The QA/QC and uncertainty findings also inform overall improvement planning, and specific improvements are noted in the Planned Improvements sections of respective categories. QA processes are outlined below.

Expert, Public, and UNFCCC Reviews

The compilation of the inventory includes a two-stage review or QA process, in addition to international technical expert review following submission of the report to the UNFCCC. During the first stage (the 30-day Expert Review period), a first draft of sectoral chapters of the document are sent to a select list of technical experts outside of EPA who are not directly involved in preparing estimates. The purpose of the Expert Review is to provide an objective review, encourage feedback on the methodological and data sources used in the current Inventory, especially for sources and sinks which have experienced any changes since the previous Inventory.

Once comments are received and addressed, the second stage, or second draft of the document is released for public review by publishing a notice in the U.S. Federal Register and posting the entire draft Inventory document on the EPA website. The Public Review period allows for a 30-day comment period and is open to the entire U.S. public. Comments received may require further discussion with experts and/or additional research, and specific Inventory improvements requiring further analysis as a result of comments are noted in the relevant category's Planned Improvement section. EPA publishes responses to comments received during both reviews with the publication of the final report on its report website.

Following completion and submission of the report to the UNFCCC, the report also undergoes review by an international team of independent experts for adherence to UNFCCC reporting guidelines and IPCC methodological guidance.[34] Feedback from all review processes that contribute to improving inventory quality over time are described within each planned improvement section and further in Annex 8. See also the Improvement Planning process discussed below.

Final Submittal to UNFCCC, Document and Data Publication

After the final revisions to incorporate any comments from the Expert Review and Public Review periods, EPA prepares the final NIR and the accompanying CRF tables for electronic reporting. EPA, as the National Inventory focal point, sends the official submission of the U.S. Inventory to the UNFCCC using the CRF Reporter software, coordinating with the U.S. Department of State, the overall UNFCCC focal point. Concurrently, for timely public access, the report is also published on EPA's website.[35] On EPA's website, users can also visualize and download

[34] See https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/review-process.

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

the current time-series estimates from the GHG Inventory Data Explorer Tool,[36] and also download more detailed data presented in tables within the report and report annex in CSV format.

Improvement Planning

Each year, many emission and sink estimates in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* are recalculated and revised, through the use of better methods and/or data with the goal of improving inventory quality and reducing uncertainties, including the transparency, completeness, consistency, and overall usefulness of the report. In this effort, the United States follows the *2006 IPCC Guidelines* (IPCC 2006), which state, "Both methodological changes and refinements over time are an essential part of improving inventory quality. It is *good practice* to change or refine methods when available data have changed; the previously used method is not consistent with the IPCC guidelines for that category; a category has become key; the previously used method is insufficient to reflect mitigation activities in a transparent manner; the capacity for inventory preparation has increased; improved inventory methods become available; and/or for correction of errors." The EPA's OAP coordinates improvement planning across all sectors and also cross-cutting analyses based on annual review and input from the technical teams leading compilation of each sector's estimates, including continuous improvements to the overall data and document compilation processes. Planned improvements are identified through QA/QC processes (including completeness checks), the key category analysis, and the uncertainty analysis. The inventory coordinator, with input from EPA source and sink category leads, maintains a log of all planned improvements, by sector and cross-cutting, tracking the category significance, specific category improvement, prioritization, anticipated time frame for implementation of each proposed improvement, and status of progress in implementing improvement. Improvements for significant or key categories are usually prioritized across all improvements unless effort would require disproportionate levels of effort and resources relative to improvements for other key categories to address.

1.4 Methodology and Data Sources

Emissions and removals of greenhouse gases from various source and sink categories have been estimated using methodologies that are consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) and its supplements and refinements. To a great extent, this report makes use of published official economic and physical statistics for activity data, emission factors and other key parameters. Depending on the category, activity data can include fuel consumption or deliveries, vehicle-miles traveled, raw material processed, etc. Emission factors are factors that relate quantities of emissions to an activity. For more information on data sources see Section 1.2 above, Box 1-1 on use of GHGRP data, and categories' methodology sections for more information on other data sources. In addition to official statistics, the report utilizes findings from academic studies, trade association surveys and statistical reports, along with expert judgment, consistent with the *2006 IPCC Guidelines*.

The methodologies provided in the *2006 IPCC Guidelines* represent foundational methodologies for a variety of source and sink categories, and many of these methodologies continue to be improved and refined as new research and data become available. This report uses those IPCC methodologies when applicable, and supplements them with refined guidance, other available country-specific methodologies and data where possible (e.g., EPA's GHGRP). For example, as noted earlier in this chapter, this report does apply recent supplements and refinements to *2006 IPCC Guidelines* in estimating emissions and removals from coal mining, wastewater treatment and discharge, low voltage anode effects (LVAE) during aluminum production, drained organic soils, and management of wetlands, including flooded lands. Choices made regarding the methodologies and data sources used are provided in the Methodology and Time Series Consistency discussion of each category within each sectoral chapter of the report. Where additional detail is helpful and necessary to explain methodologies and data sources used to estimate emissions, complete documentation is provided in the annexes as indicated in the methodology sections

[36] See https://cfpub.epa.gov/ghgdata/inventoryexplorer/.

of those respective source categories (e.g., Annex 3.13 for Forest Land Remaining Forest Land and Land Converted to Forest Land).

1.5 Key Categories

The *2006 IPCC Guidelines* (IPCC 2006) defines a key category as a "[category] that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals."[37] A key category analysis identifies source or sink categories for focusing efforts to improve overall Inventory quality.

The *2006 IPCC Guidelines* (IPCC 2006) defines several approaches, both quantitative and qualitative, to conduct a key category analysis and identify key categories both in terms of absolute level and trend, along with consideration of uncertainty. This report employs all approaches to identify key categories for the United States. The first approach, Approach 1, identifies significant or key categories without considering uncertainty in its calculations. An Approach 1 level assessment identifies all source and sink categories that cumulatively account for 95 percent of total level, i.e., total emissions (gross) in a given year when assessed in descending order of absolute magnitude. The level analysis was performed twice, including and excluding sources and sinks from the Land Use, Land-Use Change, and Forestry (LULUCF) sector categories. Similarly, an Approach 1 trend analysis can identify categories with trends that differ significantly from overall trends by identifying all source and sink categories that cumulatively account for 95 percent of the sum all the trend assessments (e.g., percent change relative to national trend) when sorted in descending order of absolute magnitude.

The next method, Approach 2, was then implemented to identify any additional key categories not already identified from the Approach 1 level and trend assessments by considering uncertainty. The Approach 2 analysis differs from Approach 1 by incorporating each category's uncertainty assessments in its calculations and was also performed twice, including and excluding LULUCF categories. An Approach 2 level assessment identifies all sources and sink categories that cumulatively account for 90 percent of the sum of all level assessments when sorted in descending order of magnitude. Similarly, an Approach 2 trend analysis can identify categories that whose trends differ significantly from overall trends and also weighting the relative trend difference with the category's uncertainty assessment for 2020.

For 2021, based on the key category analysis, excluding the LULUCF sector and uncertainty, 34 categories accounted for 95 percent of emissions. Four categories account for 55 percent of emissions: CO_2 from road transport-related fuel combustion, CO_2 from coal-fired electricity generation, CO_2 from gas fired electricity generation, and CO_2 from gas-fired industrial combustion. When considering uncertainties, additional categories such as CH_4 from abandoned oil and gas wells were also identified as a key category. In the trend analysis, 32 categories were identified as key categories, and when considering uncertainties, 7 additional categories were identified as key. The trend analysis shows that HFC and PFC emissions from Substitutes of Ozone Depleting Substances, in addition to CO_2 from coal-fired electricity generation and CO_2 from gas fired electricity generation, and CO_2 from road transport related combustion are also significant with respect to trends over the time series.

When considering the contribution of the LULUCF sector to 2021 emissions and sinks, 42 categories accounted for 95 percent of emissions and sinks, with the most significant category from LULUCF being net CO_2 emission from Forest Land Remaining Forest Land. When considering uncertainties and the contribution of the LULUCF sector, additional categories such as CO_2 emissions from Grasslands Remaining Grasslands were also identified as a key category. In the trend analysis, 39 categories were identified as key, and when considering uncertainties, 8 additional categories were identified as key. The trend analysis includes additional categories such as non-CO_2 emissions from forest fires as key categories in the LULUCF sector.

[37] See Chapter 4 Volume 1, "Methodological Choice and Identification of Key Categories" in IPCC (2006). See http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

Finally, in addition to conducting Approach 1 and 2 level and trend assessments as described above, a qualitative assessment of the source and sinks categories was conducted to capture any additional key categories that were not identified using the previously described quantitative approaches. For this Inventory, no additional categories were identified using qualitative criteria recommend by IPCC, but EPA continues to review its qualitative assessment on an annual basis. Find more information on the key category analysis, including the approach to disaggregation of inventory estimates, see Annex 1 to this report.

Table 1-4: Summary of Key Categories for the United States (1990 and 2021) by Sector

CRF Code and Source/Sink Categories	Gas	Approach 1				Approach 2 (includes uncertainty)				2021 Emissions (MMT CO_2 Eq.)
		Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	
Energy										
1.A.3.b CO_2 Emissions from Transportation: Road	CO_2	•	•	•	•	•	•	•	•	1,482.3
1.A.1 CO_2 Emissions from Stationary Combustion - Coal - Electricity Generation	CO_2	•	•	•	•	•	•	•	•	909.7
1.A.1 CO_2 Emissions from Stationary Combustion - Gas - Electricity Generation	CO_2	•	•	•	•	•	•	•	•	615.1
1.A.2 CO_2 Emissions from Stationary Combustion - Gas - Industrial	CO_2	•	•	•	•	•	•	•	•	498.4
1.A.4.b CO_2 Emissions from Stationary Combustion - Gas - Residential	CO_2	•	•	•	•	•		•		258.6
1.A.2 CO_2 Emissions from Stationary Combustion - Oil - Industrial	CO_2	•	•	•	•	•	•	•	•	220.3
1.A.4.a CO_2 Emissions from Stationary Combustion - Gas - Commercial	CO_2	•	•	•	•	•	•	•	•	180.9
1.A.3.a CO_2 Emissions from Transportation: Aviation	CO_2	•	•	•	•	•		•		164.5
1.A.5 CO_2 Emissions from Non-Energy Use of Fuels	CO_2	•	•	•	•	•	•	•	•	143.2
1.A.3.e CO_2 Emissions from Transportation: Other	CO_2	•	•	•	•		•			64.2

CRF Code and Source/Sink Categories	Gas	Approach 1				Approach 2 (includes uncertainty)				2021 Emissions (MMT CO_2 Eq.)
		Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	
1.A.4.b CO_2 Emissions from Stationary Combustion - Oil - Residential	CO_2	•	•	•	•		•		•	51.5
1.A.2 CO_2 Emissions from Stationary Combustion - Coal - Industrial	CO_2	•	•	•	•	•	•	•	•	43.7
1.A.4.a CO_2 Emissions from Stationary Combustion - Oil - Commercial	CO_2	•	•	•	•		•			41.6
1.A.3.d CO_2 Emissions from Transportation: Domestic Navigation	CO_2	•		•						41.0
1.B.2 CO_2 Emissions from Natural Gas Systems	CO_2	•		•		•				36.8
1.A.3.c CO_2 Emissions from Transportation: Railways	CO_2	•		•						32.1
1.B.2 CO_2 Emissions from Petroleum Systems	CO_2	•	•	•	•		•		•	24.7
1.A.5 CO_2 Emissions from Stationary Combustion - Oil - U.S. Territories	CO_2	•		•						17.5
1.A.1 CO_2 Emissions from Stationary Combustion - Oil - Electricity Generation	CO_2	•	•	•	•	•	•		•	17.1
1.A.5.b CO_2 Emissions from Transportation: Military	CO_2		•		•					5.2
1.A.4.a CO_2 Emissions from Stationary Combustion - Coal - Commercial	CO_2		•		•					1.4
1.A.4.b CO_2 Emissions from Stationary Combustion - Coal - Residential	CO_2						•		•	NO

CRF Code and Source/Sink Categories	Gas	Approach 1				Approach 2 (includes uncertainty)				2021 Emissions (MMT CO_2 Eq.)
		Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	
1.B.2 CH_4 Emissions from Natural Gas Systems	CH_4	•	•	•	•	•	•	•	•	181.4
1.B.2 CH_4 Emissions from Petroleum Systems	CH_4	•		•		•		•		50.2
1.B.1 Fugitive Emissions from Coal Mining	CH_4	•	•	•	•	•	•	•	•	44.7
1.B.2 CH_4 Emissions from Abandoned Oil and Gas Wells	CH_4					•		•		8.2
1.A.4.b CH_4 Emissions from Stationary Combustion - Residential	CH_4					•	•	•	•	4.6
1.A.1 N_2O Emissions from Stationary Combustion - Coal - Electricity Generation	N_2O					•				15.1
1.A.3.b N_2O Emissions from Transportation: Road	N_2O	•	•	•	•	•	•		•	9.6
1.A.1 N_2O Emissions from Stationary Combustion - Gas - Electricity Generation	N_2O						•			3.9
Industrial Processes and Product Use										
2.C.1 CO_2 Emissions from Iron and Steel Production & Metallurgical Coke Production	CO_2	•	•	•	•	•	•	•	•	42.0
2.A.1 CO_2 Emissions from Cement Production	CO_2	•	•	•	•					41.3
2.B.8 CO_2 Emissions from Petrochemical Production	CO_2	•	•	•	•					33.2
2.B.3 N_2O Emissions from Adipic Acid Production	N_2O				•					6.6
2.F.1 Emissions from Substitutes for Ozone Depleting Substances: Refrigeration and Air conditioning	HFCs, PFCs	•	•	•	•	•	•	•	•	139.1

CRF Code and Source/Sink Categories	Gas	Approach 1				Approach 2 (includes uncertainty)				2021 Emissions (MMT CO_2 Eq.)
		Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	
2.F.4 Emissions from Substitutes for Ozone Depleting Substances: Aerosols	HFCs, PFCs	•	•	•	•	•	•	•	•	17.7
2.F.2 Emissions from Substitutes for Ozone Depleting Substances: Foam Blowing Agents	HFCs, PFCs		•		•					10.8
2.G SF_6 and CF_4 Emissions from Electrical Transmission and Distribution	SF_6, CF_4			•	•				•	6.0
2.E PFC, HFC, SF_6, and NF_3 Emissions from Electronics Industry	PFCs, HFCs, SF_6, NF_3	•	•				•			4.5
2.B.9 HFC-23 Emissions from HCFC-22 Production	HFCs	•	•	•	•		•		•	2.2
2.C.4 SF_6 Emissions from Magnesium Production and Processing	SF_6	•	•							1.1
2.C.3 PFC Emissions from Aluminum Production	PFCs			•	•					0.9
Agriculture										
3.A.1 CH_4 Emissions from Enteric Fermentation: Cattle	CH_4	•	•	•	•	•	•	•		188.2
3.B.1 CH_4 Emissions from Manure Management: Cattle	CH_4	•	•	•	•	•	•		•	37.9
3.B.4 CH_4 Emissions from Manure Management: Other Livestock	CH_4	•		•	•					28.1
3.C CH_4 Emissions from Rice Cultivation	CH_4	•				•		•		16.8
3.D.1 Direct N_2O Emissions from Agricultural Soil Management	N_2O	•		•		•	•	•	•	257.7
3.D.2 Indirect N_2O Emissions from Applied Nitrogen	N_2O	•		•		•	•	•	•	27.5
Waste										
5.A CH_4 Emissions from MSW Landfills	CH_4	•	•	•	•	•	•	•	•	103.7

CRF Code and Source/Sink Categories	Gas	Approach 1				Approach 2 (includes uncertainty)				2021 Emissions (MMT CO_2 Eq.)
		Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	
5.A CH_4 Emissions from Industrial Landfills	CH_4	•		•			•		•	18.9
5.D CH_4 Emissions from Domestic Wastewater Treatment	CH_4					•				13.9
5.D N_2O Emissions from Domestic Wastewater Treatment	N_2O	•		•		•	•	•	•	20.4
Land Use, Land-Use Change, and Forestry										
4.E.2 Net CO_2 Emissions from Land Converted to Settlements	CO_2			•	•			•	•	81.0
4.B.2 Net CO_2 Emissions from Land Converted to Cropland	CO_2			•				•		56.5
4.C.1 Net CO_2 Emissions from Grassland Remaining Grassland	CO_2							•	•	10.0
4.B.1 Net CO_2 Emissions from Cropland Remaining Cropland	CO_2			•				•	•	(18.9)
4.C.2 Net CO_2 Emissions from Land Converted to Grassland	CO_2			•	•			•	•	(24.7)
4.A.2 Net CO_2 Emissions from Land Converted to Forest Land	CO_2			•				•		(98.3)
4.E.1 Net CO_2 Emissions from Settlements Remaining Settlements	CO_2			•	•			•	•	(134.5)
4.A.1 Net CO_2 Emissions from Forest Land Remaining Forest Land	CO_2			•	•			•	•	(695.4)
4.D.1 CH_4 Emissions from Flooded Land Remaining Flooded Land	CH_4			•						45.4

CRF Code and Source/Sink Categories	Gas	Approach 1				Approach 2 (includes uncertainty)				2021 Emissions (MMT CO_2 Eq.)
		Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	Level Without LULUCF	Trend Without LULUCF	Level With LULUCF	Trend With LULUCF	
4.A.1 CH_4 Emissions from Forest Fires	CH_4				•				•	15.5
4.A.1 N_2O Emissions from Forest Fires	N_2O								•	8.9
Subtotal of Key Categories Without LULUCF[b]										**6,172.6**
Total Gross Emissions Without LULUCF										**6,347.7**
Percent of Total Without LULUCF										**97%**
Subtotal of Key Categories With LULUCF[c]										**5,393.2**
Total Net Emissions With LULUCF										**5,593.5**
Percent of Total With LULUCF										**96%**

NO (Not Occurring)
[a] Other includes emissions from pipelines.
[b] Subtotal includes key categories from Level Approach 1 Without LULUCF, Level Approach 2 Without LULUCF, Trend Approach 1 Without LULUCF, and Trend Approach 2 Without LULUCF.
[c] Subtotal includes key categories from Level Approach 1 With LULUCF, Level Approach 2 With LULUCF, Trend Approach 1 With LULUCF, and Trend Approach 2 With LULUCF.
Note: Parentheses indicate negative values (or sequestration).

1.6 Quality Assurance and Quality Control (QA/QC)

As part of efforts to achieve its stated goals for inventory quality, transparency, and credibility, the United States has developed a quality assurance and quality control plan designed to check, document, and improve the quality of its inventory over time. QA/QC activities on the Inventory are undertaken within the framework of the U.S. *Quality Assurance/Quality Control and Uncertainty Management Plan* (QA/QC plan) *for the U.S. Greenhouse Gas Inventory: Procedures Manual for QA/QC and Uncertainty Analysis*.

Key attributes of the QA/QC plan are summarized in Figure 1-2. These attributes include:

- *Procedures and Forms:* detailed and specific systems that serve to standardize the process of documenting and archiving information, as well as to guide the implementation of QA/QC and the analysis of uncertainty
- *Implementation of Procedures:* application of QA/QC procedures throughout the whole Inventory development process from initial data collection, through preparation of the emission and removal estimates, to publication of the Inventory
- *Quality Assurance (QA):* expert and public reviews for both the inventory estimates and the Inventory report (which is the primary vehicle for disseminating the results of the inventory development process). The expert technical review conducted by the UNFCCC supplements these QA processes, consistent with the QA good practice and the *2006 IPCC Guidelines* (IPCC 2006)
- *Quality Control (QC)*: application of *General (Tier 1) and Category-specific (Tier 2)* quality controls and checks, as recommended by *2006 IPCC Guidelines* (IPCC 2006), along with consideration of secondary data and category-specific checks (additional Tier 2 QC) in parallel and coordination with the uncertainty assessment; the development of protocols and templates, which provides for more structured communication and integration with the suppliers of secondary information
- *General (Tier 1) and Category-specific (Tier 2) Checks:* quality controls and checks, as recommended by

IPCC Good Practice Guidance and *2006 IPCC Guidelines* (IPCC 2006)

- *Record Keeping:* provisions to track which procedures have been followed, the results of the QA/QC, uncertainty analysis, and feedback mechanisms for corrective action based on the results of the investigations which provide for continual data quality improvement and guided research efforts.
- *Multi-Year Implementation*: a schedule for coordinating the application of QA/QC procedures across multiple years, especially for category-specific QC, prioritizing key categories
- *Interaction and Coordination:* promoting communication within the EPA, across Federal agencies and departments, state government programs, and research institutions and consulting firms involved in supplying data or preparing estimates for the Inventory. The QA/QC Management Plan itself is intended to be revised and reflect new information that becomes available as the program develops, methods are improved, or additional supporting documents become necessary.

Figure 1-2: U.S. QA/QC Plan Summary

	Data Gathering	Data Documentation	Calculating Emissions	Cross-Cutting Coordination

Inventory Analyst	• Obtain data in electronic format (if possible)
	• Review data input/calculation workbooks
	  ○ Avoid hardwiring
	  ○ Use data validation
	  ○ Protect cells
	• Develop automatic checkers for:
	  ○ Outliers, negative values, or missing data
	  ○ Variable types match values
	  ○ Time series consistency
	• Maintain tracking tab for status of gathering efforts
		• Contact reports for non-electronic communications
		• Provide cell references for primary data elements
		• Obtain copies of all data sources
		• List and location of any working/external data or input/calculation workbooks
		• Document assumptions
		• Complete QA/QC checklists
		• CRF and summary tab links
			• Clearly label parameters, units, and conversion factors
			• Review data input/calculation workbooks integrity
			  ○ Equations
			  ○ Units
			  ○ Inputs and outputs
			• Develop automated checkers for:
			  ○ Input ranges
			  ○ Calculations
			  ○ Emission aggregation
			  ○ Trend and IEF checks
				• Common starting versions for each inventory year
				• Utilize unalterable summary and CRF tab for each source data input/calculation workbook for linking to a master summary workbook
				• Follow strict version control procedures
				• Document QA/QC procedures

QA/QC Analyst	• Check input data for transcription errors • Inspect automatic checkers • Identify data input/calculation workbooks modifications that could provide additional QA/QC checks	• Check citations in data input/calculation workbooks and text for accuracy and style • Check reference docket for new citations • Review documentation for any data / methodology changes • Complete QA/QC checklists • CRF and summary tab links	• Reproduce calculations • Review time series consistency • Review changes in data/consistency with IPCC methodology	

1 **Box 1-3: Examples of Verification Activities**

Consistent with IPCC guidance for national GHG inventories, verification activities include comparisons with emission or removal estimates prepared by other bodies and comparisons with estimates derived from fully independent assessments, e.g., atmospheric concentration measurements. Verification activities provide information to improve inventories and are part of the overall QA/QC system.

Use of lower tier methods. The UNFCCC reporting guidelines require countries to complete a "top-down" reference approach for estimating CO_2 emissions from fossil fuel combustion in addition to their "bottom-up" sectoral methodology for purposes of verification. This estimation method uses alternative methodologies and different data sources than those contained in that section of the Energy chapter. The reference approach estimates fossil fuel consumption by adjusting national aggregate fuel production data for imports, exports, and stock changes rather than relying on end-user consumption surveys (see Annex 4 of this report). The reference approach assumes that once carbon-based fuels are brought into a national economy, they are either saved in some way (e.g., stored in products, kept in fuel stocks, or left unoxidized in ash) or combusted, and therefore the carbon in them is oxidized and released into the atmosphere. Accounting for actual consumption of fuels at the sectoral or sub-national level is not required.

Use of Ambient Measurements Systems for Validation of Emission Inventories. In following the UNFCCC requirement under Article 4.1 to develop and submit national greenhouse gas emission inventories, the emissions and sinks presented in this report are organized by source and sink categories and calculated using internationally accepted methods provided by the IPCC.[38] 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.[39] 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 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 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) given the technical complexity of such comparisons. Further, it identified fluorinated gases as particularly suitable for such comparisons. The *2019 Refinement* makes this conclusion for fluorinated gases based on their lack of significant natural sources, their generally long atmospheric lifetimes, their well-known loss mechanisms, and the potential uncertainties in bottom-up inventory methods for some of their sources. Unlike emissions of CO_2, CH_4, and N_2O, emissions of fluorinated greenhouse gases are almost exclusively anthropogenic, meaning that the fluorinated GHG emission sources included in this Inventory account for the majority of the total U.S. emissions of these gases detectable in the atmosphere.

In this Inventory, EPA presents the results of two comparisons between fluorinated gas emissions inferred from atmospheric measurements and fluorinated gas emissions estimated based on bottom-up measurements and modeling consistent with guidance from the *2019 Refinement*. These comparisons, performed for HFCs and SF_6 respectively, are described under the QA/QC and Verification discussions in Chapter 4, Sections 4.24

---

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

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

Substitution of Ozone Depleting Substances and 4.25 Electrical Transmission and Distribution in the IPPU chapter of this report.

Consistent with the *2019 Refinement*, a key element to facilitate such comparisons is a gridded prior inventory as an input to inverse modeling. To improve the ability to compare the national-level greenhouse gas inventory with measurement results that may be at other scales, a team at Harvard University along with EPA and other coauthors developed a gridded inventory of U.S. anthropogenic methane emissions with 0.1° x 0.1° spatial resolution, monthly temporal resolution, and detailed scale-dependent error characterization. The gridded inventory is designed to be consistent with the 1990 to 2014 U.S. EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks* estimates for the year 2012, which presents national totals for different source types.[40] 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 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.

In addition, based on the national QA/QC plan for the Inventory, some sector, subsector and category-specific QA/QC and verification checks have been developed. These checks follow the procedures outlined in the national QA/QC plan, tailoring the procedures to the specific documentation and data files associated with individual sources. For each greenhouse gas emissions source or sink category included in this Inventory, a minimum of general or Tier 1 QC analysis has been undertaken. Where QC activities for a particular category go beyond the minimum Tier 1 level, and include category-specific checks (Tier 2) or include verification, further explanation is provided within the respective source or sink category text. Similarly, responses or updates based on comments from the expert, public and the international technical expert reviews (e.g., UNFCCC) are also addressed within the respective source or sink category sections in each sectoral chapter and Annex 8.

The quality control activities described in the U.S. QA/QC plan occur throughout the inventory process; QA/QC is not separate from, but is an integral part of, preparing the Inventory. Quality control—in the form of both good practices (such as documentation procedures) and checks on whether good practices and procedures are being followed—is applied at every stage of inventory development and document preparation. In addition, quality assurance occurs during the Expert Review and the Public Review, in addition to the UNFCCC expert technical review. While all phases significantly contribute to improving inventory quality, the public review phase is also essential for promoting the openness of the inventory development process and the transparency of the inventory data and methods.

The QA/QC plan guides the process of ensuring inventory quality by describing data and methodology checks, developing processes governing peer review and public comments, and developing guidance on conducting an analysis of the uncertainty surrounding the emission and removal estimates. The QA/QC procedures also include feedback loops and provide for corrective actions that are designed to improve the inventory estimates over time.

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

1.7 Uncertainty Analysis of Emission Estimates

Emissions and removals calculated for the U.S. Inventory reflect best estimates for greenhouse gas source and sink categories in the United States and are continuously revised and improved as new information becomes available. Uncertainty assessment is an essential element of a complete and transparent emissions inventory because it helps inform and prioritize Inventory improvements. For the U.S. Inventory, uncertainty analyses are conducted for each source and sink category as well as for the uncertainties associated with the overall emission (current and base year) and trends estimates. These analyses reflect the quantitative uncertainty in the emission (and removal) estimates associated with uncertainties in their input parameters (e.g., activity data and EFs) and serve to evaluate the relative contribution of individual input parameter uncertainties to the overall Inventory, its trends, and each source and sink category.

The overall level and trend uncertainty estimates for total U.S. greenhouse gas emissions was developed using the IPCC Approach 2 uncertainty estimation methodology (assuming a Normal distribution for Approach 1 estimates), which employs a Monte Carlo Stochastic Simulation technique. The IPCC provides good practice guidance on two approaches—Approach 1 and Approach 2—to estimating uncertainty for both individual and combined source categories. Approach 2 quantifies uncertainties based on a distribution of emissions (or removals), built-up from repeated calculations of emission estimation models and the underlying input parameters, randomly selected according to their known distributions. Approach 2 methodology is applied to each individual source and sink category wherever data and resources are permitted and is also used to quantify the uncertainty in the overall Inventory and its Trends. Source and sink chapters in this report provide additional details on the uncertainty analysis conducted for each source and sink category. See Annex 7 of this report for further details on the U.S. process for estimating uncertainty associated with the overall emission (base and current year) and trends estimates. Consistent with IPCC (IPCC 2006), the United States has ongoing efforts to continue to improve the overall Inventory uncertainty estimates presented in this report.

The United States has also implemented many improvements over the last several years to reduce uncertainties across the source and sink categories and improve Inventory estimates. These improvements largely result from new data sources that provide more accurate data and/or increased data coverage, as well as methodological improvements. Following IPCC good practice, additional efforts to reduce Inventory uncertainties can occur through efforts to incorporate excluded emission and sink categories (see Annex 5), improve estimation methods, and collect more detailed, measured, and representative data. Individual category chapters and Annex 7 both describe current ongoing and planned Inventory and uncertainty analysis improvements. Consistent with IPCC (2006), the United States has ongoing efforts to continue to improve the category-specific uncertainty estimates presented in this report, largely prioritized by considering improvements categories identified as significant by the Key Category Analysis.

Estimates of quantitative uncertainty for the total U.S. greenhouse gas emissions in 1990 (base year) and 2020 are shown below in Table 1-5 and Table 1-6, respectively. The overall uncertainty surrounding the Total Net Emissions is estimated to be -5 to +6 percent in 1990 and -6 to +6 percent in 2020. When the LULUCF sector is excluded from the analysis the uncertainty is estimated to be -2 to +5 percent in 1990 and -3 to +3 percent in 2020.

Table 1-5: Estimated Overall Inventory Quantitative Uncertainty for 1990 (MMT CO_2 Eq. and Percent) – TO BE UPDATED FOR FINAL INVENTORY REPORT

Gas	1990 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Greenhouse Gas Estimate[a] (MMT CO_2 Eq.)		Uncertainty Range Relative to Greenhouse Gas Estimate[a] (%)		Mean[b] (MMT CO_2 Eq.)	Standard Deviation[b] (MMT CO_2 Eq.)
		Lower	Upper	Lower	Upper		

		Bound[c]	Bound[c]	Bound	Bound		
CO_2	5,122.5	5,017.3	5,357.6	-2%	5%	5,186.5	88.0
CH_4[d]	780.8	720.1	871.5	-8%	12%	794.9	38.8
N_2O[d]	450.5	365.6	574.9	-19%	28%	457.8	54.1
PFC, HFC, SF_6, and NF_3[d]	99.7	90.2	112.5	-9%	13%	100.4	5.6
Total Gross Emissions	**6,453.5**	**6,330.2**	**6,761.5**	**-2%**	**5%**	**6,539.5**	**110.6**
LULUCF Emissions[e]	31.4	29.3	33.8	-7%	8%	31.5	1.1
LULUCF Carbon Stock Change Flux[f]	(892.0)	(1,183.9)	(709.3)	33%	-20%	(944.1)	119.3
LULUCF Sector Net Total[g]	**(860.6)**	**(1,152.7)**	**(677.7)**	**34%**	**-21%**	**(912.6)**	**119.3**
Net Emissions (Sources and Sinks)	**5,592.8**	**5,306.8**	**5,953.6**	**-5%**	**6%**	**5,626.9**	**163.9**

[a] The lower and upper bounds for emission estimates correspond to a 95 percent confidence interval, with the lower bound corresponding to 2.5[th] percentile and the upper bound corresponding to 97.5[th] percentile.
[b] Mean value indicates the arithmetic average of the simulated emission estimates; standard deviation indicates the extent of deviation of the simulated values from the mean.
[c] The lower and upper bound emission estimates for the sub-source categories do not sum to total emissions because the low and high estimates for total emissions were calculated separately through simulations.
[d] The overall uncertainty estimates did not take into account the uncertainty in the GWP values for CH_4, N_2O and high GWP gases used in the Inventory emission calculations for 1990.
[e] 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, Land Converted to Flooded Land, and Flooded Land Remaining Flooded Land; and N_2O emissions from forest soils and settlement soils.
[f] 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. Since the resulting flux is negative the signs of the resulting lower and upper bounds are reversed.
[g] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.
Notes: Total emissions (excluding emissions for which uncertainty was not quantified) are presented without LULUCF. Net emissions are presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

Table 1-6: Estimated Overall Inventory Quantitative Uncertainty for 2020 (MMT CO_2 Eq. and Percent) – TO BE UPDATED FOR FINAL INVENTORY REPORT

Gas	2020 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Greenhouse Gas Estimate[a]				Mean[b]	Standard Deviation[b]
		(MMT CO_2 Eq.)		(%)		(MMT CO_2 Eq.)	
		Lower Bound[c]	Upper Bound[c]	Lower Bound	Upper Bound		
CO_2	4,715.7	4,610.6	4,908.0	-3%	3%	4,759.8	76.4
CH_4[d]	650.4	595.9	723.6	-10%	10%	659.7	32.6
N_2O[d]	426.1	342.4	551.1	-21%	27%	436.1	53.3
PFC, HFC, SF_6, and NF_3[d]	189.2	182.6	213.7	-8%	8%	198.2	7.9
Total Gross Emissions	**5,981.4**	**5,863.8**	**6,253.0**	**-3%**	**3%**	**6,053.7**	**98.2**
LULUCF Emissions[e]	53.2	44.4	62.9	-17%	18%	53.5	4.9
LULUCF Carbon Stock Change Flux[f]	(812.2)	(1,075.7)	(647.8)	25%	-25%	(860.2)	109.4
LULUCF Sector Net Total[g]	**(758.9)**	**(1,023.2)**	**(594.5)**	**27%**	**-26%**	**(806.7)**	**109.6**
Net Emissions (Sources and Sinks)	**5,222.4**	**4,956.9**	**5,540.9**	**-6%**	**6%**	**5,247.0**	**148.1**

[a] The lower and upper bounds for emission estimates correspond to a 95 percent confidence interval, with the lower bound corresponding to 2.5th percentile and the upper bound corresponding to 97.5th percentile.
[b] Mean value indicates the arithmetic average of the simulated emission estimates; standard deviation indicates the extent of deviation of the simulated values from the mean.
[c] The lower and upper bound emission estimates for the sub-source categories do not sum to total emissions because the low and high estimates for total emissions were calculated separately through simulations.
[d] The overall uncertainty estimates did not take into account the uncertainty in the GWP values for CH_4, N_2O and high GWP gases used in the Inventory emission calculations for 2020.
[e] 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, Land Converted to Flooded Land, and Flooded Land Remaining Flooded Land; and N_2O emissions from forest soils and settlement soils.
[f] 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. Since the resulting flux is negative the signs of the resulting lower and upper bounds are reversed.
[g] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.
Notes: Total emissions (excluding emissions for which uncertainty was not quantified) are presented without LULUCF. Net emissions are presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

In addition to the estimates of uncertainty associated with the current and base year estimates, Table 1-7 presents the estimates of inventory trend uncertainty. The *2006 IPCC Guidelines* defines trend as the difference in emissions between the base year (i.e., 1990) and the current year (i.e., 2020) Inventory estimates. However, for purposes of understanding the concept of trend uncertainty, the trend is defined in this Inventory as the percentage change in the gross emissions (or net emissions) estimated for the current year, relative to the gross emission (or net emissions) estimated for the base year. The uncertainty associated with this trend is referred to as trend uncertainty and is reported as between -14 and 1 percent at the 95 percent confidence level between 1990 and 2020. This indicates a range of approximately -7 percent below and 8 percent above the trend estimate of -7 percent. See Annex 7 for trend uncertainty estimates for individual source and sink categories by gas.

Table 1-7: Quantitative Assessment of Trend Uncertainty (MMT CO_2 Eq. and Percent)

Gas/Source	Base Year Emissions[a]	2020 Emissions	Emissions Trend	Trend Range[b]	
	(MMT CO_2 Eq.)		(%)	(%)	
				Lower Bound	Upper Bound
CO_2	5,122.5	4,715.7	-8%	-12%	-4%
CH_4	780.8	650.4	-17%	-28%	-5%
N_2O	450.5	426.1	-5%	-31%	32%
HFCs, PFCs, SF_6, and NF_3	99.7	189.2	90%	73%	125%
Total Gross Emissions[c]	**6,453.5**	**5,981.4**	**-7%**	**-12%**	**-3%**
LULUCF Emissions[d]	31.4	53.2	70%	39%	103%
LULUCF Carbon Stock Change Flux[e]	(892.0)	(812.2)	-9%	-37%	30%
LULUCF Sector Net Total[f]	**(860.6)**	**(758.9)**	**-12%**	**-40%**	**28%**
Net Emissions (Sources and Sinks)[c]	**5,592.8**	**5,222.4**	**-7%**	**-14%**	**1%**

[a] Base Year is 1990 for all sources.
[b] The trend range represents a 95 percent confidence interval for the emission trend, with the lower bound corresponding to 2.5th percentile value and the upper bound corresponding to 97.5th percentile value.
[c] Totals exclude emissions for which uncertainty was not quantified.
[d] 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, Land Converted to Flooded Land, and Flooded Land Remaining Flooded Land; and N_2O emissions from forest soils and settlement soils.

[e] LULUCF Carbon Stock Change is the net C stock change from the following categories: Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements, and Land Converted to Settlements.
[f] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.
Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration. Total emissions (excluding emissions for which uncertainty was not quantified) are presented without LULUCF. Net emissions are presented with LULUCF.

1.8 Completeness

This report, along with its accompanying CRF tables, serves as a thorough assessment of the anthropogenic sources and sinks of greenhouse gas emissions for the United States for the time series 1990 through 2021. This report is intended to be comprehensive and includes the vast majority of emissions and removals identified as anthropogenic, consistent with IPCC and UNFCCC guidelines. In general, sources or sink categories not accounted for in this Inventory are excluded because they are not occurring in the United States and its territories, or because data are unavailable to develop an estimate and/or the categories were determined to be insignificant[41] in terms of overall national emissions per UNFCCC reporting guidelines.

The United States is continually working to improve upon the understanding of such sources and sinks currently not included and seeking to find the data required to estimate related emissions and removals, focusing on categories that are anticipated to be significant. As such improvements are implemented, new emission and removal estimates are quantified and included in the Inventory, improving completeness of national estimates. For a list of sources and sink categories not included and more information on significance of these categories, see Annex 5 and the respective category sections in each sectoral chapter of this report.

1.9 Organization of Report

In accordance with the revision of the UNFCCC reporting guidelines agreed to at the nineteenth Conference of the Parties (UNFCCC 2014), this *Inventory of U.S. Greenhouse Gas Emissions and Sinks* is grouped into five sector-specific chapters consistent with the UN Common Reporting Framework, listed below in Table 1-8. In addition, chapters on Trends in Greenhouse Gas Emissions, Other information, and Recalculations and Improvements to be considered as part of the U.S. Inventory submission are included.

Table 1-8: IPCC Sector Descriptions

Chapter (IPCC Sector)	Activities Included
Energy	Emissions of all greenhouse gases resulting from stationary and mobile energy activities including fuel combustion and fugitive fuel emissions, and non-energy use of fossil fuels.
Industrial Processes and Product Use	Emissions resulting from industrial processes and product use of greenhouse gases.

[41] See paragraph 32 of Decision 24/CP.19, the UNFCCC reporting guidelines on annual inventories for Parties included in Annex 1 to the Convention. Paragraph notes that "…An emission should only be considered insignificant if the likely level of emissions is below 0.05 per cent of the national total GHG emissions, and does not exceed 500 kt CO_2 Eq. The total national aggregate of estimated emissions for all gases and categories considered insignificant shall remain below 0.1 percent of the national total GHG emissions."

Agriculture	Emissions from agricultural activities except fuel combustion, which is addressed under Energy.
Land Use, Land-Use Change, and Forestry	Emissions and removals of CO_2, and emissions of CH_4, and N_2O from land use, land-use change and forestry.
Waste	Emissions from waste management activities.

Within each chapter, emissions are identified by the anthropogenic activity that is the source or sink of the greenhouse gas emissions being estimated (e.g., coal mining). Overall, the following organizational structure is consistently applied throughout this report:

Chapter/IPCC Sector: Overview of emissions and trends for each IPCC defined sector.

CRF Source or Sink Category: Description of category pathway and emission/removal trends based on IPCC methodologies, consistent with UNFCCC reporting guidelines.

Methodology: Description of analytical methods (e.g., from *2006 IPCC Guidelines,* or country-specific methods) employed to produce emission estimates and identification of data references, primarily for activity data and emission factors.

Uncertainty and Time-Series Consistency: A discussion and quantification of the uncertainty in emission estimates and a discussion of time-series consistency.

QA/QC and Verification: A discussion on steps taken to QA/QC and verify the emission estimates, consistent with the U.S. QA/QC plan, and any key QC findings.

Recalculations Discussion: A discussion of any data or methodological changes that necessitate a recalculation of previous years' emission estimates, and the impact of the recalculation on the emission estimates, if applicable.

Planned Improvements: A discussion on any category-specific planned improvements, if applicable.

Special attention is given to CO_2 from fossil fuel combustion relative to other sources because of its share of emissions and its dominant influence on emission trends. For example, each energy consuming end-use sector (i.e., residential, commercial, industrial, and transportation), as well as the electricity generation sector, is described individually. Additional information for certain source categories and other topics is also provided in several Annexes listed in Table 1-9.

Table 1-9: List of Annexes

ANNEX 1 Key Category Analysis	
ANNEX 2 Methodology and Data for Estimating CO_2 Emissions from Fossil Fuel Combustion	
2.1.	Methodology for Estimating Emissions of CO_2 from Fossil Fuel Combustion
2.2.	Methodology for Estimating the Carbon Content of Fossil Fuels
2.3.	Methodology for Estimating Carbon Emitted from Non-Energy Uses of Fossil Fuels
ANNEX 3 Methodological Descriptions for Additional Source or Sink Categories	
3.1.	Methodology for Estimating Emissions of CH_4, N_2O, and Indirect Greenhouse Gases from Stationary Combustion
3.2.	Methodology for Estimating Emissions of CH_4, N_2O, and Indirect Greenhouse Gases from Mobile Combustion and Methodology for and Supplemental Information on Transportation-Related Greenhouse Gas Emissions
3.3.	Methodology for Estimating Emissions from Commercial Aircraft Jet Fuel Consumption
3.4.	Methodology for Estimating CH_4 Emissions from Coal Mining
3.5.	Methodology for Estimating CH_4 and CO_2 Emissions from Petroleum Systems
3.6.	Methodology for Estimating CH_4 Emissions from Natural Gas Systems
3.7.	Methodology for Estimating CO_2 and N_2O Emissions from Incineration of Waste
3.8.	Methodology for Estimating Emissions from International Bunker Fuels used by the U.S. Military
3.9.	Methodology for Estimating HFC and PFC Emissions from Substitution of Ozone Depleting Substances
3.10.	Methodology for Estimating CH_4 Emissions from Enteric Fermentation
3.11.	Methodology for Estimating CH_4 and N_2O Emissions from Manure Management
3.12.	Methodology for Estimating N_2O Emissions, CH_4 Emissions and Soil Organic C Stock Changes from

Agricultural Lands (Cropland and Grassland)
3.13. Methodology for Estimating Net Carbon Stock Changes in Forest Land Remaining Forest Land and Land Converted to Forest Land
3.14. Methodology for Estimating CH_4 Emissions from Landfills
ANNEX 4 IPCC Reference Approach for Estimating CO_2 Emissions from Fossil Fuel Combustion
ANNEX 5 Assessment of the Sources and Sinks of Greenhouse Gas Emissions Not Included
ANNEX 6 Additional Information
6.1. Global Warming Potential Values
6.2. Ozone Depleting Substance Emissions
6.3. Greenhouse Gas Precursors: Cross-Walk of NEI categories to the Inventory
6.4. Constants, Units, and Conversions
6.5. Chemical Formulas
ANNEX 7 Uncertainty
7.1. Overview
7.2. Methodology and Results
7.3. Reducing Uncertainty
7.4. Planned Improvements
7.5. Additional Information on Uncertainty Analyses by Source
ANNEX 8 QA/QC Procedures
8.1. Background
8.2. Purpose
8.3. Assessment Factors
8.4. Responses During the Review Process
ANNEX 9 Use of Greenhouse Gas Reporting Program (GHGRP) in Inventory