1. Introduction

This report presents estimates by the United States government of U.S. anthropogenic greenhouse gas emissions and sinks for the years 1990 through 2017. 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 estimates in these tables are presented on both a full molecular 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 these emission 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]

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…"[4] The United States views this report as an opportunity to fulfill these commitments under the UNFCCC.

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 2014). 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

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[1] More information provided in "Global Warming Potentials" section of this chapter on the use of *IPCC Fourth Assessment Report* (AR4) 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). Subsequent decisions by the Conference of the Parties elaborated the role of Annex I Parties in preparing national inventories. See <http://unfccc.int>.

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 at the Nineteenth Conference of the Parties (Warsaw, November 11-23, 2013). This report presents information in accordance with these guidelines.

Overall, this Inventory of anthropogenic greenhouse gas emissions and sinks provides a common and consistent mechanism through which Parties to the UNFCCC can estimate emissions and compare the relative contribution of individual sources, gases, and nations to climate change. The Inventory provides a national estimate of sources and sinks for the United States, including all states and U.S. Territories.[5] 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.

Box 1-1: Methodological Approach for Estimating and Reporting U.S. Emissions and Removals

In following the UNFCCC requirement under Article 4.1 to develop and submit national greenhouse gas emissions inventories, the gross emissions total presented in this report for the United States excludes emissions and removals from Land Use, Land-Use Change, and Forestry (LULUCF). The net emissions total presented in this report for the United States includes emissions and removals from LULUCF. All emissions and removals are calculated using internationally-accepted methods consistent with the IPCC Guidelines.[6] Additionally, the calculated emissions and removals in a given year for the United States are presented in a common manner in line with the UNFCCC reporting guidelines for the reporting of inventories under this international agreement.[7] The use of consistent methods to calculate emissions and removals by all nations providing their inventories to the UNFCCC ensures that these reports are comparable. The report itself follows this standardized format and provides an explanation of the IPCC methods used to calculate emissions and removals.

On October 30, 2009, the U.S. Environmental Protection Agency (EPA) published a rule for the mandatory reporting of greenhouse gases from large greenhouse gas emissions sources in the United States. Implementation of 40 CFR Part 98 is referred to as the EPA's Greenhouse Gas Reporting Program (GHGRP). 40 CFR Part 98 applies to direct greenhouse gas emitters, fossil fuel suppliers, industrial gas suppliers, and facilities that inject CO_2 underground for sequestration or other reasons.[8] Reporting is at the facility level, except for certain suppliers of fossil fuels and industrial greenhouse gases. The GHGRP dataset and the data presented in this Inventory are complementary.

EPA's 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. GHGRP data also allow EPA to disaggregate national Inventory estimates in new ways that can highlight differences across regions and sub-categories of emissions. The GHGRP will continue to enhance QA/QC procedures and assessment of uncertainties.

EPA continues to analyze the data on an annual basis to improve the national estimates presented in this Inventory and uses that data for a number of categories consistent with IPCC guidance.[9] EPA has already integrated GHGRP information for several categories[10] since 2012 and also identifies other categories[11] where EPA plans to integrate

[5] U.S. Territories include American Samoa, Guam, Puerto Rico, U.S. Virgin Islands, Wake Island, and other U.S. Pacific Islands.

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

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

[8] See <https://www.epa.gov/ghgreporting>.

[9] See <http://www.ipcc-nggip.iges.or.jp/public/tb/TFI_Technical_Bulletin_1.pdf>.

[10] Energy Sector (Coal Mining, Stationary Combustion [Industrial Combustion Disaggregation], and Oil and Gas Systems); Industrial Processes and Product Use (Adipic Acid Production, Aluminum Production, Carbon Dioxide Consumption, Electrical Transmission and Distribution, HCFC-22 Production, Lime Production, Magnesium Production and Processing, ODS Substitutes, Nitric Acid Production, Petrochemical Production, Semiconductor Manufacture); and Waste (Landfills).

[11] Industrial Process and Product Use (Ammonia Production, Cement Production, and Other Fluorinated Gas Production)

additional GHGRP data in the next edition of this report (see the Planned Improvement sections of those specific categories for details).

1.1 Background Information

Science

For over the past 200 years, the burning of fossil fuels such as coal and oil, deforestation, land-use changes, and other activities have caused the concentrations of heat-trapping "greenhouse gases" to increase significantly in our atmosphere (NOAA 2017). 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 2013). 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 2013). IPCC concluded in its most recent scientific assessment report that it is extremely likely that human influences have been the dominant cause of warming since the mid-20th century (IPCC 2013).

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 1.8 degrees Fahrenheit from 1901 to 2016 (USGCRP 2017). The last three decades have each been the warmest decade successively at the Earth’s surface since 1850 (IPCC 2013). 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 surface is likely to increase from 0.5 to 8.6 degrees Fahrenheit above 1986 through 2005 levels by the end of this century, depending on future emissions and the responsiveness of the climate system (IPCC 2013).

For further information on greenhouse gases, radiative forcing, and implications for climate change, see the recent scientific assessment reports from the IPCC,[12] the U.S. Global Change Research Program (USGCRP),[13] and the National Academies of Sciences, Engineering, and Medicine (NAS).[14]

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 2013).

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

[12] See <http://www.ipcc.ch/report/ar5>.

[13] See < https://science2017.globalchange.gov/>.

[14] See <http://nas-sites.org/americasclimatechoices/>.

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.[15] 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. Comparatively, however, while the understanding of aerosols has increased in recent years, they still account for the largest contribution to uncertainty estimates in global energy budgets (IPCC 2013).

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 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	0.700 ppm	0.270 ppm	0 ppt	40 ppt
Atmospheric concentration	407 ppm[a]	1.850 ppm[b]	0.330 ppm[c]	9.3 ppt[d]	79 ppt[e]
Rate of concentration change	2.2 ppm/yr[f]	7 ppb/yr[f,g]	0.8 ppb/yr[f]	0.27 ppt/yr[f]	0.7 ppt/yr[f]
Atmospheric lifetime (years)	See footnote[h]	12.4[i]	121[i]	3,200	50,000

[a] The atmospheric CO_2 concentration is the 2017 annual average at the Mauna Loa, HI station (NOAA/ESRL 2018a). The concentration in 2018 at Mauna Loa was 409 ppm. The global atmospheric CO_2 concentration, computed using an average of sampling sites across the world, was 405 ppm in 2017.
[b] The values presented are global 2017 annual average mole fractions (NOAA/ESRL 2018b).
[c] The values presented are global 2017 annual average mole fractions (NOAA/ESRL 2018c).
[d] The values presented are global 2017 annual average mole fractions (NOAA/ESRL 2018d).
[e] The 2011 CF_4 global mean atmospheric concentration is from the Advanced Global Atmospheric Gases Experiment (IPCC 2013).
[f] The rate of concentration change for CO_2 and CH_4 is the average rate of change between 2007 and 2017 (NOAA/ESRL 2018a). The rate of concentration change for N_2O, SF_6, and CF_4 is the average rate of change between 2005 and 2011 (IPCC 2013).

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

[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 7 ppb/year.
[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.
Source: Pre-industrial atmospheric concentrations, atmospheric lifetime, and rate of concentration changes for CH_4, N_2O, SF_6, and CF_4 are from IPCC (2013). The rate of concentration change for CO_2 is an average of the rates from 2007 through 2017 and has fluctuated between 1.5 to 3.0 ppm per year over this period (NOAA/ESRL 2017a).

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 2013). 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 2013).

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 407 ppmv in 2017, a 45 percent increase (IPCC 2013; NOAA/ESRL 2018a).[16,17] The IPCC definitively states that "the increase of CO_2 … is caused by anthropogenic emissions from the use of fossil fuel as a source of energy and from land use and land use changes, in particular agriculture" (IPCC 2013). 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 *Fifth Assessment Report*, the IPCC stated "it is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together," of which CO_2 is the most important (IPCC 2013).

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. 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 164 percent since 1750, from a pre-industrial value of about 700 ppb to 1,849 ppb in 2017[18] although the rate of increase decreased to near zero in the early 2000s, and has recently increased again to about 7 ppb/year. The IPCC has

[16] The pre-industrial period is considered as the time preceding the year 1750 (IPCC 2013).
[17] 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 ±10 ppmv around 280 ppmv (IPCC 2013).
[18] This value is the global 2017 annual average mole fraction (NOAA/ESRL 2018b).

estimated that slightly more than half of the current CH_4 flux to the atmosphere is anthropogenic, from human activities such as agriculture, fossil fuel use, and waste disposal (IPCC 2007).

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 2013). 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.

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 22 percent since 1750, from a pre-industrial value of about 270 ppb to 330 ppb in 2017,[19] a concentration that has not been exceeded during the last 800 thousand years. Nitrous oxide is primarily removed from the atmosphere by the photolytic action of sunlight in the stratosphere (IPCC 2013).

Ozone (O_3). Ozone is present in both the upper stratosphere,[20] where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,[21] 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 ozone in the stratosphere has resulted in negative radiative forcing, representing an indirect effect of anthropogenic emissions of chlorine and bromine compounds (IPCC 2013). The depletion of stratospheric ozone and its radiative forcing remains relatively unchanged since 2000 and recovery is expected to start occurring in the middle of the twenty-first century (WMO/UNEP 2014, WMO 2015).

The past increase in tropospheric ozone, which is also a greenhouse gas, is estimated to provide the fourth largest increase in direct radiative forcing since the pre-industrial era, behind CO_2, black carbon, 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 2013).

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[22] countries, including the United States, beginning in 1996, and then followed by intermediate requirements and a complete phase-out by the year 2030. While ozone depleting gases

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[19] This value is the global 2017 annual average (NOAA/ESRL 2018c).

[20] 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.

[21] 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.

[22] 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.

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 (IPCC 2013). An amendment to the Montreal Protocol was adopted in 2016 which includes obligations for Parties to phase down the production and consumption of HFCs.

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 2013).

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.

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.[23] Additionally, NO_x emissions are also likely to decrease CH_4 concentrations, thus having a negative radiative forcing effect (IPCC 2013). 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[24] 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 2013). Despite advances in understanding of cloud-aerosol interactions, the contribution of aerosols to radiative forcing are difficult to quantify

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

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

because aerosols generally have short atmospheric lifetimes, and have number concentrations, size distributions, and compositions that vary regionally, spatially, and temporally (IPCC 2013).

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, "despite the large uncertainty ranges on aerosol forcing, there is high confidence that aerosols have offset a substantial portion of GHG forcing" (IPCC 2013).[25] Although because they remain in the atmosphere for only days to weeks, their concentrations respond rapidly to changes in emissions.[26] 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 2013). 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 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 2014). Direct radiative effects occur when the gas itself absorbs radiation. Indirect radiative forcing occurs when 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.).[27] The relationship between kilotons (kt) of a gas and MMT CO_2 Eq. can be expressed as follows:

$$MMT\ CO_2\ Eq. = (kt\ of\ gas) \times (GWP) \times \left(\frac{MMT}{1{,}000\ kt}\right)$$

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 ±35 percent. Parties to the UNFCCC have also agreed to use GWPs based upon a 100-year time horizon, although other time horizon values are available.

> *...the global warming potential values used by Parties included in Annex I to the Convention (Annex I Parties) to calculate the carbon dioxide equivalence of anthropogenic emissions by sources and removals by sinks of greenhouse gases shall be those listed in the column entitled "Global warming potential for given time horizon" in table 2.14 of the errata to the contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, based on the effects of greenhouse gases over a 100-year time horizon...*[28]

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[25] The IPCC (2013) defines high confidence as an indication of strong scientific evidence and agreement in this statement.

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

[27] Carbon comprises 12/44^{ths} of carbon dioxide by weight.

[28] Framework Convention on Climate Change; Available online at: <http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf>; 31 January 2014; Report of the Conference of the Parties at its nineteenth session; held in Warsaw from 11 to 23 November 2013; Addendum; Part two: Action taken by the Conference of the Parties at its nineteenth session; Decision 24/CP.19; Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention; p. 2. (UNFCCC 2014).

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.

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	25
N_2O	114	298
HFC-23	270	14,800
HFC-32	4.9	675
HFC-125	29	3,500
HFC-134a	14	1,430
HFC-143a	52	4,470
HFC-152a	1.4	124
HFC-227ea	34.2	3,220
HFC-236fa	240	9,810
HFC-4310mee	15.9	1,640
CF_4	50,000	7,390
C_2F_6	10,000	12,200
C_4F_{10}	2,600	8,860
C_6F_{14}	3,200	9,300
SF_6	3,200	22,800
NF_3	740	17,200

[a] 100-year time horizon.
[b] For a given amount of carbon dioxide 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.
Source: (IPCC 2007)

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

In 2014, the IPCC published its *Fifth Assessment Report* (AR5), which updated its comprehensive scientific assessment of climate change. Within the AR5 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), and the *IPCC Fourth Assessment Report* (AR4) (IPCC 2007). Although the AR4 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 AR5, the IPCC applied an improved calculation of CO_2 radiative forcing and an improved CO_2 response function in presenting updated GWP values. Additionally, the atmospheric lifetimes of some gases have been recalculated, and updated background concentrations were used. In addition, the values for radiative forcing and lifetimes have been recalculated for a variety of halocarbons, and the indirect effects of methane on ozone have been adjusted to match more recent science. Table 1-3 presents the new GWP values, relative to those presented in the AR4 and 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 GWP values, as required by the 2013 revision to the UNFCCC reporting guidelines for national inventories.[29] All estimates provided throughout this report are also presented in unweighted units. For informational purposes, emission estimates that use GWPs from other 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				Comparison to AR4		
Gas	SAR	AR4	AR5[a]	AR5 with feedbacks[b]	SAR	AR5	AR5 with feedbacks[b]
CO_2	1	1	1	1	NC	NC	NC
CH_4[c]	21	25	28	34	(4)	3	9
N_2O	310	298	265	298	12	(33)	0
HFC-23	11,700	14,800	12,400	13,856	(3,100)	(2,400)	(944)
HFC-32	650	675	677	817	(25)	2	142
HFC-125	2,800	3,500	3,170	3,691	(700)	(330)	191
HFC-134a	1,300	1,430	1,300	1,549	(130)	(130)	119
HFC-143a	3,800	4,470	4,800	5,508	(670)	330	1,038
HFC-152a	140	124	138	167	16	14	43
HFC-227ea	2,900	3,220	3,350	3,860	(320)	130	640
HFC-236fa	6,300	9,810	8,060	8,998	(3,510)	(1,750)	(812)
HFC-4310mee	1,300	1,640	1,650	1,952	(340)	10	312
CF_4	6,500	7,390	6,630	7,349	(890)	(760)	(41)
C_2F_6	9,200	12,200	11,100	12,340	(3,000)	(1,100)	140
C_4F_{10}	7,000	8,860	9,200	10,213	(1,860)	340	1,353
C_6F_{14}	7,400	9,300	7,910	8,780	(1,900)	(1,390)	(520)
SF_6	23,900	22,800	23,500	26,087	1,100	700	3,287
NF_3	NA	17,200	16,100	17,885	NA	(1,100)	685

NA (Not Applicable)
NC (No Change)
[a] The GWPs presented here are the ones most consistent with the methodology used in the AR4 report.
[b] The GWP values presented here from the AR5 report 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 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.
Note: Parentheses indicate negative values.
Source: (IPCC 2013, IPCC 2007, IPCC 2001, IPCC 1996).

1.2 National Inventory Arrangements

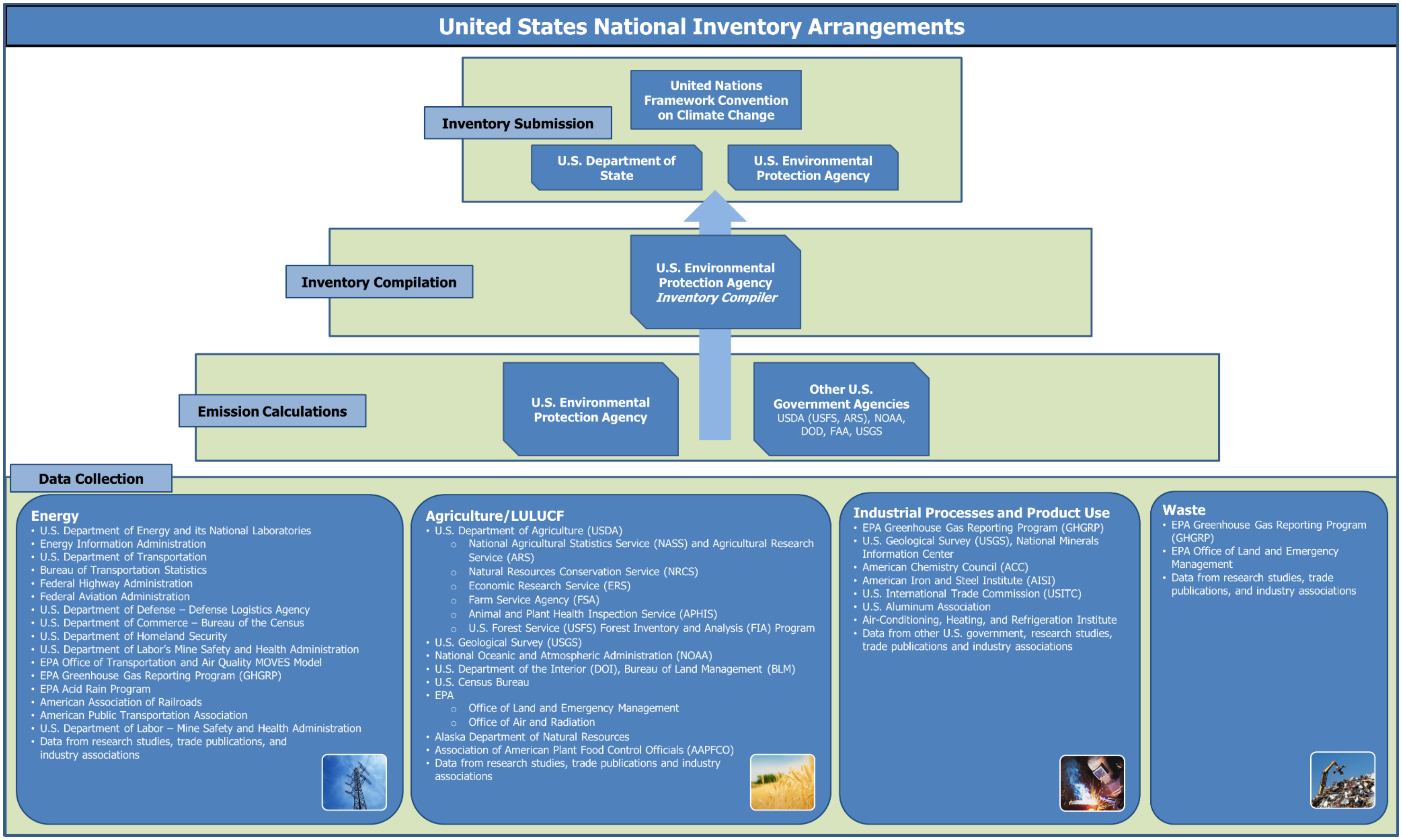
The U.S. Environmental Protection Agency (EPA), in cooperation with other U.S. government agencies, prepares the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. A wide range of agencies and individuals are involved in supplying data to, planning methodological approaches and improvements, reviewing, or preparing portions of the U.S. Inventory—including federal and state government authorities, research and academic institutions, industry associations, and private consultants.

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

Within EPA, the Office of Atmospheric Programs (OAP) is the lead office responsible for the emission 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) is also involved in calculating emissions for the Inventory. The U.S. Department of State serves as the overall 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. The staff of EPA coordinate the annual methodological choice, activity data collection, emission calculations, and QA/QC, and improvement planning at the individual source 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 collection and consistency of cross-cutting issues in the Inventory.

Several other government agencies contribute to the collection and analysis of the underlying activity data used in the Inventory calculations, 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). Formal and informal relationships exist between EPA and other U.S. agencies that 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 military fuel consumption and bunker fuels. Informal relationships also exist with other U.S. agencies to provide activity data for use in EPA's emission calculations. These 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 diagrams the National Inventory Arrangements.

Figure 1-1: National Inventory Arrangements Diagram Inventory Process Inventory Process



1.3 Inventory Process

This section describes EPA's approach to preparing the annual U.S. Inventory, which consists of a 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 estimates and ensuring consistency and quality throughout the NIR and CRF tables. Emission calculations for individual sources and/or sink categories are the responsibility of individual source and sink category leads, who are most familiar with each category and the unique characteristics of its emissions or removals profile. 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 contractors familiar with the sources. A multi-stage process for collecting information from the individual source and sink category leads and producing the Inventory is undertaken annually to compile all information and data.

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 a higher Tiered approach for that category), then the source and/or sink category lead will develop a new methodology, gather the most appropriate activity data and emission factors (or in some cases direct emission measurements) for the entire time series, and conduct a special category-specific review process involving relevant experts from industry, government, and universities (see 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 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 assurance and quality control (QA/QC) checks, and category-level uncertainty analyses.

The treatment of confidential business information (CBI) in the Inventory is based on EPA internal guidelines, as well as regulations[1] 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.[2] In the Inventory, EPA is publishing only data values that meet the GHGRP aggregation criteria.[3] Specific uses of aggregated facility-level data are described in the respective methodological

[1] 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>.

[2] 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>.

[3] 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>.

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.

Summary Data Compilation and Storage

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 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, 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. Electronic copies of each year's summary data, which contains all the emission and sink estimates for the United States, are kept on a central server at EPA under the jurisdiction of the inventory coordinator.

National Inventory Report 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 from all sources discussed in the chapters. The inventory coordinator then carries out a key category analysis for the Inventory, consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, and in accordance with the reporting requirements of the UNFCCC. Also at this time, the Introduction, Executive Summary, and Trends in Greenhouse Gas Emissions chapters are drafted, to reflect the trends for the most recent year 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. Text boxes are also created to 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 match the specification of the UNFCCC reporting guidelines for National Inventory Reports.

Common Reporting Format Table Compilation

The CRF tables are compiled from individual tables completed by each individual source or sink category lead, which contain emissions and/or removals and activity data. The inventory coordinator integrates the category data into the UNFCCC's "CRF Reporter" for the United States, assuring consistency across all sectoral tables. The summary reports for emissions, methods, and emission factors used, the overview tables for completeness and quality of estimates, the recalculation tables, the notation key completion tables, and the emission trends tables are then completed by the inventory coordinator. Internal automated quality checks on the CRF Reporter, as well as reviews by the category leads, are completed for the entire time series of CRF tables before submission.

QA/QC and Uncertainty

QA/QC and uncertainty analyses are guided by the QA/QC and uncertainty coordinators, who help maintain the QA/QC plan and the overall uncertainty analysis procedures in coordination with the Inventory coordinator (see sections on QA/QC and Uncertainty, below). These coordinators work closely with the Inventory coordinator and source and sink category leads to ensure that a consistent QA/QC plan and uncertainty analysis is implemented across all inventory sources. The inventory QA/QC plan, outlined in Section 1.6 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 Review Periods

During 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 which have experienced any changes since the previous Inventory.

Once comments are received and addressed, a 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 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 categories Planned Improvement sections. See those sections for specific details. EPA publishes comments received during both reviews with the publication of the final report on its website.

Following completion and submission of the report to the UNFCCC, the report also undergoes review by an independent international team of experts for adherence to UNFCCC reporting guidelines and IPCC Guidance.[4] Feedback from these review processes all contribute to improving inventory quality over time.

Final Submittal to UNFCCC and Document Printing

After the final revisions to incorporate any comments from the Expert Review and Public Review periods, EPA prepares the final National Inventory Report and the accompanying Common Reporting Format Reporter database. EPA as the National Inventory focal point and sends the official submission of the U.S. Inventory to the UNFCCC, coordinating with the U.S. Department of State. The document is then formatted and posted online, available for the public.[5]

1.4 Methodology and Data Sources

Emissions 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). To a great extent, this report makes use of published official economic and physical statistics for activity data and emission factors. Depending on the emission source 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 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 categories, and many of these methodologies continue to be improved and refined as new research and data become available. This report uses the IPCC methodologies when applicable, and supplements them with other available country-specific methodologies and data where possible. Choices made regarding the methodologies and data sources used are provided in conjunction with the discussion of each source category in the main body of the report. Complete documentation is provided in the annexes on the detailed methodologies and data sources utilized in the calculation of each source category.

[4] See <http://unfccc.int/national_reports/annex_i_ghg_inventories/review_process/items/2762.php>.

[5] See <http://epa.gov/climatechange/ghgemissions/usinventoryreport.html>.

Box 1-3: IPCC Reference Approach

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. 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.

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.”[6] By definition, key categories include those categories that have the greatest contribution to the absolute level of national emissions. In addition, when an entire time series of emission and removal estimates is prepared, a thorough investigation of key categories must also account for the influence of trends and uncertainties of individual source and sink categories. This analysis can identify source and sink categories that diverge from the overall trend in national emissions. Finally, a qualitative evaluation of key categories is performed to capture any categories that were not identified in any of the quantitative analyses.

Approach 1, as defined in the *2006 IPCC Guidelines* (IPCC 2006), was implemented to identify the key categories for the United States. This analysis was performed twice; one analysis included sources and sinks from the Land Use, Land-Use Change, and Forestry (LULUCF) sector, the other analysis did not include the LULUCF categories. Following Approach 1, Approach 2, as defined in the *2006 IPCC Guidelines* (IPCC 2006), was then implemented to identify any additional key categories not already identified in Approach 1 assessment. This analysis, which includes each source category’s uncertainty assessments (or proxies) in its calculations, was also performed twice to include or exclude LULUCF categories.

In addition to conducting Approach 1 and 2 level and trend assessments, a qualitative assessment of the source categories, as described in the *2006 IPCC Guidelines* (IPCC 2006), was conducted to capture any key categories that were not identified by either quantitative method. For this inventory, no additional categories were identified using criteria recommend by IPCC, but EPA continues to update its qualitative assessment on an annual basis.

Table 1-4: Key Categories for the United States (1990-2017)

CRF Source Category	Gas	Approach 1 Level Without LULUCF	Approach 1 Trend Without LULUCF	Approach 1 Level With LULUCF	Approach 1 Trend With LULUCF	Approach 2 Level Without LULUCF	Approach 2 Trend Without LULUCF	Approach 2 Level With LULUCF	Approach 2 Trend With LULUCF	Qual[a]	2017 Emissions (MMT CO_2 Eq.)
Energy											
CO_2 Emissions from Mobile Combustion: Road	CO_2	•	•	•	•	•	•	•	•		1,493.6
CO_2 Emissions from Stationary Combustion - Coal -	CO_2	•	•	•	•	•	•	•	•		1,210.0

[6] 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>.

Electricity Generation											
CO_2 Emissions from Stationary Combustion - Gas - Electricity Generation	CO_2	•	•	•	•	•	•	•	•		505.1
CO_2 Emissions from Stationary Combustion - Gas - Industrial	CO_2	•	•	•	•	•	•	•	•		486.0
CO_2 Emissions from Stationary Combustion - Oil - Industrial	CO_2	•	•	•	•	•	•	•	•		276.4
CO_2 Emissions from Stationary Combustion - Gas - Residential	CO_2	•		•		•		•			242.1
CO_2 Emissions from Mobile Combustion: Aviation	CO_2	•	•	•	•	•					177.0
CO_2 Emissions from Stationary Combustion - Gas - Commercial	CO_2	•	•	•	•	•	•				173.6
CO_2 Emissions from Non-Energy Use of Fuels	CO_2	•		•		•		•			124.6
CO_2 Emissions from Mobile Combustion: Other	CO_2	•	•	•	•						83.2
CO_2 Emissions from Stationary Combustion - Oil - Commercial	CO_2	•	•	•	•						59.3
CO_2 Emissions from Stationary Combustion - Oil - Residential	CO_2	•	•	•	•	•	•				56.4
CO_2 Emissions from Stationary Combustion - Coal - Industrial	CO_2	•	•	•	•	•	•	•	•		55.1
CO_2 Emissions from Mobile Combustion: Marine	CO_2	•	•	•	•						40.4
CO_2 Emissions from Stationary Combustion - Oil - U.S. Territories	CO_2	•	•	•	•						34.3
CO_2 Emissions from Natural Gas Systems	CO_2	•		•							26.3
CO_2 Emissions from Petroleum Systems	CO_2		•		•	•	•		•		23.3
CO_2 Emissions from Stationary Combustion - Oil - Electricity Generation	CO_2	•	•	•	•	•	•		•		18.5
CO_2 Emissions from Stationary	CO_2						•				3.0

Combustion - Gas - U.S. Territories											
CO_2 Emissions from Stationary Combustion - Coal - Commercial	CO_2		•		•						2.0
CO_2 Emissions from Stationary Combustion - Coal - Residential	CO_2						•		•		0.0
CH_4 Emissions from Natural Gas Systems	CH_4	•	•	•	•	•	•	•	•		166.2
Fugitive Emissions from Coal Mining	CH_4	•	•	•	•	•	•		•		62.6
CH_4 Emissions from Petroleum Systems	CH_4	•		•		•	•				37.7
CH_4 Emissions from Abandoned Oil and Gas Wells	CH_4					•		•			6.9
Non-CO_2 Emissions from Stationary Combustion - Residential	CH_4					•	•		•		3.1
CH_4 Emissions from Mobile Combustion: Other	CH_4						•				1.9
Non-CO_2 Emissions from Stationary Combustion - Electricity Generation	N_2O					•					24.4
N_2O Emissions from Mobile Combustion: Road	N_2O	•	•	•	•		•		•		12.1
Non-CO_2 Emissions from Stationary Combustion - Industrial	N_2O					•					2.6
International Bunker Fuels[b]	Several									•	2.0
Industrial Processes and Product Use											
CO_2 Emissions from Iron and Steel Production & Metallurgical Coke Production	CO_2	•	•	•	•	•	•	•	•		41.8
CO_2 Emissions from Cement Production	CO_2	•		•	•						39.4
CO_2 Emissions from Petrochemical Production	CO_2	•	•	•	•						28.2
N_2O Emissions from Adipic Acid Production	N_2O		•		•						7.0
Emissions from Substitutes for Ozone Depleting Substances	HiGWP	•	•	•	•	•	•	•	•		152.2
HFC-23 Emissions from HCFC-22 Production	HiGWP	•	•	•	•		•		•		5.2
SF_6 Emissions from Electrical	HiGWP	•	•		•		•				4.3

Transmission and Distribution											
PFC Emissions from Aluminum Production	HiGWP		•		•		•				1.1
Agriculture											
CO_2 Emissions from Liming	CO_2						•				3.2
CH_4 Emissions from Enteric Fermentation	CH_4	•	•	•	•	•		•			175.4
CH_4 Emissions from Manure Management	CH_4	•	•	•	•	•	•		•		61.7
CH_4 Emissions from Rice Cultivation	CH_4					•	•				11.3
Direct N_2O Emissions from Agricultural Soil Management	N_2O	•	•	•	•	•	•	•			227.7
Indirect N_2O Emissions from Applied Nitrogen	N_2O	•		•		•		•			38.8
Waste											
CH_4 Emissions from Landfills	CH_4	•	•	•	•	•	•	•	•		107.7
N_2O Emissions from Wastewater Treatment	N_2O						•				5.0
Land Use, Land Use Change, and Forestry											
Net CO_2 Emissions from Land Converted to Settlements	CO_2			•	•			•	•		86.2
Net CO_2 Emissions from Land Converted to Cropland	CO_2			•	•			•	•		66.9
Net CO_2 Emissions from Land Converted to Grassland	CO_2							•			8.3
Net CO_2 Emissions from Grassland Remaining Grassland[c]	CO_2									•	(0.1)
Net CO_2 Emissions from Cropland Remaining Cropland	CO_2			•	•			•	•		(10.3)
Net CO_2 Emissions from Land Converted to Forest Land	CO_2			•							(120.6)
Net CO_2 Emissions from Settlements Remaining Settlements	CO_2			•	•			•	•		(134.5)
Net CO_2 Emissions from Forest Land Remaining Forest Land	CO_2			•	•			•	•		(620.3)
Subtotal Without LULUCF											6,317.8
Total Emissions Without LULUCF											6,472.3
Percent of Total Without LULUCF											98%
Subtotal With LULUCF											5,542.1
Total Emissions With LULUCF											5,758.9

Percent of Total With LULUCF	96%

[a] Qualitative criteria.
[b] Emissions from this source not included in totals.
[c] This source category was excluded from the analysis and is identified as a key category using qualitative criteria. Emissions from this source are not included in the Subtotal With LULUCF for key categories.
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 estimates, to publication of the Inventory
- *Quality Assurance:* 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 *2006 IPCC Guidelines* (IPCC 2006)
- *Quality Control*: consideration of secondary data and category-specific checks (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.

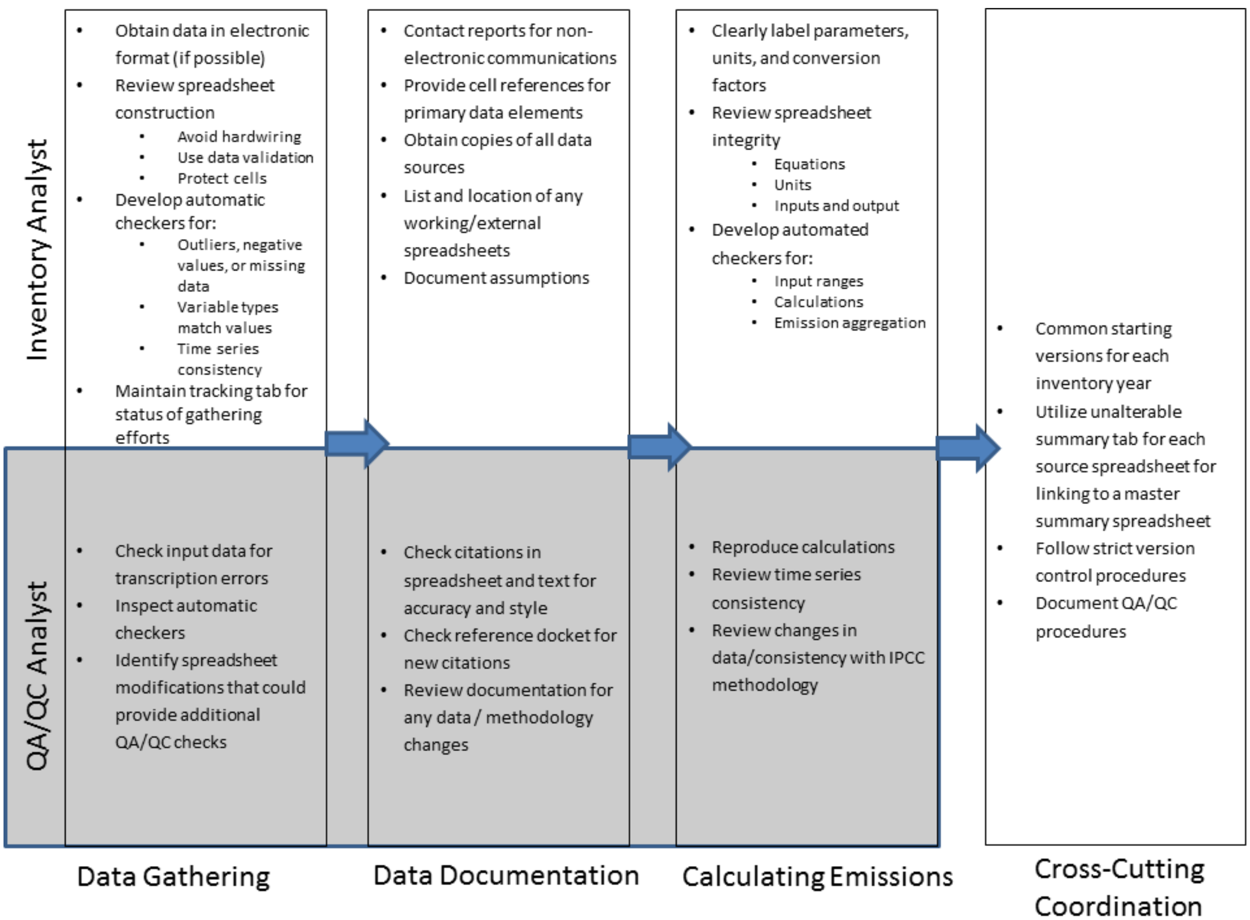
In addition, based on the national QA/QC plan for the Inventory, some sector, subsector and category-specific QA/QC plans have been developed. These plans follow the procedures outlined in the national QA/QC plan, tailoring the procedures to the specific text and data files of the individual sources. For each greenhouse gas emissions source or sink included in this Inventory, a minimum of general or Tier 1 QA/QC analysis has been undertaken. Where QA/QC activities for a particular category go beyond the minimum Tier 1 level, and include category-specific checks (Tier 2), 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.

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 estimates. The QA/QC procedures also include feedback loops and provide for corrective actions that are designed to improve the inventory estimates over time.

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



1.7 Uncertainty Analysis of Emission Estimates

Uncertainty estimates are an essential element of a complete and transparent emissions inventory. Uncertainty information is not intended to dispute the validity of the Inventory estimates, but to help prioritize efforts to improve the accuracy of future Inventories and guide future decisions on methodological choice. While the U.S. Inventory calculates its emission estimates with the highest possible accuracy, uncertainties are associated to a varying degree with the development of emission estimates for any inventory. For some of the current estimates, such as CO_2 emissions from energy-related combustion activities, the impact of uncertainties on overall emission estimates is believed to be relatively small. For some other limited categories of emissions, uncertainties could have a larger impact on the estimates presented (i.e. storage factors of non-energy uses of fossil fuels). The UNFCCC reporting guidelines follow the recommendation in the *2006 IPCC Guidelines* (IPCC 2006) and require that countries provide single point estimates for each gas and emission or removal source category. Within the discussion of each emission source, specific factors affecting the uncertainty associated with the estimates are discussed.

Additional research in the following areas could help reduce uncertainty in the U.S. Inventory:

- *Incorporating excluded emission sources*. Quantitative estimates for some of the sources and sinks of greenhouse gas emissions are not available at this time. In particular, emissions from some land-use activities (e.g., emissions and removals from interior Alaska) and industrial processes are not included in the inventory either because data are incomplete or because methodologies do not exist for estimating emissions from these source categories. See Annex 5 of this report for a discussion of the sources of greenhouse gas emissions and sinks excluded from this report.
- *Improving the accuracy of emission factors*. Further research is needed in some cases to improve the accuracy of emission factors used to calculate emissions from a variety of sources. For example, the accuracy of current emission factors applied to CH_4 and N_2O emissions from stationary and mobile combustion is highly uncertain.
- *Collecting detailed activity data*. Although methodologies exist for estimating emissions for some sources, problems arise in obtaining activity data at a level of detail where more technology or process-specific emission factors can be applied.

The overall uncertainty estimate for total U.S. greenhouse gas emissions was developed using the IPCC Approach 2 uncertainty estimation methodology. Estimates of quantitative uncertainty for the total U.S. greenhouse gas emissions are shown below, in Table 1-5.

The IPCC provides good practice guidance on two approaches—Approach 1 and Approach 2—to estimating uncertainty for individual source categories. Approach 2 uncertainty analysis, employing the Monte Carlo Stochastic Simulation technique, was applied wherever data and resources permitted; further explanation is provided within the respective source category text and in Annex 7. Consistent with good practices in the *2006 IPCC Guidelines* (IPCC 2006), over a multi-year timeframe, the United States expects to continue to improve the uncertainty estimates presented in this report, prioritizing key categories.

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

Gas	2016 Emission Estimate	Uncertainty Range Relative to Emission Estimate[a]				Mean[b]	Standard Deviation[b]
	(MMT CO_2 Eq.)	(MMT CO_2 Eq.)		(%)		(MMT CO_2 Eq.)	
		Lower Bound[c]	Upper Bound[c]	Lower Bound	Upper Bound		
CO_2	5,310.9	5,211.4	5,555.2	-2%	5%	5,379.4	88.4
CH_4[d]	657.4	637.0	780.8	-3%	19%	699.0	36.3
N_2O[d]	369.5	321.7	451.8	-13%	22%	375.1	33.4
PFC, HFC, SF_6, and NF_3[d]	173.5	168.4	192.1	-3%	11%	180.3	6.1
Total	**6,511.3**	**6,439.6**	**6,835.2**	**-1%**	**5%**	**6,633.8**	**101.2**
LULUCF Emissions[e]	**38.1**	**22.8**	**65.7**	**-40%**	**73%**	**38.4**	**11.2**
LULUCF Total Net Flux[f]	**(754.9)**	**(979.5)**	**(598.2)**	**-30%**	**21%**	**(790.5)**	**96.9**
LULUCF Sector Total[g]	**(716.8)**	**(940.3)**	**(560.5)**	**-31%**	**22%**	**(752.0)**	**97.4**
Net Emissions (Sources and Sinks)	**5,794.5**	**5,607.0**	**6,155.0**	**-3%**	**6%**	**5,881.8**	**140.9**

Notes: Total emissions (excluding emissions for which uncertainty was not quantified) is presented without LULUCF. Net emissions is presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate net sequestration.
[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 2016.
[e] LULUCF emissions include the CH_4 and N_2O emissions reported for Non-CO_2 Emissions from Forest Fires, Emissions from Drained Organic Soils, N_2O Fluxes from Forest Soils, Non-CO_2 Emissions from Grassland Fires, N_2O Fluxes from Settlement Soils, Coastal Wetlands Remaining Coastal Wetlands, Peatlands Remaining Peatlands, and CH_4 Emissions from Land Converted to Coastal Wetlands.
[f] Net CO_2 flux is the net C stock change from the following categories: *Forest Land Remaining Forest Land*, *Land Converted to Forest Land*, *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, *Land Converted to Grassland, Changes in Organic Soils Carbon Stocks*, *Changes in Urban Tree Carbon Stocks, Changes in Yard Trimmings and Food Scrap Carbon Stocks in Landfills*, *Land Converted to Settlements*, *Wetlands Remaining Wetlands,* and *Land Converted to Wetlands*.
[g] The LULUCF Sector Total is the net sum of all emissions (i.e., sources) of greenhouse gases to the atmosphere plus removals of CO_2 (i.e., sinks or negative emissions) from the atmosphere.

Emissions calculated for the U.S. Inventory reflect current best estimates; in some cases, however, estimates are based on approximate methodologies, assumptions, and incomplete data. As new information becomes available in the future, the United States will continue to improve and revise its emission estimates. See Annex 7 of this report for further details on the U.S. process for estimating uncertainty associated with the emission estimates and for a more detailed discussion of the limitations of the current analysis and plans for improvement. Annex 7 also includes details on the uncertainty analysis performed for selected source categories.

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 2017. 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, or because data are unavailable to develop an estimate and/or the categories were determined to be insignificant[7] 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 and seeking to find the data required to estimate related emissions and removals. As such improvements are implemented, new emission and removal estimates are quantified and included in the Inventory, focusing on categories that are significant. 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 chapter of this report.

[7] 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."

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 segregated into five sector-specific chapters consistent with the UN Common Reporting Framework, listed below in Table 1-6. In addition, chapters on Trends in Greenhouse Gas Emissions and Other information to be considered as part of the U.S. Inventory submission are included.

Table 1-6: 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.
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 emission trends for each IPCC defined sector.

CRF Source or 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 findings.

Recalculations: 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 1-7.

Table 1-7: 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