Methodology Report: Inventory of U.S. Greenhouse Gas Emissions and Sinks by State: 1990-2019

EPA-430-R-22-001

U.S. Environmental Protection Agency
Office of Atmospheric Programs
Climate Change Division
March 7, 2022

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RECOMMENDED CITATION

EPA. 2022. *Methodology Report: Inventory of U.S. Greenhouse Gas Emissions and Sinks by State: 1990-2019*. U.S. Environmental Protection Agency, EPA 430-R-22-001. https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals

1 Introduction

This report describes methods used to compile the first annual publication of U.S. anthropogenic greenhouse gas (GHG) emissions and sinks disaggregated by U.S. State consistent with the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (national *Inventory* hereafter). By April of each year, the U.S. Environmental Protection Agency (EPA) prepares the official national *Inventory*, presenting time-series estimates by gas, source/sink, and sector. The latest annual report includes estimates from 1990–2019 and is available here https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks. This state-level report will be an ongoing, complementary publication released annually after the national *Inventory* report.

The EPA recognizes that a number of states have compiled or are developing their own state-level GHG inventories on a regular or periodic basis. The state-level inventory data presented here should not be viewed as official data of any state government, and the EPA provides users information on where they can find official state-level data from the EPA's website, i.e., please visit https://www.epa.gov/ghgemissions/learn-more-about-official-state-greenhouse-gas-inventories. In addition, for states where an official inventory is available, links are also provided with the published state-level data in the EPA's GHG Data Explorer so that when users query information for a particular state, the link to view the official state inventory will be shown. States themselves may find this information useful to facilitate comparisons, for quality assurance/quality control (QA/QC), to supplement and complement existing state efforts, or to serve as official estimates, depending on their own circumstances and policy needs.

The state-level estimates described in this document are consistent with the national *Inventory,* meaning they

- Adhere to international standards, including the Intergovernmental Panel on Climate Changes (IPCC) Guidelines and United Nations Framework Convention on Climate Change (UNFCCC) transparency reporting system (i.e., the emissions and removals presented in this report and the report are organized by source and sink categories within IPCC sectors [energy, industrial processes and product use (IPPU), agriculture, Land Use, Land-Use Change, and Forestry (LULUCF) and waste] and their respective source and sink categories).
- Are based on the same methodologies as the national *Inventory* and reflect the latest methodological improvements in the national *Inventory*, including the use of Greenhouse Gas Reporting Program (GHGRP) data.
- Cover the complete time series consistent with the national *Inventory*, starting with 1990 through the latest national Inventory year (i.e., 2019)
- Cover all anthropogenic sources and sinks, and all seven gases (carbon dioxide [CO_2], methane [CH_4], nitrous oxide [N_2O], hydrofluorocarbons [HFCs], perfluorocarbons [PFCs], sulfur hexafluoride [SF_6], and nitrogen trifluoride [NF_3]). The completeness and geographic disaggregation of the report are consistent with the national *Inventory,* meaning in addition to estimates for states, the methods also address emissions and removals occurring in the District of Columbia, U.S. territories, and tribal lands.
- Estimates were compiled to avoid double counting or gaps in emissions coverage between states. This ensures that state totals, when summed, will equal totals in the national *Inventory*. This is important for those looking for consistent, comparable, and complete state data for analyses and other purposes where double counting or omissions would be problematic.

The report’s chapters are organized by UNFCCC reporting sectors[1] and their respective source and sink categories. Domestic and international users alike will recognize this format given its long-established use by countries for UNFCCC reporting. The chapter and category section titles all include a reference to the corresponding section in the national *Inventory* report (NIR), e.g., NIR Section 3.1. This is to facilitate understanding national inventory methods in relation to approaches applied to allocate national emission to the state-level and, for each category, we recommend reading this report in conjunction with the referenced with national *Inventory* sections. Each category section within a chapter includes a background discussion, a description of methods/approaches, and a discussion of planned improvements. The background includes a brief overview of the source or sink category consistent with the national *Inventory*. The methods section includes the approach to develop state-level estimates and the gases covered. The planned improvements indicate areas for improvement identified during this first effort to disaggregate state-level emissions and sinks.

1.1 Areas where differences between state GHG inventories and the EPA state-level estimates may occur

The EPA recognizes that there will be differences between the EPA’s state-level estimates and some inventory estimates developed independently by individual state governments. Inventories compiled by states may differ for several reasons and differences do not necessarily mean that one set of estimates is more accurate, or "correct”. The EPA has strived to ensure that the coverage, methodological and accounting approaches are clearly described so that users can clearly understand differences with how states may compile their inventories. The results should be viewed as complementary and supplement existing state data.

- **Organization of sectors.** The EPA has organized estimates by sector and their respective source and sink categories consistent with the national Inventory and international reporting guidelines. Standardization of sectors in international reporting promotes comparability across countries and supports cooperation on climate action. States may use alternate organization of data, such as economic sectors, for presenting emissions rather than IPCC sectors. Some states may use IPCC sectors as the basis of their inventory, but allocate some categories differently across sectors, such as reporting some Industrial Process and Product Use categories in the Energy sector (e.g., SF_6 from electrical transmission and distribution). Comparability also depends on similar coverage. The completeness and geographic disaggregation of the estimates are consistent with the national *Inventory,* meaning in addition to estimates for states, the methods also address emissions and removals occurring in the District of Columbia, U.S. territories, and tribal lands.
- **Methods and data.** In some cases, the EPA may be using different methodologies, activity data, and emission factors, or may have access to the latest facility-level information through the EPA’s Greenhouse Gas Reporting Program (GHGRP). The EPA used as a basis, or starting point, the same methods or methods based on those used to compile the national-level estimates. States may use the same methods but use different sources of activity data.
- **Accounting approaches**. In other cases, states may have adopted different accounting decisions that differ from those adopted by the IPCC and UNFCCC, (e.g., use of different category definitions and emission scopes consistent with state laws and regulations). For example, the EPA’s approach is to focus on emissions that occur within geographic state boundaries (“Scope 1”), whereas some states include emissions that are caused by activity within their borders but which actually occur in other states (“Scope

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[1] The international reporting guidelines under the UNFCCC require reporting of GHG emissions and removals across five sectors: energy, industrial processes and product use (IPPU), agriculture, land use, land use change and forestry (LULUCF) and waste. Note, while the UNFCCC reporting guidelines require use of methods from the 2006 IPCC Guidelines for estimating GHG emissions and removals, they require separate, rather than combined reporting of emission and sinks from agriculture, forestry and other land use sectors as presented in the IPCC guidelines.

2 or 3") or use consumption-based accounting approaches. For example, some states include emissions from imported electricity, or electricity production that occurs outside state boundaries. EPA's use of geographic state boundaries to allocate emissions is consistent with IPCC guidelines.[2] Differences in accounting approaches also include differences in the approach to estimating transportation, cross-border aviation and marine emissions, or treatment of biogenic CO_2. For example, the EPA does not include biogenic CO_2 emissions in state energy sector totals because, in accordance with IPCC methodological guidelines, CO_2 emissions and removals due to the harvesting, combustion and growth of biomass are included in the carbon stock changes of the relevant land use category of the Agriculture and LULUCF sectors, where the biomass originates, and inclusion of these emissions in energy sector totals would result in double-counting.[3] Users of state GHG data should take care to review and understand differences in accounting approaches to ensure that any comparisons of estimates is equivalent or an apples to apples comparison of estimates.

- **Time Series.** The EPA has developed state-level estimates for 1990-2019 consistent with the national Inventory published in April 2021 and current UNFCCC reporting requirements. States may estimate emissions and sinks over a different time period based on state goals, designation of different base years, legislation and available state data. Some states may not estimate back to 1990 and include only more recent years. Other states may have published estimates for earlier years previously, but which have not been recalculated or otherwise updated in more recent publications despite changes in methods, activity data, or emissions factors. Similarly, new emissions sources may be added in recent years but not estimated for more distant years.
- **Global Warming Potentials (GWPs).** States may use different metrics for carbon equivalency of non-CO2 gases, such as different values for global warming potentials (GWPs). Consistent with the national Inventory, in this report the EPA is using 100-year Global Warming Potentials (GWP) from IPCC's Fourth Assessment Report (AR4) calculate carbon dioxide equivalency of non-CO_2 emissions, as required in reporting annual inventories to the UNFCCC. The EPA will be shifting to use of 100-year GWPs from the IPCC's Fifth Assessment Report (AR5) in 2024 with the first reporting under the Paris Agreement starting in 2024. Until then, consistent with UNFCCC reporting guidelines the EPA will continue to use AR4 100-year GWPs.

1.2 Institutional Arrangements for Compiling State-Level Inventory Estimates

In preparing the state-level inventory, the EPA took advantage of existing data arrangements used to compile the national *Inventory* (see Chapter 1.2 of the national *Inventory*). The EPA acknowledges the additional contributions from the U.S. Department of Agriculture's U.S. Forest Service (USDA-USFS) and National Oceanic and Atmospheric Administration (NOAA). USDA-USFS has ongoing efforts to prepare state-level data to track emissions and sinks from land use and land use change in forested lands and settlement lands. NOAA has compiled the state-level emissions and removals from coastal wetlands. The EPA also acknowledges additional effort from the USDA for providing state level data on energy use in agriculture and the Department of Energy, Energy Information Administration for providing state level energy use data.

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[2] Per the 2006 IPCC Guidelines, national inventories include greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction with some minor exceptions. For example, an exception, "CO_2 emissions from road vehicles should be attributed to the country where the fuel is sold to the end user." See Volume 1, Chapter 8, Section 8.2.1 on Coverage available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_8_Ch8_Reporting_Guidance.pdf.

[3] See Q2-10 of Frequently Asked Questions on general guidance and other inventory issues, https://www.ipcc-nggip.iges.or.jp/faq/faq.html.

The EPA also collects GHG emissions data from individual facilities and suppliers of certain fossil fuels and industrial gases through its GHGRP.[4] The GHGRP does not provide full economy-wide coverage of total annual U.S. greenhouse emissions and sinks (e.g., the GHGRP does not collect data on emissions from the agricultural, land use, and forestry sectors), but it is an important input to the calculations of state-level estimates in the *Inventory*. 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.

Data presented in this state-level inventory report and the EPA's GHGRP are complementary. As discussed across this report, in addition to annual emissions information, the GHGRP also provides other annual information such as activity data and emission factors that can improve and refine state-level trends over time. More information on the relationship between GHGRP and the *national* Inventory is available online at: https://www.epa.gov/ghgreporting/greenhouse-gas-reporting-program-and-us-inventory-greenhouse-gas-emissions-and-sinks.

1.3 Methods Overview

In developing the state-level estimates consistent with the national *Inventory*, the EPA used as a basis, or starting point, the same methods or methods based on those used to compile the national-level estimates. From this starting point, there were three different approaches taken to arrive at state-level estimates:

- Approach 1—Estimates were built by applying national methods directly to more geographically disaggregated data (at state or finer level). For example, estimates of Forest land remaining Forest land and Lands Converted to Forestland are built from existing data sets that already disaggregate to the state-Level (See Section 5.1.1). Also, portions of fossil fuel combustion emissions were based on the same approach as the national estimates using state disaggregated energy consumption data (See Section 2.1.1).
- Approach 2—Estimates were disaggregated from national-level estimates using geographic proxies or other indicators (i.e., population, production capacity, GHGRP, etc.). This approach was used for categories where the type of state data used in Approach 1 were not available or were incomplete. For example, Approach 2 is used to estimate state-level emissions from other process uses of carbonates (see Section 3.1.4) where state level population is used as an proxy to allocate national emissions. A key factor in Approach 2 is how well emissions correlate with proxies, and where multiple options exist, how to choose among them.
- Hybrid approach: Under this approach, estimates used a combination of Approach 1 and Approach 2 methods over the time series because data availability limited the use of Approach 1 for all years of the time series. For example, some estimates may use the EPA's Greenhouse Gas Reporting Program which began collecting data in 2010, as a basis for national and state level estimates. For these categories, the EPA uses Approach 1 for 2010–2019 and uses Approach 2 for earlier years of the time series to arrive at state-level estimates, using IPCC guidance to ensure consistency over the time series to the extent possible. For example, the Hybrid approach is used to estimate state-level CO_2 and PFC emission from Aluminum Production (see Section 3.3.3).

Across this report, in addition to a sector-level summary, under each category, the EPA has indicated the approach used to disaggregate national estimates to the state-level. Where appropriate for explaining methods used under Approach 2 or the Hybrid approach, the EPA has included equations to enhance understanding of the

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[4] https://www.epa.gov/ghgreporting

implementation of disaggregation methods. The EPA has also included data appendices to provide underlying data to estimate emissions and sinks.

1.4 Quality Assurance and Quality Control (QA/QC) Procedures

In disaggregating emissions and sinks from the national *Inventory*, the EPA implemented QC procedures during the compilation process to ensure quality, transparency, and credibility of the state GHG data. The EPA implemented general QC procedures drawn from the existing QA/QC plan[5] for the national *Inventory* to ensure that data processing and application of methods could easily identify and correct errors (i.e., data/unit transcription, computation, and trend checks). The EPA also implemented additional category-specific QC procedures to assess disaggregation approaches (e.g., comparisons with other data such as available state GHG inventories) to further review methods estimates, including comparing category estimates to available state GHG inventories and comparing the sum of State estimates to national estimates. When additional category-specific QC procedures were implemented, this procedure and findings are discussed in the respective category section.

The EPA also implemented QA procedures outlined by the EPA and IPCC good practices. The EPA conducted a peer review and state expert review from September 17 to November 1, 2021. Both reviews are described further below. The QA/QC findings also informed the overall improvement planning, and specific improvements are noted in the planned improvements sections of respective categories.

1.4.1 Peer Review

This methodology report and the resulting state-level estimates was independently peer reviewed. Seventeen external experts participated in a process independently coordinated by RTI International and an EPA peer-review coordinator.

The EPA gratefully acknowledges all the peer reviewers for their useful comments. The peer review report is available online here: https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals. The information and views expressed in this report do not necessarily represent those of the peer reviewers, who also bear no responsibility for any remaining errors or omissions. Details describing this review can be found below. Peer review of this report followed the procedures in the EPA's Peer Review Handbook, 4th Edition (EPA/100/B-15/001) for reports that do not provide influential scientific information.

The review was managed by a contractor under the direction of a designated EPA peer review leader, who coordinated the preparation of a peer review plan, the scope of work for the review contract, and the charge for the reviewers. The peer review leader played no role in producing the draft report. Each sectoral reviewer was charged with reviewing the introduction and sector or subsector of the report relevant to their expertise, resulting estimates and data appendices. Peer reviewers were charged with making specific comments and edits as well as providing written response to a set of general and category-specific charge questions. The EPA author team then responded to and addressed all comments from the peer reviewers in a written summary and revised the report accordingly.

1.4.2 State Expert Review

Concurrent with the peer review, technical staff from each state (e.g., environmental agencies, other state agencies, and/or institutions) were provided with an opportunity to review the draft data and a draft of this methodology report. The methodology report and state-level estimates were shared with state experts from all 50 US States and DC for review, with the same review charge. As part of the data review, the EPA organized four

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[5] See the Introduction section 1.6 and Annex 8 of the national *Inventory* for more information on the QA/QC plan available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019.

webinars (three in fall of 2021, and one in January 2022) with state experts and groups representing states (e.g. NACAA, AAPCA, ECOS, etc.). During the webinars, the EPA introduced the review process, the approach to developing this data, its relationship to the national *Inventory*, and its relationship to other EPA data (EPA's GHGRP) and existing EPA tools (State Inventory Tool (SIT)).

The EPA gratefully acknowledges all the state experts for their useful comments. The EPA asked state experts for feedback on materials, the resulting estimates and data appendices. State experts were asked to provide feedback to the same set of general and category-specific charge questions shared with peer reviewers. State experts were also encouraged to provide feedback outside the specific questions as well.

The EPA author team then responded to and addressed all comments from the state expert reviewers and revised the report accordingly. The report with responses to comments from state review report is available here: https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals.

1.5 Uncertainty

The EPA has not assessed quantitative uncertainties for the activity data and other parameters used to estimate state-level emissions for this current publication but has included qualitative information on how uncertainties compare to those assessed quantitively for each category in the national *Inventory*[6].

The uncertainties of state-level emissions estimates are generally expected to be comparable or higher than the uncertainties of national-level emissions estimates for two reasons. First, where emissions are estimated at the national level and then allocated to states based on proxy or surrogate data and indicators other than those used to estimate emissions (i.e., where Approach 2 is used), uncertainties in the relationship between the allocation indicator and the emissions increase the uncertainty of the allocation. For example, where total US production is multiplied by an emission factor to obtain total national-level emissions, but production capacity rather than production is used to allocate the US emissions to facilities and states, variation in each facility's capacity utilization will not be reflected in the estimates, increasing their uncertainty. Second, for some categories where state-level emissions are estimated using the same facility-based methods as are used for national-level emissions (i.e., where Approach 1 is used), state-level uncertainties will generally be higher than US-level uncertainties (in percentage terms), assuming the uncertainties in the estimates for each facility and state are independent of each other. For example, the EPA estimates the uncertainties in emissions from aluminum production at individual smelters to be +/-6%, +/-16%, and +/-20% for CO_2, CF_4, and C_2F_6 emissions respectively, but when propagated to the US level across the seven smelters that operated in 2019, these uncertainties decline to -2.3/+2.4% for CO_2 and -7.8/+7.7% for PFCs. Since the states with aluminum production each have just one to two smelters, the uncertainties in the state-level emissions will be closer to the uncertainties in the emissions for individual smelters than to the uncertainties in the national-level emissions.

For more information on uncertainties with national-level GHG estimates, see the Section 1.7 of the Introduction chapter to the national *Inventory*. Category-specific uncertainties for national estimates are included in the category-specific methodological discussions across the national *Inventory* report.

1.6 Planned Improvements

Across the report, per the EPA's quality control and feedback from both the peer and state reviews, the EPA has outlined areas for improving future annual publications of this data at the category level across the report.

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[6] Within the Forest Land remaining Forest Land and Lands Converted to Forest Land categories, U.S. Forest Service has quantified uncertainties for State-Level Estimates for net CO_2 flux from Forest Ecosystem C Pools and non-CO_2 emissions from forest fires that are the basis for the estimates also in the national Inventory. The quantified uncertainties are available in the USFS Resource Update FS–307 (Domke, 2021) available https://www.fs.fed.us/nrs/pubs/download/ru_fs307_Appendix2.pdf.

Based on feedback, the EPA is also prioritizing the following cross-cutting improvements for future annual publications of this data:

- A key category analysis for each state consistent with IPCC guidance and international reporting guidelines to help identify categories that are more significant at the state level
- Improve disaggregation of state-level data so it is consistent with disaggregation at the national level. For some categories, the disaggregation approach (e.g., use of Approach 2 or Hybrid approach) may impact the feasibility to present disaggregated estimates.

2 Energy (NIR Chapter 3)

For this methodology report, energy emissions are broken into two main categories: emissions associated with fuel use (including fossil fuel combustion [FFC] and nonenergy use [NEU]–related emissions) and fugitive emissions mainly from fuel production. The energy emissions presented here include some categories that are not added to Energy sector totals in the national *Inventory* but are instead presented as memo items (including bunker fuels[7] and biomass emissions[8]), consistent with UNFCCC reporting guidelines. This approach directly affects state-level energy sector estimates and, in some cases, may account for differences with official estimates published by individual state governments. For more information on energy sector emissions, see Chapter 3 of the national *Inventory*. Table 2-1 summarizes the different approaches used to estimate state-level energy emissions and completeness across states. Geographic completeness is consistent with the national *Inventory*. The sections below provide more detail on each category.

Table 2-1. Overview of Approaches for Estimating State-Level Energy Sector GHG Emissions

Category	Gas	Approach	Geographic Completeness
Fossil Fuel Combustion	CO_2, CH_4, N_2O	Hybrid Approach • Approach 1 used for most fuels and sectors • Approach 2 proxy data used to allocate national totals for some fuels and sectors	Includes emissions from all states, Washington D.C., and territories (i.e., American Soma, Guam, Puerto Rico, U.S. Virgin Islands, Northern Mariana Islands and other outlying minor islands) as applicable.
Non Energy Uses of Fossil Fuels	CO_2	Approach 2	Includes emissions from all states, Washington D.C., and territories (i.e., American Soma, Guam, Puerto Rico, U.S. Virgin Islands, Northern Mariana Islands and other outlying minor islands) as applicable.
Geothermal Emissions	CO_2	Approach 2	Includes emissions from all states and Washington D.C. as applicable[1].
Incineration of Waste	CO_2, CH_4, N_2O	Hybrid Approach • 1990-2000: Approach 1 • 2001-2019: Approach 2	Includes emissions from all states and Washington D.C. as applicable[1].
International Bunker Fuels (memo item)	CO_2, CH_4, N_2O	Approach 2	Includes emissions from all states and Washington D.C as applicable.
Wood Biomass and Biofuels Consumption (memo item)	CO_2	Approach 2	Includes emissions from all states and Washington D.C. as applicable[1].
Coal Mining	CH_4	Approach 1: Active Underground Mines Approach 1: Surface Mining and Post-mining Activities	Includes emissions from all states and Washington D.C. as applicable[1].

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[7] Emissions from International Bunker Fuels are not included specifically in summing Energy sector totals. The values are presented for informational purposes only, in line with the *2006 IPCC Guidelines* and UNFCCC reporting obligations.

[8] Emissions from Wood Biomass, Ethanol, and Biodiesel Consumption are not included specifically in summing Energy sector totals. The values are presented for informational purposes only, in line with the *2006 IPCC Guidelines* and UNFCCC reporting obligations net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for LULUCF.

Abandoned Underground Coal Mines	CH_4	Approach 2	Includes emissions from all states and Washington D.C. as applicable[1].
Petroleum and Natural Gas Systems	CO_2, CH_4, N_2O	Approach 2	Includes emissions from all states, Washington D.C. and territories (i.e., American Soma, Guam, Puerto Rico, U.S. Virgin Islands, Northern Mariana Islands and other outlying minor islands) as applicable[1].
Abandoned Oil and Gas Wells	CO_2, CH_4	Approach 2	Includes emissions from all states, Washington D.C. and territories (i.e., American Soma, Guam, Puerto Rico, U.S. Virgin Islands, Northern Mariana Islands and other outlying minor islands) as applicable[1].

[1] Emissions are not likely occurring in US territories; due to a lack of available data and the nature of this category, territories not listed are not estimated.

2.1 Emissions Related to Fuel Use

This section presents the methodology used to estimate the fuel use portion of emissions, which consists of the following sources:

- FFC (CO_2, CH_4, N_2O)
- Carbon emitted from NEUs of fossil fuels (CO_2)
- Geothermal emissions (CO_2)
- Incineration of waste (CO_2, CH_4, N_2O)
- International bunker fuels (IBFs) (CO_2, CH_4, N_2O)
- Wood biomass and biofuels consumption (CO_2)

2.1.1 Fossil Fuel Combustion (NIR Section 3.1)

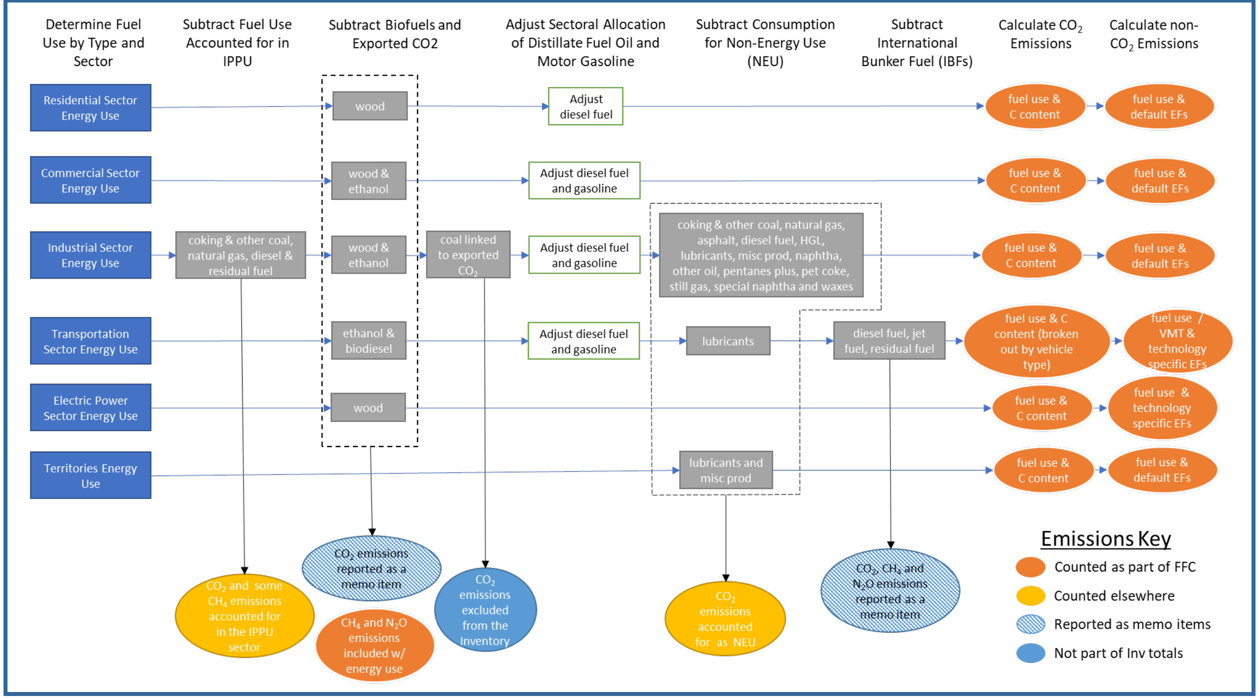
2.1.1.1 Background

Emissions from the combustion of fossil fuels include the GHGs CO_2, CH_4, and N_2O. CO_2 is the primary gas emitted from FFC and represents the largest share of U.S. total GHG emissions. The methods for estimating CO_2 emissions from FFC and the methods used to estimate CH_4 and N_2O emissions from stationary and mobile combustion rely in large part on the same underlying data. However, there are some differences; therefore, the methods used to estimate CO_2 and non-CO_2 emissions are presented separately.

2.1.1.2 Methods/Approach

The approach for determining national-level FFC emissions is based on multiplying emissions factors times activity data on fuel consumption. The activity data on fuel consumption was taken from national-level energy balances prepared by the U.S. Energy Information Administration (EIA) *Monthly Energy Review* (MER) estimates (EIA 2020). The EIA prepares national-level energy statistics that consider energy production imports/exports and stock changes to determine energy supply/consumption. The fuel consumption information is used as a starting point for determining emissions.[9] The approach starts with determining fuel use by fuel type because different types of fuels have different C content and therefore different emissions factors. The information is also broken out by energy-consuming sectors of U.S. society to provide more detail and information on trends; the sectors included are residential, commercial, industrial, transportation, and electric power. Data from U.S. territories were also included in the analysis as per international reporting requirements. Several adjustments were made to the data to account for fuel use and emissions that are either excluded or reported in other parts of the national *Inventory*, as shown in Figure 2-1.

Figure 2-1: Adjustments to Energy Consumption for Emissions Estimates



This section describes how national-level estimates for FFC were disaggregated to the state level for the following separate sources:

- FFC CO_2
- Stationary non-CO_2 emissions
- Mobile non-CO_2 emissions

This section also discusses how energy use data were broken out at the state level as part of the adjustments noted in Figure 2-1 and then used to report emissions elsewhere in the national *Inventory*. Emissions from energy use that were excluded from FFC are discussed in other sections of the report as follows:

- Energy used in the IPPU sector—see Chapter 3
- Biofuel use-see Section 1.1.6
- NEUs of fuels-see Section 1.1.2
- IBFs-see Section 1.1.5

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[9] The energy balance data include information on all energy sources. Emissions estimates exclude data on non-emitting sources (e.g., nuclear, wind, solar); however, they are considered when looking at overall energy use and efficiency.

Disaggregating FFC emissions to the state level largely followed the same process and energy consumption data that are used at the national level. However, in several instances the data used to develop national estimates are not available at the state level, and additional steps were needed to distribute national-level emissions across the states while maintaining consistency with national-level totals. Therefore, Approach 3, the Hybrid Approach as described in Section 1.2 of the introduction chapter, was used to determine state-level emissions for FFC, including some data that were directly used in the national *Inventory* and some surrogate data as discussed in the following sections.

FFC CO_2 State-Level Breakout

CO_2 emissions from FFC at the national level are estimated with a Tier 2 method described by the IPCC in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). As discussed above, this method is based on multiplying activity data on fuel use (that have been adjusted to allocate and report data consistent with UNFCCC reporting guidelines and avoid double counting) by emissions factors to determine emissions.

Determining adjusted fuel use activity data is based on the seven steps discussed in Table 2-2. The result of these seven steps is an adjusted amount of fuel use activity data that are then used to determine FFC CO_2 emissions. In Appendix A to this document (included as separate Excel files), the “National 2019 FFC CO2” Tab provides more details on an example of the adjustments made to the national-level energy use data to determine adjusted fuel use activity data for 2019. Three additional steps (Steps 8–10 in Table 2-1) are required to determine CO_2 emissions in the national *Inventory,* also discussed below.

Ideally, to determine state-level FFC CO_2 emissions estimates, the same approach could be used, and adjusted energy use, as shown in Appendix A, the “National 2019 FFC CO2” Tab, could be developed for each state. However, the national-level emissions were developed based on multiple factors and inputs, some of which were not available or readily published at the state level. Therefore, a Hybrid Approach was taken where state-level data were used when available and in cases where state-level data were not available, national-level estimates were used with available surrogate data to determine state-level percentages of each fuel use. Table 2-1 shows a high-level comparison of the different data sources used for the different steps to determine national-level and state-level estimates.

Table 2-2. Comparison of Approaches/Data Sources Used to Determine FFC Emissions

Calculation Step	National-Level Estimates	State-Level Estimates
	Determine Activity Data	
Step 1: Determine Total Fuel Consumption by Fuel Type and Sector	Based on EIA MER	Based on EIA SEDS (adjusted to match national totals as applicable)
Step 2: Subtract Uses that are Accounted for in the IPPU Sector	Taken from industry data or based on national-level emissions	National-level data allocated to states based on state-level emissions estimates for each IPPU category in question as calculated in Chapter 3
Step 3: Adjust for Biofuels and Petroleum Denaturant	Based on national-level data from EIA MER	Not needed (see Step 5)
Step 4: Adjust for CO_2 Exports	Based on industry data and Canadian import data	Based on industry data and Canadian import data
Step 5: Adjust Sectoral Allocation of Diesel Fuel and Gasoline	Based on bottom-up transportation sector data on fuel use by vehicle type	National-level data (already excluding biofuels) allocated to states based on

		state-level fuel use data (not vehicle specific)
Step 6: Subtract Consumption for Nonenergy Uses (NEUs)	Based on data from EIA MER	National-level data allocated to states based on SEDS
Step 7: Subtract Consumption of IBFs	Based on data from Federal Aviation Administration (FAA) and other national-level sources	National-level data allocated to states based on SEDS and other sources
Calculate CO_2 Emissions		
Step 8: Determine the Carbon content of each fuel consumed	National-level average C content values	National-level average C content values
Step 9: Estimate CO_2 Emissions –	Multiply C content by activity data and oxidation percentage	Multiply C content by activity data and oxidation percentage
Step 10: Allocate transportation emissions by vehicle type	Allocated at the national level based on data from Step 5	Not done

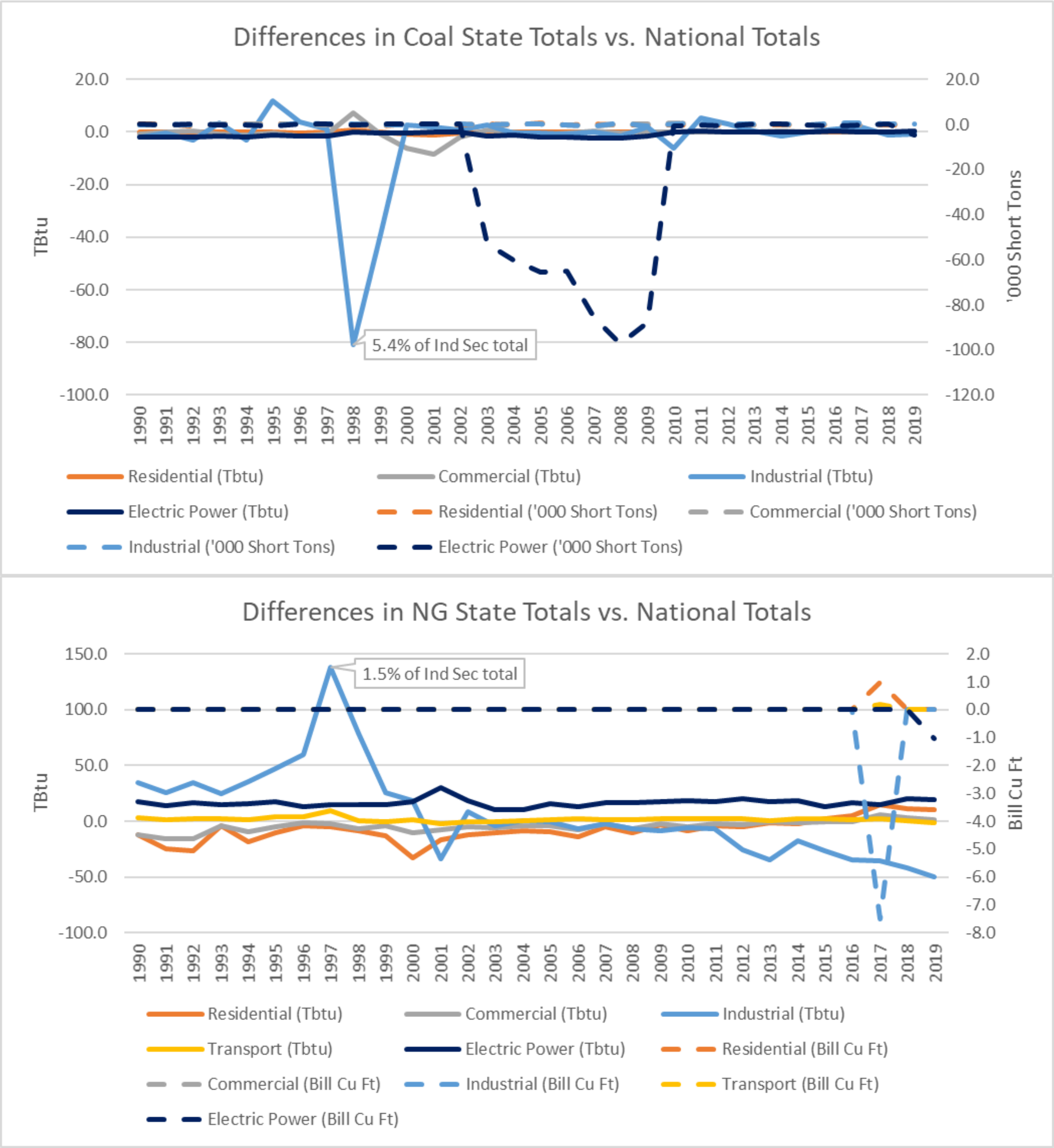
The following discussion details what data were used for each step in Table 2-1 to determine national and state-level FFC emissions. Appendix A Table A-1 in the “FCC CO_2” Tab provides more details on where state-level data were used directly and where other data were used to make adjustments to disaggregate national numbers across fuel types and sectors for each of the steps identified.

Step 1: Determine Total Fuel Consumption by Fuel Type and Sector

As discussed above, national-level data on fuel supply/consumption comes from EIA’s national energy balance in the MER. Because not all fuel supplied/consumed directly results in GHG emissions or could be included as part of other emissions reporting in the national *Inventory*, adjustments have to be made as shown above and described in the following steps. state-level energy data are available from the EIA’s State Energy Data System (SEDS). Those data are broken out by fuel type and sector (residential, commercial, industrial, transportation, and electric power) and are available for the years 1960–2019 (EIA 2021b). SEDS estimates energy consumption using data from surveys of energy suppliers that report consumption, sales, or distribution of energy at the state level. Most of the SEDS estimates rely directly on collected state-level consumption data. For example, SEDS uses state-level sales survey data and other proxies of consumption to allocate the national petroleum product supplied totals to the states. The sums of the state estimates equal the national totals as closely as possible for each energy type and end-use sector, and energy consumption estimates are generally comparable to the national statistics in EIA’s MER because both datasets rely largely on the same survey returns for producers and consumers.

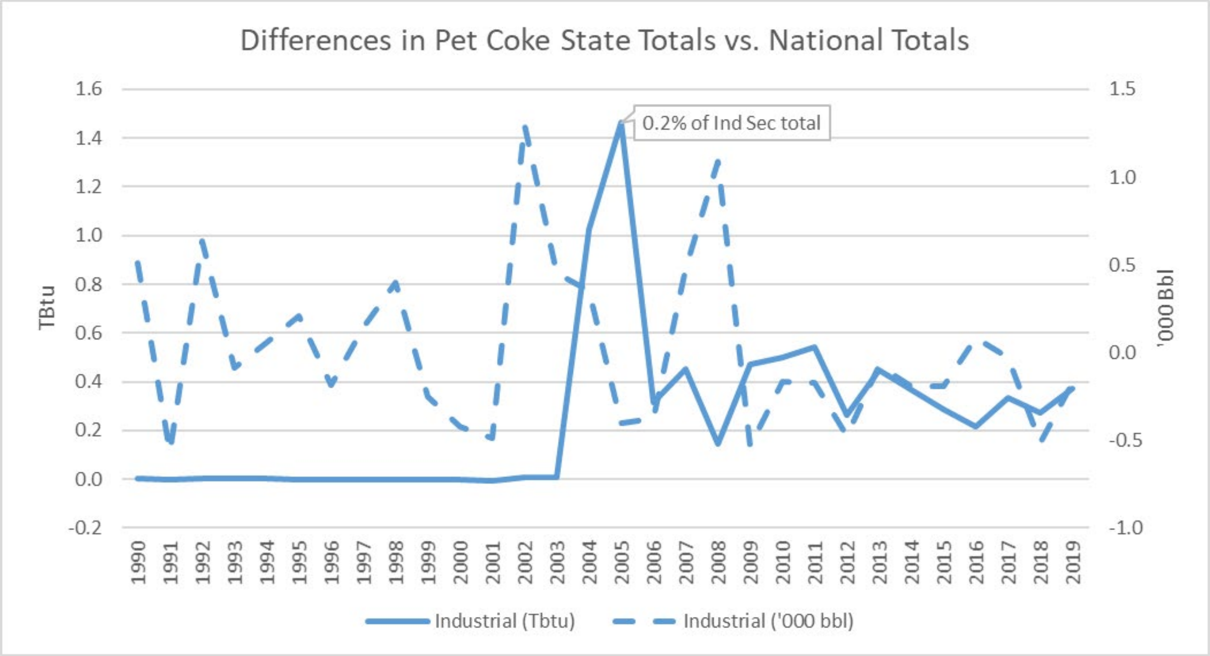
However, the totals across all states (and the District of Columbia) from SEDS do not always match the U.S. total energy data used in the national *Inventory*, which is based on the EIA November 2020 MER estimates (EIA 2020). The main differences are for coal and natural gas and primarily in the industrial sector, as shown in Figure 2-2. For coal, there are differences in both energy content and short tons, but the differences are not consistent across time or sectors. For natural gas, the difference is mainly in the energy content. The reason for the differences is that SEDS uses state-level energy content conversion factors for coal and natural gas, while the MER uses national-level conversion factors. This sometimes causes the sums of the SEDS states to be different than the MER values. Although the percentage differences are not large (max 5.4% and 1.5% for coal and natural gas, respectively, in the industrial sector), they cause noticeable differences when comparing emissions totals across all states to national totals, especially by sector.

Figure 2-2: Differences Between State-Level and National Total Energy Use for Coal and Natural Gas



The petroleum categories generally line up well across state-level and national totals. There are only minor differences in petroleum coke, mainly in the industrial sector, as shown in Figure 2-3. For petroleum coke, there are differences in energy content and barrels, but the difference in energy content appears in 2004, which is when petroleum coke heating values were changed from a constant value to values based on marketable and catalyst coke. Again, this difference is because of different national-level and state-level conversion factors. Beginning in 2004, the MER uses an annual national-level “quantity-weighted” average petroleum coke conversion factor (instead of a fixed factor). SEDS applies the marketable and catalyst coke conversion factors to the state-level consumption of each petroleum coke category within each state.

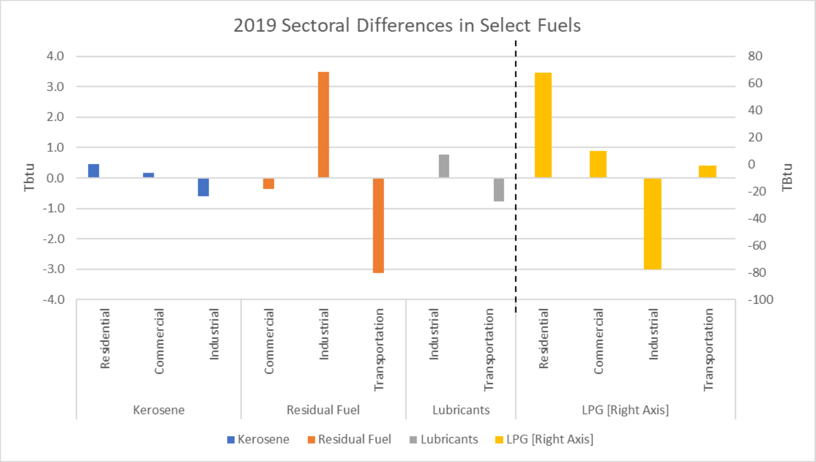
Figure 2-3: Differences Between State-Level and National Total Energy Use for Petroleum Coke



For diesel fuel and gasoline, the totals generally line up, but there are differences across sectors. This is discussed in Step 5 below.

In addition to the differences in gasoline and diesel fuel across sectors over the time series, there are also differences in some petroleum fuels across sectors, specifically in 2019. This is because the SEDS represents the latest data from EIA in terms of sector breakouts that were not reflected in the national *Inventory* 2019 values that relied on data from November 2020. Again, the totals for the fuels line up, but there are differences across sectors, as shown in Figure 2-4. The updated SEDS data were used in the state-level breakout because it represents the latest data available. This results in differences in 2019 results across sectors for the state totals vs. the national *Inventory*. However, the national *Inventory* numbers will be updated to match the 2019 SEDS data during the next national *Inventory* cycle.

Figure 2-4: 2019 Differences Between Sectors for Petroleum Fuels (SEDS – National *Inventory*)



Furthermore, some of the fuel use reported in SEDS is different from the reporting in the national *Inventory*. For example, natural gas reported in SEDS includes supplemental gas, which is included in the national *Inventory* under the primary fuel used to make the supplemental gas so including it would result in double counting. Liquefied petroleum gas (LPG) in SEDS is reported differently over time, including as total hydrocarbon gas liquids (HGLs) that include natural gasoline (pentanes plus) and as a mix of different gases. Natural gasoline (called pentanes plus in the national *Inventory*) is accounted for separately from other HGLs in the national *Inventory*. Gasoline and distillate fuels in SEDS include biofuels (fuel ethanol and biodiesel only, renewable diesel and other biofuels are included in the MER but not estimated in SEDS yet), which were reported separately in the national *Inventory*. These differences make it difficult to use the SEDS data directly to determine state-level fuel use data, in a manner consistent with the national *Inventory*.

Therefore, the following approach was used in determining fuel use by type by sector at the state level:

- If SEDS data totals matched the national totals and there were no further adjustments needed (as per Steps 2-7), the SEDS data were used directly to represent state-level energy use.
- For fuels where the SEDS totals did not match the national totals (i.e., coal, natural gas, and petroleum coke), fuel use in each sector was adjusted to match the national totals used in the national *Inventory*. This calculation was based on the percentage of each fuel used in each state from the SEDS data. For the industrial sector, this adjustment was made after subtracting for uses in the IPPU sector (see Step 2 below).
- For other fuels where sector totals did not match up (e.g., gasoline and diesel fuel), totals for each fuel type were generally taken from the national *Inventory* (see Step 5), and the SEDS data or other proxy data sources were used to determine state-level percentages of each fuel use.

This approach generally results in state-level energy use data that are consistent with national totals used in the national *Inventory*. More details on further adjustments made during the different steps are discussed below.

Appendix A has details on how the SEDS data were adjusted to determine state-level energy use by fuel type and sector. Tables A-2 through A-6 in the "FFC CO_2 Residential" Tab describe the residential sector adjustments. Tables A-9 to A-13 in the "FFC CO_2 Commercial" Tab describe the commercial sector adjustments. Tables A-44 through A-47 in the "FFC CO_2 Industrial" Tab describe the industrial sector adjustments for petroleum coke and HGL, the remaining industrial sector adjustments are described further in Steps 2 and 3 below. Tables A-50 and A-

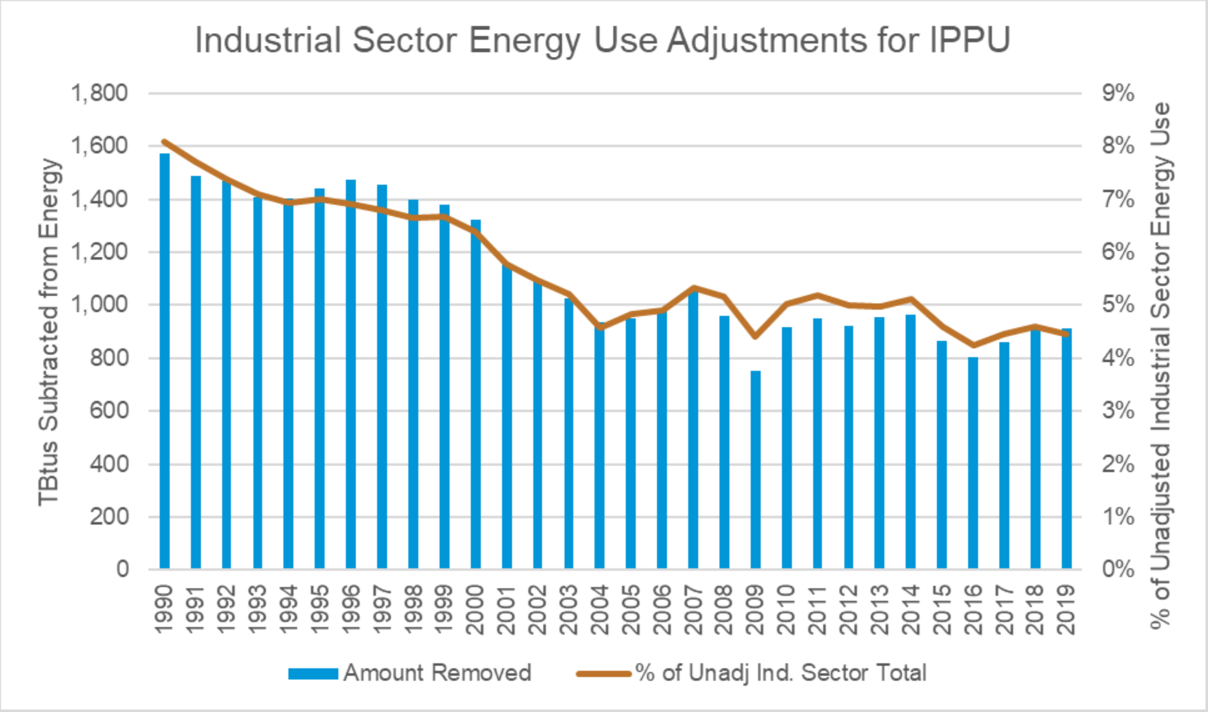
51 in the "FFC CO_2 Transportation" Tab describe the transportation sector adjustments. Tables A-52 to A-56 in the "FFC CO_2 Electricity" Tab describe the electricity production sector adjustments.

Step 2: Subtract Uses That Are Accounted for in the IPPU Sector

In the national *Inventory*, portions of fuel consumption data for several fuel categories (coking coal, other coal, natural gas, residual fuel, and distillate fuel) are reallocated from Energy to the Industrial Processes and Product Use (IPPU) chapter, because these portions were consumed as raw materials during nonenergy-related industrial processes. As per IPCC Guidelines that distinguish between the Energy and IPPU sector reporting (IPCC 2006, Volume 3, Chapter 1), emissions from fuels used as raw materials are presented as part of IPPU and are removed from the energy use estimates. Portions of fuel use were therefore subtracted from the industrial sector fuel consumption data before determining combustion emissions. Note: Other adjustments were also made to the NEU calculations to reflect energy use accounted for under IPPU; see Step 6 and the NEU emissions discussion below.

The adjustments vary over time and represent from about 4 to 8% of total unadjusted industrial sector energy use, as shown in Figure 2-5.

Figure 2-5: Adjustments Made to Industrial Sector Energy Use to Account for Emissions Reported in IPPU



Adjustments for each fuel type were made based on industry data or assumptions about fuel use based on emissions reported under IPPU. The following bullets discuss the assumptions made regarding the different industrial sector fuel types at the national and state levels to reflect their use in IPPU:

- Coking coal: Coking coal is used to make coke that, in turn, is used in industrial processes. The national total amount of coking coal used in IPPU was back-calculated based on the amount of coking coal needed to make the coke used as input to iron and steel (I&S) and lead and zinc production (the majority ~94% is used in I&S). National-level coke use in I&S production was based on industry data that are not available at the state level. Coke used in lead and zinc production was based on the amount of carbon emitted from the processes and is also not available specifically at the state level. Therefore, the national total amount of coking coal used in IPPU was allocated per state based on the percentage of total coking coal used per state from the SEDS data. This approach assumes that coke use in I&S and lead and zinc production is proportional to the amount of coking coal used in a state. This assumption may not be the case because state-level coking coal use is based on coke production in a given state, not necessarily coke use. The coke could be produced in one state and shipped for use in another state. However, given the lack of specific data, coking coal use was determined to be a good surrogate for coke use within a given state because coke production is often integrated with I&S production where the coke is used. As one further adjustment, if the amount of coking coal used in IPPU was greater than the total coking coal reported in the national energy statistics, the amount of coking coal used in the energy sector results were zeroed out to avoid negative values (this only occurs in 1990, 1991, 1992, and 1997), and additional other coal use was subtracted to make up the difference (see other coal below). Appendix A, Tables A-19 and A-20 in the "FFC CO2 Industrial" Tab describe the coking coal use in IPPU.

- Other coal: Two adjustments were made to account for other coal used in the industrial sector. The first adjustment was to subtract the extra amount of coking coal required for years where the coking coal adjustment was more than coking coal total (see above). Similar to coking coal, this adjustment was based on the percentage of coking coal consumption per state from SEDS. Appendix A, Tables A-21 and A-22 in the "FFC CO2 Industrial" Tab describe this adjustment. The second adjustment was to subtract coal used as direct use in the I&S sector. In addition to being used indirectly to produce coke, coal can be used directly as a process input to I&S production; note, this does not include coal combusted at I&S facilities to produce power. National-level other coal used in I&S production was based on industry data that are not available at the state level. Therefore, this adjustment was based on the percentage of I&S emissions per state. I&S emissions per state were taken from the IPPU breakout for I&S, as described in Section 3.3.1, and the percentage for basic oxygen furnaces (BOFs) was assumed to best represent other coal use in I&S. BOF emissions were determined to be a good surrogate for other coal direct use in I&S because coal is primarily used in the BOF process and would be proportional to emissions from the process. Appendix A, Table A-24 in the "FFC CO2 Industrial" Tab describes this adjustment. An IPPU-adjusted other coal total was then calculated by subtracting the adjustments described above (note: this also included the adjustments for conversion of fuels and CO_2 exports as described in Step 4 below). Appendix A, Table A-25 in the "FFC CO2 Industrial" Tab shows this total. The total other coal use was then adjusted to match the total other coal from the national *Inventory* (as per Step 1); this adjustment was based on the percentage of other coal used after the IPPU adjustment. Appendix A, Table A-26 in the "FFC CO2 Industrial" Tab describes this adjustment.
- Natural gas: Two adjustments were made to account for natural gas used in the industrial sector. The first adjustment was to subtract the amount of natural gas consumption that was used in ammonia production from energy sector natural gas use. The national-level natural gas used in ammonia production was back-calculated based on assumed CO_2 emissions from ammonia production and calculations on the amount of C in natural gas needed to produce those CO_2 emissions. Therefore, the state-level natural gas used for ammonia was based on the percentage of ammonia emissions per state. Ammonia emissions per state were taken from the IPPU breakout for ammonia, as described in Section 3.2.1. Appendix A, Tables A-27 through A-29 in the "FFC CO2 Industrial" Tab describe this adjustment. The second adjustment was to subtract natural gas used as direct use in I&S. National-level natural gas used in I&S production was based on industry data that are not available at the state level. Therefore, similar to other coal, the adjustment was based on the percentage of I&S emissions per state from the IPPU breakout for I&S, as described in Section 3.3.1, and the percentage for BOFs was assumed to best represent natural gas use in I&S. Similar to other coal direct use, BOF emissions were determined to be a good surrogate for natural gas direct use in I&S. Appendix A, Table A-30 in the "FFC CO2 Industrial" Tab describes this adjustment. An IPPU-

adjusted natural gas total was then calculated by subtracting the adjustments described above. Appendix A, Table A-31 in the "FFC CO2 Industrial" Tab shows this total. The total natural gas use was then adjusted to match the total natural gas use from the national *Inventory* (as per Step 1); this adjustment was based on the percentage of natural gas used after the IPPU adjustment. Appendix A, Table A-32 in the "FFC CO2 Industrial" Tab describes this adjustment.

- Residual fuel: The residual fuel use was adjusted to subtract the amount of residual fuel used in carbon black production. Carbon black was the only IPPU use of residual oil. The national-level residual oil used in IPPU was based on NEUs of residual oil from EIA data, which are not available at the state level. Therefore, the residual oil IPPU state-level adjustment was based on the percentage of carbon black emissions per state. Carbon black emissions per state were taken from the IPPU breakout for petrochemicals, as described in Section 3.2.9, and the percentage for carbon black specifically was used. Carbon black emissions were determined to be a good surrogate for residual oil use because the emissions from carbon black production would be directly proportional to residual oil use. Appendix A, Tables A-33 and A-34 in the "FFC CO2 Industrial" Tab describe this adjustment. An IPPU-adjusted residual fuel total was then calculated. Appendix A, Table A-35 in the "FFC CO2 Industrial" Tab shows this total. The total residual fuel use was then adjusted to match the total residual fuel from the national *Inventory* (similar to what was done for coal and natural gas in Step 1); this adjustment was based on the percentage of residual fuel used after the IPPU adjustment. This was done because after the adjustment the residual fuel use summed across states did not match the national totals anymore (likely due to the distribution of adjustment based on petrochemical production, which resulted in negative emissions in some states that were then zeroed out). Appendix A, Table A-36 in the "FFC CO2 Industrial" Tab describes this adjustment.
- Distillate fuel: Distillate fuel use was adjusted to subtract the amount of distillate fuel used as direct use in I&S production. National-level diesel fuel used in I&S production was based on industry data that are not available at the state level. Therefore, similar to other coal and natural gas direct use in I&S, the adjustment was based on the percentage of I&S emissions per state from the IPPU breakout for I&S, as described in Section 3.3.1, and the percentage for BOFs was assumed to best represent distillate fuel use. Similar to other coal and natural gas direct use in I&S, BOF emissions were determined to be a good surrogate for diesel fuel direct use in I&S. Appendix A, Tables A-37 and A-38 in the "FFC CO2 Industrial" Tab describe this adjustment. An IPPU-adjusted distillate fuel total was then calculated. Appendix A, Table A-39 in the "FFC CO2 Industrial" Tab shows this total. This total was adjusted further based on reallocation of diesel fuel use across sectors, as shown in Step 5 below.

Step 3: Adjust for Biofuels and Petroleum Denaturant

Fuel consumption estimates used for CO_2 calculations were adjusted downward to exclude fuels with biogenic origins consistent with the IPCC Guidelines. CO_2 emissions from ethanol and biodiesel consumption are not included in fuel combustion totals in line with the 2006 IPCC Guidelines and UNFCCC reporting obligations to avoid double counting with net carbon fluxes from changes in biogenic carbon reservoirs accounted for in the estimates for LULUCF. CO_2 emissions from biogenic fuels under fuel combustion are estimated separately and reported as memo items for informational purposes under the energy sector. Furthermore, for several years of the time series, denaturant used in ethanol production was double counted in both transportation and industrial sector energy use statistics. It was therefore subtracted from transportation sector energy use to avoid double counting. Fuels with biogenic origins (ethanol and biodiesel) and ethanol denaturant adjustments at the state level are handled by adjusting gasoline and diesel fuel use based on the total nonbiogenic components of those fuels only, as described in Step 5 below (which also include any adjustments for denaturant). So, in effect the state-level energy use calculations used to determine FFC emissions for gasoline and diesel fuel combine this Step 3 with Step 5 below. See Section 1.1.6 for more detail on biofuel use at the state level used to calculate biomass CO_2 as a memo item.

Step 4: Adjust for CO_2 Exports

Since October 2000, the Dakota Gasification Plant has been exporting CO_2 produced in a coal gasification process to Canada by pipeline. Because this CO_2 is not emitted to the atmosphere in the United States, the coal that is gasified to create the exported CO_2 is subtracted from fuel consumption statistics used to calculate combustion emissions in the national *Inventory*. Consistent with the approach currently used in the national *Inventory*, the coal used to produce exported CO_2 from the Dakota gas plant to Canada was subtracted from other coal use to determine state-level emissions. This was all assumed to be subtracted from North Dakota, the location of the Dakota gas plant. Appendix A, Table A-23 in the "FFC CO2 Industrial" Tab describes this adjustment.

Step 5: Adjust Sectoral Allocation of Distillate Fuel Oil and Motor Gasoline

Motor gasoline and diesel fuel are used across all sectors. The total amount of motor gasoline and diesel fuel consumed as reported in the MER is based on petroleum supply data from refineries. Gasoline use is allocated across the sectors in proportion to aggregations of categories reported by the U.S. Department of Transportation, Federal Highway Administration (FHWA), Highway Statistics data (FHWA 2020). Diesel fuel use is allocated to the electric power sector based on industry surveys. The remaining diesel fuel use is allocated across the remaining sectors in a similar way to gasoline use based on sales data to different categories from EIA's Fuel Oil and Kerosene Sales (FOKS) data (EIA 2021b). For the national *Inventory*, data are needed on fuel use by vehicle type to determine emissions, so a bottom-up method is used to estimate transportation sector gasoline and diesel fuel use. The national *Inventory* determines gasoline and diesel fuel use by vehicle type based on FHWA and DOE data (FHWA & DOE, numerous years). The national *Inventory* then allocates the remaining fuel use to the remaining sectors based on the proportions in the EIA data. The differences in the EIA and national *Inventory* gasoline and diesel fuel allocation approach across sectors are shown in Figure 2-6 and Figure 2-7, including information on the categories of use included in each sector and data for 2019 as an example.

Figure 2-6: Comparison of Gasoline Sector Allocation

EIA National Energy Balance

From the MER, Based on Refinery Supply Data

Total Supply	2019 ('000 Gal)
Motor Gasoline	142,706,970

From FHWA Data

Commercial Sector	2019 ('000 Gal)	% of Total
Public non-highway	112,897	
Lawn and garden*	2,982,755	
Misc.	26,495	
Sector Total:	3,122,147	2.1

Industrial Sector	2019 ('000 Gal)	% of Total
Ag	129,354	
Construction	386,714	
Ind. & comm.	1,738,881	
Sector Total:	2,254,949	1.6

Transportation Sector	2019 ('000 Gal)	% of Total
Highway	136,075,824	
Boating	2,127,566	
Rec. vehicles*	1,643,276	
Sector Total:	139,846,666	96.3

Total	2019 ('000 Gal)
Motor Gasoline	145,223,762

National Sector Split

Commercial Sector	2019 ('000 Gal)
Motor Gasoline	3,066,000

Industrial Sector	2019 ('000 Gal)
Motor Gasoline	2,222,850

Transportation Sector	2019 ('000 Gal)
Motor Gasoline	137,433,450

Non-Transportation Percent

58%

42%

* Note FHWA added the lawn and garden and recreational vehicle use categories in 2015 which causes a time series discontinuity in the split between the different sectors. EPA for the national Inventory back calculated fuel use for those categories and adjusts the FHWA data accordingly.

EPA National Inventory

From the MER, Based on Refinery Supply Data

Total Supply	2019 ('000 Gal)
Motor Gasoline	142,706,970

From FHWA & DOT Data

Remaining
5,273,273

Transportation Sector	2019 ('000 Gal)
Automobiles	93,868,957
Motorcycles	452,276
Buses	126,633
Light Trucks	36,560,116
Other Trucks	5,070,217
Boats (Recreational)	1,355,498
Sector Total:	137,433,697

Non-Transportation Percent from EIA

58%

42%

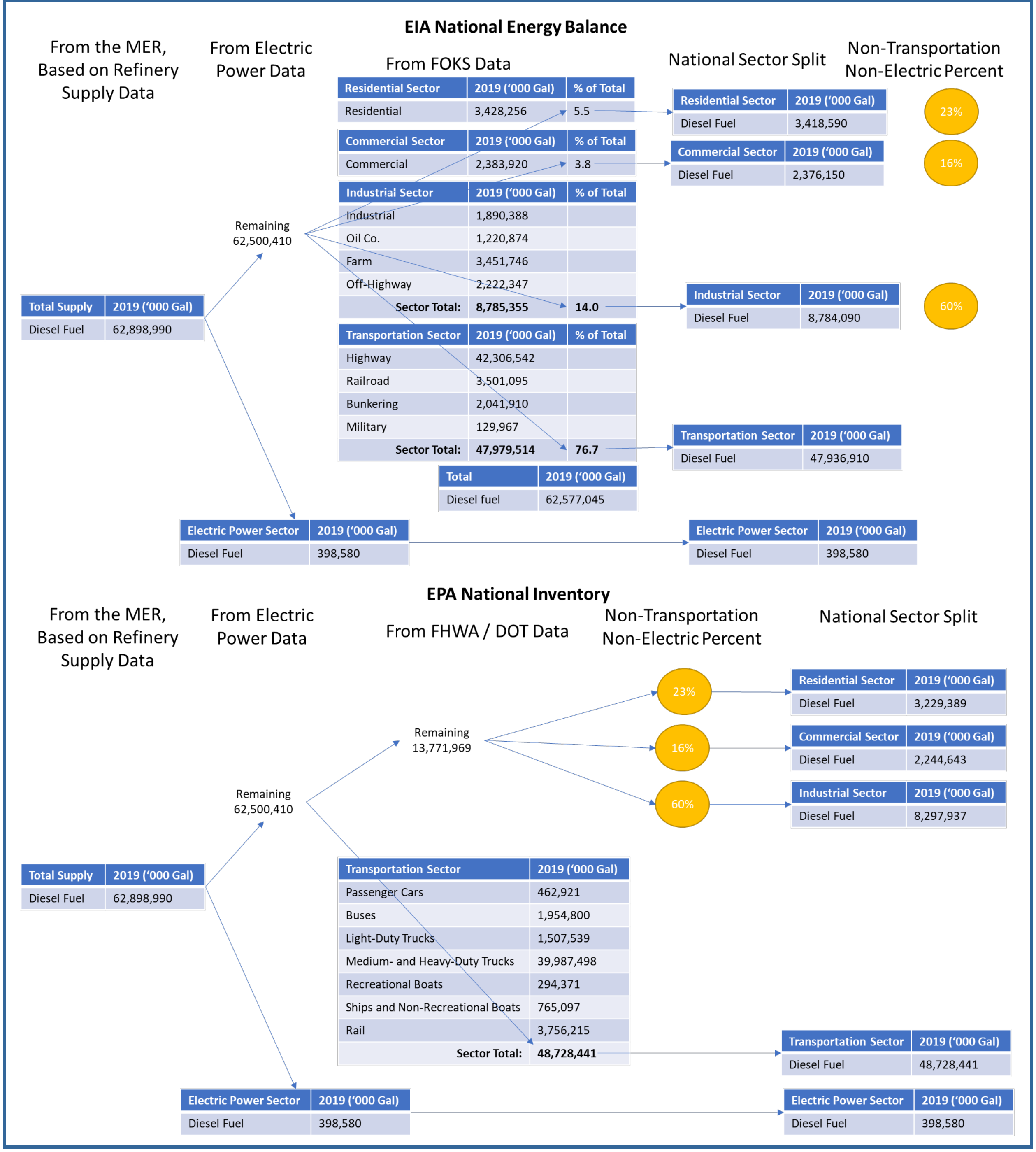
National Sector Split

Commercial Sector	2019 ('000 Gal)
Motor Gasoline	3,056,970

Industrial Sector	2019 ('000 Gal)
Motor Gasoline	2,216,303

Transportation Sector	2019 ('000 Gal)
Motor Gasoline	137,433,697

Figure 2-7: Comparison of Diesel Fuel Sector Allocation



EIA National Energy Balance

Total Supply	2019 ('000 Gal)
Diesel Fuel	62,898,990

Residential Sector	2019 ('000 Gal)	% of Total
Residential	3,428,256	5.5

Commercial Sector	2019 ('000 Gal)	% of Total
Commercial	2,383,920	3.8

Industrial Sector	2019 ('000 Gal)	% of Total
Industrial	1,890,388	
Oil Co.	1,220,874	
Farm	3,451,746	
Off-Highway	2,222,347	
Sector Total:	**8,785,355**	**14.0**

Transportation Sector	2019 ('000 Gal)	% of Total
Highway	42,306,542	
Railroad	3,501,095	
Bunkering	2,041,910	
Military	129,967	
Sector Total:	**47,979,514**	**76.7**

Total	2019 ('000 Gal)
Diesel fuel	62,577,045

Electric Power Sector	2019 ('000 Gal)
Diesel Fuel	398,580

Residential Sector	2019 ('000 Gal)
Diesel Fuel	3,418,590

Commercial Sector	2019 ('000 Gal)
Diesel Fuel	2,376,150

Industrial Sector	2019 ('000 Gal)
Diesel Fuel	8,784,090

Transportation Sector	2019 ('000 Gal)
Diesel Fuel	47,936,910

Electric Power Sector	2019 ('000 Gal)
Diesel Fuel	398,580

EPA National Inventory

Total Supply	2019 ('000 Gal)
Diesel Fuel	62,898,990

Transportation Sector	2019 ('000 Gal)
Passenger Cars	462,921
Buses	1,954,800
Light-Duty Trucks	1,507,539
Medium- and Heavy-Duty Trucks	39,987,498
Recreational Boats	294,371
Ships and Non-Recreational Boats	765,097
Rail	3,756,215
Sector Total:	**48,728,441**

Electric Power Sector	2019 ('000 Gal)
Diesel Fuel	398,580

Residential Sector	2019 ('000 Gal)
Diesel Fuel	3,229,389

Commercial Sector	2019 ('000 Gal)
Diesel Fuel	2,244,643

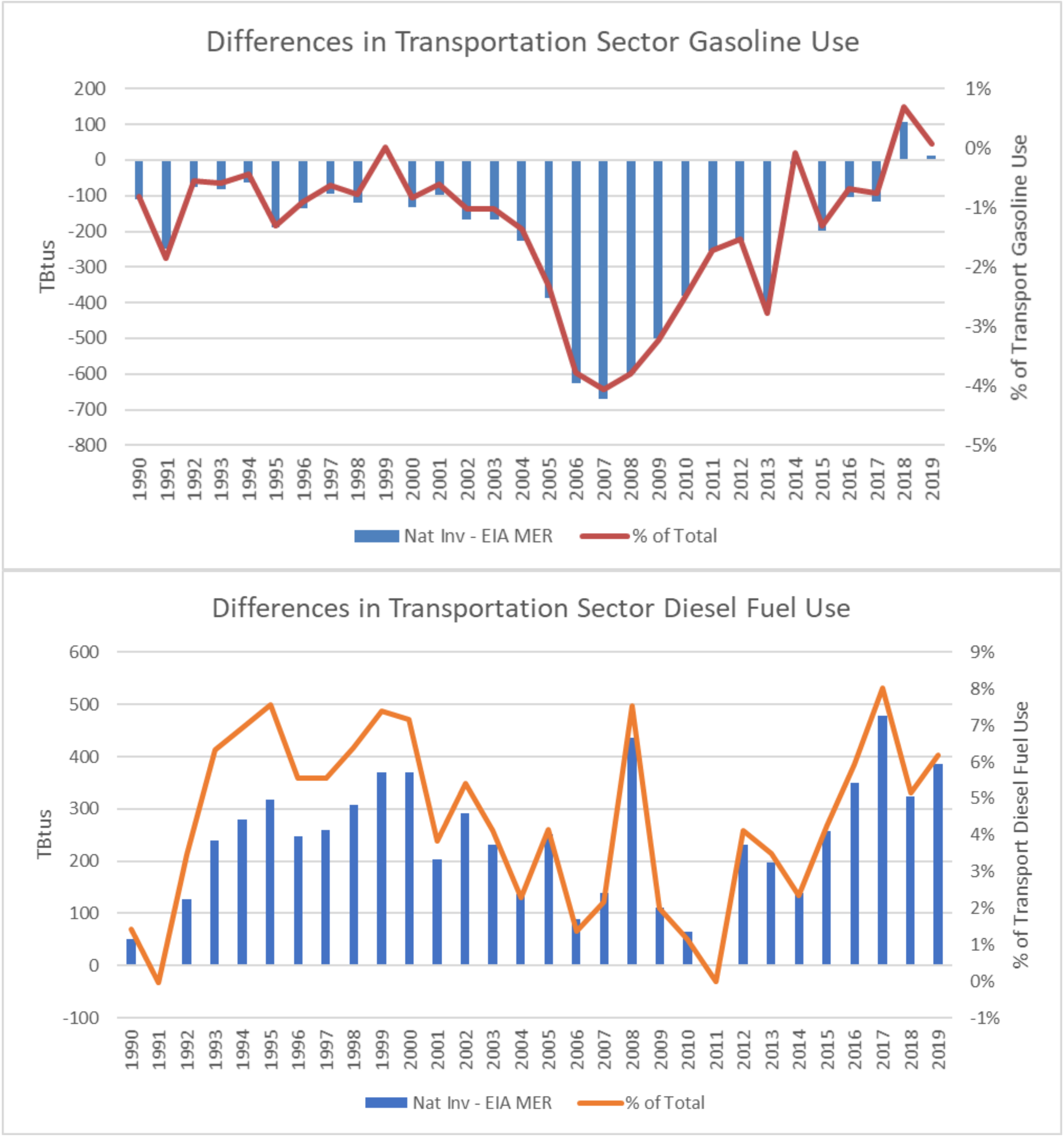
Industrial Sector	2019 ('000 Gal)
Diesel Fuel	8,297,937

Transportation Sector	2019 ('000 Gal)
Diesel Fuel	48,728,441

Electric Power Sector	2019 ('000 Gal)
Diesel Fuel	398,580

The bottom-up approach used by the national *Inventory* to determine transportation sector fuel use generally results in less allocation of gasoline to the transportation sector (and more to other sectors) and more diesel fuel allocated to the transportation sector (and less to other sectors) compared with the original MER energy balance data as shown in Figure 2-8.

Figure 2-8: Comparison of Transportation Sector Fuel Use

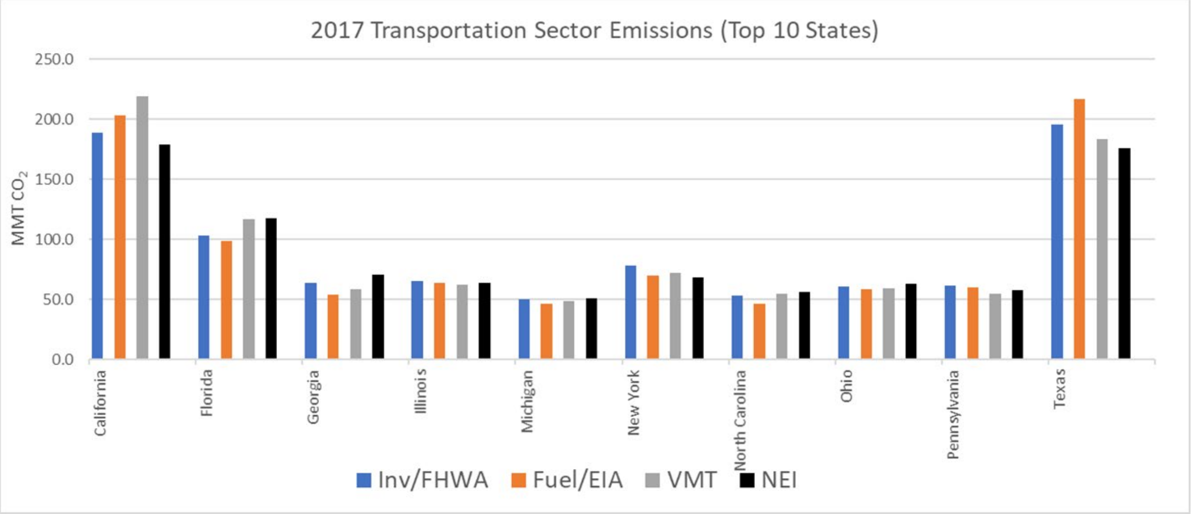


The national-level data on gasoline and diesel fuel use by vehicle type used in the bottom-up analysis was not readily available at the state level. Therefore, the following assumptions and adjustments were made to distillate fuel and motor gasoline consumption at the state level across the different sectors to reflect the national *Inventory* bottom-up transportation fuel use approach:

- Transportation sector: The total amount of distillate fuel and motor gasoline used in the transportation sector was taken from the national *Inventory* totals (these totals already subtract biofuel use, subtract denaturants if needed, and are based on multiple factors to determine transportation sector fuel use).

This total amount of distillate fuel and motor gasoline use and emissions was allocated across states based on the percentage of fuel use by state in gallons from FHWA data (FHWA 2020). For distillate fuel, the total was based on FHWA form MF-225, and the motor gasoline total was based on FHWA form MF-226, both of which have time series of fuel use by state. Appendix A, Tables A-48 and A-49 in the "FFC CO2 Transportation" Tab describes this adjustment. The FHWA data reflect on-highway fuel use, but, as seen in Figure 2-6 and Figure 2-7, the transportation sector fuel use includes some mobile sources that are considered off-highway (e.g., recreational boating, railroads). However, because the majority of the motor gasoline and diesel fuel use is for on-highway purposes, using FHWA data to allocate transportation sector fuel use to the state level is reasonable. Note that FHWA state-level fuel consumption data are representative of the point-of-sale and not the point-of-use, so fuel sold in one state that may be combusted in other states is assigned to the state where the fuel was purchased. This approach is consistent with IPCC Guidelines (IPCC 2006) for country-level reporting that indicate that "where cross-border transfers take place in vehicle tanks, emissions from road vehicles should be attributed to the country where the fuel is loaded into the vehicle." Therefore, when applying the IPCC approach to the state-level inventory, vehicle emissions are attributed to the state where the vehicle fuel is sold. This approach could introduce some differences in state-level transportation sector fuel use and emissions allocations reported here and those reported by individual states. For example, in addition to fuel sales data, state-level vehicle miles traveled (VMT) data are another potential surrogate for allocating fuel use to the state level, but that approach does not account for vehicle and fleet fuel economy variability between states. The EPA will consider alternative or complementary approaches to allocate transportation fuel across states, including VMT data and other sources (e.g., NEI—based on county-level fleet and activity data to generate a bottom-up inventory [NEI 2017]). [10] Figure 2-9 shows the transportation sector emissions in 2017[11] from the top 10 emitting states using different allocation approaches. As seen in the figure, the approach used will lead to different allocations across states.

Figure 2-9: Transportation Sector State-Level Allocation Examples



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[10] Note the NEI uses a bottom-up method for determining transportation sector fuel use and emissions based on VMT and assumed vehicle fleet fuel efficiency, etc. at the county level through the MOVES model. However, that approach if applied across all States could lead to differences with national totals. The approach used here is to allocate national totals to States and not perform a bottom-up analysis for each State.

[11] 2017 is shown because that is the latest year of NEI data that are produced every 3 years.

- Residential sector: The total amount of distillate fuel used in the residential sector was taken from the national *Inventory* totals. It was allocated across states based on the percentage of existing fuel use in the residential sector per state from SEDS. Appendix A, Tables A-7 and A-8 in the "FFC CO2 Residential" Tab describes this adjustment. Based on the reallocation of sector fuel use, the residential sector fuel use from the national *Inventory* is different from the value in SEDS; therefore, the state-level allocation from SEDS may not represent exactly the fuel values from the national *Inventory*. However, residential sector fuel use represented by the national *Inventory* should be consistent with what is included in SEDS (e.g., home heating); therefore, the SEDS state-level breakout is assumed to be representative.
- Commercial sector: The total amount of distillate fuel and motor gasoline used in the commercial sector was taken from the national *Inventory* totals. It was allocated across states based on the percentage of existing fuel use in the commercial sector per state from SEDS. Appendix A, Tables A-14 to A-18 in the "FFC CO2 Commercial" Tab describes this adjustment. Based on the reallocation of sector fuel use, the commercial sector fuel use from the national *Inventory* is different from the value in SEDS; therefore, the state-level allocation from SEDS may not represent exactly the fuel values from the national *Inventory*. However, commercial sector fuel use represented by the national *Inventory* should be consistent with what is included in SEDS (e.g., construction equipment); therefore, the SEDS state-level breakout is assumed to be representative.
- Industrial sector: The total amount of distillate fuel and motor gasoline used in the industrial sector was taken from the national *Inventory* totals. Distillate fuel was allocated across states based on the percentage of existing fuel use in the industrial sector per state after the IPPU adjustments described in Step 2. Motor gasoline was allocated across states based on the percentage of existing fuel use in the industrial sector per state from SEDS. Appendix A, Tables A-40 and A-43 in the "FFC CO2 Industrial" Tab describes this adjustment. Based on the reallocation of sector fuel use, the industrial sector fuel use from the national *Inventory* is different from the value in SEDS; therefore, the state-level allocation from SEDS may not represent exactly the fuel values from the national *Inventory*. However, industrial sector fuel use represented by the national *Inventory* should be consistent with what is included in SEDS (e.g., process energy use); therefore, the SEDS state-level breakout is assumed to be representative.
- Electric power sector: The total amount of distillate fuel used in the electric power sector was taken from the national *Inventory* totals. It was allocated across states based on the percentage of existing fuel use in the electric power sector per state from SEDS. Appendix A, Tables A-57 and A-58 in the "FFC CO2 Electricity" Tab describes this adjustment. The electric power sector fuel use was not adjusted in the national *Inventory* compared with what is represented in SEDS; therefore, the SEDS state-level breakout is considered representative.

Step 6: Subtract Consumption for NEU

The energy statistics include consumption of fossil fuels for nonenergy purposes. Most fossil fuels consumed are combusted to produce heat and power. However, some are used directly for noncombustion use as construction materials, chemical feedstocks, lubricants, solvents, and waxes.[12] For example, asphalt and road oil are used for roofing and paving, and hydrocarbon gas liquids are used to create intermediate products. In the national *Inventory*, emissions from these NEUs are estimated separately under the Carbon Emitted and Stored in Products from NEUs source category. Therefore, the amount of fuels used for nonenergy purposes needs to be subtracted from fuel consumption data for determining combustion emissions.

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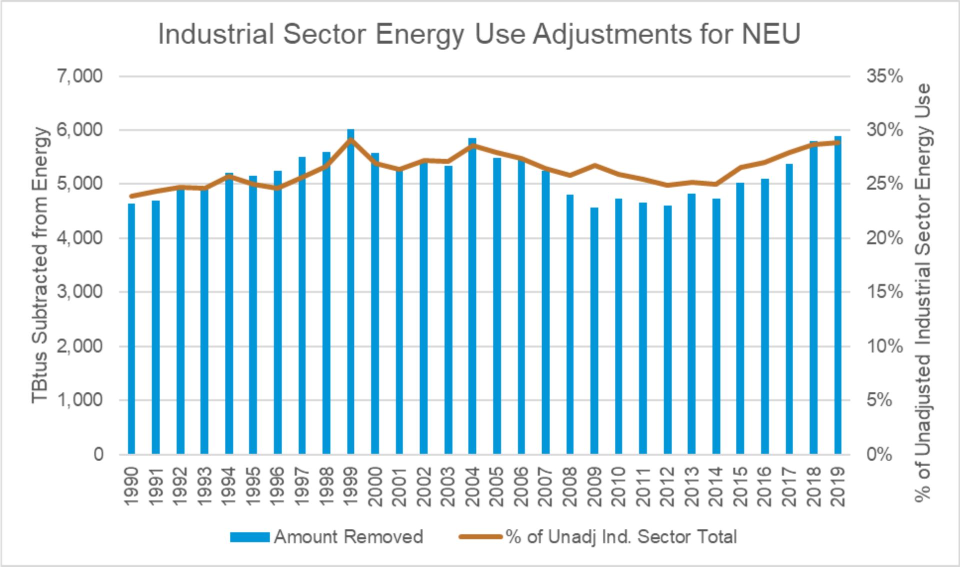
[12] Under IPCC Inventory guidance, emissions from these noncombustion sources should be reported as part of IPPU. However, because of national circumstances and the inability to separate these uses from the national energy balance, the United States reports these emissions as part of Energy. This is an area for future planned improvement as part of the national *Inventory*, and any updates will be carried over to the State-level reporting.

The adjustments vary over time and represent from about 25 to 30% of total unadjusted industrial sector energy use, as shown in Figure 2-10.

Figure 2-10: Adjustments Made to Industrial Sector Energy Use to Account for Emissions Reported as NEUs



Adjustments for each fuel type were made at the national level based on data and assumptions from the EIA as used in the national energy balance. More detail on the amount and types of fuels used for NEU at the national level are shown in Appendix A in the “National 2019 NEU CO2” Tab.

The following approaches were taken to determine the amounts of different fuels used for NEUs that needed to be subtracted from energy combustion estimates at the state level. The subtractions were all made in the industrial sector except for lubricants; those subtractions were used in both the industrial and transportation sectors and for NEU from territories:

- Coking coal: As per the national *Inventory*, the amount of coking coal used for NEUs was determined to be the total of the adjusted coking coal (after subtracting for IPPU use, as per Step 2). Therefore, the state-level totals from Step 2 for coking coal were used to represent NEUs. Appendix A, Table A-59 in the “NEU” Tab shows this state-level breakout.
- Other coal: The coal used to produce synthetic natural gas at the Eastman gas plant (based on data from the national *Inventory*) was assumed to be used for chemical feedstock and therefore was accounted for under NEU. This other coal NEU was allocated across states by assuming it all occurred in Tennessee, the location of the Eastman facility. Appendix A, Table A-60 in the “NEU” Tab shows this state-level breakout.
- Natural gas: The total national-level amount of natural gas used for NEUs was taken from the national *Inventory* (based on data from EIA) and represents natural gas used for chemical plants and other uses. Natural gas used for NEUs was allocated across states based on the percentage of petrochemical emissions per state. This is an area where there was not any specific data on natural gas used for NEU in chemical plants and other uses by state. Using petrochemical emissions to allocate natural gas NEU use by state was considered a reasonable approach as emissions are a good indication of petrochemical production in a state, and therefore a good indication of how much NEU fuel was used in that state. Petrochemical emissions per state were taken from the IPPU breakout for petrochemicals, as described in

Section 3.2.9, and the total percentage for all petrochemicals was used. Appendix A, Table A-61 in the "NEU" Tab shows this state-level breakout.

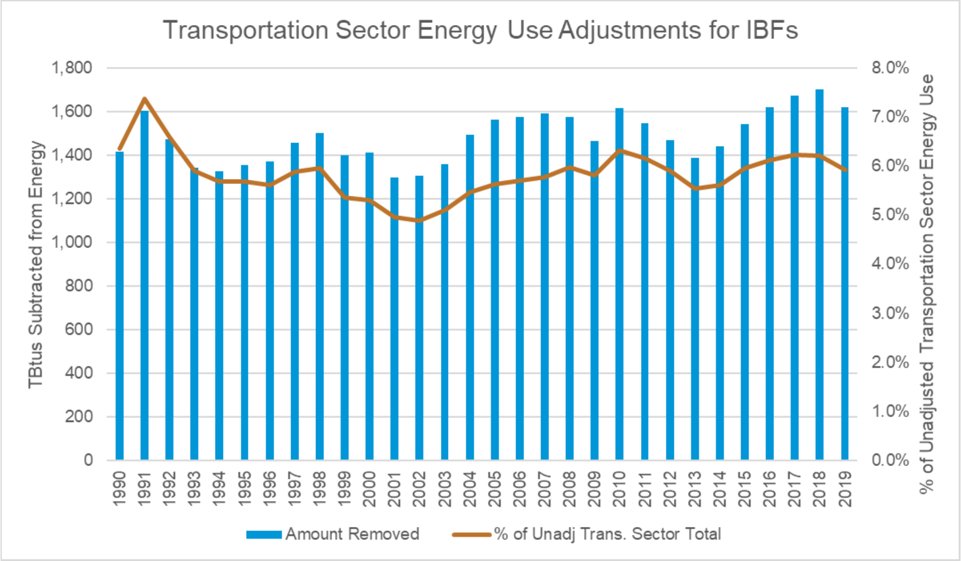
- LPG, pentanes plus, still gas, and petroleum coke: The national-level amount of these fuels used for NEUs was taken from the national *Inventory* (from EIA data) and assumed to be used primarily as chemical feedstocks. The amount of NEUs was allocated across states based on the percentage of each total fuel use in the industrial sector per the original state-level data from SEDS. This approach assumes that the percentage of these fuel products used in NEU applications per state are proportional to the overall or other, fuel combustion, uses of these fuel products in a given state. This assumption was felt to be reasonable as the fuel and NEU applications of these fuel products are likely to be in the same types of chemical facilities. Appendix A, Table A-63, Table A-64, Table A-65, Table A-69, Table A-70, Table A-71 and Table A-72 in the "NEU" Tab show these state-level breakouts.
- Distillate fuel: The total national-level amount of distillate fuel used for NEUs was taken from the national *Inventory* (based on data from EIA). Distillate fuel used for NEUs was allocated across states based on the percentage of distillate fuel use in the industrial sector per state after IPPU adjustments described in Step 2. As per the previous group of fuel products, this approach assumed that the percentage of distillate fuel used in NEU applications per state is proportional to the overall or other, fuel combustion, uses of distillate fuel in a given state. The national-level data on distillate fuel used in NEU applications are based on industry surveys for nonfuel uses in the chemical industry. Therefore, the assumption that NEUs of distillate fuel are proportional to the total industrial sector amount of distillate fuel use in a given state may not be completely representative because other or fuel uses of distillate fuel in the industrial sector could be very broad. However, it was felt to be a reasonable approach because specific state-level distillate fuel used in NEU applications was not readily available and the percentage of NEUs of distillate fuel was a small fraction of overall industrial sector distillate fuel use (less than 1%). The EPA will continue to examine other possible sources for distillate fuel NEU state-level data for future reports. Appendix A, Table A-74 in the "NEU" Tab shows this state-level breakout.
- Asphalt and road oil, lubricants (in both industrial and transportation sector), naphtha (<401 deg. F), other oil (>401 deg. F), special naphtha, waxes and miscellaneous products: As per the national *Inventory*, the total amounts of these fuel products were all assumed to be used in NEUs. Therefore, the total state-level data from SEDS were used to represent NEUs for these fuel products. Appendix A, Table A-62, Table A-66, Table A-67, Table A-68, Table A-73, Table A-75, Table A-76 and Table A-77 in the "NEU" Tab show these state-level breakouts.

Emissions associated with NEUs were calculated and reported separately from FFC emissions. Some further adjustments were made to NEU energy use, and carbon factors were applied; see further discussion in Section 1.1.2 below.

Step 7: Subtract Consumption of International Bunker Fuel

The energy statistics include consumption of fossil fuels that are ultimately used for international bunkers. In the national *Inventory*, emissions from bunker fuel consumption are not included in national totals and are instead reported separately as a memo item, as required by the IPCC and UNFCCC inventory reporting guidelines. There are other international organizations, including the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO), that consider global action from these sectors. Therefore, the amount of each fuel type used for international bunkers was subtracted from fuel consumption data when determining fuel combustion emissions. The adjustments vary over time and represent about 5 to 7% of total unadjusted transportation sector energy use as shown in Figure 2-11.

Figure 2-11: Adjustments Made to Transportation Sector Energy Use to Account for IBFs



Adjustments for each fuel type were made at the national level based on data and assumptions from different data sources, including FAA flight data and information on international shipping; see the national *Inventory* report for more details. More details on the amount and types of fuels used for IBFs at the national level are shown in Appendix A in the “National 2019 FFC CO2” Tab.

The following approaches were taken to determine the state-level amount of different fuels used for IBFs that needed to be subtracted from energy combustion estimates. The subtractions were all made in the transportation sector:

- Residual fuel and distillate fuel: The total national-level amount of residual and distillate fuel used for IBF was taken directly from the national *Inventory* (IBF subtractions). The fuels used for IBF were allocated across states based on the percentage of fuel use for bunkers from the EIA FOKS data (EIA 2021b). This approach was considered reasonable because the FOKS data have information directly on bunker fuel used at the state level. Appendix A, Table A-78 and Table A-79 in the “IBF” Tab show these state-level breakouts.
- Jet fuel: The total national-level amount of jet fuel used for IBF was taken directly from the national *Inventory* (IBF subtractions). Jet fuel used for IBF was allocated across states based on the percentage of total jet fuel use in the transportation sector by state per the original state-level data from SEDS. Appendix A, Table A-80 and Table A-81 in the “IBF” Tab show the state-level breakout data on jet fuel specifically used for international flights were difficult to find at the state level. The approach used here to allocate bunker fuels by state based on the total amount of jet fuel used by state could potentially lead to an overestimation of bunker fuel emissions for some states with below average international flight activity or underestimation for other states with significantly greater than average international flight activity. This is an area of future planned improvements. Also note that this adjustment is for IBFs. Fuel use and emissions from interstate flights are still included in the national and state-level FFC emissions. They were allocated to the state where the jet fuel is purchased/sold as per the SEDS data.

The result of these previous seven steps is an adjusted amount of fuel use activity data that is then used to determine FFC CO_2 emissions. Three additional steps are then required to determine CO_2 emissions discussed further below.

Step 8: Determine the Carbon Content of All Fuels

To determine emissions, the amount of carbon per unit of energy in each fuel was needed. Because different fuels have different C contents, a different factor was determined for each fuel type. The total C estimate defines the maximum amount of C that could potentially be released to the atmosphere if all of the C in each fuel was converted to CO_2. Fuel-specific carbon content coefficients for each fuel type were taken from the national *Inventory*; see Annex 2 of the national *Inventory* for more details on carbon factors used. The national total factors for each fuel used in the national *Inventory* were applied for fuel use at the state level. This was considered a reasonable assumption since fossil fuels are widely traded and regulated, and carbon contents within the United States do not vary appreciably. Two possible exceptions to this are coal and gasoline where state-specific carbon contents could vary based on the type of coal used and the gasoline blend and grade used. Those fuel emissions factors in the national *Inventory* were based on weighted averages of state-level factors. For these factors, the EPA will look into using specific state-level factors in the state-level estimates in future reports.

Step 9: Estimate CO_2 Emissions

Total CO_2 emissions for each fuel are the product of the adjusted energy consumption (from the previous methodology Steps 1–7), the carbon content of the fuels consumed (from Step 8), and the fraction of C that is oxidized. Carbon emissions were multiplied by the molecular-to-atomic weight ratio of CO_2 to C (44/12) and the fraction of carbon that was oxidized to obtain total CO_2 emitted from FFC. The fraction oxidized was assumed to be 100% for petroleum, coal, and natural gas.

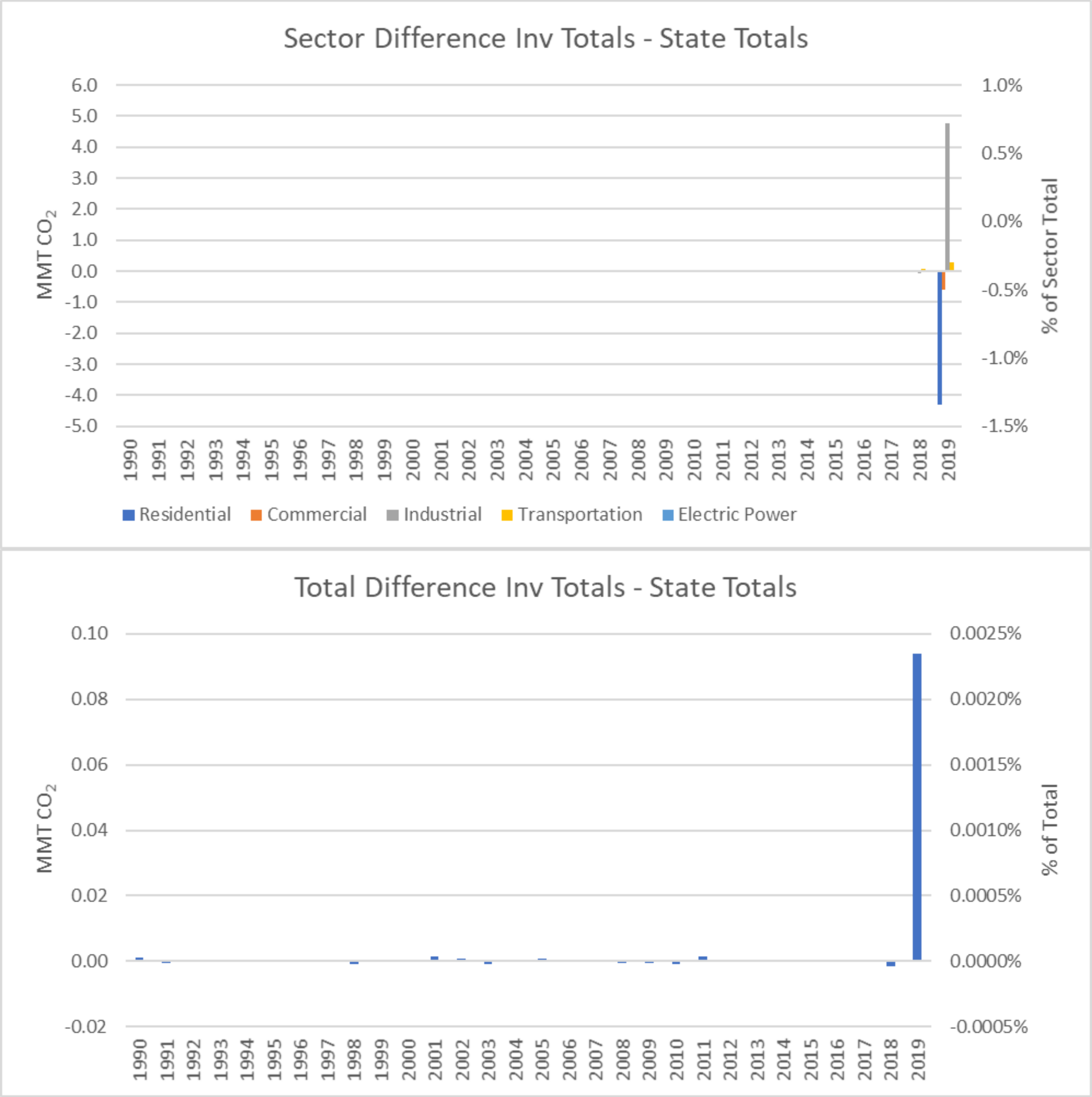
State-level fuel use by fuel type per sector from Steps 1–7 was multiplied by national-level carbon factors from Step 8 (and also multiplied by molecular weight ratios and oxidation fractions) to determine state-level emissions by fuel type and by sector.

Step 10: Allocate Transportation Emissions Step 10: Allocate Transportation Emissions by Vehicle Type

As discussed in Step 5 above, fuel use at the national level was determined by specific vehicle type in the transportation sector because non-CO_2 emissions differ by vehicle type and activity data were needed by vehicle type to use higher tier methods for non-CO_2 emissions. The national *Inventory* is, therefore, also able to provide the same level of detail for CO_2 emissions by specific vehicle type from transportation. For fuel types other than jet fuel, fuel consumption data by vehicle type and transportation mode were used to allocate emissions by fuel type calculated for the transportation end-use sector in the national *Inventory*. However, as also discussed in Step 5 above, state-level information on fuel use by vehicle type was not readily available. For CO_2 emissions, vehicle type is not critical for determining emissions because they are based primarily on fuel use; therefore, vehicle type by state was not specifically needed for the state-level calculations, and a state-level CO_2 emissions breakout by vehicle type was not done at this time. This is an area of future planned improvements.

The above calculations resulted in state-level GHG estimates that generally add up to the total estimates in the national *Inventory* with small differences occurring at the more disaggregated sector level, as shown in Figure 2-12 for FFC CO_2 emissions in 2019. The differences are due to the vintage of the different data sources used. As discussed above in Step 1, the national *Inventory* was based on the November 2020 MER, while the state-level values were based on the June 2021 SEDS. The SEDS used updated information on the sector allocation of some fuels, which will be reflected in the next national *Inventory* report. There is also a minor difference in total emissions due to the differences in emissions factors for LPG across sectors. The updated SEDS data had less LPG in the industrial sector, which has a higher emissions factor than LPG use in other sectors, so the result is slightly lower total emissions in the state-level estimates. The percentage differences in the 2019 sector totals are small (a 1.3% difference in the residential sector, a 0.2% difference in the commercial sector, a 0.6% difference in the industrial sector, and a 0.02% difference in the transportation sector). The percentage difference in total emissions is also very minor, a 0.002% difference.

Figure 2-12: Differences in State-Level and National Total FFC CO_2 Emissions



Stationary Non-CO_2 State-Level Breakout

Stationary non-CO_2 emissions include CH_4 and N_2O emissions from four energy consumption sectors (residential, commercial, industrial, and electric power) and four fuel types (coal, fuel oil, natural gas, and wood).

Non-CO_2 emissions from FFC at the national level were estimated in line with Tier 1 and 2 methods described by the IPCC in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). For most categories, a Tier 1 approach was used, which multiplies the adjusted activity data on fuel use by default emissions factors to determine emissions. The electric power sector used a Tier 2 approach that relied on the adjusted fuel use activity data and country-specific emissions factors by combustion technology type.

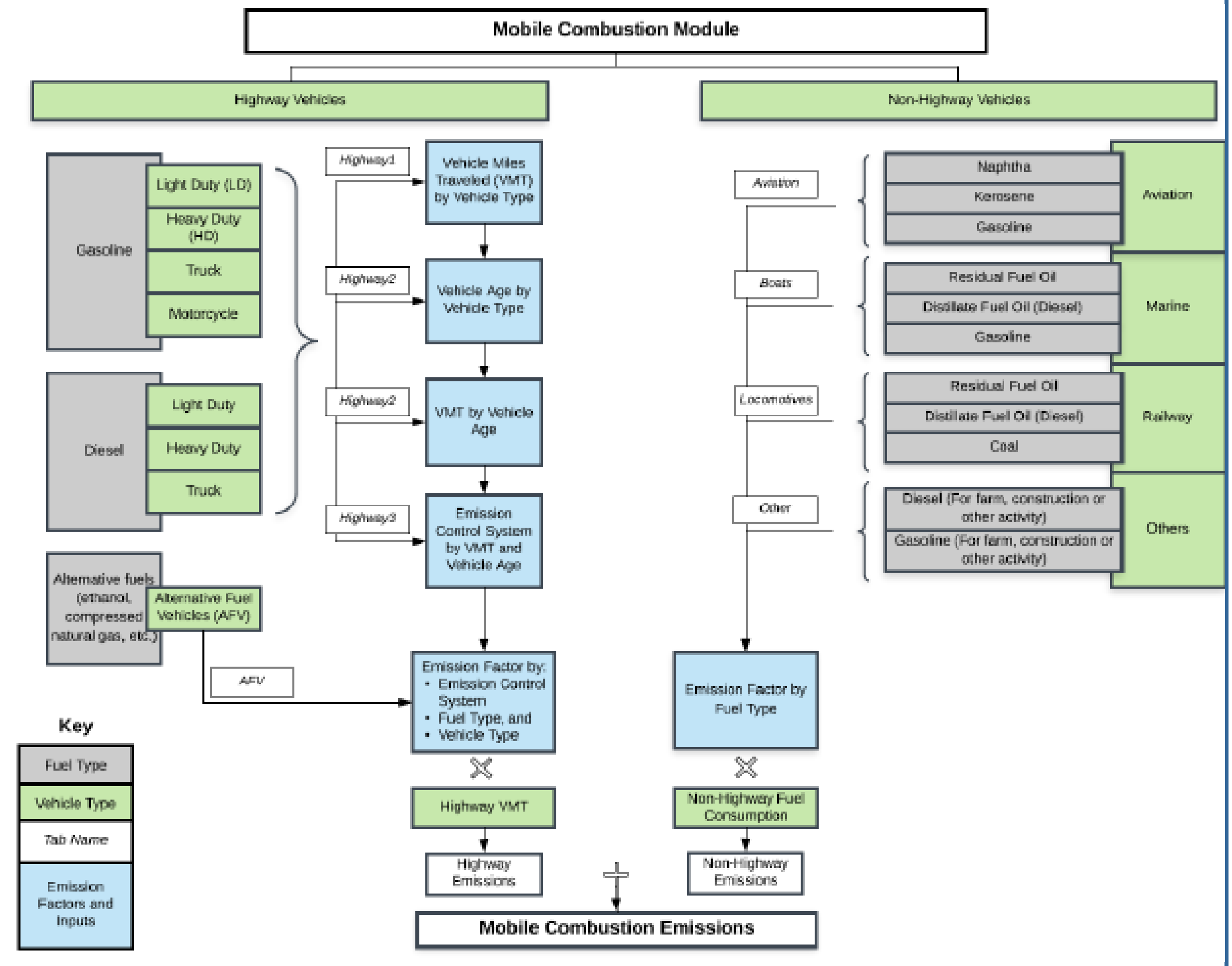
National-level emissions for all sectors were allocated across states based on the same percentage as CO_2 emissions from those sectors and fuel types as described in the previous section. Appendix A, Table A-89 through Table A-104 in the “Stationary non-CO2” Tab show the percentage breakout of each fuel across sectors that were used in the analysis. For the residential, commercial, and industrial sector, it is reasonable to assume non-CO_2 emissions by fuel type would be proportional to CO_2 emissions across states because the fuel use activity data are the same and only one non-CO_2 emissions factor was applied per fuel type per category for each gas.

Electric power sector non-CO_2 emissions could differ across states based on the type of combustion technology used, but the analysis was not able to assess these potential differences. The overall impact of these simplifying assumptions on total state combustion emissions is expected to be small.

Mobile Non-CO_2 State-Level Breakout

Mobile non-CO_2 emissions include CH_4 and N_2O emissions. National-level estimates of CH_4 and N_2O emissions from mobile combustion are calculated by multiplying emissions factors by measures of activity for each fuel and vehicle type (e.g., light-duty gasoline trucks). Activity data include VMT for on-road vehicles and fuel consumption for nonroad mobile sources. State-level mobile non-CO_2 emissions were calculated for four main categories of mobile source emissions: gasoline highway, diesel highway, alternative fuel highway, and nonhighway. More detail on the approach and what is included under each of the categories is shown in Figure 2-13 (EPA 2020).

Figure 2-13: Mobile Source Non-CO_2 Calculation Methodology



The approach was to develop state-level estimates by fuel type/category and use those estimates to develop the percentage of emissions by state. The percentage of emissions by state were then applied to the national totals from the national *Inventory* to disaggregate national totals at the state level. Table 2-3 shows the default data type and source used in developing the state-level estimates. Appendix A, Table A-105 through Table A-116 in the "Mobile non-CO2" Tab show the percentages of emissions by vehicle type by state that were used in the analysis.

Table 2-3: Default Data Sources for Mobile Source Non-CO_2 Emissions

Source/Category	Type of Input	Default Source
Highway Vehicles—Emissions Factors and VMT	CH_4 and N_2O emissions factors (g/km traveled) for each type of control technology	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
	State total VMT, 1990–present, for all vehicle types	VMT by state for each year from FHWA Table VM-2. Apportioned to vehicle type based on national vehicle type distributions from FHWA Table VM-1. The fuel type distribution within each vehicle type (i.e., the distribution between

		gasoline and diesel) was taken from the national *Inventory*
Highway Vehicles—Allocating VMT by Model Year	Annual vehicle mileage accumulation (miles) for each model year in use and age distribution of vehicles (%) in the current year	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
Highway Vehicles—Allocating Control Technology by Model Year	Percentage of vehicles with each control type, 1960–present	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
Aviation	N_2O and CH_4 emissions factors (g/kg fuel) for each type of fuel	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
	Aviation fuel consumption (million BTU), 1990–present by fuel type	EIA SEDS (EIA 2021a)
Marine	N_2O and CH_4 emissions factors (g/kg fuel) for each type of fuel	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
	Marine fuel consumption (gallons), 1990–present	Gasoline from FHWA Highway Statistics, Table MF-24, boating column, other fuels from EIA SEDS
Locomotive	N_2O and CH_4 emissions factors (g/kg fuel) for each type of fuel	Not state specific, using national factors; see Annex 3.2 of the national *Inventory* (EIA 2021b)
	Locomotive fuel consumption (gal or tons), 1990–present	EIA FOKS
Other Nonhighway	N_2O and CH_4 emissions factors (g/kg fuel) for diesel and gasoline tractors, construction equipment, and other equipment	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*
	Fuel consumption (gal), 1990–present, for agriculture equipment	Gasoline from FHWA Table MF-24, agriculture column, diesel fuel from EIA FOKS
	Fuel consumption (gal), 1990–present, for construction equipment	Gasoline from FHWA Table MF-24, construction column, diesel fuel total from the national *Inventory* apportioned based on gasoline percentage
	Fuel consumption (gal), 1990–present, for other equipment	Gasoline from FHWA Table MF-24, industrial and commercial column plus totals from other small sources from the national *Inventory*, diesel fuel from EIA FOKS
Alternative Fuel Vehicles	CH_4 and N_2O emissions factors (g/km traveled) for each type of alternative fuel (methanol, ethanol, LPG, liquefied natural gas, compressed natural gas)	Not state specific, using national factors; see Annex 3.2 of the national *Inventory*

	State total VMT, 1990–present, for alternative fuel vehicles	Based on national totals and assumptions on alternative fuel vehicle use by state from EIA alternative fuel vehicle data

The bottom-up approach to develop mobile source non-CO_2 state-level estimates by fuel type/category described above results in a different overall emissions total compared with the national *Inventory* values. That is why the estimates are used to develop the percentage of emissions by state that are applied to the national totals from the national *Inventory* to disaggregate national totals at the state level. The approach above could also over- or underestimate emissions by state by assuming a national average of age distribution of vehicles across states when each state could have a different mix of vehicle fleet age distribution. However, the approach is considered reasonable, and the overall impact of these simplifying assumptions on state emissions is expected to be small.

Breaking Out Data by Economic Sector

The EIA data used for this analysis report fuel use for five sectors (residential, commercial, industrial, transportation, and electric power). The reporting of emissions at the state level in this analysis also included emissions from the combustion of fossil fuels in the agriculture economic sector (which is not the case with the agriculture sector as defined by the IPCC). Agriculture sector fuel use at the national level was based on supplementary sources of data because EIA includes agriculture equipment in the industrial fuel-consuming sector. state-level agriculture fuel use estimates were obtained from USDA survey data, in combination with EIA FOKS data. Agricultural operations are based on annual energy expense data from the Agricultural Resource Management Survey (ARMS) conducted by the National Agricultural Statistics Service (NASS) of the USDA. NASS collects information on farm production expenditures including expenditures on diesel fuel, gasoline, LP gas, natural gas, and electricity use on the farm with the annual ARMS. A USDA publication (USDA/NASS 2020) shows national totals, as well as select states and ARMS production regions. State estimates were survey derived for 15 states (AK, CA, FL, GA, IA, IL, IN, KS, MN, MO, NC, NE, TX, WA, and WI) and model derived for the remaining states using data and methods developed by the Economic Research Service of USDA.

These supplementary data were subtracted from the industrial fuel use reported by the EIA to obtain agriculture fuel use. CO_2 emissions from FFC and CH_4 and N_2O emissions from stationary and mobile combustion were then apportioned to the agriculture economic sector based on agricultural fuel use.

2.1.1.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 and non-CO_2 emissions from FFC was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 for FFC were −2%/+4% for CO_2, −36%/+133% for stationary source CH_4, −25%/+51% for stationary source N_2O, −2%/+46% for mobile source CH_4, and −9%/+19% for mobile source N_2O.

The uncertainty estimates for the national *Inventory* largely account for uncertainty in the magnitude of emissions and consider uncertainty in activity data and emissions factors used to develop the national estimates. state-level estimates of annual emissions will likely have a higher relative uncertainty compared with these national estimates as a result of the additional requirement in some cases of apportioning national emissions to each state using spatial proxy and supplemental surrogate datasets. As discussed above, the steps involved in determining state-level FFC emissions could result in some over- or underestimation of state-level emissions in some cases. The sources of uncertainty for this category are consistent over time because the same approaches are applied across the entire time series. As with the national *Inventory*, the state-level uncertainty estimates for this category may change as the understanding of the uncertainty of estimates and underlying datasets and methodologies improves.

2.1.1.4 Planned Improvements

For coking coal, the percentage subtracted by state could be based on other factors like BOFs I&S production in each state, as opposed to the percentage of total coking coal use. For all fuels in some cases, a state could have negative emissions if the amount subtracted determined from assumed distribution was greater than consumption data from SEDS for that state. This value was corrected to zero if that was the case, but alternative ways to readjust it across other states will be considered.

For petrochemical feedstocks, natural gas NEU was allocated across states based on GHGRP petrochemicals emissions data per state, while other fuels NEU use was allocated based on the underlying SEDS data. Allocating across states based on the underlying SEDS data ensures that in no states is NEU use larger than in the original SEDS data which, if that was the case, would result in negative numbers associated with subtracting NEU (it is not an issue for natural gas because use is so high overall compared with NEU). However, the EPA will explore different percentages or a way to use GHGRP petrochemical data without resulting in negative use in any given state.

The EPA will look into using state-level bottom-up data for bunkers directly from FOKS, as opposed to basing IBF on top-down estimates from the national *Inventory* and allocating to states based on the FOKS percentage, taking into account how FOKS data line up with national *Inventory* totals. We will look for better ways to allocate jet fuel bunker data across states as opposed to basing it on percentage of total use, for example, FAA data or assuming based on states with international airports and flights.

The EPA will look into more state-level activity data for different mobile combustion sources to better allocate mobile non-CO_2 emissions.

The coal carbon factors in the national *Inventory* are based in part on state-level data. It might be possible to build out weighted state-level coal carbon factors that would still amount to the national totals. For natural gas, state-level heat content data could be used to develop state-level carbon factors for natural gas, but they would have to be compared with national totals. It might be possible to develop gasoline and distillate fuel factors per state for the transportation sector, but we would have to ensure they are consistent with the national-level factors.

The EPA will look into allocating power sector non-CO_2 emissions based on other sources like eGRID and EPA Air Markets Program Data, for instance.

The national *Inventory* distributes electricity emissions across end-use sectors to present results with electricity distributed by sector. That calculation was not done at the state level. The national *Inventory* also breaks out transportation sector emissions by vehicle type; that calculation was also not done at the state level. The EPA will look into reporting this disaggregated data in future state-level reports.

2.1.1.5 References

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2.1.2 Carbon Emitted from Nonenergy Uses of Fossil Fuel (NIR Section 3.2)

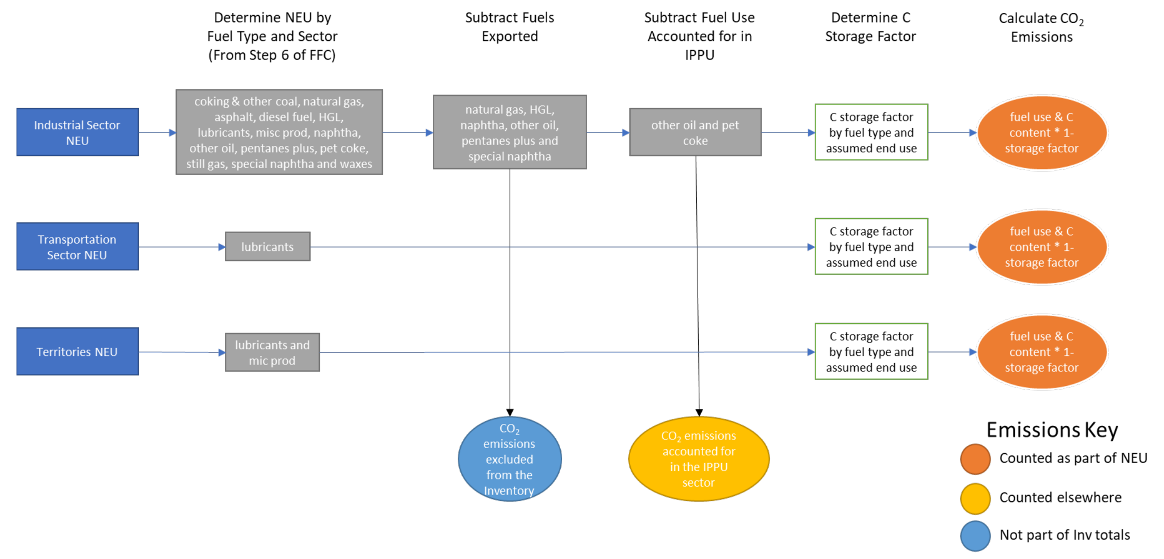
2.1.2.1 Background

In addition to being combusted for energy, fossil fuels are consumed for NEUs. The fuels used for these purposes and the nonenergy applications of these fuels are diverse, including feedstocks for the manufacture of plastics, rubber, synthetic fibers, and other materials; reducing agents for the production of various metals and inorganic products; and products such as lubricants, waxes, and asphalt. CO_2 emissions arise via several pathways. Emissions may occur during the manufacture of a product, as is the case in producing plastics or rubber from fuel-derived feedstocks. Additionally, emissions may occur during the product's lifetime, such as during solvent use. As discussed above in the FFC section, emissions from these NEUs are estimated separately and, therefore, the amount of fuels used for non-energy purposes are subtracted from fuel consumption data. Given the linkages between NEUs and combustion emissions, the NEU adjustments and calculations are presented here.

2.1.2.2 Methods/Approach

FFC CO_2 emissions calculations discussed above (as per Step 6) were adjusted for fuels used for NEUs. CO_2 emissions arise from NEUs via several pathways, including emissions from the manufacture of a product and during the product's useful lifetime and ultimate disposal. The approach for determining national-level NEU emissions is based for the most part on multiplying NEU activity data by C contents and assumed C storage factors. The activity data on NEU by fuel were taken from the FFC adjustments. Then several adjustments were made to the data to account for fuel exports and IPPU emissions that are either excluded or reported in other parts of the national *Inventory* as shown in Figure 2-14. C storage factors are based on the end use of the fuel and assumed fate of the C in the products. Appendix A in the "National 2019 NEU CO2" Tab provides more details on an example of the adjustments made to the national-level NEU data to determine adjusted NEU activity data for 2019.

Figure 2-14: Adjustments to Energy Consumption for Emissions Estimates



NEU emissions at the state level were calculated based on the same approach as used to determine national-level NEU emissions. The following steps describe the approach used to determine state-level NEU emissions.

Step 1: Determine Total NEU by Fuel Type and Sector

State-level NEU energy data by sector and fuel type were calculated from Step 6 of the FFC calculations, as discussed above. The NEU adjustments to the FFC data were used as the input to the NEU calculations. The same state-level breakout of the NEU data used in the FFC calculations was used here.

Step 2: Adjust for Portions of NEU in Exported Products

State-level NEU energy data calculated from Step 6 above were adjusted to account for exports. Natural gas, HGL, pentanes plus, naphtha (<401 °F), other oil (>401 °F), and special naphtha were adjusted down to subtract out net exports of these products that are not reflected in the raw NEU data from the EIA. Consumption values were also adjusted to subtract net exports of HGL components (e.g., propylene, ethane). Similar to exported CO_2 discussed in the FFC calculations, because any potential CO_2 emissions from exported products are not emitted to the atmosphere in the United States, the fuel that is used to create the exported products is subtracted from statistics used to calculate NEU emissions. The national-level total export energy adjustment data were taken from the national *Inventory*. The export adjustments were allocated to states based on the total amount of NEU fuel use by state from Step 1 under the simplifying assumption that the share of nonenergy fuels exported matched the amount of nonenergy fuels used by a given state. This could lead to an over- or underestimation of NEU emissions in a given state based on the actual amount of product exported. However, it was felt to be a reasonable assumption given the lack of export data by state and the small overall adjustment made (2019 export adjustments represent 5.6% of unadjusted nonenergy fuel use). Appendix A, Table A-82 through Table A-86 and Table A-88 in the “NEU Adj” Tab show these adjusted totals.

Step 3: Adjust for Portions of NEU Accounted for in IPPU

State-level NEU energy data were also adjusted down to account for other oil (>401 °F) and petroleum coke use in IPPU. As per Step 2 in the FFC calculations, emissions from fuels used as raw materials presented as part of IPPU were removed from the NEU estimates. Portions of nonenergy fuel use were, therefore, subtracted from the industrial sector nonenergy fuel consumption data before determining NEU emissions. The national-level total IPPU energy adjustment data for NEU were taken from the national *Inventory*. The IPPU adjustments were allocated to states based on the total amount of NEU fuel use by state from Step 1 under the simplifying assumption that the share of nonenergy fuels used in IPPU matched the amount of nonenergy fuels used by a given state. This assumption could lead to an over- or underestimation of NEU emissions in a given state based on the actual amount of fuel used in IPPU. However, it was felt to be a reasonable assumption given the lack of data by state on NEU fuels used in IPPU and the small overall adjustment made (2019 IPPU adjustments represent 1.1% of unadjusted NEU fuel use). Appendix A, Table A-86 and Table A-87 in the "NEU Adj" Tab show these adjusted totals.

Step 4: Determine C Storage Factor by Fuel Type

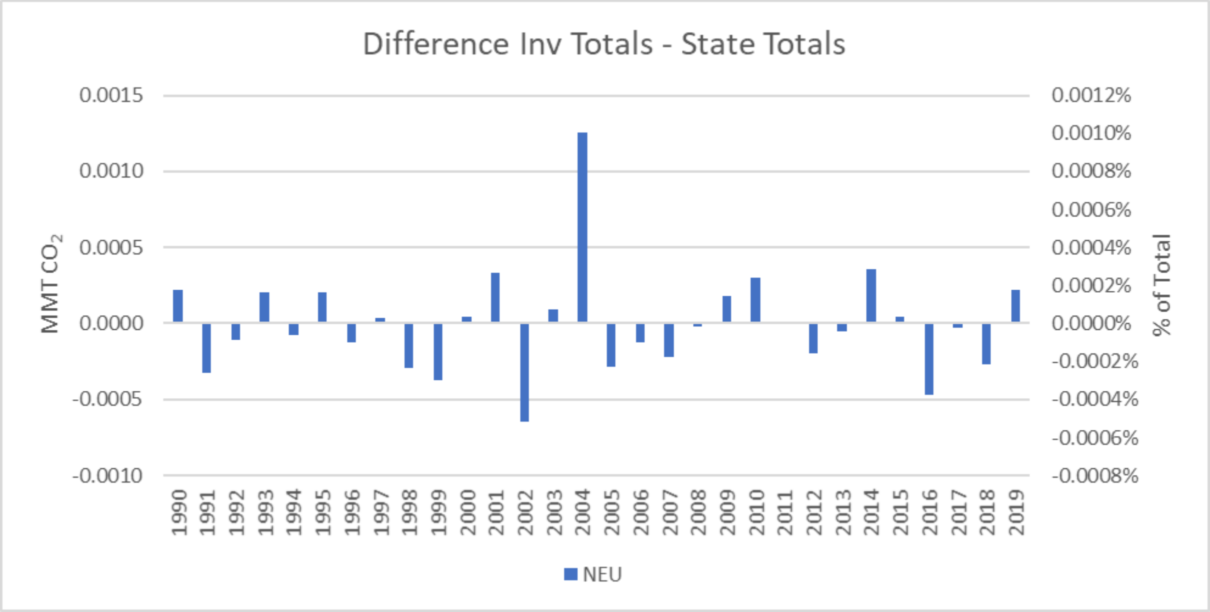
CO_2 emissions can arise from NEUs via several pathways. Emissions may occur during the manufacture of a product, as is the case in producing plastics or rubber from fuel-derived feedstocks, or emissions may occur during the product's lifetime, such as during solvent use. C can also be stored from NEUs such as in a final product like plastics or asphalt. Overall, at a national level, about 62% of the total C consumed for nonenergy purposes is stored in products (e.g., plastics), and not released to the atmosphere. For state-level calculations, the storage factors per fuel type were taken from the national *Inventory* values and vary across fuel types and, for some fuels, over time. See Annex 2.3 of the national *Inventory* for more details on storage factors used.

Step 5: Calculate NEU CO_2 Emissions

Emissions from NEUs were calculated based on multiplying the adjusted NEU fuel use by state (from Steps 1–3) by the national-level carbon factors by fuel type (same as used in the FFC calculations, including oxidation and molecular weight ratio with the exception that HGLs and still gas have separate carbon factors for combustion and NEUs) and by 1 minus the storage factor of each fuel type (from Step 4). See Annex 2.2 of the national *Inventory* for more details on carbon factors used.

There are some small differences in the NEU-calculated state-level emissions totals compared with what is reported in the national *Inventory*, as shown in Figure 2-15. As with FFC, these differences represent a very small percentage of total NEU emissions (the maximum percentage difference over time is 0.001% of total NEU emissions).

Figure 2-15: Differences in State-Level and National Total NEU CO_2 Emissions



2.1.2.3 *Uncertainty*

The overall uncertainty associated with the 2019 national estimates of CO_2 from NEUs was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −37%/+45% for CO_2. State-level estimates are expected to have a higher uncertainty because some of the national-level data were apportioned to each state. For example, the allocations of export and IPPU adjustments are likely to add to the uncertainty at a state level compared with the national totals.

2.1.2.4 *Planned Improvements*

Planned improvements are consistent with those planned for improving national estimates for NEUs. The EPA will also look into the export and IPPU adjustments to see if they could be done based on state-level data, if these data are available, as opposed to assuming the percentage based on SEDS state-level totals.

2.1.2.5 *References*

See References Section for FFC 2.1.1.5.

2.1.3 *Geothermal Emissions*

2.1.3.1 *Background*

Although not a fossil fuel, geothermal energy does cause CO_2 emissions, which are included in the national *Inventory*. The source of CO_2 is non-condensable gases in subterranean heated water that is released during the process.

2.1.3.2 *Methods/Approach*

National-level geothermal electricity production emissions were estimated by multiplying technology-specific net generation by technology-specific C contents based on geotype (i.e., flash steam and dry steam).

For state-level geothermal emissions, the total national-level geothermal emissions were taken from the national *Inventory*, and they were allocated across states based on the amount of geothermal energy consumed by each state from the SEDS data. All geothermal emissions were assumed to be in the electricity sector. Almost every state reported some level of geothermal energy consumption across the time series. The top 5 states in 2019 were California, Nevada, Florida, Michigan, and Indiana, accounting for about 80% of all geothermal energy consumption.

2.1.3.3 Uncertainty

Given its small contribution to the overall FFC portion of the national *Inventory* (0.008% in 2019), an uncertainty analysis was not performed for CO_2 emissions from geothermal production.

2.1.3.4 Planned Improvements

The EPA will consider if geothermal emissions could be allocated by the type of geothermal production per state (because different types have different emissions factors) if that data are available.

2.1.3.5 References

See References Section for FFC 1.1.1.5.

2.1.4 Incineration of Waste (NIR Section 3.3)

2.1.4.1 Background

In the context of this section, waste includes all municipal solid waste (MSW) and scrap tires. In the United States, incineration of MSW tends to occur at waste-to-energy facilities or industrial facilities where useful energy is recovered; thus, emissions from waste incineration are accounted for as part of the energy sector. Similarly, scrap tires are combusted for energy recovery in industrial and utility boilers, pulp and paper mills, and cement kilns. Incineration of waste results in conversion of the organic inputs to CO_2. Thus, the CO_2 emissions from waste incineration are calculated by estimating the quantity of waste combusted and the fraction of the waste that is carbon derived from fossil sources.

2.1.4.2 Methods/Approach

The different categories of national-level waste incinerations emissions include CO_2 emissions from MSW fossil components (plastics, synthetic rubber, and synthetic fibers), tire fossil components (synthetic rubber and carbon black), and non-CO_2 emissions of CH_4 and N_2O from total waste combustion. Any net CO_2 that ultimately results from incinerated biogenic waste is counted through carbon stock change methodologies in the agriculture and land use, land use change and forestry sectors discussed in Chapters 4 and 5 of this report.

National emissions from all the categories were allocated to states based on the percentage of total MSW combusted. The amount of waste combusted by state was estimated based on several different sources depending on the year of data, as shown in Table 2-3.

Table 2-4. Summary of Approaches to Disaggregate Waste Incineration Emissions Across Time Series

Time Series Range	Summary of Data Used
1990–2000	• Waste combusted by state was based on Biocycle report data (the same as currently used in the national *Inventory*).
2001–2010	• Waste combusted was based on data from EIA on waste combustion.
2011–2019	• Waste combustion data were based on the U.S. EPA GHGRP.

The methodology used for 1990–2000 was to estimate waste combusted by state based on data from multiple years of Biocycle reports (the same as currently used in the national *Inventory*) (EPA 2021a). The national *Inventory* has more information on the Biocycle data.

The methodology used for 2001–2010 was to estimate waste combusted by state based on data from EIA on waste combustion (EIA 2019). EIA collects data from electric power producers including waste incinerators and including the type and amounts of fuels used by facility. That data were used to estimate tons of MSW combusted by state. The methodology used for 2011–2019 was to estimate waste combustion based on the U.S. EPA GHGRP (EPA 2021b). The GHGRP reports facility-level emissions of GHG by fuel type from Subpart C data. The CH_4 and N_2O data from MSW combustion by facility/unit can be divided by default CH_4 and N_2O emissions factors to back-calculate tons of MSW combusted.

See Appendix A, Table A-117 in the “Waste Incineration” Tab the for the tonnage of MSW assumed by state by year from the different sources.

The approach used assumed that individual states’ waste combustion emissions are proportional to their share of waste combusted. This assumption is considered reasonable because currently there is no distinction in the national *Inventory* on different MSW compositions and fossil component (e.g., plastics) percentages across states. There could potentially be differences in waste compositions and, therefore, emissions across states, for example, because of state waste management policies. The EPA is considering updates to the national-level waste incineration emissions estimates, which could provide more information on state-level CO_2 emissions factors per ton of MSW. This is an area for future work. Assuming scrap tire emissions are produced in proportion to MSW combustion per state could lead to over- or underestimating tire combustion emissions at the state level. However, given the lack of readily available data, the assumption that tire combustion emissions occur in proportion to MSW tons combusted in a given state is considered reasonable.

2.1.4.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 and N_2O from waste incineration was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −25%/+27% for CO_2 and −50%/+325% for N_2O. State-level estimates are expected to have a higher uncertainty because the national-level data were apportioned to each state based on MSW tonnage. In particular, assuming emissions are proportional to total MSW combusted adds uncertainty associated with different waste compositions across different states. Furthermore, assuming tire combustion emissions are proportional to MSW tonnage also adds uncertainty associated with the differences in tire and MSW combustion across states.

2.1.4.4 Planned Improvements

Planned improvements are consistent with those planned for improving national estimates for waste incineration. Planned improvements for the 1990–2020 national *Inventory* include substantial updates to the methods for calculating CO_2 emissions. The updates include a new methodology using a carbon emissions factor per ton of total MSW (as opposed to per specific waste component) calculated from the EPA’s GHGRP data for 2011–2020. An emissions factor for years before 2011 was estimated using the average of 2011 through 2020 emissions factors. State-level estimates will be updated based on the new approach once it is finalized. The EPA will also look into separating emissions by state based on the category of emissions (e.g., MSW combustion vs. tire combustion).

2.1.4.5 References

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U.S. Environmental Protection Agency. (April 2021a). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019 (EPA 430-R-21-005), Chapter 3: Energy. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

U.S. Environmental Protection Agency. (2021b). Greenhouse Gas Reporting Program Data. Washington, DC: U.S. Environmental Protection Agency. Available online at: https://www.epa.gov/ghgreporting/ghg-reporting-program-data-sets

2.1.5 International Bunker Fuels (NIR Section 3.10)

2.1.5.1 Background

Emissions resulting from the combustion of fuels used for international transport activities, termed IBFs under the UNFCCC, are not included in national emissions totals but are reported separately based on location of fuel sales. Two transport modes are addressed under the IPCC definition of IBFs: aviation and marine. GHGs emitted from the combustion of IBFs, like other fossil fuels, include CO_2, CH_4, and N_2O for marine transport modes and CO_2 and N_2O for aviation transport modes. Emissions from ground transport activities—by road vehicles and trains—even when crossing international borders are allocated to the country where the fuel was loaded into the vehicle and, therefore, are not counted as bunker fuel emissions.

Although reporting on IBFs is a memo item in national-level reports, it does affect the total jet fuel emissions that are reported because it is a subtraction from total jet fuel use. The same is true at the state level where subtraction of bunker fuel affects jet fuel emissions that are reported in a given state (as per Step 7 of the FFC emissions calculations).

2.1.5.2 Methods/Approach

As noted, emissions resulting from the combustion of fuels used for international transport activities, termed IBF under the UNFCCC, are not included in national emissions totals but are reported separately as a memo item based on the location of fuel sales. The same approach was used at the state level where estimates of bunker fuels were determined by state. Although bunker fuels are memo items and do not affect state-level total GHG emissions, the allocation of bunker fuels across states could affect the total amount of jet fuel used per state, including domestic jet fuel use and emissions. Bunker fuel emissions include CO_2, CH_4, and N_2O emissions from jet fuel, diesel fuel, and residual fuel. The jet fuel emissions are broken into commercial and military use. See Appendix A, Tables A-78 through Table A-81 in the "IBF" Tab for details on IBF energy use breakout by state.

The approach used here at the state level to allocate and report IBF and other cross state transportation sector emissions to the state where the fuel is sold is considered reasonable. However, it is an accounting decision and may differ from how individual states account for those cross state and international fuel use emissions in their own inventories.

Jet Fuel

National-level jet fuel CO_2 emissions from commercial aircraft came directly from FAA emissions data, CO_2 emissions from military use were based on fuel use data times the national *Inventory* CO_2 emissions factor. National-level CH_4 and N_2O emissions were based on fuel use data times an emissions factor, CH_4 emissions were assumed to be 0 from jet fuel use. N_2O emissions were split between commercial and military based on the percentage of total CO_2 emissions.

Jet fuel emissions from bunker fuels were allocated to states based on jet fuel use sales data from SEDS.

Residual and Diesel Fuel

National-level residual and diesel fuel emissions were based on fuel use data times emissions factors for the different emissions. The emissions were allocated to states based on EIA FOKS data for bunker fuel use for diesel and residual fuels.

2.1.5.3 Uncertainty

A quantitative uncertainty analysis associated with the national estimates of CO_2, CH_4, and N_2O from IBFs was not calculated because the estimates are only considered memo items. However, there is a qualitative discussion of uncertainty associated with national-level IBF emissions in the national *Inventory*. State-level estimates are expected to have a higher uncertainty because of the assumptions related to allocating IBF fuels to the state level. For example, a high degree of uncertainty is associated with allocating jet fuel bunkers to states based on the total amount of jet fuel used per state.

2.1.5.4 Planned Improvements

As discussed previously, the approach used here to allocate bunker fuels by state based on the total amount of jet fuel used by state could potentially lead to an over- or underestimation for some states of bunker fuel emissions. Therefore, the EPA will look into data specific to jet fuel bunkers by state, for example, flight-level data on departures and destinations.

Currently, the approach used here allocates total IBF use to the 50 states and the District of Columbia. The EPA will examine if it is possible to allocate some jet fuel and marine bunkers to territories as they are also covered as part of the National *Inventory*.

2.1.5.5 References

See References Section for FFC 1.1.1.5.

2.1.6 Wood Biomass and Biofuels Consumption (NIR Section 3.11).

2.1.6.1 Background

In line with the reporting requirements for national level inventories submitted under the UNFCCC, CO_2 emissions from biomass combustion are estimated separately from fossil fuel CO_2 emissions and are not directly included in the energy sector contributions to U.S. totals. In accordance with IPCC methodological guidelines, any such emissions are calculated by accounting for net carbon fluxes from changes in biogenic C reservoirs in the AFOLU sector. Biomass non-CO_2 emissions are reported as part of emissions totals and are included under fossil fuel non-CO_2 emissions for both stationary and mobile sources.

2.1.6.2 Methods/Approach

The combustion of biomass fuels—such as wood, charcoal, and wood waste and biomass-based fuels such as ethanol, biogas, and biodiesel—generates CO_2 in addition to CH_4 and N_2O already covered earlier. In line with the reporting requirements for inventories submitted under the UNFCCC, CO_2 emissions from biomass combustion have been estimated separately from fossil fuel CO_2 emissions and are not directly included in the energy sector contributions to U.S. totals. In accordance with IPCC methodological guidelines, any such emissions were calculated by accounting for net carbon fluxes from changes in biogenic C reservoirs in the AFOLU sector.

Therefore, CO_2 emissions from wood biomass and biofuel consumption were not included specifically in summing energy sector totals. However, they are presented here for informational purposes and to provide detail on wood biomass and biofuels consumption. See Appendix A, Tables A-118 through Table A-129 in the "Biomass CO2" Tab for the breakout of biomass CO_2 emissions by fuel type and sector.

Biomass—Ethanol, Transportation

National-level ethanol CO_2 emissions from the transportation sector were taken from the national *Inventory*. Emissions were allocated to states based on the percentage of gasoline used in the transportation sector by state, which is based on FHWA data.

Biomass—Ethanol, Industrial

National-level ethanol CO_2 emissions from the industrial sector were taken from the national *Inventory*. Emissions were allocated to states based on the percentage of gasoline used in the industrial sector by state, which is based on SEDS data.

Biomass—Ethanol, Commercial

National-level ethanol CO_2 emissions from the commercial sector were taken from the national *Inventory*. Emissions were allocated to states based on the percentage of gasoline used in the commercial sector by state, which is based on SEDS data.

Biomass—Biodiesel, Transportation

National-level biodiesel CO_2 emissions from the transportation sector were taken from the national *Inventory*. Emissions were allocated to states based on the percentage of diesel fuel used in the transportation sector by state, which is based on FHWA data.

Biomass—Wood, Industrial/Residential/Commercial/Electric Power

National-level wood CO_2 emissions from all sectors were taken from the national *Inventory*. Emissions were allocated to states based on the percentage of wood used in each sector by state, which is based on SEDS data.

2.1.6.3 Uncertainty

A quantitative uncertainty analysis associated with the national estimates of CO_2, CH_4, and N_2O from wood biomass and biofuels combustion has not been considered a priority and has not been estimated. The priority is to estimate uncertainty for estimates that get rolled into national totals as opposed to estimates that are considered memo items. However, a qualitative discussion of uncertainty is associated with national-level wood biomass and biofuels combustion emissions in the national *Inventory*. State-level estimates are expected to have a higher uncertainty because of the assumptions related to allocating emissions to the state level based on fuel use data.

2.1.6.4 Planned Improvements

For CO_2 emissions from wood fuels, there is likely considerable variation among states. The EPA will look into other data sources, including from the USFS on wood used as a fuel.

The EPA will look into variability in ethanol consumption across states. It is not likely that ethanol is blended in the same percentage annually across all states.

2.1.6.5 References

See References Section for FFC 2.1.1.5.

2.2 Fugitive Emissions

This section presents the methodology used to estimate the fugitive portion of energy emissions and consists of the following sources:

- Coal mining (CH_4)[13]
- Abandoned underground coal mines (CH_4)
- Petroleum and natural gas systems (CO_2, CH_4, N_2O)
- Abandoned oil and gas wells (CO_2, CH_4)

2.2.1 Coal Mining (NIR Section 3.4)

2.2.1.1 Background

Three types of coal mining–related activities release CH_4 to the atmosphere: underground mining, surface mining, and post-mining (i.e., coal-handling) activities. For the national *Inventory*, the EPA compiles emissions estimates for each mine into a national total for active underground mines and compiles coal production data to estimate emissions from surface coal mining and post-mining activity.

2.2.1.2 Methods/Approach

The methods used to determine state-level estimates for Coal Mining fugitive emissions consists of two separate sources consistent with the national *Inventory*:

- Active underground mines
- Surface mining and post-mining activities

Active Underground Mines

To compile national estimates of CH_4 emissions from active underground coal mines for the national *Inventory*, the EPA develops emissions estimates for each mine into a national total, as described below. The approach to arrive at state-by-state estimates of CH_4 emissions from active underground mines is consistent with the national methods (i.e., using Approach 1 as defined in the Introduction of this report). Rather than summing estimates to a national total, the EPA instead totals these mine-specific estimates into a state-level total for each state, based on the estimates for each of the mines located in a state. In prior years, these estimates have been published in Annex 3.4 to the national *Inventory* (EPA 2021a).

As described in Section 3.4 of the national *Inventory*, the EPA uses an IPCC Tier 3 method for estimating CH_4 emissions from underground coal mining. These emissions have two sources: ventilation systems and degasification systems. Emissions are estimated using mine-specific data, then summed to determine total CH_4 liberated. The CH_4 recovered and used is then subtracted from this total, resulting in an estimate of net emissions to the atmosphere. See Section 3.4 of the national *Inventory* (EPA 2021b) for more detail.

To estimate CH_4 liberated from ventilation systems, the EPA uses data collected through its GHGRP[14] (Subpart FF, "Underground Coal Mines"), data provided by the U.S. Mine Safety and Health Administration (MSHA) (2019), and occasionally data collected from other sources on a site-specific level (e.g., state gas production databases). Since 2011, the Nation's "gassiest" underground coal mines—those that liberate more than 36,500,000 actual

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[13] The EPA anticipates including estimates for fugitive CO_2 emissions from active underground coal mining in the next *Inventory* based on methods in the *IPCC 2019 Refinement.* See p. 3-66 of Chapter 3: Energy of the latest annual *Inventory* found here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-3-energy.pdf.

[14] In implementing improvements and integrating data from EPA's GHGRP, the EPA follows the latest guidance from the IPCC in its Technical Bulletin on the use of Facility-Specific Data in National Greenhouse Gas Inventories (IPCC 2011).

cubic feet of CH_4 per year (about 17,525 MT CO_2 Eq.)—have been required to report to the EPA's GHGRP (EPA 2019).[15] Mines that report to the EPA's GHGRP must report quarterly measurements of CH_4 emissions from ventilation systems; they have the option of recording and reporting their own measurements or using the measurements taken by MSHA as part of that agency's quarterly safety inspections of all mines in the United States with detectable CH_4 concentrations.[16] More information can be found in the national *Inventory* (Chapter 3, Section 3.4 and Annex 3.4) per links included above.

Surface Mining and Post-mining Activities

Mine-specific data are not available for estimating CH_4 emissions from surface coal mines or for post-mining activities. For surface mines, basin-specific coal production obtained from the EIA's Annual Coal Report (EIA 2020) was multiplied by basin-specific CH_4 contents (EPA 1996, 2005) and a 150% emissions factor (to account for CH_4 from over- and under-burden) to estimate CH_4 emissions (King 1994, Saghafi 2013). For post-mining activities, basin-specific coal production was multiplied by basin-specific gas contents and a mid-range 32.5% emissions factor for CH_4 desorption during coal transportation and storage (Creedy 1993). Basin-specific in situ gas content data were compiled from AAPG (1984) and U.S. Bureau of Mines (1986).

To determine state-level CH_4 emissions estimates for surface coal mining and post-mining activities, emissions estimates were apportioned based on the coal production in each state, as reported in the EIA Annual Coal Report (i.e., using Approach 1 as defined in the Introduction of this report). The appropriate basin-specific CH_4 content for the coal produced in a state was assigned based on the coal basin in which the state is located. For post-mining activities, these emissions were assigned to the state where the coal was produced, even if a portion of such emissions may occur outside the state, for example, during interstate transport and storage before use. More information can be found in the national *Inventory* (Chapter 3, Section 3.4 and Annex 3.4).

2.2.1.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CH_4 emissions from coal mining was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 3 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), the level of uncertainty in the 2019 national CH_4 estimate is −8.8% to +20.3%. Because emissions estimates from underground mine ventilation and degasification systems were based on actual measurement data from EPA's GHGRP and from MSHA, uncertainty is relatively low. Surface mining and post-mining emissions, which are based on coal production and the application of emission factors, are associated with considerably more uncertainty than underground mines because of the difficulty in developing accurate basin-level emissions factors from field measurements. However, because underground mine emissions constitute the majority of total coal mining emissions, the uncertainty associated with underground emissions is the primary factor that determines the overall uncertainty of the emissions estimates.

National-level emissions estimates for underground mines were developed by aggregating mine-level estimates. Similarly, state-level emissions estimates for underground mines were developed by aggregating mine-level estimates for all the coal mines located within each state. The relatively low uncertainty associated with underground mine emissions at the national level is assumed to be same for state-level underground mine emissions estimates. State-level emissions estimates for surface mining and post-mining emissions are associated with higher uncertainty than underground estimates because they are based on coal production within a state and the application of emissions factors. Because state-level estimates are based on the coal production within a state,

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[15] Underground coal mines report to the EPA under Subpart FF of the GHGRP (40 CFR Part 98). In 2018, 76 underground coal mines reported to the program.

[16] MSHA records coal mine CH_4 readings with concentrations of greater than 50 ppm (parts per million) CH_4. Readings below this threshold are considered nondetectable.

the uncertainty associated with surface mining and post-mining emissions at the national level is assumed to be the same for state-level estimates. However, as with the national estimates, underground emissions account for the majority of state-level coal mining emissions, and the uncertainty associated with underground emissions is the primary factor that determines overall uncertainty for state-level emissions estimates.

2.2.1.4 Planned Improvements

Planned improvements are consistent with those planned for improving national estimates, given that the underlying methods for state GHG estimates are the same as those in the national *Inventory.* The EPA intends to include estimates of fugitive CO_2 emissions from underground and surface mining, based on methods included in the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. For more information, see Chapter 3, Section 3.4 of the national *Inventory*.

2.2.1.5 References

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2.2.2 Abandoned Underground Coal Mines (NIR Section 3.5)

2.2.2.1 Background

Underground mines continue to release CH_4 after closure. As mines mature and coal seams are mined through, mines are closed and abandoned. Many are sealed, and some flood through intrusion of groundwater or surface water into the void. Shafts or portals are generally filled with gravel and capped with a concrete seal, while vent pipes and boreholes are plugged in a manner similar to oil and gas wells. Some abandoned mines are vented to the atmosphere to prevent the buildup of CH_4 that may find its way to surface structures through overburden fractures. As work stops within the mines, CH_4 liberation decreases, but it does not stop completely. Following an initial decline, abandoned mines can liberate CH_4 at a near-steady rate over an extended period of time, or, if flooded, produce gas for only a few years. The gas can migrate to the surface through the conduits described above, particularly if they have not been sealed adequately. In addition, diffuse emissions can occur when CH_4 migrates to the surface through cracks and fissures in the strata overlying the coal mine.

2.2.2.2 Methods/Approach

For the national *Inventory*, the EPA estimates national-level CH_4 emissions from abandoned underground coal mines using the Abandoned Mine Methane (AMM) model. The AMM model predicts mine-level CH_4 estimates from the time of abandonment through the inventory year of interest. The flow of CH_4 from the coal to the mine void is primarily dependent on the mine's emissions when active and the extent to which the mine is flooded, sealed, or vented. For each abandoned mine, the AMM model takes into account mine status, date of abandonment, and the reported average daily emission rate at the time of abandonment to estimate emissions using decline curves specific to mine status and coal basin. The model results, by coal basin and mine status, are then aggregated to the national level.[17] More information on the estimation methodology and model input data can be found in the national *Inventory* (Chapter 3, Section 3.5) (EPA 2021).

The AMM model is not currently designed to estimate state-level CH_4 emissions. State-level emissions estimates for the time series were developed from the national-level emissions estimates using Approach 2 as defined in the Introduction to this report. Specifically, estimates were disaggregated using mine-level average daily CH_4 emissions at the time of abandonment, mine status (i.e., flooded, sealed, vented, and unknown), date of abandonment, and mine location (basin and state) as follows:

Step 1: Develop state allocation factors by basin and mine status

For liberated CH_4, the estimated mine-level average daily emissions from the AMM model were totaled by state, mine status, and coal basin (Central Appalachia, Illinois, Northern Appalachia, Warrior, and Western basin) for each year in the 1990–2019 time series. Using these state-level totals of average daily emissions and the basin-level totals of average daily emissions by mine status, state allocation factors (percent) were developed by state, mine status, and coal basin such that allocation factors across all states within the same coal basin and same mine status total to 100% for each year in the time series (see Appendix B, Tables B-2 to B-4 for this data).

State allocation factors for recovered CH_4 were calculated similarly to liberated CH_4 state allocation factors, with the exception that allocation factors were calculated by basin only (not mine status). There are very few CH_4 recovery projects for each year in the time series, so the breakdown by coal basin was sufficient to develop state allocation factors.

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[17] The AMM model is run using @Risk software, which is a stochastic Monte Carlo simulation software.

For pre-1972 emissions,[18] state allocation factors for mines abandoned before 1972 (referred to as "pre-1972 mines") were developed using 2019 emissions estimates. For these mines, 2019 emissions estimates serve as a good proxy for the entire time series because the pre-1972 mine estimates are developed using county-level default percentages built into the AMM model.

As an example, Table 2-4 presents the state allocation factors for liberated CH_4 for all states in the Illinois Basin with sealed abandoned mines for year 2019 in the time series.

Table 2-4. Example State Allocation Factors for the Illinois Coal Basin (Sealed Mines)

State	Basin	Status	Percentage (%) of Emissions
IL	Illinois	Sealed	77%
IN	Illinois	Sealed	6%
KY	Illinois	Sealed	17%

Step 2: Develop master table of basin and mine status-level emissions for 1990–2019.

Compile data from previous AMM models. The AMM model only estimates annual emissions for a single reporting year (i.e., for the 1990–2019 time series, there are 29 separate AMM models, each addressing a single year in the time series). The EPA compiled into a master table the time-series estimates of liberated CH_4, recovered CH_4, and CH_4 emissions from pre-1972 mines from previous annual versions of the AMM model for the 1990–2019 time series.

Normalize direct calculations to match model iterations. The master table contains the following AMM model outputs for each year in the time series (under separate categories for liberated emissions, recovered emissions, and emissions from pre-1972 mines):

1. Annual emissions subtotals by coal basin and by mine status (calculated using in-built decline curves in the AMM model and input data, such as average daily emissions at the time of abandonment, date of abandonment, and mine status indicator)
2. Annual national-level total emissions (based on an average of 10,000 stochastic iterations performed on the AMM model output #1 above and their associated uncertainty ranges)

The master table contains annual subtotals by coal basin and mine status; however, the aggregate of the annual subtotals by basin and mine status (i.e., sum of AMM model output #1 above) does not match the annual national-level total emissions estimate (AMM model output #2 above). Model output #2 above is the average value for 10,000 model iterations. Therefore, there is a very small difference between the two national-level totals for each year in the time series (typically less than 0.5% in any year of the time series). For this reason, the annual estimates in the master table (i.e., annual subtotals by coal basin and by mine status; AMM model output #1) must be normalized[19] to equal the national-level emissions estimate (AMM model output #2) that represents the national emissions estimates used in the national *Inventory*.

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[18] Because of limited data availability for mines abandoned before 1972, a different approach was used in the AMM model to estimate emissions from these mines (referred to as "pre-1972 mines") compared with mines abandoned in 1972 and later years. The AMM model estimates emissions for the pre-1972 mines at the county level and does not use mine-level average daily emissions at the time of abandonment. Refer to the national *Inventory* Chapter 3, Section 3.5 for further details.

[19] The difference between the national total and summed total of modeled emissions by coal basin and mine status was allocated to a coal basin and mine status grouping based on their share of the national total (before normalization).

Step 3: Apply state allocation factors to basin- and mine status-level emissions.

The emissions values from the master table generated in Step 2 were multiplied by the state allocation factors generated in Step 1 to develop 1990–2019 annual state-level CH_4 estimates.

For pre-1972 mines, 2019 state allocation factors were applied to the annual pre-1972 national estimates in the master table.

For mines abandoned after 1972, annual basin and mine status-level state allocation factors were applied to the normalized basin- and mine status-level emissions estimates in the master table.

2.2.2.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CH_4 emissions from abandoned coal mines was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described in Chapter 3 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), the level of uncertainty in the 2019 national CH_4 emission estimate is −20% to +23%.

National-level abandoned mine emissions estimates were developed by predicting the emissions of a mine since the time of abandonment using basin-level decline curves. Multiple aspects of the estimation method introduce uncertainty for the emissions estimates. In developing national estimates, because of a lack of mine-specific data, abandoned mines are grouped by basin with the assumption that they will generally have the same initial pressures, permeability, and isotherm. Other sources of uncertainty in the national estimates are mine status (venting, flooded, or sealed) and CH_4 liberation rates at the time of abandonment. These data are not available for all the abandoned mines in the national *Inventory*. Abandoned mines with unknown status are assigned a status based on the known status of other mines located within the same basin. Mine-specific CH_4 liberation rates at the time of abandonment are not available for mines abandoned before 1972. It is assumed that pre-1972 mines are governed by the same physical, geologic, and hydrologic constraints that apply to post-1971 mines; thus, their emissions may be characterized by the same decline curves.

State-level estimates have a higher uncertainty because the national emissions estimates were apportioned to each state based on mine-specific CH_4 liberation rates, mine status, and basin information for all the abandoned mines located within the state. Additionally, the number of mines with unknown status in each state affects the relative uncertainty of state-level estimates. Estimates for states with a greater number of mines with unknown status are expected to have relatively higher uncertainty compared with states with fewer abandoned mines with unknown status. Similarly, states with a greater number of pre-1972 abandoned mines are expected to have relatively higher uncertainty compared with states with fewer pre-1972 mines.

2.2.2.4 Planned Improvements

The EPA is considering updating the AMM model to include state-level estimates as a regular output. Currently, the AMM model includes only coal basin identifiers, and the EPA is considering adding state identifiers. Under this approach, both national-level and state-level estimates would be generated for a reporting year by the AMM model. The modified model output would contain emissions subtotals by state, coal basin, and mine status. These subtotals would then be aggregated to generate state-level estimates. The final model result (i.e., national-level estimates) would be the average of 10,000 model iterations, but the calculated state estimates would not. Therefore, the sum of the state-level estimates may not exactly equal the final national-level estimate. The state-level estimates would then be normalized to the final national-level model result using the difference between the national-level total and the sum of state-level totals. This approach would rely on model simulations using decline curves based on mine location (state and basin) and mine status, rather than using state allocation factors (as described above) to develop state-level estimates. Therefore, this approach is expected to provide more accurate state-level estimates. As a further improvement, the AMM model could be modified to include the state-level estimates in the 10,000 iterations. This improvement would require additional resources to implement.

2.2.2.5 References

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019 (EPA 430-R-21-005), Chapter 3 Energy, Section 3.5. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

2.2.3 Petroleum Systems (NIR Section 3.6)

2.2.3.1 Background

This section describes methods used to estimate state-level CO_2, CH_4, and N_2O emissions from petroleum systems. This category includes fugitive emissions from leaks, venting, and flaring. Methane emissions from petroleum systems are primarily associated with onshore and offshore crude oil production, transportation, and refining operations. During these activities, CH_4 is released to the atmosphere as emissions from leaks, venting (including emissions from operational upsets), and flaring. CO_2 emissions from petroleum systems are primarily associated with onshore and offshore crude oil production and refining operations. Note, CO_2 emissions in petroleum systems exclude all combustion emissions (e.g., engine combustion) except for flaring CO_2 emissions. All combustion CO_2 emissions (except for flaring) are accounted for in the FFC section. Emissions of N_2O from petroleum systems are primarily associated with flaring.

The methods used to develop the state-level estimates for Petroleum Systems primarily rely on relative differences in basic activity levels (e.g., petroleum production), and do not reflect differences between states due to differences in practices, technologies, or formation types. Future state-level inventory reports may incorporate additional state or region-specific data to improve estimates and better reflect these differences.

2.2.3.2 Methods/Approach

The state-level methodology for petroleum systems is to allocate source-specific emissions within each segment to all U.S. states, territories, and federal offshore waters (production segment only) using activity datasets with information broken out at a state level, such as the number of wells or amount of oil or gas production in each state (i.e., using Approach 2 as defined in the Introduction to this report). These datasets are chosen to align with current activity datasets used to develop national estimates. See Appendix B for information underlying the estimates, i.e., Tables B-5 to B-7.

To compile national estimates of GHG emissions (CH_4, CO_2, and N_2O) from petroleum systems for the national *Inventory*, the EPA compiles emissions estimates for emissions sources in each segment of petroleum systems into a national total (EPA 2021). Additional information on emissions estimates and data used to develop the national-level emissions estimates for petroleum systems is available at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2019-ghg. To arrive at state-by-state estimates of GHG emissions from petroleum systems, the EPA disaggregates total segment-specific estimates into a total for each state. The approach to disaggregate emissions to the state level varies by segment.

Exploration and Production

For the national *Inventory*, the EPA uses emissions data collected by the GHGRP to quantify emissions for most sources in recent years (i.e., 2010–2019). For sources for which recent data are unavailable, and for many sources in earlier years of the time series, estimates are developed using emissions factors from EPA/GRI (1996) and Radian (1999) studies. Other key data sources include oil well counts and production levels from Enverus, Bureau of Ocean Energy Management (BOEM), and total crude oil production from the EIA.

To develop state-level emissions from petroleum exploration and production, national *Inventory* emissions were largely allocated to each state based on the fraction of oil wells in each state relative to the national total well count. Other key proxy datasets include the number of oil well completions with and without hydraulic fracturing in each state, as well as the volume of oil produced by each well. In this work, state counts were derived from time series of oil and gas well data from Enverus, consistent with the Enverus dataset used as activity data to derive total national emissions.

For the onshore production segment, data for the disaggregation include state-level counts of oil wells and total production levels of oil wells in each state relative to the national total (Appendix B Table B-5 – B-6). In addition, emissions from offshore activities in state waters in the Gulf of Mexico were allocated based on relative state-level well production levels, while emissions from activities in federal waters were retained as a separate category (i.e., not allocated to states). For both exploration and production segments, the sources of proxy data used for state allocation were consistent across the entire emissions time series.

Crude Oil Transport

For the national *Inventory*, the EPA estimates emissions of CH_4, CO_2, and N_2O from crude oil transport for petroleum systems using a combination of crude oil transportation and pipeline and crude deliveries data from the EIA, American Petroleum Institute, and *Oil and Gas Journal*.

To develop state-level emissions from crude oil transport, national *Inventory* emissions were allocated to each state based on a number of state proxy variables. For example, vented emissions from marine loading were allocated based on oil production from offshore wells from the Enverus dataset (Appendix B Table B-6). Similarly, vented emissions from truck loading and rail loading were allocated based on onshore levels of oil well production in each state. All other transport emissions, including tanks, pump stations, and floating roof tanks, were allocated based on the relative state counts of oil refineries from the GHGRP after 2001 and EIA atmospheric crude oil distillation capacity for 1990–2009, as described below (Appendix B Table B-7).

Refineries

To compile national emissions estimates from refineries for the national *Inventory*, the EPA uses data from the GHGRP and national-level activity data. All U.S. refineries have been required to report CH_4, CO_2, and N_2O emissions for all major activities starting with emissions that occurred in 2010. The reported total CH_4, CO_2, and N_2O emissions for each activity was used for the emissions in each year from 2010 forward. Certain activities that are not reported to GHGRP were estimated using data from Radian (1999). These sources accounted for a small fraction of refinery emissions. To estimate emissions for 1990–2009, the emissions data from GHGRP, along with the refinery feed data, were used to derive emissions factors that were then applied to the annual refinery feed in years 1990–2009.

To develop state-level estimates for refineries for 2010–2019, total national *Inventory* emissions were apportioned to each state based on that state's share of refinery emissions of that gas in GHGRP subpart Y. For 1990–2009, total national *Inventory* emissions were apportioned to each state based on that state's share of national operating atmospheric crude oil distillation capacity (barrels per calendar day) (EIA) (Appendix B Table B-7).

2.2.3.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 and CH_4 from petroleum systems was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −27%/+41% for CO_2 and −24%/+29% for CH_4.

The uncertainty estimates for the national *Inventory* largely account for uncertainties in the magnitude of emissions and activity factors used to develop the national estimates for the largest contributing sources. State-level estimates of annual emissions and removals have a higher relative uncertainty compared with these national estimates because of the additional step of apportioning national emissions to each state using spatial proxy datasets. This allocation method introduces additional uncertainty due to sources of uncertainty associated with the location information in each underlying dataset (e.g., number of oil wells in each state), as well as the ability of each proxy to accurately represent the point of emission from each source within the petroleum supply chain. Where possible, this second source of uncertainty was minimized in the petroleum state-level analysis by selecting proxy datasets that are consistent with activity factors used in the national *Inventory*. For example, national CO_2 and CH_4 from vented emissions in the production segment largely relied on national counts of oil wells and production volumes as activity factors; therefore, additional uncertainty in the state-level estimates is largely associated with the uncertainty in oil well locations. The sources of uncertainty for this category are also consistent over time because the same proxy datasets were applied across the entire time series. This allocation method, however, cannot account for state-specific mitigation programs and reduction efforts or state-specific variations in emissions factors, which each introduce additional uncertainty in the emissions estimates. As with the national *Inventory*, the state-level uncertainty estimates for this category may change as the understanding of the uncertainty and underlying datasets and methodologies improve.

Given the variability of practices and technologies across oil and gas systems and the occurrence of episodic events, it is possible that the EPA's estimates do not include all methane emissions from abnormal events. For many equipment types and activities, the EPA's emissions estimates include the full range of conditions, including "super-emitters." For other situations, where data are available, emissions estimates for abnormal events were calculated separately and included in the GHG Inventory (e.g., Aliso Canyon leak event). The EPA continues to work through its stakeholder process to review new data from the EPA's GHGRP and research studies to assess how emissions estimates can be improved.

2.2.3.4 Planned Improvements

Potential refinements to exploration and production estimates in future state-level inventories include the refinement of state proxies used within each segment and the incorporation of additional GHGRP data.

Potential refinements to crude transport estimates in future state-level inventories include the refinement of state proxies used for individual sources within each segment.

2.2.3.5 References

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2.2.4 Natural Gas Systems (NIR Section 3.7)

2.2.4.1 Background

This section describes methods used to estimate state-level CO_2, CH_4, and N_2O emissions from natural gas systems. Similar to petroleum systems, this category includes fugitive emissions from leaks, venting, and flaring.

The U.S. natural gas system encompasses hundreds of thousands of wells, hundreds of processing facilities, and over a million miles of transmission and distribution pipelines. Methane and CO_2 emissions from natural gas systems include those resulting from normal operations, routine maintenance, and system upsets. Emissions from normal operations include natural gas engine and turbine uncombusted exhaust, flaring, and leak emissions from system components. Routine maintenance emissions originate from pipelines, equipment, and wells during repair and maintenance activities. Pressure surge relief systems and accidents can lead to system upset emissions. Emissions of N_2O from flaring activities are included in the national *Inventory*, with most of the emissions occurring in the processing and production segments. Note, CO_2 emissions exclude all combustion emissions (e.g., engine combustion) except for flaring CO_2 emissions. All combustion CO_2 emissions (except for flaring) are accounted for in the FFC section.

The methods used to develop the state-level estimates for Natural Gas Systems primarily rely on relative differences in basic activity levels (e.g., gas production), and do not reflect differences between states due to differences in practices, technologies, or formation types. Future state-level inventory reports may incorporate additional state-state or region-specific data to improve estimates and better reflect these differences.

2.2.4.2 Methods/Approach

The state-level methodology for natural gas systems is to allocate source-specific emissions within each segment to all U.S. states, territories, and federal offshore waters (production segment only) using activity datasets with information broken out at a state level, such as the number of wells or amount of oil or gas produced in each state (i.e., using Approach 2 as defined in the introduction to this report). These datasets are chosen to align with current activity datasets used to develop national estimates. See Appendix B for information underlying the estimates, i.e., Tables B-8 to B-12.

To compile national estimates of CH_4, CO_2, and N_2O emissions from natural gas systems for the national *Inventory*, the EPA compiles emissions estimates for emissions sources in each segment of natural gas systems into a national total. Additional information on emissions estimates and data used to develop the national-level emissions estimates for natural gas systems are available online at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2019-ghg.

Exploration and Production

For the national *Inventory*, the EPA uses emissions data collected by the GHGRP to quantify emissions for most sources in recent years (i.e., 2011–2019) and data from a GRI/EPA 1996 study for earlier years of the time series and for sources for which recent data are unavailable. Other key data sources include data provided in Zimmerle et al. (2019), production and well count data from Enverus, and offshore production emissions data from the BOEM. Each emissions source for production in the national *Inventory* was generally scaled to the national level using either well counts, gas production, or condensate production.

To develop state-level emissions from natural gas exploration and production, national *Inventory* emissions were generally allocated to states using the key activity data for each source as used in the national *Inventory* (i.e., well counts, gas production, or condensate production). State well counts were derived from time series of gas well data from Enverus, consistent with the Enverus data used as national-level activity data in the national *Inventory* (see Appendix B Table B-8). Other proxy data for onshore production sources include state-level natural gas production from the Enverus data (Appendix B Table B-9) and state-level lease condensate production from the EIA (2020). Proxy data for exploration include the number of wells and well completions with and without hydraulic fracturing, as well as the total number of gas wells drilled in each state relative to the national total. Offshore emissions in the Gulf of Mexico and the state of Alaska were allocated based on natural gas production at each platform. Additional production emissions from offshore federal waters were not allocated to individual states but were included as a separate total, and emissions from gathering and boosting were allocated based on the fractions in each state of emissions from all other production sources. For both exploration and production segments, the sources of proxy data used for state allocation were consistent across the entire emissions time series.

Processing

For the national *Inventory*, the EPA uses emissions data collected by GHGRP to quantify emissions for most sources in recent years (i.e., 2011–2019) and data from GRI/EPA (1996) for earlier years of the time series and for sources for which recent data are unavailable. Key activity data include processing plant counts from the *Oil and Gas Journal*. To develop state-level estimates for the processing segment for each year of the time series, the EPA apportioned the total national processing segment emissions to each state based on the fraction of national onshore natural gas production (EIA 2020) occurring in each state (Appendix B Table B-10).

Transmission and Storage

For the national *Inventory*, the EPA uses emissions data collected by the GHGRP, data from a Zimmerle et al. (2015) study to quantify emissions from most sources in recent years (i.e., 2011–2019), and GRI/EPA (1996) data for earlier years of the time series and for sources for which recent data are unavailable. Key activity data include transmission stations (calculated using the GHGRP data and Zimmerle et al.), storage stations (calculated using Zimmerle et al. and EIA data), and transmission pipeline miles (Pipeline and Hazardous Materials Safety Administration [PHMSA] 2019).

To develop state-level estimates for the transmission and storage segment for each year of the time series, the EPA apportioned the total national transmission and storage segment emissions to each state based on the fraction of national transmission pipeline mileage occurring in each state (Appendix B Table B-11).

Distribution

For the national *Inventory*, the EPA uses emissions data collected by the GHGRP and data from a Lamb et al. (2015) study to quantify emissions from most sources in recent years (i.e., 2011–2019) and GRI/EPA (1996) data for earlier years of the time series and for sources for which recent data are unavailable. Key activity data include pipeline mileage by material from the PHMSA station counts from subpart W of the GHGRP and number of natural gas residential, commercial, and industrial consumers from the EIA.

To develop state-level estimates for the distribution segment for each year of the time series, the EPA national total emissions from pipeline leaks were allocated based on the relative pipeline mileage (by material [cast iron, unprotected/protected steel, plastic]) in each state; the relative number of natural gas residential, commercial, and industrial consumers in each state from the EIA; and the number of above- and below-grade stations in each state as reported to the GHGRP (scaled up by the ratio of PHMSA to GHGRP pipeline mileage in each state to include nonreporters). Complete PHMSA data are available starting in the year 2003 and GHGRP data are available for all years starting in 2011. For all earlier years, national emissions were allocated using the same relative state contributions as those values in the earliest available years (e.g., relative state-level pipeline mileage amounts held constant before 2003) (Appendix B Table B-12).

2.2.4.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 and CH_4 from natural gas systems was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −16%/+19% for CO_2 and −15%/+14% for CH_4.

The uncertainty estimates for the national *Inventory* largely account for uncertainty in the magnitude of emissions and activity factors used to develop the national estimates for the largest contributing sources. State-level estimates of annual emissions and removals have a higher relative uncertainty compared with these national estimates due to the additional step of apportioning national emissions to each state using spatial proxy datasets. This allocation method introduces additional uncertainty due to sources of uncertainty associated with the location information in each underlying dataset (e.g., number of nonassociated gas wells in each state), as well as the ability of each proxy to accurately represent the point of emission from each source within the natural gas supply chain. Where possible, this second source of uncertainty is minimized in the natural gas state-level analysis by selecting proxy datasets that are consistent with activity factors used in the national *Inventory*. However, this is not always possible when activity factor datasets only include national aggregate statistics. For example, national CO_2 and CH_4 emissions from transmission and storage compressor stations largely rely on national station counts. In the state-level estimates, these emissions are allocated based on relative state-level gas production volumes from the EIA and will therefore include additional uncertainty associated with the accuracy of the state-specific data in the EIA dataset, as well as the accuracy in which relative state-level gas production volumes reflect the relative state-level emissions from compressor stations. In contrast, the national *Inventory* estimates for sources within the natural gas production segment typically use national well counts and production volumes as activity factors. Therefore, additional uncertainty in the state-level estimates for these sources will largely be the spatial representation of gas wells in the activity factor dataset. The sources of uncertainty for this category are also consistent over time because the same proxy datasets are applied across the entire time series. This allocation method, however, cannot account for state-specific mitigation programs and reduction efforts or state-specific variations in emissions factors, which each introduce additional uncertainty in the emissions estimates. As with the national *Inventory*, the state-level uncertainty estimates for this category may change as the understanding of the uncertainty of estimates and underlying datasets and methodologies improve.

Given the variability of practices and technologies across oil and gas systems and the occurrence of episodic events, it is possible that the EPA's estimates do not include all methane emissions from abnormal events. For many equipment types and activities, the EPA's emissions estimates include the full range of conditions, including "super-emitters." For other situations, where data are available, emissions estimates for abnormal events were calculated separately and included in the GHG *Inventory* (e.g., Aliso Canyon leak event). The EPA continues to work through its stakeholder process to review new data from the EPA's GHGRP and research studies to assess how emissions estimates can be improved.

2.2.4.4 Planned Improvements

Potential refinements to exploration and production estimates in future state-level inventories include the refinement of state proxies used for individual sources within each segment and the incorporation of additional GHGRP data for the allocation of emissions within the production segment.

Potential refinements to processing estimates in future state-level inventories include the use of emissions level reported to the GHGRP (along with other data) to apportion emissions to each state. In addition, information on processing plant locations from other datasets or use of Oil and Gas Journal or EIA data on gas processing volumes could be incorporated to improve estimates. Potential refinements to transmission and storage estimates in future state-level inventories include the use of emissions levels reported to the GHGRP (along with other data) to apportion emissions to each state. In addition, information on transmission and storage station locations from other datasets could be incorporated to improve estimates.

2.2.4.5 References

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2.2.5 Abandoned Oil and Gas Wells (NIR Section 3.8)

2.2.5.1 Background

This section describes methods used to estimate state-level CO_2 and CH_4 emissions from Abandoned Oil and Gas Wells. The term “abandoned wells” encompasses various types of wells, including orphaned wells and other nonproducing wells:

- Wells with no recent production, and not plugged. Common terms (such as those used in state databases) might include inactive, temporarily abandoned, shut-in, dormant, and idle.
- Wells with no recent production and no responsible operator. Common terms might include orphaned, deserted, long-term idle, and abandoned.
- Wells that have been plugged to prevent migration of gas or fluids.

The U.S. population of abandoned wells (including orphaned wells and other nonproducing wells) is around 3.4 million (with around 2.7 million abandoned oil wells and 0.6 million abandoned gas wells). The methods to calculate emissions from abandoned wells involved calculating the total populations of plugged and unplugged abandoned oil and gas wells in the United States.

2.2.5.2 Methods/Approach

The state-level methodology for abandoned oil and gas wells is to allocate emissions from this segment to all U.S. states and territories using activity datasets with information broken out at the state level, including well counts, type (e.g., oil vs. gas), and plugging status (i.e., using Approach 2 as defined in the introduction of this report). These data were chosen to align with the current activity datasets used to develop national estimates. See Appendix B, Table B-13 for the underlying datasets.

To compile national estimates of CH_4 and CO_2 emissions from abandoned oil and gas wells for the national *Inventory*, the EPA compiles emissions estimates for plugged and unplugged abandoned wells for two regions: Appalachia and outside of Appalachia. Key data sources are two research studies (Kang et al. [2016] and Townsend-Small et al. [2016]) for emissions factors and Enverus database and historical state-level datasets for abandoned well counts. Additional information on emissions estimates and data used to develop the national-level emissions estimates for abandoned wells is available at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990–2019-ghg.

To develop state-level estimates of GHG emissions from abandoned natural gas and oil wells, national emissions were allocated based on an estimate of the number of abandoned wells in each state (developed using Enverus and historical datasets, consistent with the approach used in the national *Inventory*), as well as their type and plugging status. As a result of the use of regional-specific emissions factors (described above), the national estimates in the national *Inventory* were derived from the sum of emissions estimates from plugged and unplugged natural gas and oil wells in Appalachia and outside of Appalachia. Emissions from the national *Inventory* for each region were then allocated based on the counts of abandoned wells in each state and their plugging status. For example, emissions from plugged natural gas wells in the Appalachia region (OH, PA, WV, NY, KY, TN) were allocated to each of the six Appalachia states based on the fraction of plugged abandoned natural gas wells in each state relative to the total for all six states. For all remaining states, emissions from plugged natural gas wells were allocated to each state based on the fraction of plugged abandoned natural gas wells in each of the non-Appalachia states relative to the total for all 44 states. State-level counts of abandoned oil and natural gas wells are from the Enverus dataset supplemented with historical estimates of state-level abandoned well counts from state databases, as described in a previous EPA memo on abandoned oil and gas wells (EPA 2018) (see Appendix B, Table B-13 for data). The state-level well plugging status was derived from the fraction of plugged and unplugged wells in each state, also derived from the Enverus dataset.

2.2.5.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 and CH_4 from abandoned oil and gas wells was each calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 for both abandoned oil and gas wells were −83%/+217% for CO_2 and −83%/+217% for CH_4.

The uncertainty estimates for the national *Inventory* largely account for uncertainty in the magnitude of emissions and activity factors used to develop the national estimates. State-level estimates of annual emissions and removals have a higher relative uncertainty compared with these national estimates because of the additional step of apportioning national emissions to each state using spatial proxy datasets. This allocation method for abandoned oil and gas wells used the same activity factor dataset used in the national *Inventory*. However, this method introduces additional uncertainty in the state estimates due to uncertainties in the reported locations of abandoned oil and gas wells in each state. The sources of uncertainty for this category are consistent over time and the same proxy datasets were applied across the entire time series. This allocation method, however, cannot account for state-specific mitigation programs and reduction efforts or state-specific variations in emissions factors, which each introduce additional uncertainty in the emissions estimates. As with the national *Inventory*, the state-level uncertainty estimates for this category may change as the understanding of the uncertainty of estimates and underlying datasets and methodologies improve.

2.2.5.4 Planned Improvements

Potential refinements include the incorporation of improved state-level abandoned well counts for each year of the time series. The approach taken here to estimate state-level well count data uses estimates developed for select years (1990 and 2015) and interpolated for other years.

2.2.5.5 References

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3 Industrial Processes and Product Use (IPPU) (NIR Chapter 4)

For this methodology report, the IPPU sector is organized into four subsectors: minerals, chemicals, metals, and product use (fluorinated sources, N_2O). For more information on IPPU sector emissions, see Chapter 4 of the national *Inventory*. Table 3-1 summarizes the different approaches used to estimate state-level IPPU sector emissions and completeness. Geographic completeness is consistent with the national *Inventory*. The sections below provide more detail on each category.

Table 3-1. Overview of Approaches for Estimating State-Level IPPU Sector GHG Emissions

Category	Gas	Approach	Geographic Completeness
Cement Production	CO_2	Hybrid Approach • 1990-2009: Approach 1 • 2010-2019: Approach 2	Includes emissions from all states, Washington D.C., and territories (i.e., Puerto Rico) as applicable.
Lime Production	CO_2	Approach 2	Includes emissions from all states, Washington D.C., and territories (i.e., Puerto Rico) as applicable.
Glass Production	CO_2	Approach 2	Includes emissions from all states, Washington D.C., and territories[1] (i.e., Puerto Rico) as applicable.
Other Process Uses of Carbonates	CO_2	Approach 2	Includes emissions from all states, Washington D.C., and territories[1] (i.e., Puerto Rico) as applicable.
Carbon Dioxide Consumption	CO_2	Approach 2	Includes emissions from all states, Washington D.C., and territories[1] (i.e., Puerto Rico) as applicable.
Ammonia Production	CO_2	Approach 2	Includes emissions from all states, Washington D.C., and territories as applicable.
Urea Consumption for Nonagricultural Purposes	CO_2	Approach 2	Includes emissions from all states, Washington D.C., and territories[1] (i.e., Puerto Rico) as applicable.
Nitric Acid Production	N_2O	Approach 2	Includes emissions from all states, Washington D.C., and territories as applicable.
Adipic Acid Production	N_2O	Approach 1	Includes emissions from all states, Washington D.C., and territories as applicable.
Caprolactam, Glyoxal and Glyoxylic Acid Production	N_2O	Approach 2	Includes emissions from all states, Washington D.C., and territories as applicable.
Carbide Production and Consumption	CO_2 CH_4	Hybrid Approach • Production: Approach 1 • Consumption: Approach 2	Includes emissions from all states, Washington D.C., and territories[1] (i.e., Puerto Rico) as applicable.
Titanium Dioxide Production	CO_2	Approach 2	Includes emissions from all states, Washington D.C., and territories as applicable.
Soda Ash Production	CO_2	Approach 1	Includes emissions from all states, Washington D.C., and territories as applicable.

Petrochemical Production	CO_2 CH_4	Approach 2	Includes emissions from all states, Washington D.C., and territories as applicable.
HCFC-22 Production	HFCs	Hybrid Approach • 1990-2009: Approach 2 • 2010-2019: Approach 1	Includes emissions from all states, Washington D.C., and territories as applicable.
Phosphoric Acid Production	CO_2	Approach 2	Includes emissions from all states, Washington D.C., and territories as applicable.
Iron & Steel Production and Metallurgical Coke Production	CO_2 CH_4	Approach 2	Includes emissions from all states, Washington D.C., and territories as applicable.
Ferroalloys Production	CO_2 CH_4	Approach 2	Includes emissions from all states, Washington D.C., and territories as applicable.
Aluminum Production	CO_2 PFCs	Hybrid Approach • 1990-2009: Approach 2 • 2010-2019: Approach 1	Includes emissions from all states, Washington D.C., and territories as applicable.
Magnesium Production and Processing	CO_2 SF_6 HFCs	Hybrid Approach • 1990-1998: Approach 2 • 1999-2019: Approach 1 & 2	Includes emissions from all states, Washington D.C., and territories as applicable.
Lead Production	CO_2	Approach 2	Includes emissions from all states, Washington D.C., and territories as applicable.
Zinc Production	CO_2	Approach 2	Includes emissions from all states, Washington D.C., and territories as applicable.
Electronics Industry	N_2O NF_3 SF_6 HFCs PFCs	Hybrid Approach • 1990-2010: Approach 2 • 2011-2019: Approach 1 & 2	Includes emissions from all states, Washington D.C., and territories as applicable.
Substitution of Ozone-Depleting Substances	HFCs PFCs	Hybrid Approach	Includes emissions from all states, Washington D.C., and territories[1] (i.e., Puerto Rico, American Samoa, Guam, Northern Mariana Islands, U.S. Virgin Islands) as applicable.
Electrical Transmission and Distribution	SF_6	Hybrid Approach • 1990-2010: Approach 2 • 2011-2019: Approach 1 & 2	Includes emissions from all states, Washington D.C., and territories[1] (i.e., Puerto Rico, U.S. Virgin Islands) as applicable.
Nitrous Oxide from Product Uses	N_2O	Approach 2	Includes emissions from all states, Washington D.C., and territories[1] (i.e., Puerto Rico) as applicable.

[1] Emissions are likely occurring in other US territories; however, due to a lack of available data and the nature of this category, this analysis includes emissions for only the territories indicated. Territories not listed are not estimated.

3.1 Minerals

This section presents the methodology used to estimate the minerals portion of IPPU emissions, which consist of the following sources:

- Cement production (CO_2)
- Lime production (CO_2)
- Glass production (CO_2)
- Other process uses of carbonates (CO_2)
- Carbon dioxide consumption (CO_2)

3.1.1 Cement Production (NIR Section 4.1)

3.1.1.1 Background

Cement Production is an energy- and raw material–intensive process that results in the generation of CO_2 both from the energy consumed in making the clinker precursor to cement and from the chemical process to make the clinker. Emissions from fuels consumed for energy purposes during the production of cement are accounted for in the energy sector. Process emissions from cement production are based primarily on clinker production. During the clinker production process, the key reaction occurs when calcium carbonate (CaCO3), in the form of limestone or similar rocks, is heated in a cement kiln at a temperature range of about 700 to 1,000 degrees Celsius (1,300 to 1,800 degrees Fahrenheit) to form lime (i.e., calcium oxide, or CaO) and CO_2 in a process known as calcination or calcining. The quantity of CO_2 emitted during clinker production is directly proportional to the lime content of the clinker. During clinker production, some of the raw materials, partially reacted raw materials, and clinker enter the kiln line's exhaust system as noncalcinated, partially calcinated, or fully calcinated cement kiln dust (CKD). To the degree that the CKD contains carbonate raw materials that are returned to the kiln and calcined, there are associated CO_2 emissions.

Cement is produced in 34 states and Puerto Rico, and production is most concentrated in Texas, California, Missouri, Florida, Alabama, Michigan, and Pennsylvania, with almost 60% of total U.S. production in 2019 (EPA 2021).

3.1.1.2 Methods/Approach

To develop state-level estimates of emissions from cement production, the EPA disaggregated national emissions from the national *Inventory* using a combination of facility-level emissions data reported to the GHGRP from 2010–2019 as a surrogate for clinker production data and U.S. Geological Survey (USGS) clinker production data for 1990–2009 (EPA 2021), as shown in Table 3-2. See Appendix C, Table C-1 and C-2 in the "Cement" Tab for more details on the data used.

This Hybrid Approach, as defined in the Introduction chapter of this report, is used due to limitations in the availability of state-specific activity data for the time series. While GHGRP clinker production data by state are considered confidential business information, emissions data by state are not and are available for this analysis. State-level emissions of CO_2 from the production of cement were calculated using the Tier 2 method provided by the 2006 IPCC Guidelines (IPCC 2006).

Table 3-2. Summary of Approaches to Disaggregate the National *Inventory* for Cement Production Across Time Series

Time Series Range	Summary of Method
1990–2009	• Applied the national *Inventory* emissions factors to actual and estimated clinker production data from USGS (IPCC 2006 Tier 2).

2010–2019	- Applied national *Inventory* emissions factors to clinker production data estimated using GHGRP emissions data (IPCC 2006 Tier 2).

The Approach 1 method used for 1990–2009 relied on USGS clinker production data, which is the same data source for the national *Inventory*. At the state level, the USGS reports clinker production for a few individual states and combines other states in groups of two to four to protect company proprietary data. Because of limited information about clinker production or other relevant proxy data by state, production for grouped states was evenly divided among the states in the group to estimate clinker production.

The Approach 2 method used for 2010–2019 was based on state-level emissions data from GHGRP to distribute clinker production by state. Facilities that use the Continuous Emissions Monitoring System (CEMS) to measure emissions reported combined combustion and process emissions, while facilities that do not use CEMS reported their process and combustion emissions separately. Using the data from facilities that do not use CEMS, average annual process emissions factors were estimated and applied to the CEMS emissions data to estimate process-only emissions by state. Those process emissions by state were converted into a percentage of national process emissions and applied to national clinker production data to estimate state-level clinker production. Under the GHGRP, any facility that manufactures Portland cement must report their GHG emissions regardless of the level of emissions.

National emissions factors for CO_2 from clinker production and CKD from the national *Inventory* were applied to state clinker production to calculate GHG emissions by state.

3.1.1.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from cement production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −6%/+6% for CO_2.

State-level estimates are expected to have an overall higher uncertainty because the national emissions estimates were apportioned to each state based on a combination of state-level clinker production data from the same source used in the national *Inventory* and GHGRP emissions data by state as a surrogate for clinker production data. These assumptions were required because of a general lack of more granular state-level data. While the USGS reports the clinker production for a few individual states, most state clinker production is combined with the clinker production of multiple other states to protect sensitive production data of individual facilities. For 1990–2009, the method of apportioning the grouped clinker production evenly among individual states to estimate state GHG emissions likely results in overestimating emissions for some states and underestimating emissions for others. On a national scale, GHGRP clinker production closely approximates that reported by the USGS.

For the period 2010–2019, GHGRP emissions by state were used to apportion clinker production over individual states. Over 90% of the cement facilities use CEMS to measure CO_2 emissions, which includes combustion emissions as well as process emissions. Using the data from facilities that do not use CEMS, average annual process emissions factors were estimated and applied to the CEMS emissions data to estimate process-only emissions by state. Although this approach approximates GHG emissions from CEMS-monitored kilns, it is not possible to state whether emissions are overestimated or underestimated.

3.1.1.4 Planned Improvements

An important data gap is the production of clinker by each cement-producing state for the full time series 1990–2019. The USGS Mineral Yearbook series reports clinker production data for 11 individual states and Puerto

Rico; the remainder of the clinker production data are reported for groups of states to protect industry-sensitive data. The EPA will assess whether industry GDP per state or other state-level data would provide a better way to disaggregate this grouped data. Clinker capacity by facility for these states was considered, but incomplete data on facilities' clinker capacity limited the ability to estimate clinker production in these groups of states. Additionally, cement kilns do not typically operate at 100% capacity for an entire year, and utilization rates vary from kiln to kiln, facility to facility, and year to year. Furthermore, the EPA is looking to reflect changes occurring in the cement industry to modernize production methods that affect process emissions (e.g., improve kiln efficiency and capacity). These and other factors will be examined to identify improvements in the methods used to estimate state-level GHG emissions.

3.1.1.5 References

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3.1.2 Lime Production (NIR Section 4.2)

Lime is an important manufactured product with many industrial, chemical, and environmental applications. Lime Production involves three main processes: stone preparation, calcination, and hydration. CO_2 is generated during the calcination stage, when limestone—consisting of calcium ($CaCO_3$) and/or magnesium ($MgCO_3$) carbonate—is roasted at high temperatures in a kiln to produce calcium oxide (CaO) and CO_2. The CO_2 is given off as a gas and is normally emitted to the atmosphere. Emissions are also generated with the formation of calcined waste produced during lime production, primarily lime kiln dust (LKD) and also off-spec lime, scrubber sludge, and other miscellaneous waste. Some of the CO_2 generated during the production process, however, is recovered at some facilities for use in sugar refining and precipitated calcium carbonate production. Emissions from fuels consumed for energy purposes during the production of lime are included in the energy sector. Lime production emissions from the national *Inventory* were disaggregated to 28 states in 2019.

3.1.2.1 Methods/Approach

National estimates were downscaled across states because of limitations in availability of state-specific data across the time series needed to apply national methods (i.e., IPCC Tier 2 methods) at the state level. The Approach 2 methodology allocated gross process emissions from lime production to each producing state using a combination of the number of facilities in a state and process emissions reported to the GHGRP as surrogates for lime production data. The number of facilities in a state that captured CO_2 for use in on-site processes was then used to calculate captured process emissions, which was subtracted from gross emissions to estimate net process emissions, as shown in Table 3-3. The sum of emissions by state is consistent with national process emissions as reported in the national *Inventory*. See Appendix C, Table C-3 through Table C-5 in the "Lime" Tab for more details on the data used.

Table 3-3. Summary of Approaches to Disaggregate the National *Inventory* for Lime Production Across Time Series

Time Series Range	Summary of Method
1990–2009	• USGS data on number of lime facilities was used to estimate the percentage of lime production by state, multiplied by the national emissions (IPCC 2006 Tier 2).

	• GHGRP data on number of facilities that captured CO_2 for use in on-site processes from 2010–2019 was used to estimate the percentage of emissions captured, multiplied by national emissions, and subtracted from gross emissions to get net emissions from lime production.
2010–2019	• GHGRP process emissions data were used to estimate the percentage of gross emissions by state, multiplied by the national emissions (IPCC 2006 Tier 2). • GHGRP data on number and type of facilities that captured CO_2 for use in on-site processes was used to estimate the CO_2 emissions captured and subtracted from gross emissions to get net emissions from lime production.

The methodology used for 1990–2009 was based on dividing the number of facilities in each state by the number of facilities nationally to calculate a percentage of total U.S. facilities in each state for each year. This percentage was applied to the gross national CO_2 emissions from lime production per year (EPA 2021) to calculate disaggregated gross CO_2 emissions by state for each year. The number of facilities per state was compiled from the USGS Minerals Yearbooks for Lime, Table 2, "Lime Sold or Used by Producers in the United States, by State" (USGS 1991–2010). For some years, USGS aggregated the number of facilities for some states to avoid disclosing proprietary information related to individual facility production. For those states and years, the individual state facility counts were estimated based on the knowledge of facility locations in 2010–2019 and the number of facilities in a state reported in the USGS Minerals Yearbook for Lime, Table 2 when that state was not aggregated. In the absence of state-specific activity data, using the number of facilities per state to determine the state allocation percentage assumes that each facility has the same amount of input and output.

The methodology used for 2010–2019 was based on process emissions data reported to the GHGRP summed by state (EPA 2010–2019) to calculate a percentage of gross emissions from each state. That percentage was then applied to the national emissions from lime production per year to calculate disaggregated gross CO_2 emissions by state. The GHGRP has a reporting threshold of 25,000 metric tons of CO_2 equivalent for lime production, so these emissions data are representative of the larger facilities in the industry. Using GHGRP emissions data means that emissions from states with smaller facilities were possibly underestimated.

The USGS Mineral Commodity Summaries for lime (1990–2019) only contain U.S. total lime production, with no breakdown by lime type or state. Specifically, while the USGS Minerals Yearbooks for Lime (1990–2017) have hydrated and quicklime production data by regions (Northeast, Midwest, South Atlantic, East South Central, West South Central, and West), but do not provide additional detail by high-calcium or dolomitic lime or by individual states, these data could not be used as activity data in the state disaggregation estimates. Thus, the following activity data were not available by state from current data sources used to estimate national emissions (USGS Minerals Yearbooks) (i.e., lime production data for high-calcium quicklime; dolomitic quicklime; high-calcium, hydrated; dolomitic, hydrated; and dead-burned dolomite and CO_2 captured on-site). As such, these data could not be used as activity data in the state disaggregation estimates.

Although the national *Inventory* value was adjusted to account for CO_2 emissions from the production of LKD, the state disaggregated values do not account for specific facility per state-level CO_2 emissions from the production of LKD. The adjustment to the national *Inventory* value was spread equally across the states with facilities. In addition, the national *Inventory* value was not adjusted to account for CO_2 emissions from other waste production (e.g., off-spec lime, scrubber sludge, or other miscellaneous site-specific waste).

CEMS Adjustment for 2010–2019

In 2010, facilities producing lime started reporting both process and combustion emissions to the GHGRP. For facilities using a CEMS approach to measure and report CO_2 emissions, a combined total value for process and combustion emissions were reported together under subpart S; otherwise, facilities reported process emissions under subpart S and combustion emissions under subpart C using engineering and calculation approaches. To disaggregate process emissions for those facilities reporting CO_2 with CEMS, an industrywide ratio of process emissions to total emissions for facilities that do not report using CEMS was calculated for each year from 2010–2019. While some facilities produce lime as a secondary product, facilities using CEMS were found to produce lime as a primary product with a primary North American Industry Classification System (NAICS) code of 327410 for lime manufacturing. Emissions reported to subpart S and C were compiled for all facilities with this NAICS code, and the ratio of process emissions to total emissions for non-CEMS facilities was applied to the total CO_2 emissions for each CEMS facility to calculate process emissions for each year that emissions were reported using CEMS. The results were an estimated process CO_2 emissions-only value for that CEMS facility.

Because the methodology for 1990–2009 does not use GHGRP emissions data to calculate the state emissions, there is no need to adjust for CEMS facilities for those years.

Adjustment for CO_2 Captured for Use in On-Site Processes

Some facilities recover CO_2 generated during the lime production process for use in sugar refining and precipitated calcium carbonate (PCC) production. Emissions from use of lime for sugar refining are reported under Section 3.1.4 Other Process uses of Carbonates. PCC is used as a filler or coating in the paper, food, and plastic industries and is derived from reacting hydrated high-calcium quicklime with CO_2. Per the IPCC Guidelines, it is assumed that the recovery of CO_2 for use in the sugar refining process and PCC production does not result in net emissions of CO_2 to the atmosphere. Consistent with the national *Inventory* methodology, gross emissions per state from lime production were adjusted to subtract the amount of CO_2 captured for use in on-site processes such as purification.

For 2010–2019, although the quantity of CO_2 captured on-site at a facility was reported to the GHGRP, these data are considered confidential business information (CBI) and are not available by facility or state; they are, however, available at the aggregated national level and are used in the national *Inventory*. Which facilities captured CO_2 for on-site use in 2010–2019 and the states where these facilities are located are publicly available through the GHGRP. The GHGRP indicator of CO_2 capture on-site along with each facility's reported primary NAICS code were used to identify two types of facilities capturing CO_2 on-site: Beet Sugar Manufacturing (NAICS 311313) and Lime Manufacturing (NACIS 327410). For beet sugar manufacturing facilities capturing CO_2 on-site in 2010–2019, all process emissions generated from the lime kiln were assumed to be captured and used on-site for further beet sugar manufacturing, resulting in net zero CO_2 emissions.

To estimate the quantity of CO_2 captured for beet manufacturing facilities per state per year for 2010–2019, each facility's reported GHGRP process CO_2 emissions per year were divided by the total annual GHGRP process CO_2 value per year. The facility percentage values were summed by state and applied to the national *Inventory* gross CO_2 emissions value. The resulting state quantities of CO_2 captured for beet manufacturing facilities were summed for a total value of CO_2 captured for beet sugar manufacturing facilities, which was subtracted from the GHGRP national captured CO_2 value to calculate the quantity of captured CO_2 at lime manufacturing plants. The quantity of captured CO_2 for lime manufacturing facilities was divided by the total number of lime manufacturing facilities capturing CO_2 per year to calculate a per-facility CO_2 captured value per year. The lime manufacturing per facility CO_2 captured value was then allocated to each lime manufacturing plant that captures CO_2 per state and year.

For 1990–2009, because of a lack of available data on both the quantity of CO_2 captured on-site at facilities per state for all years and on the number of facilities that captured CO_2 on-site–2009, an alternative methodology was devised to estimate the quantity of emissions captured, based on available GHGRP data. The number of facilities that captured CO_2 for on-site use in 2010–2019 and their locations were used to estimate the number of facilities in each state that captured CO_2 for use in on-site processes in 1990–2009. The number of facilities that captured CO_2 on-site in a state was divided by the total number of facilities in the state was divided by the total number for 2010–2019 to calculate a percentage of facilities in the state capturing CO_2. The annual percentages for 2010–2019 were averaged and then applied to the number of facilities per state for each year in 1990–2009 to estimate the number of facilities per state that captured CO_2 on-site.

In the absence of available state or facility data, the current methodology for 1990–2009 distributed annual CO_2 captured on-site evenly among all facilities that reported capturing CO_2 on-site to the GHGRP, assuming that all facilities that captured CO_2 on-site captured the same quantity of emissions each year. To estimate the quantity of CO_2 captured on-site for 1990–2009 per state, the number of facilities per state that captured CO_2 on-site in 2010–2019 was divided by the total number of facilities across the country that captured CO_2 on-site for each year over the same time period to calculate state allocation percentages. Each state's percentage was applied to the national data on CO_2 captured on-site to estimate the quantity of CO_2 captured on-site per state per year. These values were subtracted from the gross CO_2 emissions to calculate net CO_2 emissions by state.

3.1.2.2 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from Lime Production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −11.9%/+12.4% for CO_2.

State-level estimates are expected to have an overall higher uncertainty because the national emissions estimates were apportioned to each state based on a combination of the estimated number of facilities for 1990–2009 and GHGRP emissions data for 2010–2019. These assumptions were required because of a general lack of more granular state-level data.

For 1990–2009, the methodology does not differentiate between the type of lime produced at a facility because of a lack of available data, which increases uncertainty. The chemical composition of the limestone and dolomite feedstocks is different, resulting in different emissions factors for calculating CO_2. This difference has the potential to under- or overestimate CO_2 emissions from a facility, depending on the types of lime produced.

The diversity of lime manufacturing facility types adds uncertainty to the analysis. The current methodology for 1990–2009 assumes that each facility has the same amount of inputs and outputs, which overestimates emissions for smaller facilities (e.g., beet sugar manufacturing) and underestimates emissions for larger facilities (e.g., lime manufacturing). The 1990–2009 methodology for estimating the quantity of CO_2 captured on-site does not differentiate between the type of facility (e.g., beet sugar manufacturing compared with lime manufacturing), which increases uncertainty. The resulting captured CO_2 values may overestimate the quantify of CO_2 captured from beet manufacturing facilities, while underestimating the quantity of CO_2 captured from lime manufacturing facilities.

Additionally, some lime facilities go idle for periods of time, and the lack of data on when a facility is in operation or idle during the year increases uncertainty in the analysis. The GHGRP does not currently acquire information on whether or how long plants are idled.

3.1.2.3 Planned Improvements

The EPA will consider weighting gross CO_2 emissions and captured CO_2 emissions by the type of facility (primary NAICS code) to better allocate CO_2 emissions and reduce the uncertainty around over- or underestimating emissions for certain facility types. Of the facilities reporting to the lime subpart S under the GHGRP, seven different types of facilities reported using the following primary NAICS codes: 212312 (Crushed and Broken Limestone Mining and Quarrying), 212391 (Potash, Soda, and Borate Mineral Mining), 311313 (Beet Sugar Manufacturing), 327125 (Nonclay Refractory Manufacturing), 327310 (Cement Manufacturing), 327410 (Lime Manufacturing), and 331111 (Iron and Steel Mills).

Further refinements include identifying additional sources of data to confirm facilities within each state for 1990–2009 and better reflect their associated production (including production by type of lime), especially for the states that were aggregated in the USGS Minerals Yearbooks. Another potential refinement includes assessing the range of facilities' production quantity or capacity and improving on the current underlying assumption associated with using the number of facilities to estimate emissions.

Another potential refinement is to improve the CaO contents and emissions factors used for estimating CO_2 emissions from high-calcium lime and dolomitic lime. Consistent with the 2006 IPCC Guidelines, the current CaO content is assumed to be 95% for both high-calcium and dolomitic lime, which results in emissions factors of 0.785 metric ton CO_2 per metric ton CaO for high-calcium and 0.913 metric ton CO_2 per metric ton CaO for dolomitic lime. The average CaO contents and emissions factors per product are reported to the GHGRP but are considered CBI. Data aggregation may address CBI concerns.

Potential refinements also include identifying additional information to determine which facilities captured CO_2 on-site in 1990–2009, prior to GHGRP reporting. Most but not all of the beet sugar manufacturing facilities reporting to the GHGRP captured CO_2 on-site; in 2019, three lime manufacturing facilities that reported to GHGRP captured CO_2 on-site. In addition, further research on the use and prevalence of capturing CO_2 for use in on-site processes in 1990–2009 is needed. The current methodology assumes that facilities captured CO_2 on-site over the full time series and that the quantity of emissions captured is evenly distributed among those facilities. More research on the range of CO_2 captured on-site per facility and per year is needed. EPA plans to initiate a review to understand if PCC production practices have changed and if literature is available since the publication of the 2006 IPCC guidelines to understand if any CO_2 is ultimately emitted from the use of captured CO_2 in PCC production or during sugar refining purification processes.

The EPA will review time-series consistency issues, due to the two methodologies for 1990–2009 and 2010-2019. Surrogate data (number of facilities per state and number of facilities per state capturing CO_2 on-site) were used in place of activity data for the 1990–2009 portion of the time series, and more research is needed so that calculations more closely simulate state trends in emissions.

3.1.2.4 References

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U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019 (EPA 430-R-21-005), Chapter 4: References. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

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3.1.3 Glass Production (NIR Section 4.3)

3.1.3.1 Background

Glass Production is an energy- and raw material–intensive process that results in the generation of CO_2 from both the energy consumed in making glass and the glass production process itself. Emissions from fuels consumed for energy purposes during the production of glass are included in the energy sector. The raw materials (primarily soda ash, limestone, and dolomite) release CO_2 emissions in a complex high-temperature chemical reaction during the glass melting process. This process is not directly comparable to the calcination process used in lime manufacturing, cement manufacturing, and process uses of carbonates (i.e., limestone/dolomite use) but has the same net effect in terms of CO_2 emissions. In 2019, glass was produced in 29 states (GHGRP 2020).

3.1.3.2 Methods/Approach

The national *Inventory* method was adapted to calculate state-level GHG emissions from glass production to ensure consistency with national estimates (EPA 2021). National estimates were downscaled across states, instead of reapplying the national Tier 3 methodology at the state level, because of limitations in availability of state-specific data across the time series.

To compile process emissions by state from glass production, an Approach 2 methodology was used to allocate process emissions to all states with glass production using a combination of the number of glass facilities in each state and process emissions reported to the GHGRP, as shown in Table 3-4. The sum of emissions by state is consistent with national process emissions as reported in the national *Inventory*. See Appendix C, Tables C-6 and C-7 in the "Glass" Tab for more details on the data used.

Table 3-4. Summary of Approaches to Disaggregate the National *Inventory* for Glass Production Across Time Series

Time Series Range	Summary of Method
1990–2009	• Data on number of glass facilities were used to estimate the percentage of production by state, multiplied by the national emissions (2006 IPCC Guidelines Tier 3).
2010–2019	• GHGRP process emissions data were used to estimate the percentage of emissions by state, multiplied by the national emissions (2006 IPCC Guidelines Tier 3).

The method used for 1990–2009 was based on the number of glass facilities in each state divided by the number of facilities nationally to calculate a percentage of glass facilities in each state for each year. This percentage was applied to the national CO_2 emissions from glass production per year (GHGRP 2020) to calculate disaggregated CO_2 emissions by state for each year. The number of facilities per state was estimated based on the knowledge of facility locations in 2010–2019 and research on when these facilities and others began or ceased operations. Using the number of facilities per state to determine the state allocation percentage assumes that each facility has the same amount of input and output.

The method used for 2010–2019 was based on process emissions reported to the GHGRP summed by state (GHGRP 2020) to calculate a percentage of emissions from each state. That percentage was then applied to the national emissions from glass production per year to calculate disaggregated CO_2 emissions by state. GHGRP has a reporting threshold of 25,000 metric tons CO_2 for glass production, so these emissions data are representative of the larger glass producers in the industry. The GHGRP threshold excludes small entities (i.e., artisan facilities). Using GHGRP emissions data means that emissions from states with smaller facilities were possibly underestimated.

CEMS Adjustment for 2010–2019

Starting in 2010, facilities producing glass and emitting more than 25,000 metric tons of CO_2 Eq. per year reported both process and combustion emissions to the GHGRP. For facilities using a CEMS approach to measure and report CO_2 emissions, process and combustion emissions were reported together under subpart N; otherwise, facilities reported process emissions under subpart N and combustion emissions under subpart C using engineering and calculation approaches.[20] To disaggregate process emissions for those facilities reporting CO_2 with CEMS, the ratio of process emissions to total emissions for facilities that do not report using CEMS was calculated for each

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[20] For more information on the GHGRP, see 74 FR 56374, Oct. 30, 2009. Available online at: https://www.govinfo.gov/content/pkg/FR-2009-10-30/pdf/E9-23315.pdf.

year from 2010–2019. The ratio of process emissions to total emissions for non-CEMS facilities was applied to the total CO_2 emissions for each CEMS facility to calculate process emissions for each year that emissions were reported using CEMS. The results were an estimated process CO_2 emissions-only value for that CEMS facility.

Because the methodology for 1990–2009 does not use GHGRP emissions data to calculate the state emissions, there was no need to adjust for CEMS facilities for those years.

3.1.3.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from Glass Production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −4%/+4% for CO_2.

State-level estimates are expected to have an overall higher uncertainty because the national emissions estimates were apportioned to each state based on a combination of the estimated number of facilities for 1990–2009 and GHGRP emissions data for 2010–2019.

For 1990–2009, this allocation method does not address facilities' production capacities or utilization rates, which vary from facility to facility and from year to year. Because this approach assumes emissions from all facilities are equal regardless of production capacity or utilization rates, this approach could overestimate emissions in states with higher shares of smaller facilities and underestimate emissions in states with larger facilities.

For 2010–2019, uncertainty is expected to be lower than the period from 1990–2009 because of the use of GHGRP emissions data by state to calculate emissions; however, because the sum of GHGRP emissions from glass production is higher than the national *Inventory* emissions from glass production and the GHGRP does not include emissions from smaller glass production facilities, this methodology could underestimate emissions in states with smaller facilities and overestimate emissions in states with larger facilities, potentially increasing the uncertainty of the state-by-state percentage compared with the national *Inventory.*

3.1.3.4 Planned Improvements

Potential refinements include identifying data to improve the completeness of state allocation and reflect smaller facilities. Data gaps to calculate emissions from glass production include partial datasets on glass production by state and the number of glass facilities by state for the full time series. GHGRP has a reporting threshold for glass production facilities; facilities emitting more than 25,000 metric tons of CO_2 Eq. per year must report to the program. Facilities emitting less emissions per year were not captured in GHGRP data and are not reflected in this state-level estimate; therefore, it is likely that emissions from smaller facilities are being attributed to larger facilities that report to GHGRP. Facilities with lower emissions (e.g., artisan glass production facilities) were not captured in this estimation. The EPA could apply other methods that may improve estimates if more complete activity data are available by state (e.g., glass production, carbonate consumption used for glass production, glass sales data by state, or gross domestic product related to glass production by state).

The EPA will assess the consistency of the estimates over time, given the use of two approaches to compile state-level estimates, to ensure that changes in estimates over time are not significantly biased by methodological and data approaches to the extent possible.

3.1.3.5 References

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3.1.4 Other Process Uses of Carbonates (NIR Section 4.4)

3.1.4.1 Background

Limestone, dolomite, and other carbonates such as soda ash, magnesite, and siderite are basic materials used by a wide variety of industries, including construction, agriculture, chemical, metallurgy, glass production, and environmental pollution control. This section addresses only limestone, dolomite, and soda ash use. For industrial applications, carbonates such as limestone and dolomite are heated sufficiently enough to calcine the material and generate CO_2 as a by-product. Emissions from limestone and dolomite used in other process sectors, such as cement, lime, glass production, and I&S, were excluded from this category and are reported under their respective source sections (e.g., glass production). Emissions from soda ash production are reported under soda ash production. Emissions from soda ash consumption associated with glass manufacturing are reported under glass production. Emissions from the use of limestone and dolomite in liming of agricultural soils are included in the agriculture chapter under liming. Emissions from fuels consumed for energy purposes during these processes are accounted for in the energy sector. Both lime and limestone can be used as a sorbent for flue gas desulfurization (FGD) systems. Emissions from lime consumption for FGD systems are reported under lime production.

3.1.4.2 Methods/Approach

The Approach 2 state-level methodology for Other Process Uses of Carbonates allocates total national process emissions to all applicable U.S. states and territories using state-level consumption of limestone and dolomite and state population as a surrogate for soda ash consumption, due to limitations in availability of state-specific data.

Limestone and Dolomite Consumption

National CO_2 emissions from the consumption of limestone and dolomite for emissive sources, including flux stone, FGD systems, chemical stone, mine dusting or acid water treatment, acid neutralization, and sugar refining, were calculated based on USGS data on the national-level consumption of each carbonate for each end use. The USGS does not provide the state-level consumption of limestone and dolomite for each end use; however, USGS does publish annual state-level data on the total consumption of each carbonate. The exception is for dolomite consumption in the magnesium production process, where only one facility in Washington state is responsible for the emissions for the 1990–2001 time series. Because no other source of data on state-level limestone and dolomite consumption were identified for any of the emissive sources, the USGS total consumption data by state were used.

For 1991 and 1993–2018, state-level CO_2 emissions for the national *Inventory* were estimated using the USGS annual state-level values for limestone and dolomite sold or used by producers compiled from the USGS Minerals Yearbook for Crushed Stone (U.S. Bureau of Mines 1991–1995, USGS 1995–2020, 2020a). The national CO_2 emissions from limestone and dolomite consumption were disaggregated independently by calculating the fraction of each state-level consumption for each carbonate and applying that fraction to the national-level CO_2 estimated for each of the two carbonates in the national *Inventory*. For the calculation of emissions from dolomite consumption, the emissions from magnesium were removed because those emissions are attributed to Washington state. The USGS state-level consumption data exclude the District of Columbia and Puerto Rico; therefore, CO_2 emissions from limestone and dolomite consumption were not estimated for those states.

During 1990 and 1992, the USGS did not publish limestone and dolomite consumption by state. Data on consumption by state for 1990 were estimated by applying the 1991 ratios of total limestone and dolomite consumption by state to total 1990 limestone and dolomite consumption values. Similarly, the 1992 consumption figures were approximated by applying an average of the 1991 and 1993 ratios of total limestone and dolomite use by state to the 1992 total values. For 2018 and 2019, no data on limestone and dolomite consumption were available from USGS, so state-level consumption values from 2017 were used as a proxy for these years.

In 1991 and 1993–2006, certain state-level limestone and dolomite consumption data were withheld from the USGS publications to avoid disclosing proprietary information. Those limestone and dolomite values were aggregated and included in a category entitled “Other.” To ensure that the total reported consumption values for both limestone and dolomite were accounted for, the “Other” value was equally distributed to the states for which consumption data were withheld. In 1991, USGS provided an “Other” value for limestone consumption; however, no states that were included in the state-level table contained an indication that data were withheld. To account for this limestone usage, the “Other” value was proportionally allocated to all of the states for which data were reported in 1991 based on their reported usage. See Appendix C, Table C-8 through Table C-11 in the “Other Process Uses of Carbonates” Tab for more details on the data used.

Soda Ash Consumption Not Associated with Glass Manufacturing

The national *Inventory* also estimates national CO_2 emissions from the consumption of soda ash. Most soda ash is consumed in chemical production, with minor amounts used in soap production, pulp and paper, FGD, and water treatment (excluding soda ash consumption for glass manufacturing). Emissions from soda ash consumption from glass manufacturing are accounted for under Section 4.3 Glass production. Data on the consumption of soda ash by state, however, are not available, and due to the distribution of these end uses across the country state and lack of other surrogate data on end uses by state, population was used to allocate emissions. To calculate state-level CO_2 emissions from soda ash consumption, national CO_2 estimates from the national *Inventory* were distributed among the 50 states, the District of Columbia, and Puerto Rico using U.S. population statistics as a proxy for data on soda ash consumption not associated with glass manufacturing (U.S. Census Bureau 2002, 2011, 2019, Instituto de Estadísticas de Puerto Rico 2021). For each year in the 1990–2019 time series, the fraction of the total U.S. population in each state, the District of Columbia, and Puerto Rico was calculated by dividing the state population by the total U.S. population. To estimate CO_2 emissions for each year by state, national *Inventory* CO_2 emissions from soda ash consumption were multiplied by each state’s fraction of the total population for that year. See Appendix G, Table G-1 in the “Population Data” Tab for more details on the data used.

3.1.4.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from other process uses of carbonate was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −12%/+15% for CO_2.

State-level estimates are expected to have a higher uncertainty because the national emissions estimates were apportioned to each state based on state data of total limestone and dolomite consumption and state population for soda ash consumption.

3.1.4.4 Planned Improvements

The disaggregation methodology for limestone and dolomite consumption does not take into account the consumption of these carbonates from the I&S sector, as is done in the national *Inventory* CO_2 emissions calculations. Given that the methodology for the disaggregation of the I&S sector was developed concurrently with this sector, the EPA was not able to fully assess if the state-level percentages for the I&S sector could be applied to the I&S limestone and carbonate consumption and then subtracted out from each of the state-level CO_2 emissions calculated using the methodology described above. Initial attempts yielded negative CO_2 emissions in certain states, thus requiring additional review and likely refinement of approaches to disaggregate these emissions.

Additionally, further research is needed to determine if data sources may be available to attribute CO_2 emissions more accurately from each of the emissive sources for limestone and dolomite consumption to each state. Currently, it is assumed that limestone and dolomite consumption for flux stone, FGD systems, chemical stone, mine dusting or acid water treatment, acid neutralization, and sugar refining activities is distributed equally geographically among all states, excluding the District of Columbia and Puerto Rico.

Data gaps for the soda ash consumption category include data on soda ash consumption by state.

3.1.4.5 References

Instituto de Estadísticas de Puerto Rico. (2021). Population of Puerto Rico from 1990-1999 from “Estimados anuales poblacionales de los municipios desde 1950.” Accessed February 2021. Available online at: https://censo.estadisticas.pr/EstimadosPoblacionales

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U.S. Census Bureau, Population Division. (2011). Table 1. Intercensal Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2010 (ST-EST00INT-01), Release Date: September 2011.

U.S. Census Bureau, Population Division. (2019). Table 1. Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2019 (NST-EST2019-01), Release Date: December 2019.

U.S. Geological Survey. (1995 through 2020). Minerals Yearbook: Crushed Stone Annual Report. U.S. Geological Survey, Reston, VA.

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3.1.5 Carbon Dioxide Consumption (NIR Section 4.15)

3.1.5.1 Background

CO_2 is used for a variety of commercial applications, including food processing, chemical production, carbonated beverage production, and refrigeration, and is also used in petroleum production for enhanced oil recovery (EOR). CO_2 used for EOR is injected underground to enable additional petroleum to be produced. For the purposes of this analysis, CO_2 used in commercial applications other than EOR is assumed to be emitted to the atmosphere. A further discussion of CO_2 used in EOR is described in the national *Inventory* Energy chapter in Box 3-6 titled “Carbon Dioxide Transport, Injection, and Geological Storage” and is not included in this section.

3.1.5.2 Methods/Approach

Data on the consumption of CO_2 by state are not readily available; therefore, using an Approach 2 method, the state-level methodology for emissions from CO_2 consumption allocates emissions from CO_2 consumption across all U.S. states and territories using population as a surrogate. See Appendix G, Table G-1 in the “Population Data” Tab for more details on the data used. National estimates were used to disaggregate emissions by state because of the limitations in the availability of state-specific data for the time series. The approach is considered reasonable given many of the sources are end-use categories (e.g., carbonated beverage use, dry ice), where per capita use is not likely to vary across states.

To calculate state-level CO_2 emissions from CO_2 consumption, national CO_2 estimates from the national *Inventory* were distributed among the 50 states, the District of Columbia, and Puerto Rico using U.S. population statistics as a surrogate for CO_2 consumption data (U.S. Census Bureau 2002, 2011, 2019; Instituto de Estadísticas de Puerto Rico 2021). For each year in the 1990–2019 time series, the fraction of the total U.S. population in each state, as well as the District of Columbia and Puerto Rico, was calculated by dividing the state population by the total U.S. population.

3.1.5.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 consumption was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −5%/+5% for CO_2.

State-level estimates are expected to have a higher uncertainty because the national emissions estimates were apportioned to each state based solely on state population. This assumption was required because of a general lack of more granular state-level data. This allocation method introduces additional uncertainty because of limited data on the quantity of CO_2 consumption by state or nationally for the full time series. The sources of uncertainty for this category are also consistent over time because the same surrogate data are applied across the entire time series.

3.1.5.4 Planned Improvements

The EPA will explore other sources of data on the consumption of CO_2 by state for the full time series 1990–2019.

3.1.5.5 References

Instituto de Estadísticas de Puerto Rico. (2021). Population of Puerto Rico from 1990-1999 from “Estimados anuales poblacionales de los municipios desde 1950.” Accessed February 2021. Available online at: https://censo.estadisticas.pr/EstimadosPoblacionales

U.S. Census Bureau, Population Division. (2002). Table CO-EST2001-12-00 - Time Series of Intercensal State Population Estimates: April 1, 1990 to April 1, 2000, Release Date: April 11, 2002.

U.S. Census Bureau, Population Division. (2011). Table 1. Intercensal Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2010 (ST-EST00INT-01), Release Date: September 2011.

U.S. Census Bureau, Population Division. (2019). Table 1. Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2019 (NST-EST2019-01), Release Date: December 2019.

3.2 Chemicals

This section presents the methodology used to estimate the chemicals portion of IPPU emissions, which consist of the following sources:

- Ammonia production (CO_2)
- Urea consumption for nonagricultural purposes (CO_2)
- Nitric acid production (N_2O)
- Adipic acid production (N_2O)
- Caprolactam, glyoxal and glyoxylic acid production (N_2O)

- Carbide production and consumption (CO_2, CH_4)
- Titanium dioxide production (CO_2)
- Soda ash production (CO_2)
- Petrochemical production (CO_2)
- HCFC-22 production (HFCs)
- Phosphoric acid production (CO_2)

3.2.1 Ammonia Production (NIR Section 4.5)

3.2.1.1 Background

Emissions of CO_2 occur during the production of synthetic ammonia, primarily through the use of natural gas, petroleum coke, or naphtha as a feedstock. The natural gas-, naphtha-, and petroleum coke–based processes produce CO_2 and hydrogen, the latter of which is used in the production of ammonia. Natural gas is also used as a fuel in the process. The 2006 IPCC Guidelines recommend including emissions from fuels consumed for energy purposes during the production of ammonia along with feedstock emissions; however, data on total fuel use (including fuel used for ammonia feedstock and fuel used for energy) for Ammonia Production are not known in the U.S. National energy use information does not provide data broken out by industrial category, only at the broad industry sector level. Emissions from fuel used for energy at ammonia plants are included in the overall fuel combustion industrial sector energy use and accounted for in the Energy section. In 2019, 16 companies operated 35 ammonia producing facilities in 16 states. As of 2019, approximately 60% of domestic ammonia production capacity was concentrated in the states of Louisiana, Oklahoma, and Texas (USGS 2020).

3.2.1.2 Methods/Approach

To compile emissions by state from ammonia production, the state-level inventory disaggregated national emissions from the national *Inventory* with an Approach 2 method as defined in the Introduction chapter of this report, using a combination of ammonia production capacity by state by year for 1990–2009 and process emissions reported to the GHGRP for 2010–2019, as shown in Table 3-5. The sum of emissions by state is consistent with the process emissions reported in the national *Inventory* (EPA 2021). See Appendix D, Tables D-1 and D-2 in the “Ammonia” Tab for more on the data used.

Table 3-5. Summary of Approaches to Disaggregate the National *Inventory* for Ammonia Production Across Time Series

Time Series Range	Summary of Method
1990–2009	• USGS data on ammonia production capacity were used to estimate the percentage of production by state, multiplied by the national emissions (IPCC 2006 Tier 2).
2010–2019	• GHGRP (Subpart G) process emissions data were used to estimate the percentage of emissions by state, multiplied by the national emissions (IPCC 2006 Tier 2).

State-level activity data on ammonia production by feedstock or feedstock consumption for ammonia production are unavailable, so national estimates were downscaled. Initial research looked at using state-level or region-specific permit websites to determine whether facilities in operation in 2010, known through the GHGRP, were also in operation each year from 1990–2009 and to estimate production data by facility; however, the permit information lacked relevant data on ammonia production or feedstock consumption for all states and years, and better data was available in the USGS data sources.

Because the activity data are unavailable to use the method applied in the national *Inventory*, the methodology used for 1990–2009 was based on the total ammonia production capacity in each state divided by the total ammonia capacity in the United States to calculate a percentage of ammonia capacity in each state for each year. This percentage was applied to the national CO_2 emissions from ammonia production per year to calculate disaggregated CO_2 emissions by state for each year. The ammonia capacities per facility per state were compiled from the Minerals Yearbook: Metals and Minerals for Nitrogen, Table 5, "Domestic Producers of Anhydrous Ammonia" for 1990 and 1991 (U.S. Bureau of Mines 1990–1991); the Minerals Yearbook: Metals and Minerals for Nitrogen, Table 4, "Domestic Producers of Anhydrous Ammonia" for 1992 and 1993 (U.S. Bureau of Mines 1992–1993); and the Minerals Yearbook: Nitrogen, Table 4, "Domestic Producers of Anhydrous Ammonia" for 1994 through 2009 (USGS 1994–2010). Using the ammonia capacity per state to determine the state allocation percentage assumes that facility utilization rates are roughly the same from state to state and that production capacity is a reasonable surrogate for production.

The methodology used for 2010–2019 was based on process emissions reported to the GHGRP and summed by state (GHGRP 2020) to calculate a percentage of emissions from each state. That state percentage was then applied to the national *Inventory* emissions from ammonia production per year to disaggregate CO_2 emissions by state and by year and ensure emissions are consistent with estimates in the national *Inventory*. GHGRP has no reporting threshold for ammonia production, so all facilities are included, and these emissions data are, therefore, representative of the industry.

3.2.1.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from ammonia production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −11%/+11% for CO_2.

State-level estimates are expected to have an overall higher uncertainty because the national emissions estimates were apportioned to each state based on a combination of ammonia production capacity by state by year for 1990–2009 and process emissions reported to the GHGRP for 2010–2019. These assumptions were required because of a general lack of more granular state-level data.

For 1990–2009, this allocation method does not address utilization rates, which vary from facility to facility and from year to year. While this approach implicitly accounts for the size of a facility in a state, it could overestimate emissions in states where facilities used less of their capacity and underestimate emissions in states where facilities used more of their capacity, as a result of the lack of data on utilization rates.

For 2010–2019, uncertainty is expected to be lower due to the use of GHGRP emissions data by state as a surrogate for using ammonia production data by state to calculate emissions; however, because the sum of GHGRP emissions from ammonia production is higher than the national *Inventory* emissions from ammonia production, the uncertainty of the state-by-state percentage may be higher. This may have led to over- or underestimating the percentage of emissions apportioned to each state.

3.2.1.4 Planned Improvements

For the state-level ammonia capacity data used for years 1990–2009, additional research is needed to determine whether the capacities can be adjusted to account for facilities that also produce urea, to be consistent with the national *Inventory*.

For the GHGRP emissions data used for years 2010–2019, the quantity of CO_2 that is captured at ammonia production facilities and used to produce urea has not been subtracted and allocated under Urea Consumption for Nonagricultural Purposes (Section 3.2.2) and Urea Fertilization (Section 5.1.6). Reporters must report all CO_2

created during the ammonia production process under subpart G of the GHGRP. The amount of CO_2 from the production of ammonia that is then captured and used to produce urea is reported to the GHGRP but is considered CBI. More research on possible aggregation options is needed.

The EPA will review potential time-series consistency issues due to the two methodologies for 1990–2009 and for 2010–2019. Surrogate data (production capacity) are used in place of activity data for the 1990–2009 portion of the time series, and more research is needed so that calculations more closely simulate state trends in emissions.

3.2.1.5 References

U.S. Bureau of Mines. (1990 through 1993). Minerals Yearbook: Metals and Minerals: Nitrogen. Available online at: https://www.usgs.gov/centers/nmic/bureau-mines-minerals-yearbook-1932-1993

U.S. Environmental Protection Agency Greenhouse Gas Reporting Program (GHGRP). (2020). Dataset as of September 26. 2020. Available online at: https://ghgdata.epa.gov/ghgp/

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

U.S. Geological Survey. (1994 through 2010). Minerals Yearbook: Nitrogen. Available online at: https://www.usgs.gov/centers/nmic/nitrogen-statistics-and-information

U.S. Geological Survey. (2020) 2020 Mineral Commodity Summaries: Nitrogen (Fixed) - Ammonia. January 2020. Available online at: https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-nitrogen.pdf

3.2.2 Urea Consumption for Nonagricultural Purposes (NIR Section 4.6)

3.2.2.1 Background

Urea is produced using ammonia and CO_2 as raw materials. All urea produced in the United States was assumed to be produced at ammonia production facilities where both ammonia and CO_2 are generated. This section accounts for CO_2 emissions associated with urea consumed exclusively for nonagricultural purposes. Emissions of CO_2 resulting from agricultural applications of urea are accounted for in the urea fertilization section of the agriculture chapter.

3.2.2.2 Methods/Approach

The national *Inventory* methodology was adapted to calculate state-level GHG emissions resulting from nonagricultural applications of urea to ensure consistency with national estimates (EPA 2021). National estimates were disaggregated to estimate state-level emissions for Urea Consumption purposes across states with an Approach 2 method as defined in the Introduction chapter of this report, using U.S. population statistics as a surrogate for data on nonagricultural applications of urea because of the limitations in the availability of state-specific data. See Appendix G, Table G-1 in the “Population Data” Tab for more details on the data used.

The national *Inventory* estimates national CO_2 emissions from the consumption of urea for nonagricultural purposes consistent with the Tier 1 method for ammonia production in the 2006 IPCC Guidelines (IPCC 2006). While data on the consumption of urea by state are not available, due to the widespread use of urea for nonagricultural purposes, population by state is a reasonable surrogate. To calculate state-level CO_2 emissions from urea consumption, national CO_2 estimates from the national *Inventory* were distributed among the 50 states, the District of Columbia, and Puerto Rico using U.S. population statistics as a surrogate (U.S. Census Bureau 2002, 2011, 2019; Instituto de Estadísticas de Puerto Rico 2021). For each year in the 1990–2019 time series, the fraction of the total U.S. population in each state, as well as the District of Columbia and Puerto Rico, was calculated by dividing the state population by the total U.S. population. To estimate CO_2 emissions for each year by state, national *Inventory* CO_2 emissions from urea consumption were multiplied by each state's fraction of the total population for that year.

3.2.2.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from urea consumption for nonagricultural purposes was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −13%/+14% for CO_2.

State-level estimates are expected to have a higher uncertainty because the national emissions estimates were apportioned to each state based solely on state population. This assumption was required because of a general lack of more granular state-level data. This allocation method introduces additional uncertainty due to limited data on the quantity of urea used for industrial applications by state or nationally for the full time series. The sources of uncertainty for this category are consistent over time because the same surrogate data are applied across the entire time series.

3.2.2.4 Planned Improvements

Data gaps include data on urea consumption for nonagricultural purposes by state for the full time series 1990–2019.

3.2.2.5 References

Instituto de Estadísticas de Puerto Rico. (2021). Population of Puerto Rico from 1990-1999 from "Estimados anuales poblacionales de los municipios desde 1950." Accessed February 2021. Available online at: https://censo.estadisticas.pr/EstimadosPoblacionales

Intergovernmental Panel on Climate Change. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change. [H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.)]. Hayama, Kanagawa, Japan.

U.S. Census Bureau, Population Division. (2002). Table CO-EST2001-12-00 - Time Series of Intercensal State Population Estimates: April 1, 1990 to April 1, 2000, Release Date: April 11, 2002.

U.S. Census Bureau, Population Division. (2011). Table 1. Intercensal Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2010 (ST-EST00INT-01), Release Date: September 2011.

U.S. Census Bureau, Population Division. (2019). Table 1. Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2019 (NST-EST2019-01), Release Date: December 2019.

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

U.S. Geological Survey. (2020) 2020 Mineral Commodity Summaries: Nitrogen (Fixed) - Ammonia. January 2020. Available at: https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-nitrogen.pdf

3.2.3 Nitric Acid Production (NIR Section 4.7)

3.2.3.1 Background

Nitrous oxide (N_2O) is emitted during the production of nitric acid (HNO_3), an inorganic compound used primarily to make synthetic commercial fertilizers. Nitric acid is also a major component in the production of adipic acid—a feedstock for nylon—and explosives. Virtually all of the nitric acid produced in the United States is manufactured by the high-temperature catalytic oxidation of ammonia. The basic process technology for producing nitric acid has not changed significantly over time. During this process, N_2O is formed as a by-product and is released from reactor vents into the atmosphere, unless mitigation measures are put in place. Emissions from fuels consumed for energy purposes during the production of nitric acid are included in the energy sector. As of 2019, there were 31 active nitric acid production plants in 18 states (EPA 2020).

3.2.3.2 Methods/Approach

The national *Inventory* methodology was adapted to calculate state-level GHG emissions from nitric acid production to ensure consistency with national estimates (EPA 2021). For the national *Inventory*, the 2006 IPCC Guidelines Tier 2 method was used to estimate emissions from nitric acid production for 1990–2009, and a country-specific approach similar to the IPCC Tier 3 method was used to estimate N_2O emissions for 2010–2019. (IPCC 2006).

To compile emissions by state from nitric acid production, the state-level inventory disaggregated national emissions from the national *Inventory* using Approach 2 as defined in the Introduction chapter of this report and a combination of nitric acid production capacity by state by year for 1990–2009 and process emissions reported to the GHGRP for 2010–2019, as shown in Table 3-6. The sum of emissions by state is consistent with the national process emissions reported in the national *Inventory*. See Appendix D, Tables D-3 and D-4 in the “Nitric Acid” Tab for more details on the data used.

Table 3-6. Summary of Approaches to Disaggregate the National Inventory for Nitric Acid Production Across Time Series

Time Series Range	Summary of Method
1990–2009	• ICIS data on nitric acid production capacity were used to estimate the percentage of production by state, multiplied by the national emissions (IPCC 2006 Tier 2).
2010-2019	• GHGRP process emissions data were used to estimate the percentage of emissions by state, multiplied by the national emissions (country-specific approach similar to IPCC 2006 Tier 3).

The methodology used for 1990–2009 was based on the total nitric acid production capacity in each state divided by the total nitric acid production capacity in the United States to calculate a percentage of nitric acid capacity in each state for each year. This percentage was applied to the national CO_2 emissions from nitric acid production per year to calculate disaggregated CO_2 emissions by state for each year. The nitric acid capacities per facility per state were compiled from the EPA for 1984 and from ICIS for 2008 (EPA 1984, ICIS 2008). The capacity data for 1984 were applied to years 1990–2007, and the capacity data for 2008 were applied to years 2008 and 2009. Using the nitric acid capacity per state to determine the state allocation percentage assumed that facility utilization rates are roughly the same from state to state.

The methodology used for 2010–2019 was based on process emissions reported to the GHGRP summed by state (GHGRP 2020) to calculate a percentage of emissions from each state. That percentage was then applied to the national *Inventory* emissions from nitric acid production per year to disaggregate CO_2 emissions by state and by year. The GHGRP has no reporting threshold for nitric acid production, so these emissions data are representative of the industry.

Initial research included using state-level or region-specific permit websites to determine whether facilities in operation in 2010, known through the GHGRP, were also in operation each year from 1990–2009 and to estimate production data by facility. Because of the lack of permit data available online for all states and years, this approach was not used.

3.2.3.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of N_2O from nitric acid production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −5%/+5% for N_2O.

State-level estimates are expected to have an overall higher uncertainty because the national emissions estimates were apportioned to each state based on a combination of nitric acid production capacity by state by year for 1990–2009 and process emissions reported to the GHGRP for 2010–2019. These assumptions were required because of a general lack of more granular state-level data.

For 1990–2009, this allocation method does not address utilization rates, which vary from facility to facility and from year to year. While this approach implicitly accounts for the size of a facility in a state, it could overestimate emissions in states where facilities used less of their capacity and underestimate emissions in states where facilities used more of their capacity as a result of the lack of data on utilization rates. This approach also does not account for abatement technologies at nitric acid production facilities because the information is not known for this time period; therefore, this approach could overestimate emissions in states where abatement technologies were used.

For 2010–2019, uncertainty is expected to be lower as a result of the use of GHGRP emissions data by state as a surrogate for using nitric acid production data by state to calculate emissions. The uncertainty is also lower because GHGRP emissions account for the use of any abatement technologies at nitric acid production facilities. The GHGRP emissions are comparable to the national *Inventory* totals; therefore, the use of GHGRP emissions to estimate the percentage of emissions by state does not appear to introduce greater uncertainty for this time period.

3.2.3.4 Planned Improvements

Data gaps include nitric acid capacity and utilization rates per facility and state, information about abatement technology installation and use per facility, and nitric acid production per state for the full time series.

The EPA will review time-series consistency issues due to the two methodologies for 1990–2009 and for 2010-2019. Incomplete surrogate data (production capacity) were used in place of activity data for the 1990–2009 portion of the time series, and more research is needed to refine the method to enhance accuracy and consistency of estimated state GHG emissions and trends.

3.2.3.5 References

Independent Commodity Intelligence Services. (2008). Chemical profile: nitric acid. Capacities by nitric acid company as of May 15, 2008. Available online at: https://www.icis.com/explore/resources/news/2008/05/19/9124327/chemical-profile-nitric-acid/

Intergovernmental Panel on Climate Change. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change. [H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.)]. Hayama, Kanagawa, Japan.

U.S. Environmental Protection Agency. (April 1984). Office of Air Quality Planning and Standards. Review of New Source Performance Standards for Nitric Acid Plants. EPA Document number 450/3-84-011. Available online at: https://nepis.epa.gov/Exe/ZyPDF.cgi/2000LT0V.PDF?Dockey=2000LT0V.PDF

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

U.S. Environmental Protection Agency Greenhouse Gas Reporting Program (GHGRP). (2020). Dataset as of September 26. 2020. Available online at: https://ghgdata.epa.gov/ghgp/

3.2.4 Adipic Acid Production (NIR Section 4.8)

3.2.4.1 Background

Adipic acid is produced through a two-stage process during which N_2O is generated in the second stage. Emissions from fuels consumed for energy purposes during the production of adipic acid are accounted for in the Energy sector. The first stage of manufacturing usually involves the oxidation of cyclohexane to form a cyclohexanone/cyclohexanol mixture. The second stage involves oxidizing this mixture with nitric acid to produce adipic acid. Nitrous oxide is generated as a by-product of the nitric acid oxidation stage and, without mitigation technology, is emitted in the waste gas stream. Process emissions from the production of adipic acid vary with the types of technologies and level of emissions controls employed by a facility. The largest Adipic Acid Production facility uses an N_2O abatement device, but its usage has varied considerably from year to year over the period from 2010–2019, resulting in varying levels of N_2O control at that facility and varying levels of total N_2O emissions over that time period. Four adipic acid facilities, located in Florida, Texas, and Virginia, have produced adipic acid in the United States over the period 1990–2019.

3.2.4.2 Methods/Approach

The national *Inventory* methodology was used to calculate state-level GHG emissions to ensure consistency with national estimates, using an Approach 1 method as defined in the Introduction chapter of this report. Emissions calculations for the period 1990–2009 are consistent with Tier 2 methods for two facilities and Tier 3 methods for the other two facilities, as provided by the 2006 IPCC Guidelines (IPCC 2006). Facility-level process emissions reported to the GHGRP for the period 2010–2019 were summed by state (GHGRP 2020) to calculate a percentage of emissions from each state. That percentage was then applied to the national emissions from adipic acid production over the full time series to calculate disaggregated CO_2 emissions by state. See Appendix D, Table D-5 in the “Adipic Acid” Tab for more details on the data used. GHGRP has no reporting threshold for adipic acid production, so these emissions data are representative of the industry.

3.2.4.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of N_2O from Adipic Acid Production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −5%/+5% for N_2O.

State-level estimates are expected to have a slightly higher level of uncertainty than the national *Inventory* over the full time series as a result of the rounding of the facility-level GHGRP process emissions used to calculate the percentage of emissions from each state.

3.2.4.4 Planned Improvements

There are no planned methodological refinements for the adipic acid production category.

3.2.4.5 References

Intergovernmental Panel on Climate Change. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change. [H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.)]. Hayama, Kanagawa, Japan.

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

U.S. Environmental Protection Agency Greenhouse Gas Reporting Program (GHGRP). (2020). Dataset as of September 26. 2020. Available online at: https://ghgdata.epa.gov/ghgp/.

3.2.5 Caprolactam, Glyoxal, and Glyoxylic Acid Production (NIR Section 4.9)

3.2.5.1 Background

Caprolactam is a colorless monomer produced for nylon-6 fibers and plastics. A substantial proportion of the fiber is used in carpet manufacturing. Most commercial processes used for the manufacture of caprolactam begin with benzene, but toluene can also be used. The production of caprolactam can give rise to significant emissions of N_2O. During the production of caprolactam, emissions of N_2O can occur from the ammonia oxidation step. Since 1990, caprolactam has been produced in three states: Virginia, Texas, and Georgia. The facility in Georgia closed in 2018.

The EPA does not currently estimate the emissions associated with the production of glyoxal and glyoxylic acid because of data availability and a lack of publicly available information on the industry in the United States.

3.2.5.2 Methods/Approach

To compile emissions by state from caprolactam production, the state-level inventory disaggregated national emissions from the national *Inventory* with an Approach 2 method, as defined in the Introduction chapter of this report, using caprolactam production capacity by state by year for 1990–2019 as a surrogate for caprolactam production data. The GHGRP does not currently cover caprolactam production. See Appendix D, Table D-6 in the "Caprolactam" Tab for more details on the data used. State-level emissions for 1990–2019 were estimated as a percentage of total national emissions by state and by year. Emissions of N_2O from the production of caprolactam were calculated using the Tier 1 method provided by the 2006 IPCC Guidelines.

using and For 1990–2019, the total caprolactam production capacity in each state was divided by the total caprolactam capacity in the United States to calculate a percentage of caprolactam capacity in each state for each year. This percentage was applied to the national N_2O emissions from caprolactam production per year to calculate disaggregated N_2O emissions by state for each year.

The caprolactam production capacities per facility per state were compiled from ICIS for 2004 and 2006 (ICIS 2004, ICIS 2006). The capacity data for 2004 were applied to years 1990–2005, and the capacity data for 2006 were applied to years 2006–2019. An additional caprolactam facility (Evergreen Recycling) was added for years 2000 and 2001 (ICIS 2004, Textile World 2000) and for 2007–2015 (U.S. Department of Energy 2011, Shaw Industries Group, Inc. 2015). Using the caprolactam capacity per state to determine the state allocation percentage assumes that facility utilization rates are roughly the same from state to state.

3.2.5.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of N_2O from caprolactam production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −31%/+32% for N_2O.

State-level estimates are expected to have a higher uncertainty because the national emissions estimates were apportioned to each state based on caprolactam production capacity by state by year for 1990–2019. This assumption was required because of a general lack of more granular state-level data.

For 1990–2019, this allocation method does not address utilization rates, which vary from facility to facility and from year to year. While this approach implicitly accounts for the size of a facility in a state, it could overestimate emissions in states where facilities used less of their capacity and underestimate emissions in states where facilities used more of their capacity as a result of the lack of data on utilization rates.

3.2.5.4 Planned Improvements

Data gaps to calculate emissions from caprolactam production include caprolactam production by state for the full time series. Under the current methodology, data gaps include caprolactam capacities per facility per state and utilization rates per facility for the full time series.

The EPA will review time-series consistency issues resulting from a lack of activity data (caprolactam production) by state and the use of surrogate data (facility production data) that may not reflect reduced production before facilities closed. More research is needed to refine the method to enhance accuracy and consistency of estimated state GHG emissions and trends.

3.2.5.5 References

Independent Commodity Intelligence Services (ICIS). (2004). Chemical Profile – Caprolactam. January 5, 2004. Available online at: https://www.icis.com/explore/resources/news/2005/12/02/547244/chemical-profile-caprolactam/

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Shaw Industries Group, Inc. (2015). “Shaw Carpet Recycling Facility Successfully Processes Nylon and Polyester.” July 13, 2015. Available online at: https://shawinc.com/Newsroom/Press-Releases/Shaw-Carpet-Recycling-Facility-Successfully-Proces/

Textile World. (2000). “Evergreen Makes Nylon Live Forever.” Textile World. October 1, 2000. Available online at: https://www.textileworld.com/textile-world/textile-news/2000/10/evergreen-makes-nylon-live-forever/

U.S. Department of Energy. (2011). Office of Energy Efficiency and Renewable Energy. “New Process Recovers and Reuses Nylon from Waste Carpeting Saving Energy and Costs” Available online at: https://www.energy.gov/eere/amo/nylon-carpet-recycling

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

3.2.6 Carbide Production and Consumption (NIR Section 4.10)

3.2.6.1 Background

Carbon dioxide (CO_2) and methane (CH_4) are emitted from the production of silicon carbide (SiC), a material used for industrial abrasive, metallurgical, and other nonabrasive applications in the United States. Emissions from fuels consumed for energy purposes during the production of silicon carbide are accounted for in the energy sector. CO_2 and CH_4 are also emitted during the production of calcium carbide, a chemical used to produce acetylene. CO_2 emissions from production of calcium carbide are implicitly accounted for in the storage factor calculation for the nonenergy use of petroleum coke in the energy sector. Methane emissions from calcium carbide production are not estimated because data are not available.

3.2.6.2 Methods/Approach

Total emissions for each state are the sum of emissions from SiC production and SiC consumption. SiC production data were evenly distributed among the two states identified as being home to SiC production facilities—Illinois and Kentucky—in order to estimate state-level emissions from production. A Hybrid Approach, defined in the Introduction chapter of this report, was used to calculate emissions for each state, described below. See Appendix D, Table D-7 in the "Carbide Prod" Tab for more details on the data used. State-level estimates from SiC consumption were estimated using population statistics as a surrogate for consumption data. See Appendix G, Table G-1 in the "Population Data" Tab for more details on the data used.

The national *Inventory* methodology was adapted to calculate state-level GHG emissions of SiC to ensure consistency with national estimates. National estimates were used to estimate state-level emissions across states because of limitations in the availability of state-specific data for the time series.

SiC Production

Emissions of CO_2 and CH_4 from the production of SiC were calculated using Approach 1, as defined in the Introduction chapter of this report, which is consistent with the Tier 1 method provided by the 2006 IPCC Guidelines, and the same annual USGS production data (U.S. Bureau of Mines 1990–1993, USGS 1994–2017, USGS 2020) used in the national *Inventory* to calculate national emissions (EPA 2021). Because of the lack of information on production level by state, national SiC production data were evenly distributed among the two states identified in the USGS Minerals Yearbook series as being home to SiC production facilities. The state-level SiC production was multiplied by the national emissions factors for CO_2 and CH_4 to calculate GHG emissions by state

SiC Consumption

The national *Inventory* also estimates national CO_2 emissions from the consumption of SiC using Approach 2, as defined in the Introduction chapter of this report. SiC is used primarily for abrasive but also metallurgical and other nonabrasive applications. Data on the consumption of SiC by state, however, are not available. To calculate state-level CO_2 emissions from SiC consumption, national CO_2 estimates from the national *Inventory* were distributed among the 50 states, the District of Columbia, and Puerto Rico using U.S. population statistics as a surrogate for SiC consumption data (U.S. Census Bureau 2002, 2011, 2019; Instituto de Estadísticas de Puerto Rico 2021). For each year in the 1990–2019 time series, the fraction of the total U.S. population in each state, as well as the District of Columbia and Puerto Rico, was calculated by dividing the state population by the total U.S. population. To estimate CO_2 emissions for each year by state, national *Inventory* CO_2 emissions from SiC consumption were multiplied by each state's fraction of the total population for that year.

3.2.6.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from carbides production and consumption was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −9%/+9% for CO_2.

State-level estimates of production are expected to have a higher uncertainty because the national emissions estimates were equally apportioned to each of the two states that produce SiC, which assumes that they produce the same amount of SiC. There is also uncertainty due to the lack of information on production processes and production levels at the two facilities. The state-level estimates of consumption also have a high uncertainty because national emissions estimates were apportioned to all 50 states, the District of Columbia, and Puerto Rico using U.S. population statistics as a surrogate for consumption. These assumptions were required because of a general lack of more granular state-level data.

3.2.6.4 Planned Improvements

Data gaps include the production of SiC by state and the consumption of SiC by state for the full time series. Information to better simulate production at the two SiC facilities is needed and may include researching state operating permits. The EPA will research whether GDP from metal production or a relevant NAICS code by state is available that would be a better surrogate than population for estimating SiC consumption emissions.

3.2.6.5 References

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3.2.7 Titanium Dioxide Production (NIR Section 4.11)

3.2.7.1 Background

Titanium dioxide (TiO_2) is manufactured using one of two processes: the chloride process and the sulfate process. The chloride process uses petroleum coke and chlorine as raw materials and emits process-related CO_2. Emissions from fuels consumed for energy purposes during the production of TiO_2 are accounted for in the energy sector. The sulfate process does not use petroleum coke or other forms of carbon as a raw material and does not emit process CO_2. Since 2004, all TiO_2 produced in the United States has been produced using the chloride process. Production of titanium dioxide in 2019 took place in Mississippi, Ohio, Tennessee, and Louisiana.

3.2.7.2 Methods/Approach

To develop state-level estimates of emissions from titanium dioxide production, the EPA disaggregated national emissions from the national *Inventory* with an Approach 2 method as defined in the Introduction chapter of this report, using a combination of production capacity for 1990-2009 and GHGRP emissions data for 2010-2020 as a surrogate for titanium dioxide production data (see Table 3-7) . See Appendix D, Tables D-8 and D-9 in the “TiO2” Tab for more details on the data used.

The national *Inventory* methodology was adapted to calculate state-level GHG emissions of TiO_2 to ensure consistency with national estimates. National estimates were used to estimate state-level emissions across states because of limitations in availability of state-specific activity data for the time series.

Emissions of CO_2 from the production of TiO_2 were calculated using the Tier 1 method provided by the 2006 IPCC Guidelines and the same annual USGS production data (USGS Minerals Yearbook 1991–2015, USGS Mineral Commodity Summaries 2014–2019) used in the national *Inventory* to calculate national emissions (EPA 2021). National TiO_2 production data were allocated among the eight states with TiO_2 production facilities, based on production capacity or GHGRP emissions data, and multiplied by the national emissions factor.

Table 3-7. Summary of Approaches to Disaggregate the National Inventory for Titanium Dioxide Production Across Time Series

Time Series Range	Summary of Method
1990–2009	• USGS data on TiO_2 production capacity was used to allocate production by state, multiplied by the national emissions factor to get emissions (IPCC 2006 Tier 1).
2010–2019	• GHGRP process emissions data from TiO_2 facilities were used to allocate production by state, multiplied by the national emissions factor to get emissions (IPCC 2006 Tier 1).

The methodology used for the years 1990–2009 was based on USGS information on production capacity for each facility to estimate the fraction of total TiO_2 produced in each state. The methodology used for the period 2010–2019 was based on GHGRP CO_2 emissions data reported by facilities summed to state-level totals and used to estimate the fraction of total TiO_2 produced in each state. GHGRP has no reporting threshold for TiO_2, so these emissions data are representative of the industry.

The estimated state-level TiO_2 production was multiplied by the national emissions factor for CO_2 to calculate GHG emissions by state (IPCC 2006).

3.2.7.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from TiO_2 was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −12%/+13% for CO_2.

State-level estimates are expected to have an overall higher uncertainty because the national emissions estimates were apportioned to each state based on a combination of facility production capacity for 1990–2009 and GHGRP emissions data for 2010–2019. These assumptions were required because of a general lack of more granular state-level data.

For 1990–2009, this allocation method does not address utilization rates, which vary from facility to facility and from year to year or differences in the carbon consumption rate for chloride and sulfate processes. While this approach implicitly accounts for the size of a facility in a state, it could overestimate emissions in states where facilities used less of their capacity and underestimate emissions in states where facilities used more of their capacity as a result of the lack of data on utilization rates and production data. This method also does not account for different production processes. The sulfate process does not use petroleum coke or other forms of carbon as a raw material and does not emit CO_2. Although the chloride process has been the only one used in U.S. facilities since 2004, this allocation approach could overestimate emissions in states where facilities used the sulfate process.

For 2010–2019, uncertainty is expected to be lower because of the use of GHGRP emissions data by state as a surrogate for using TiO_2 production data by state to calculate emissions. For the period 2010–2019, national *Inventory* emissions have exceeded GHGRP emissions from 25 to 35%, possibly indicating that emissions are overestimated in some states.

3.2.7.4 Planned Improvements

Data gaps include state-level data on TiO_2 production for the full time series 1990–2019. GHGRP emissions data are available for the period 2010–2019 and were used for state inventory calculations, and these data will be examined for possible use to improve data for the 1990–2009 period.

To address utilization rates that vary from facility to facility and from year to year or differences in the carbon consumption rate for chloride and sulfate processes, the EPA will research how to account for varying utilization rates and carbon consumption rate differences for sulfate (nonemissive) and chloride (emissive) processes.

The EPA will review potential time-series consistency issues due to the two methodologies for 1990–2009 and for 2010–2019. Surrogate data (production capacity) were used in place of activity data for the 1990–2009 portion of the time series, and more research on data gaps (e.g., apply overlap technique) is needed to refine method to enhance accuracy and consistency of estimated state GHG emissions and trends.

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3.2.8 Soda Ash Production (NIR Section 4.12)

3.2.8.1 Background

CO_2 is generated as a by-product of calcining trona ore to produce soda ash and is eventually emitted into the atmosphere. In addition, CO_2 may also be released when soda ash is consumed. Emissions from soda ash consumption in chemical production processes are reported under other process uses of carbonates, and emissions from fuels consumed for energy purposes during the production and consumption of soda ash are accounted for in the energy sector.

3.2.8.2 Methods/Approach

All of the national Soda Ash Production emissions can be attributed to Wyoming for the entirety of the 1990–2019 time series. See Appendix D, Table D-10 in the “Soda Ash” Tab for more details on the data used.

The national *Inventory* methodology was used to calculate state-level GHG emissions to ensure consistency with national estimates, consistent with an Approach 1 method as defined in the Introduction chapter of this report. As discussed in the national *Inventory* (EPA 2021), only two states produce natural soda ash in the United States: Wyoming and California. Only CO_2 emissions from Wyoming soda ash production facilities, which produced soda ash from trona ore, are included in the national estimate for the 1990–2019 time series because no CO_2 is emitted from the processes used in the California facility, which produced soda ash from sodium-carbonate-rich brines. Additionally, one facility in Colorado produced soda ash from nahcolite between 2000 and 2004; however, similar to the California facility, the Colorado facility’s production process did not generate CO_2 emissions. As a result, all of the national CO_2 emissions can be attributed to Wyoming for the entirety of the 1990–2019 time series. Emissions calculations are consistent with the Tier 1 method provided by the 2006 IPCC Guidelines.

3.2.8.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from Soda Ash Production was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −9%/+8% for CO_2.

State-level estimates have a consistent level of uncertainty as the national *Inventory* over the full time series because the same methodology was used and emissive soda ash production takes place in one state.

3.2.8.4 Planned Improvements

There are no planned improvements for the soda ash production category. The EPA will monitor the U.S. soda ash production sector to ensure that any new production facilities using emissive processes are accounted for in the state-level disaggregation.

3.2.8.5 References

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3.2.9 Petrochemical Production (NIR Section 4.13)

3.2.9.1 Background

The production of some petrochemicals results in the release of CO_2 and CH_4 emissions. Petrochemicals are chemicals isolated or derived from petroleum or natural gas. CO_2 emissions from the production of acrylonitrile, carbon black, ethylene, ethylene dichloride, ethylene oxide, and methanol, and CH_4 emissions from the production of methanol and acrylonitrile are presented here. The petrochemical industry uses primary fossil fuels (i.e., natural gas, coal, petroleum) for nonfuel purposes in the production of carbon black and other petrochemicals. Emissions from fuels and feedstocks transferred out of the system for use in energy purposes (e.g., fuel combustion for indirect or direct process heat or steam production) are currently accounted for in the energy sector.

In 2019, petrochemicals were produced at 71 facilities in 10 states (EPA 2020). Over 95% of total production capacity is in Texas and Louisiana.

3.2.9.2 Methods/Approach

To develop state-level estimates of emissions from petrochemical production, the EPA disaggregated national emissions from the national *Inventory* to all applicable U.S. states and territories using production capacities by petrochemical process by state as a surrogate for emissions activity data. This methodology is consistent with Approach 2, as defined in the Introduction chapter of this report. See Appendix D, Table D-11 through Table D-16 in the "Petrochemical" Tab for more details on the data used.

The national *Inventory* methodology was adapted to calculate state-level GHG emissions from petrochemical production to ensure consistency with national estimates. Consistency with the national estimates and IPCC Guidelines requires reporting emissions by petrochemical type (i.e., acrylonitrile, carbon black, ethylene, ethylene dichloride, ethylene oxide, and methanol). State-level emissions for 1990–2019 were estimated as a percentage of total national emissions by state and by year.

The national *Inventory* derived national estimates for carbon black, ethylene, ethylene dichloride, and ethylene oxide based on facility-level GHGRP emissions for 2010–2019, because GHGRP has no reporting threshold for facilities. For 1990–2009, estimates were based on emissions factors derived from GHGRP data and production data from the American Chemistry Council (ACC) and the carbon black association (EPA 2021). For all years, the national emissions estimates for acrylonitrile and methanol were based on emissions factors and production data from the ACC because the national GHGRP data are considered CBI.

The method used for the national *Inventory* is not possible for state-level petrochemical emissions because additional GHGRP CBI concerns with all the petrochemical types become an issue when considering data by state. For example, all ethylene oxide production facilities are in Louisiana and Texas. For reporting year (RY) 2019, it appears that GHGRP emissions data could pass the CBI aggregation criteria in both states; however, for RY2010–

RY2018, there were only three companies in Louisiana, so data cannot be aggregated in either state for the same reasons noted below for ethylene, ethylene dichloride, and carbon black.

GHGRP emissions data for ethylene, ethylene dichloride, and carbon black could also pass CBI aggregation criteria at the state level in Louisiana and Texas (at least for RY2019); however, because there are fewer than four companies making each of these petrochemicals in other states (typically only one facility per state), it is not possible to aggregate the emissions by petrochemical type in Louisiana and Texas without revealing the facility-specific emissions at the facilities in other states.

Aggregating total emissions from all types of petrochemical processes rather than by type of petrochemical was also not possible because of CBI concerns, particularly the concern that aggregated data for one state could reveal, or allow for back calculation of, CBI information about individual facilities in other states. For example, some states have only one facility producing one type of petrochemical and reporting GHGRP emissions by state could disclose facility-specific data considered CBI for those states.

Aggregated GHGRP production levels (the activity data used to calculate emissions when GHGRP emissions are not available or do not meet CBI aggregation criteria) also have the same CBI concerns as GHGRP emissions.

Therefore, as an alternative, production capacities were used as a surrogate for actual production and emissions levels. In effect, this approach assumes that all facilities producing a particular type of petrochemical have the same capacity utilization and that emissions are proportional to production. As a result, this approach may result in overestimating emissions for some states and underestimating emissions for other states.

Specifically, the capacities per year per type of petrochemical per state were summed. The fraction of the total capacity attributable to each facility in each year per state was determined. This percentage was multiplied by the nationwide annual national *Inventory* emissions per petrochemical (i.e., the aggregated GHGRP emissions for ethylene, ethylene dichloride, ethylene oxide, and carbon black in RY2010–RY2019, and the calculated nationwide emissions for other years and for methanol and acrylonitrile in all years). Where production capacity information for all years was not known, data were extrapolated and interpolated to fill in data gaps. Several facilities have opened and closed over the last 30 years; the precise years of facilities' operations were not always available because capacities for only a handful of years were known. Details on how capacities were determined for each petrochemical are described below.

Acrylonitrile

Facility production capacity and location data were available for 1992, 1997, and 2005 from the SRI Directory of Chemical Producers (SRI 1992, 1997, 2005) and for 2008, 2009, 2011, 2013, and 2017 from the ICIS (ICIS 2008, 2009a, 2011, 2013, 2017). The 1997 SRI data consisted of only the facility locations and the percentages of the nationwide capacity held by the two companies with the largest percentage of the total nationwide capacity.

For 1990 and 1991, production capacity per state was assumed to be equal to the 1992 values. The 1997 capacities were estimated based on adjusting the 1992 and 2005 capacities to meet the corporate percentages cited in SRI's 1997 Directory. Specifically, the capacity for one facility was assumed to be the same as in 2005, the availability of new production capacity at a second facility known to have expanded in 1996 was assumed to be evenly split between 1997 and 1998, and capacities for the other four facilities in 1997 were assumed to be the same as in 1992. For other interim years, a linear extrapolation between the different years of known data were assumed. Some further adjustments were made when plant openings or closings were known. For example, one facility in Texas closed in 2005, and another closed in 2009.

Carbon Black

ICIS capacity data were available for 1999, 2002, and 2005. For 1999, only a partial dataset was available; these data were not used because some of the data appeared to be inconsistent with data for other years (ICIS

1999, 2002a, 2005). SRI data were available for 1992, 1997, and 2005 (SRI 1992, 1997, 2005). For 2005, this analysis used ICIS data.

Capacities in 1990 and 1991 were assumed to be equal to the 1992 value. Data were extrapolated from 1992–1997 and from 1997–2002. No plant closures were assumed during those time periods.

Capacities for years between the years for which SRI or ICIS data were available, or until the year when a plant closed, were estimated using linear interpolation. The plant in Arkansas was assumed to operate in 2002 but not in 2005, so capacity was extrapolated from 2002 levels to zero in 2005. It was assumed another plant in Texas closed in 2003, so the 2005 value was set to zero. It was assumed one plant in West Virginia closed in 2008 and the other closed in 2009. It was assumed another plant in Texas closed in 2010. Capacities for 2011–2019 were assumed to be equal to the capacities in 2010.

Ethylene

SRI data on production capacities were available for 1992 and 2005. The *Oil & Gas Journal* publishes capacities of ethylene production facilities, and data were available for 2007, 2013, and 2015 (O&GJ 2007, 2013, 2015).

Capacities in 1990 and 1991 were assumed to be equal to the 1992 value. Because site-specific capacities for the intermediate years were not known, a straight-line interpolation of capacities was assumed between 1992 and 2005. This resulted in the total capacity being less than the total annual production for 3 years in the late 1990s because some of the more significant expansions must have occurred in the mid-1990s. Capacities for 2016–2019 were assumed to be the same as in 2015, except for one new plant start-up in 2017, one new plant start-up in 2019, one restart of an idled plant in 2019, one expansion in 2017, three expansions in 2018, and one expansion in 2019 (Chevon Phillips Chemical 2018, ExxonMobil 2018, Indorama Ventures 2015, LACC 2016, LyondellBasell 2017, OxyChem 2017, BIC Magazine 2019). For all other interim years, a linear extrapolation between the different years of known data were assumed.

Ethylene Dichloride

The SRI Directory of Chemical Producers production capacity data for ethylene dichloride were available for 1992, 1997, and 2005 (SRI 1992, 1997, 2005). The 1997 SRI data consisted of only the facility locations and the percentages of the nationwide capacity held by the three companies with the largest percentage of the total nationwide capacity.

ICIS data on production capacity are available for the years 2003, 2009 and 2018, although it is not clear whether the data are complete. The 2003 report has capacities listed for 16 facilities, with two being idle that year. The 2009 report lists capacities for 14 facilities, the 2018 report lists only 10 facilities, and the total capacity reporting for 2018 is less than the assumed production in that year.

Capacities in 1990 and 1991 were assumed to be equal to the 1992 value. Capacities in 1993–1997 were assumed to be the same as in 1992, with the exception of the 1997 capacity for one facility that was assumed to be the same as the capacity in the 2003 ICIS data; with this assumption, the percentages of total nationwide capacity were close to the percentages provided in the 1997 SRI Directory. Linear interpolation was used to estimate capacities for 1998–2002, with two exceptions: the capacity for the facility that expanded in 1997 was assumed to be the same over all of the years, and 0 capacity was assumed for two plants in years where ICIS indicated the plants were idle.

The capacities in 2005 were assumed to be the same as the capacities reported by ICIS for 2003. While the 2005 SRI list had similar values for most facilities, one facility seemed low compared to ICIS values for 2003 and 2009. The ICIS capacities in 2009 matched the capacities in 2005; thus, all capacities were assumed to be unchanged from 2003–2009. The capacities in 2010–2019 also were assumed to be the same as in 2009, except for one facility that closed in 2011 and one new facility that started one new unit in 2010 and a second new unit in 2011.

The capacity utilization (dividing total production from the national *Inventory* by assumed capacity) was calculated over the time period as a check on the capacity assumptions used. If production exceeded assumed capacity, it would indicate the capacity assumptions were too low, while an extremely low-capacity utilization could indicate that capacity assumptions were too high. The average total capacity utilization over time was 70%, with a high of almost 100% in 1998 and a low of 47% in 2011. While these indicate there may be some over- or underestimation of capacity in a few years, they were still within the range of possible values and no further adjustments to capacities were made.

Ethylene Oxide

SRI data were available for 1992, 1997, and 2005 (SRI 1992, 1997, 2005). ICIS data on plant capacities were available for 2004, 2010, 2012, and 2018 (ICIS 2004, 2010, 2012, 2018b). Capacities in 1990 and 1991 were assumed to be equal to the 1992 value. The 2004 ICIS capacities were very similar to the 2005 SRI capacities; the 2004 ICIS capacities were used in this analysis to maintain consistency with capacities for subsequent years that were also based on ICIS data.

There were several plant openings and closing and capacity changes over the time period. Plant openings and closings were based on data provided in ICIS writeups, press releases, and other documentation on company websites (as opposed to extrapolating over time).

Capacity utilization was calculated over the time period as a check on the capacity assumptions used. Assumed total capacity was generally greater than assumed total production across the time series, with the exception of 1995 and 2004 where production was 102% of capacity. Average capacity utilization over time was 85%. Although this may indicate some underestimation of capacity in a few years (especially 1995 and 2004), no further adjustments to capacities were made.

Methanol

SRI data on methanol production capacity were available for 1992, 1997, and 2005 (SRI 1992 1997 2005). ICIS data were available for 2002, 2014, 2016, and 2018 (ICIS 2002b, 2014, 2016, 2018c).

Capacities in 1990 and 1991 were assumed to be equal to the 1992 value. Data on plant closures between 1998 and 2005 were from OCI (OCI Partners 2016; see the Appendix). Data on start-up dates for expansions and new plants between 2012 and 2019 were obtained from documentation on company websites (Celanese 2019, OCI 2018, OCI Partners 2016, Methanex 2017). These data were used to estimate capacities for years between the years for which ICIS data were available and to prorate capacities based on the approximate percentage of the year that they operated after start-up.

3.2.9.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 and CH_4 from Petrochemical Production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −6%/+6% for CO_2 and −57%/+47% for CH_4.

State-level estimates are expected to have a higher uncertainty because the national emissions estimates were apportioned to each state based on facility production capacity for 1990–2019. These assumptions were required because the CBI concerns related to GHGRP data, and a general lack of other more granular state-level data.

For 1990–2019, this allocation method does not address actual utilization rates, which vary from facility to facility and from year to year. While this approach implicitly accounts for the size of a facility in a state, it could overestimate emissions in states where facilities used less of their capacity and underestimate emissions in states where facilities used more of their capacity.

3.2.9.4 Planned Improvements

Continued research is needed for more information on timing of facility expansions, openings, and temporary or permanent closures (e.g., permits, permit applications, trade industry data) and on facility production capacities to address data gaps (e.g., earlier versions of SRI International Directory of Chemical Producers data, annual or biannual *Oil & Gas Journal* surveys of ethylene steam cracker capacities).

For 2010–2019, the state-level inventory totals based on production capacity can be compared with the GHGRP data on total emissions by state to assess how well the estimates represent the industry. Although petrochemical production emissions by state and petrochemical type are CBI, total petrochemical production emissions by state across all petrochemical types are not CBI under the GHGRP.

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3.2.10 HCFC-22 Production (NIR Section 4.14)

3.2.10.1 Background

Trifluoromethane (HFC-23 or CHF_3) is generated as a by-product during the manufacture of chlorodifluoromethane (HCFC-22), which is used as a feedstock for several fluoropolymers. Before 2010, HCFC-22 was widely used as a refrigerant, but its production and import for this application in the United States were phased out between 2010 and 2020 under Title VI of the Clean Air Act, which controls production and consumption of HCFCs and other compounds that deplete stratospheric ozone. Production of HCFC-22 for use as a feedstock is allowed to continue indefinitely.

3.2.10.2 Methods/Approach

As discussed on page 4-68 of the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019*, methods comparable to the Tier 3 methods in the 2006 IPCC Guidelines (IPCC 2006) were used to estimate HFC-23 emissions for five of the eight HCFC-22 plants that have operated in the United States since 1990. For the other three plants, the last of which closed in 1993, methods comparable to the Tier 1 method in the 2006 IPCC Guidelines were used. However, as discussed further below, the EPA does not have access to the individual plant estimates for 1990–2009; for those years, the EPA has access only to national totals aggregated across the plants.

To develop state-level estimates of HFC-23 emissions from HCFC-22 Production, the EPA disaggregated national emissions from the national *Inventory* using a combination of facility-level reporting to the GHGRP from 2010–2019, reports verifying emissions by facility for earlier years, and production capacity data, as shown in Table 3-8. The sum of emissions by state is consistent with national process emissions as reported in the national *Inventory* over the time series (with one small exception for 2011 discussed further below).

Table 3-8. Summary of Approaches to Disaggregate the National *Inventory* for HCFC-22 Production Across Time Series

Time Series Range	Summary of Method
1990–2009	• Facility-specific information on emissions control efforts and production capacities, in combination with facility-specific GHGRP data for 2010, was used to estimate emissions by state (Approach 2).
2010–2019	• Facility-specific GHGRP data on HFC-23 emissions were compiled by state (Approach 1).

For each state, HFC-23 emissions from 2010–2019 were drawn from facility-level reporting to the GHGRP. The same data were used for the national *Inventory*, but for 2011, there is a slight discrepancy (459 kg or about 0.07%) between the U.S. total for this source and the sum of the state-level emissions provided here. The state-level estimates are correct; the national total for 2011 incorrectly includes HFC-23 emissions that do not result from HCFC-22 production for one plant. The national *Inventory* will be corrected to exclude these emissions.

Facility-level reports of HFC-23 emissions are not available for years before 2010, which was the first year of GHGRP reporting. As described in the national *Inventory*, national totals for 1990–2009 were based on totals provided to EPA by the Alliance for Responsible Atmospheric Policy, which aggregated the HFC-23 emissions and HCFC-22 production reported to the Alliance by each HCFC-22 production facility and HFC-23 destruction facility. (A list of the nine facilities that have operated in the United States since 1990, their locations, and dates of opening or closure are shown in Table 3-9 below.) These totals, as well as the individual facility reports, were reviewed and corrected, as necessary, by an EPA contractor in 1997 and 2008. The totals and qualitative information on each plant's emissions estimation methods, trends, and control measures were summarized in two reports. The EPA used the second of these reports, *Verification of Emission Estimates of HFC-23 from the Production of HCFC-22: Emissions from 1990 through 2006* (hereinafter referred to as the *2008 Verification Report*) (RTI 2008), to estimate facility-level emissions and develop state-level estimates for 1990–2009. The EPA also used GHGRP data from 2010–2019 and the estimated 2003 HCFC-22 production capacity of each facility from the 2004 edition of the *Chemical and Economics Handbook (CEH) Research Report: Fluorocarbons* (SRI 2004).

In combination with two key trends seen at the national level, these resources provide some insight into the magnitudes and trends of emissions of the various facilities. The two key national trends are a steady decrease in the HFC-23/HCFC-22 emissions factor from 1990–2010 and a slow increase in HCFC-22 production from 1990–2000, followed by fluctuating production through 2007, followed by a decline in later years. The *2008 Verification Report* indicates that the downward trend in the emissions factor was at least partially driven by (1) the closure during the early 1990s of four HCFC-22 production facilities whose emissions were uncontrolled and whose production was replaced by a facility that opened in 1993 in Alabama with tight emissions controls and (2) actions taken by a production facility in Kentucky to significantly reduce its emissions rate beginning in 2000. While HCFC-22 production and production capacity data were not available for all the plants operating before 2003, the generally upward trend in national production seen between 1990 and 2003 indicates that the closure of the four plants in the early 1990s, in combination with the opening of the Alabama plant in 1993, likely did not result in a significant net loss of production capacity in the United States as a whole during that period. Thus, the EPA estimated production at the four plants by equating their joint production capacity to that of the Alabama plant, which was available from the CEH report.

To allocate national emissions to each facility, the EPA first back-cast the relatively small emissions reported by the HCFC-22 production facility in Alabama and one HFC-23 destruction facility in West Virginia. As noted above, the Alabama HCFC-22 production facility was known to have tightly controlled HFC-23 emissions since it began operating in 1993; thus, emissions from 1996–2009 were assumed to equal the average of the emissions reported by this facility from 2010–2014, a period during which emissions were relatively flat before they began to decline in 2015. (Emissions from 1993–1996 were assumed to rise gradually as the plant replaced HCFC-22 production from closing plants.) The HFC-23 destruction facility in West Virginia is understood to have begun destroying HFC-23 in 2000 when an HCFC-22 production facility owned by the same company began capturing by-product HFC-23 and shipping some of it to the West Virginia facility for destruction. Emissions from 2000–2009 were equated to the average emissions reported by the West Virginia facility under subpart O of the GHGRP from 2010–2013 (about 3 kg per year), after which emissions dropped.

To estimate the 2003–2009 emissions from the other two HCFC-22 production facilities that operated during that period (in Kentucky and Louisiana), the emissions estimated for the Alabama and West Virginia facilities were subtracted from the national total, and the remaining emissions were then allocated to the Kentucky and Louisiana facilities based on each facility's estimated production and estimated emissions rate. The production of each facility throughout the time series was estimated based on the 2003 capacity reported in the CEH report. The 1999 emissions rates of both facilities were assumed to be equal to the national emissions rate in that year after subtracting out the estimated emissions and production of the (controlled) Alabama facility; the resulting emissions rate was 0.018 kg HFC-23/kg HCFC-22. The emissions rate of the Louisiana facility was assumed to have remained constant at this level based on the characterization of that facility's emissions control efforts in the *2008 Verification Report*. The emissions rate for the Kentucky facility was assumed to have declined linearly to 0.005 kg HFC-23/kg HCFC-22 as the facility implemented the emissions reduction efforts documented in the *2008 Verification Report*.[21] To estimate the share of national emissions attributable to each facility, each facility's estimated production was multiplied by its estimated emissions rate, resulting in a provisional emissions estimate for each facility for each year. Each facility's provisional emissions estimate was then divided by the sum of the provisional emissions estimates for both facilities. The resulting fraction was multiplied by the national emissions (less the emissions of the Alabama and West Virginia facilities) to obtain the final estimate of emissions for each facility.

To estimate facility-level emissions from 1990–2002, it was necessary to account for the emissions of the five HCFC-22 production facilities that ceased production before 2003. These facilities, which operated through 1991, 1992, 1993, 1995, and 2002, respectively, did not have production capacities listed in the CEH report and did not control their emissions, based on the *2008 Verification Report*. The production capacity of the facility that operated through 2002, in Kansas, was estimated as the difference between the total U.S. HCFC-22 production in 2000 and the sum of the CEH-estimated production capacities for the other three plants in operation during that year. (U.S. HCFC-22 production reached a peak in 2000.) This plant was assumed to have linearly decreased production to zero between 2000 and 2003. Its emissions factor was assumed to equal the value calculated for uncontrolled plants in 1999, 0.018 kg HFC-23/kg HCFC-22. U.S. emissions from 2000–2002 were then allocated to this plant and to the Kentucky and Louisiana plants as described above.

As noted earlier, the production capacities of the four facilities that closed in the early 1990s were each assumed to equal one-fourth of the production capacity of the Alabama facility that opened in 1993. Because none of the four plants controlled their emissions, their emissions factors were assumed to be equal to those of the Kansas, Kentucky, and Louisiana plants from 1990–1999. U.S. emissions (less those of the Alabama plant) from 1990–1999 were therefore allocated to each facility based on its estimated share of U.S. HCFC-22 production capacity.

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[21] The 0.005 emissions factor was estimated by subtracting the 2010 HFC-23 emissions reported by the other facilities from the national emissions total, subtracting the 2010 production estimated for the other facilities (based on their production capacities and national production) from the 2010 national production total, and dividing the first by the second.

Table 3-9. Facilities Producing HCFC-22 or Destroying HFC-23 Generated During HCFC-22 Production from 1990–2020

Company	Plant Location	Years When HCFC-22 Was Produced, or HFC-23 Was Destroyed
Arkema	Calvert City, KY	**1990–1991**
	Wichita, KS	**1990–2002**
DuPont/Chemours	Montague, MI	**1990–1995**
	Louisville, KY	**1990–2020**
	Washington, WV	**2000–2020**
Honeywell	El Segundo, CA	**1990–1992**
	Baton Rouge, LA	**1990–2012**
LaRoche Industries	Gramercy, LA	**1990–1993**
MDA Manufacturing/Daikin	**Decatur, AL**	**1993–2020**

3.2.10.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of HFC-23 from HCFC-22 production was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further on page 4-69 of the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019* (EPA 2021), the uncertainty in the national estimate in 2019 was estimated at −7% to +10%. Based on an uncertainty analysis that was performed for the *2008 Verification Report*, the uncertainties in the emissions of the individual plants that have accounted for most of the emissions since 2010 (i.e., the plants in Kentucky and Louisiana) were comparable to this in 2006 (−5% to +11% and −9% to +11%, respectively). The 2006 uncertainty in the much smaller emissions from the plant in Alabama was estimated at −48% to +47%. Because the methods used to estimate emissions at these plants are not believed to have changed significantly since 2006 and because plant-level emissions data are available for these plants for 2010 and later years, the uncertainties in the emissions of the Kentucky, Louisiana, and Alabama plants for 2010 and later years are believed to be similar to those estimated in the *2008 Verification Report*.

For the years 1990–2009, plant-level data are not available, significantly increasing the uncertainty of emissions estimates for individual facilities and states. This is particularly true for the five HCFC-22 production facilities that closed before 2003 and for which production capacity data are therefore not available. The uncertainties of the emissions of these five facilities also increased the uncertainties of the 1990–2002 emissions of the three HCFC-22 production facilities for which production capacity data are available, because the (unknown) production at the five facilities probably affected the capacity utilization of the other three. Capacity utilization can vary significantly across plants and from year to year.

3.2.10.4 Planned Improvements

During the 2007–2008 review of the HFC-23 emissions estimates provided to the EPA by the Alliance for Responsible Atmospheric Policy, RTI International (the EPA's contractor) was able to review the annual estimates of individual HCFC-22 production facilities, but under the confidentiality agreements in place at the time of the review, the EPA did not have direct access to the individual plant- or facility-level estimates. If one or more HCFC-22 production facilities were able to share their 1990–2009 emissions estimates with the EPA, this would considerably reduce the uncertainty of the EPA's 1990–2009 state-level estimates.

3.2.10.5 References

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3.2.11 Phosphoric Acid Production (NIR Section 4.16)

3.2.11.1 Background

Phosphoric acid (H_3PO_4) is a basic raw material used in the production of phosphate-based fertilizers. Phosphoric Acid Production from natural phosphate rock is a source of CO_2 emissions, due to the chemical reaction of the inorganic carbon (calcium carbonate) component of the phosphate rock. In 2019, phosphoric acid was produced in Florida, Idaho, Louisiana, North Carolina, and Wyoming.

3.2.11.2 Methods/Approach

To develop state-level estimates of emissions from phosphoric acid production, the EPA disaggregated national emissions from the national *Inventory* to all applicable U.S. states using an Approach 2 method, as defined in the Introduction chapter of this report, using a combination of estimated phosphoric acid production capacity by state for 1990–2009 and process emissions reported to the GHGRP for 2010–2019, as shown in Table 3-10. The national *Inventory* methodology was adapted to calculate state-level GHG emissions from phosphoric acid production to ensure consistency with national estimates. The sum of emissions by state are consistent with national process emissions as reported in the national *Inventory*. See Appendix D, Table D-17 through Table D-22 in the "Phosphoric Acid" Tab for more details on the data used.

Table 3-10. Summary of Approaches to Disaggregate the National *Inventory* for Phosphoric Acid Production Across Time Series

Time Series Range	Summary of Method
1990–2009	• Phosphoric acid production capacity data were used to estimate the percentage of production by state, multiplied by the national emissions (IPCC 2006 Tier 1).
2010–2019	• GHGRP process emissions data were used to estimate the percentage of emissions by state, multiplied by the national emissions (IPCC 2006 Tier 1).

The methodology used for 1990–2009 was based on state-level CO_2 emissions calculated by attributing annual national phosphate rock usage to states based on the production capacities of phosphoric acid production facilities and their assumed use of phosphate rock by origin. Using location and estimated production capacity information on phosphoric acid production facilities for 1989 and 1991, the EPA generated an initial list of facilities operating in 1990 in each state (National Fertilizer Development Center 1986, EPA 1993). Based on USGS Mineral Yearbook information on the operations of each facility, the operational status and rock origin for each facility were identified on an annual basis. Consistent with national CO_2 emissions calculations in the national *Inventory*, state-level phosphoric acid production was estimated based on the CO_2 content and usage of three categories of phosphate rock origin, where rocks sourced from each category were assumed to have consistent CO_2 content: (1) Florida and North Carolina (FL/NC), (2) Idaho and Utah (ID/UT), and (3) Imports from Morocco and Peru (Import).

Phosphoric acid production facilities operated in Florida, Idaho, Louisiana, Mississippi, North Carolina, Texas, and Wyoming over the time series. As noted in the national *Inventory*, all phosphate rock mining companies in the U.S. are vertically integrated with fertilizer plants that produce phosphoric acid located near the mines. Based on the location of mines, all phosphoric acid produced in Florida and North Carolina were attributed to the FL/NC rock type, and the phosphoric acid produced in Idaho and Wyoming was attributed to the ID/UT rock type. For production facilities in Louisiana, Mississippi, and Texas, USGS Mineral Yearbook information was used to assign the phosphate rock origin for each year 1990–2019 (USGS 1994–2020). Where the USGS Mineral Yearbook did not discuss the rock origin for a facility in a given year, the EPA made assumptions regarding the rock origin based on information available in prior or subsequent year publications. Because the rock usage by origin was not available for facilities, it was assumed that when domestic phosphate rock and imported rock were both used at a facility, they were used in equal amounts such that half of the plant capacity used each rock type. For each of the three rock origin categories, the aggregated phosphoric acid production capacities for each state were calculated and then used to allocate percentages of national emissions to each state on an annual basis.

For 2010–2019, process emissions reported to the GHGRP for each phosphoric acid facility were assigned to each of the three rock origin types, similar to the methodology for 1990–2009 (GHGRP 2020). GHGRP has no reporting threshold for phosphoric acid production, so these emissions data are representative of the industry. As discussed above, the facilities in Florida and North Carolina were assigned to the FL/NC rock origin and those in Idaho and Wyoming to ID/UT. The rock origins for the facilities in Louisiana, Mississippi, and Texas were assigned based on information contained in the USGS Mineral Yearbook publications. One facility in Louisiana was assumed to use half FL/NC phosphate rock and half imported phosphate rock, whereas another was assumed to use only imported rock. The facilities in Mississippi and Texas were assumed to only use imported phosphate rock. After allocating emissions for each facility to each rock type, the estimated emissions from each facility for each rock type were used to calculate a percentage of emissions from each state for each rock type. That percentage was then applied to the national *Inventory* emissions for each rock type per year to disaggregate national CO_2 emissions by state and by year.

3.2.11.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from Phosphoric Acid Production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −19%/+21% for CO_2.

State-level estimates are expected to have an overall higher uncertainty because the national emissions estimates were apportioned to each state based on a combination of facility production capacity for 1990–2009 and GHGRP emissions data for 2010–2019. These assumptions were required because of a general lack of more granular state-level data.

For 1990–2009, this allocation method does not address actual utilization or production rates, which vary from facility to facility and from year to year. While this approach implicitly accounts for the size of a facility in a state, it could overestimate emissions in states where facilities used less of their capacity and underestimate emissions in states where facilities used more of their capacity as a result of the lack of data on utilization rates and production data.

For 2010–2019, uncertainty is expected to be lower because of the use of GHGRP emissions data by state as a surrogate for using phosphoric acid production data by state to calculate emissions.

3.2.11.4 Planned Improvements

For the facility-level phosphoric acid production capacity data used for years 1990–2009, additional research is needed to more accurately represent the level of production and emissions associated with each state. Initial research included using corporate-level information on actual production levels at facilities in operation during the 1990–2009 time series. Because of the lack of comprehensive publicly available production data for all states and years, this approach was not used in the initial analysis. The EPA also attempted to identify phosphoric acid production facility expansions and temporary shutdowns that would affect production capacities. Similarly, because of the lack of comprehensive publicly available data on changes to annual facility production capacities, this approach was not used. Other data gaps include the origin of phosphate rock used in some facilities and some years.

3.2.11.5 References

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3.3 Metals

This section presents the methodology used to estimate the metals portion of IPPU emissions, which consist of the following sources:

- Iron & Steel production (CO_2, CH_4)
- Ferroalloy production (CO_2, CH_4)
- Aluminum production (CO_2, PFCs)
- Magnesium production and processing (CO_2, HFCs, SF_6)
- Lead production (CO_2)
- Zinc production (CO_2)

3.3.1 Iron & Steel Production and Metallurgical Coke Production (NIR Section 4.17)

3.3.1.1 Background

I&S production is a multistep process that generates process-related emissions of CO_2 and CH_4 as raw materials are refined into iron and then transformed into crude steel. Emissions from conventional fuels (e.g., natural gas, fuel oil) consumed for energy purposes (fuel combustion) during the production of I&S are accounted for in the energy sector. I&S production includes six distinct production processes: coke production, sinter production, direct reduced iron production, pig iron production, electric arc furnace (EAF) steel production, and basic oxygen furnace (BOF) steel production. In addition to the production processes, CO_2 is also generated at I&S mills through the consumption of process by-products (e.g., blast furnace gas, coke oven gas) used for various purposes including heating, annealing, and electricity generation. In general, CO_2 emissions are generated in these production processes through the reduction and consumption of various carbon-containing inputs (e.g., ore, scrap, flux, coke by-products). Fugitive CH_4 emissions can also be generated from these processes, as well as from sinter, direct iron, and pellet production.

In 2019, I&S production occurred in 27 states, and Indiana, Ohio, Pennsylvania, and Minnesota were the leading I&S-producing states, accounting for 65% of total U.S. production (EPA 2021).

3.3.1.2 Methods/Approach

Emissions by state from I&S and metallurgical coke production were estimated using a combination of state-level steel production, Census data on employment, coking coal consumption data, and process emissions reported to the GHGRP. See Appendix H, Table H-1 through Table H-4 in the “I&S” Tab for more details on the data used.

The national *Inventory* methodology was adapted to calculate state-level GHG emissions to ensure consistency with national estimates. National estimates were downscaled across states because of limitations in the availability of state-specific data across the time series to use national methods at the state level (i.e., IPCC Tier 1 and 2 methods).

To compile emissions by state from I&S and metallurgical coke production using available data, this state-level inventory disaggregated national emissions from the national *Inventory* with an Approach 2 method as defined in the Introduction chapter of this report, using a combination of steel production in a state, Census data on employment, coking coal consumption data, and process emissions reported to the GHGRP as a surrogate for steel production data. The sum of emissions by state is consistent with the national total process emissions reported in the national *Inventory*.

The emissions from I&S and metallurgical coke production were broken into the following categories for national emissions calculations in the national *Inventory* and also as part of the state-level breakout:

- sinter production
- iron production
- pellet production
- steel production—BOF
- steel production—EAF
- other activities
- metallurgical coke production

Each category was considered in terms of the state-level breakout, and some were grouped together for the analysis as detailed below.

Metallurgical Coke Production

National emissions from coke production used for I&S are estimated based on the amount of coke used in I&S and a carbon balance around the amount of coking coal used to produce the coke used and accounting for any co-products produced. Specific state-level data on coke production for I&S are not readily available; however, state-level data on coking coal consumption are available from the EIA's State Energy Data System (SEDS). Those data are broken out by fuel type and energy consumption sector (i.e., residential, commercial, industrial, transportation, and electric power) and available for the years 1960–2019 (EIA 2021). SEDS estimates energy consumption using data from surveys of energy suppliers that report consumption, sales, or distribution of energy at the state level, and most of the SEDS estimates rely directly on collected state-level consumption data. The sums of the state estimates equal the national totals as closely as possible for each energy type and end-use sector, and energy consumption estimates are generally comparable to national energy statistics. This approach assumes that emissions from metallurgical coke production are directly proportional to the amount of coking coal consumed in a state; therefore, national-level metallurgical coke production emissions from I&S were allocated to the state level based on the percentage of total coking coal consumed per state. As discussed in the Energy chapter, state-level coking coal use is based on coke production in a given state, not necessarily coke use. Given lack of specific data, however, coking coal use was determined to be a good surrogate for coke use within a given state, given coke production is often integrated with I&S production where the coke is used.

Steel Production

National-level emissions from steel production (BOF and EAF) were estimated based on a carbon balance around carbon-containing inputs and outputs. State-level data on all the process inputs and outputs were not readily available; therefore, surrogate data on steel production by state were used to allocate national-level steel production emissions to the state level. For the years 1990–2009, a combination of U.S. Census data (Census) and production data from the American Iron and Steel Institute (AISI) was used to allocate national-level emissions from steel production to the state level (Census 1992, 1997, 2002, 2007, AISI 1997–2020). AISI total steel production data were available at the state level for the top 5 I&S-producing states, with the other states being combined into regions. Percentages of steel production for these lower producing states were appropriated using the Census industry employment data as a basis. It was assumed steel production was directly proportional to the number of employees in the state.

Census data were available for the years 1992, 1997, 2002, and 2007. Data for the years 1990 and 1991 were proxied based on 1992, and data for the years 2008 and 2009 were proxied based on 2007. Data for interim years were interpolated. For 1992, data were pulled by state for the NAICS codes Subsector 331: Primary Metal Manufacturing and Subsector 332: Fabricated Metal Product Manufacturing. For 1997, 2002 and 2007, state data were pulled for NAICS codes 331111 Iron and Steel Mills and Ferroalloy Manufacturing, 331210 Iron and Steel Pipe and Tube Manufacturing from Purchased Steel, 331221 Rolled Steel Shape Manufacturing, 331222 Steel Wire Drawing, 331511 Iron Foundries, 331512 Steel Investment Foundries, 331513 Steel Foundries (except Investment), and 332111 Iron and Steel Forging. For some states, the NAICS code had a low number of employees or low number of facilities to the point where it was not reported because of anonymity concerns; therefore, these states were not included in this analysis. For some cases, states were included if data were available at a higher NAICS code. One exception was Maryland where data were withheld to maintain anonymity, but the state is known to have had sizable steel production. It was assumed Maryland had 2,000 employees in the steel sector in the latest year of Census data (2007).[22] The percentage of employees and steel production across the region aggregated with Maryland in the AISI data (Rhode Island, Connecticut, New Jersey, New York, Delaware, and Maryland) based on the 2007 data were applied across the entire time series.

Furthermore, steel production by state was broken out into BOF and EAF steel production based on the national totals of each type of steel produced from AISI data. Steel production in each state by type was assumed to be proportional to the national totals by type for each year. Once data on steel production by type were determined for each state and year, the total national emissions by steel type was attributed to each state based on steel production in each state. This approach assumes that emissions from steel production are directly proportional to the amount of steel produced in a state. This assumption could lead to over- or underestimations of emissions per state depending on the type of steel production and relative emissions profile of steel production in a given state. Furthermore, basing the state-level split of BOF and EAF on the national averages could lead to over- or underestimation of a specific type of steel production in a given state. However, given the lack of data, this approach was considered reasonable. This is an area for future improvement based on consideration of any available state-level steel production data.

For years 2010–2019, process emissions reported to the GHGRP under subpart Q (I&S facilities) were summed by state (EPA 2010–2019) to calculate a percentage of emissions from each state. Fuel combustion emissions from I&S facilities reporting to the GHGRP are reported separately under subpart C (combustion units). Generally, fuel combustion emissions are reported under the energy portion of the national *Inventory*; however, some of these emissions were included in I&S national *Inventory* calculations, specifically blast furnace emissions. Portions of fuel consumption data for several fuel categories were included in the IPPU calculations (e.g., I&S) because they are consumed during nonenergy-related industrial process activity. A consistent approach to avoid double counting emissions from I&S was taken for state-level emissions, subtracting state-level I&S process emissions from each state's energy sector emissions. More information on this allocation process is available in the Energy chapter of this report.

A combination of subpart Q and subpart C data was used when estimating state emissions percentages from I&S facilities in 2010–2019. Because emissions are reported by unit type in the GHGRP, the EPA was able to

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[22] Based on https://millstories.umbc.edu/sparrows-point/.

disaggregate state-level emissions at the process level, including steel production by type, iron, sinter, pellet, metallurgical coke, and other activities production. For steel production, GHGRP data were available by process type: BOF and EAF. The percentage of total emissions by steel type per state from the GHGRP data was then applied to the national emissions of steel production by type from the national *Inventory* per year to calculate disaggregated CO_2 emissions by state.

GHGRP has a reporting threshold of 25,000 metric tons of CO_2 equivalent for I&S production, so these emissions data are representative of the larger facilities in the industry. Using GHGRP emissions data means that emissions from states with smaller facilities were possibly underestimated.

Sinter Production, Iron Production, Pellet Production, and Other Activities

For years 1990–2009, emissions from sinter production, iron production, pellet production, and other activities were allocated to states based on the percentage of BOF steel production by state from the Census and AISI data (Census 1992, 1997, 2002, 2007, AISI 1997–2020), as described above. It was assumed that emissions from sinter production, iron production, pellet production, and other activities would be most closely aligned with BOF steel production.

For years 2010–2019, emissions from sinter production, iron production, pellet production, and other activities were allocated based on the GHGRP data for the process types. The GHGRP reporting threshold described above is applicable for these process types as well.

3.3.1.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 and CH_4 from I&S production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were –19%/+19% for both CO_2 and CH_4.

State-level estimates are expected to have a higher uncertainty because the national emissions estimates were apportioned to each state based on a combination of steel production data and census data on employment, coking coal consumption data, and process emissions reported to GHGRP. These assumptions were required because of a general lack of more granular state-level data.

Emissions from metallurgical coke production for I&S were assumed to be directly proportional to the amount of coking coal consumed in a state, and metallurgical coke was assumed to be used in the same state it was produced. While industry trends suggest mostly on-site use, this method could overestimate emissions from coking coal for states where facilities transfer coking coal off-site and underestimate emissions for states where facilities transfer coking coal for metallurgical coke production across state boundaries.

For 1990–2009, the Census data were used as a surrogate for production data for steel, sinter, iron, pellet, and other activities to disaggregate national *Inventory* data by state. Because this method assumes that all facilities produce the same amount of emissions regardless of production capacities, it could overestimate emissions in states with smaller facilities and underestimate emissions in states with larger facilities. Additionally, for sinter, iron, pellet, and other activities, emissions are based on BOF steel production for the state, which may overestimate or underestimate state-level emissions for these activities.

For 2010–2019, GHGRP data were used to disaggregate national *Inventory* emissions to the state level for steel, sinter, iron, pellet, and other activities. Because GHGRP receives detailed data down to the process unit level, uncertainty is lower. While the GHGRP data have a reporting threshold of 25,000 metric tons of CO_2 equivalent, GHGRP estimates that 99.8% of industry emissions are accounted for (EPA 2008), and the GHGRP data are likely representative of the whole industry.

By-product fuels are assumed to be used on-site in this method. Although industry trends show facilities using by-product fuels such as coke oven gas or blast furnace gas on-site, if these by-products are shipped off-site, this adds an additional level of uncertainty to state-level estimates. If these by-products are shipped across state lines for energy use, emissions may be overestimated for states where facilities transfer by-products off-site and across state boundaries and underestimated for states where facilities use by-products on-site from across state boundaries.

3.3.1.4 Planned Improvements

AISI data were only available from 1997–2019 (AISI 1997–2020), so data are incomplete at beginning of the time series. We will examine if data are available for earlier years.

Census data are released only every 5 years, and employment estimates were based on NAICS codes. The NAICS codes used might not encompass the whole industry, and generally as a method, the number of employees may not correlate well to emissions. We will examine the Census data and make adjustments as necessary.

Combustion emissions from GHGRP data are not entirely consistent across reporters because some facilities report under subpart C and some report combined emissions using CEMS. Also, fuel use data from the GHGRP might not be equivalent to data included in the national *Inventory* calculations under I&S because the GHGRP data do not specifically indicate if fuel is used in nonenergy applications. We will continue to examine the GHGRP energy use estimates in comparison to what is assumed in the national *Inventory* calculations and adjust as needed.

The EPA plans to compare coking coal consumption data from EIA SEDS to the data from the GHGRP reporting program for the years 2010–2019 as a QA/QC check.

The EPA also plans to compare BOF and EAF data by state from the GHGRP to the AISI national percentage breakout of EAF and BOF by state to see if there is a better approach to allocating BOF and EAF production by state for 1990–2009. In general, the EPA plans to compare the industry data to the GHGRP program data across time to see how close they are to see if using the industry data is a reasonable approach.

The EPA will review time-series consistency issues related particularly to steel production. Surrogate data (industry employment) were used in place of activity data for all but the top 5 producing states for the 1990–2009 portion of the time series, and more research will be undertaken to identify potential methodological refinements to enhance the accuracy and consistency of estimated state GHG emissions and trends.

3.3.1.5 References

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3.3.2 Ferroalloys Production (NIR Section 4.18)

3.3.2.1 Background

CO_2 and CH_4 are emitted from the production of several ferroalloys. Ferroalloys are composites of iron (Fe) and other elements such as silicon (Si), manganese (Mn), and chromium (Cr). Emissions from fuels consumed for energy purposes during the production of ferroalloys are accounted for in the energy sector. Emissions from the production of two types of ferrosilicon (25 to 55% and 56 to 95% silicon), silicon metal (96 to 99% silicon), and miscellaneous alloys (32 to 65%) have been calculated. Consistent with the national *Inventory*, emissions from the production of ferrochromium and ferromanganese are not included here because of the small number of manufacturers of these materials in the United States. Similar to emissions from the production of I&S, CO_2 is emitted when metallurgical coke is oxidized during a high-temperature reaction with iron and the selected alloying element. Although most of the carbon contained in the process materials is released to the atmosphere as CO_2, a percentage is also released as CH_4 and other volatiles. The amount of CH_4 that is released depends on furnace efficiency, operation technique, and control technology.

In 2019, ferroalloy production occurred in six states: Ohio, Pennsylvania, Kentucky, Michigan, Alabama, and West Virginia.

3.3.2.2 Methods/Approach

To compile emissions by state from ferroalloy production, the state-level inventory disaggregated national emissions from the national *Inventory* with an Approach 2 method as defined in the Introduction chapter of this report, using a combination of the number of facilities in a state and process emissions reported to the GHGRP (see Table 3-11). See Appendix H, Tables H-5 and H-6 in the "Ferroalloy" Tab for more details on the data used.

The national *Inventory* methodology was adapted to calculate state-level GHG emissions to ensure consistency with national estimates. National estimates were downscaled across states because of limitations in the availability of state-specific data across the time series to use national methods (i.e., IPCC Tier 1 methods) at the state level. . The sum of emissions by state is consistent with the national process emissions reported in the national *Inventory*.

Table 3-11. Summary of Approaches to Disaggregate the National *Inventory* for Ferroalloys Production Across Time Series

Time Series Range	Summary of Method
1990–2009	• Data on number of facilities from the GHGRP-reported emissions were used to allocate emissions for those facilities. Remaining emissions were allocated evenly across remaining known facilities (IPCC 2006 Tier 1).
2010–2019	• GHGRP facility process emissions data were used • Remaining emissions reported in the national *Inventory* were allocated across remaining known facilities (IPCC 2006 Tier 1).

To identify all ferroalloy-producing facilities for 1990–2019, the number of facilities in each state was compiled from the USGS Minerals Yearbooks for ferroalloys as available (USGS 2008–2016) and compared with the facilities reporting to the GHGRP. The GHGRP has a reporting threshold of 25,000 metric tons of CO_2 equivalent for ferroalloy production, so these emissions data are representative of the larger facilities in the industry. Combining GHGRP emissions data with the number of facilities in each state includes smaller facilities and improves the completeness of the state-level inventory. The total number of facilities from the 2008 USGS Minerals Yearbook for ferroalloys was used for 1990–2007 because the Mineral Yearbooks for years before 2008 did not contain the number of facilities. Additionally, facilities were not included in years that the EPA determined the facility was not operational. The EPA used internet searches to determine the opening dates of ferroalloys facilities and to determine whether they were operational during all inventory years (AMG 2017, Bloomburg Bear 2021, Bloomburg Eramet 2021, Businesswire 2020, Businesswire 2017, Centerra 2021, Chattanooga 2015, D&B 2021, Ferroglobe 2020, Global 2010, Vanadium 2019, Wikipedia 2021).

For years 2010–2019, five of the facilities listed in the USGS Mineral Yearbook also reported to the GHGRP in years 2010–2019, and the reported process emissions data were used for these facilities. To improve the completeness of this state-level inventory and estimate emissions from the remaining known facilities in 2010–2019, process emissions reported to the GHGRP were summed (EPA 2010–2019) for each year and subtracted from the national *Inventory* total emissions for each year. The remaining balance was distributed equally among the facilities listed in the USGS Minerals Yearbook that did not report to the GHGRP.

For years 1990–2009, the average GHGRP emissions from each GHGRP facility for the years 2010–2012 were applied to each year, and the remaining emissions were evenly distributed among the remaining facilities. Values for the years 2010–2012 were used because these were expected to be a more accurate representation of emissions in 1990–2009.

Once facility-level emissions were calculated, the emissions were summed by state to calculate CO_2 and CH_4 emissions by state for each year.

3.3.2.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 and CH_4 from ferroalloy production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −12%/+12% for both CO_2 and CH_4.

State-level estimates are expected to have a higher uncertainty because the national emissions estimates were apportioned to each state based on the number of facilities in a state and process emissions reported to the GHGRP. These assumptions were required because of a general lack of more granular state-level data.

For 1990–2009, this allocation method does not fully address facilities’ production capacities or utilization rates, which vary from facility to facility and from year to year. Because this approach implicitly assumes emissions from facilities that did not report to the GHGRP are equal regardless of production capacity or utilization rates and that facilities that did report to the GHGRP had the same annual emissions levels for these years, this approach could overestimate emissions in some states and underestimate emissions in others.

For 2010–2019, this allocation method relies partially on GHGRP emissions data, which have a lower uncertainty for states where those reporting facilities are located but have a higher uncertainty for states where smaller facilities that did not report to the GHGRP are located. This method could underestimate emissions from larger facilities and overestimate emissions from smaller facilities.

Emissions for ferromanganese and ferrochromium are not included in the national *Inventory* estimate because of the small number of manufacturers in the United States. The facilities producing these ferroalloys, however, are included in the state *Inventory* disaggregation; thus, state-level estimates are likely an underestimate.

3.3.2.4 Planned Improvements

There are significant differences between USGS and GHGRP data regarding which facilities are included in the ferroalloys industry. Six facilities reported to the GHGRP but were not listed by USGS, and six facilities were listed by USGS but did not report to the GHGRP. The GHGRP has a reporting threshold for ferroalloys production, which may contribute to the difference in the latter group of facilities. Clarifying why this discrepancy exists would improve inventory data accuracy both at the national and disaggregated state levels.

Because USGS does not list ferroalloys production at the state level, the EPA estimated that all facilities that did not report to the GHGRP produced equal emissions; however, data about the size and capacity of each facility would allow the EPA to distribute emissions more accurately. The EPA may use Title V or state-level permits in the future to look for capacity data for each facility to get a better estimate of facility-level emissions.

The EPA will assess whether data are available to incorporate emissions from facilities producing ferromanganese and ferrochromium in the national- and state-level *Inventories.*

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3.3.3 Aluminum Production (NIR Section 4.19)

3.3.3.1 Background

The production of primary aluminum—in addition to consuming large quantities of electricity—results in process-related emissions of carbon dioxide (CO_2) and two perfluorocarbons (PFCs): perfluoromethane (CF_4) and perfluoroethane (C_2F_6). Aluminum Production occurs or has occurred in the past in the following 14 states: Indiana, Kentucky, Maryland, Missouri, Montana, North Carolina, New York, Ohio, Oregon, South Carolina, Tennessee, Texas, Washington, and West Virginia.

Carbon dioxide is emitted during the aluminum smelting process when alumina (aluminum oxide, Al_2O_3) is reduced to aluminum using the Hall-Heroult reduction process. The reduction of the alumina occurs through electrolysis in a molten bath of natural or synthetic cryolite (Na_3AlF_6). The reduction cells contain a carbon (C) lining that serves as the cathode. Carbon is also contained in the anode, which can be a C mass of paste, coke briquettes, or prebaked C blocks from petroleum coke. During reduction, most of this C is oxidized and released to the atmosphere as CO_2.

In addition to CO_2 emissions, the aluminum production industry is also a source of PFC emissions. During the smelting process, when the alumina ore content of the electrolytic bath falls below critical levels required for electrolysis, rapid voltage increases occur, which are termed high-voltage anode effects (HVAEs) HVAEs cause C from the anode and fluorine from the dissociated molten cryolite bath to combine, thereby producing fugitive emissions of CF_4 and C_2F_6. In general, the magnitude of emissions for a given smelter and level of production depends on the frequency and duration of these anode effects. As the frequency and duration of the anode effects increase, emissions increase. Another type of anode effect, low-voltage anode effects (LVAEs), became a concern in the early 2010s as the aluminum industry increasingly began to use cell technologies with higher amperage and additional anodes (IPCC, 2019). LVAEs emit CF_4 and are included in PFC emissions totals from 2006 forward.

3.3.3.2 Methods/Approach

National emissions of CO_2 and PFCs from aluminum production are estimated using a combination of IPCC Tier 1, Tier 2 and Tier 3 methods (i.e., EPA GHGRP data) over the time series as discussed in Chapter 4, Section 4.19 (on pages 4-93 through 4-97) of the national *Inventory*. IPCC Tier 1 methods were used only to estimate PFC emissions from LVAEs.

Aluminum production emissions calculated nationally were allocated to the state level using a Hybrid approach due to lack of facility-level and/or state-level production data for earlier years of the time series. For 1990-2010, the EPA used the ratio of each state's smelter capacity to the U.S. total capacity to allocate national emissions to each state, and for 2010 and later, the EPA used the same underlying methods as the as those used for the national *Inventory*, i.e. facility-specific process emissions reported to the EPA's GHGRP under subpart F: Aluminum Production to estimate state-level emissions.

The approach summarized in Table 3-12 was taken to compile aluminum production estimates by state consistent with national totals.

Table 3-12. Summary of Approaches to Disaggregate the National *Inventory* for Aluminum Production Across Time Series

Time Series Range	Summary of Method
1990–2009	• Data on smelter capacity were used to get percentage of production by state, which was then multiplied by national emissions (Approach 2).
2010–2019	• GHGRP process emissions data were used to get emissions by state (i.e., Approach 1).

For 1990–2009, the EPA allocated national totals to each state using the ratio of each state's smelter capacity to the U.S. total capacity, on a yearly basis (i.e., state X emissions = national emissions * (ratio =state X smelter capacity/national smelter capacity)). Capacity data for the years 1990, 1993, 2001, and 2004-2020 were collected from the respective years' USGS Aluminum yearbook, and capacities for other years were interpolated from the aforementioned USGS Aluminum yearbooks' capacity data trends. Information on idle facilities and shutdowns was incorporated in determining state smelter capacities based on USGS aluminum yearbooks notes, and additional sources (including expert reviewers' feedback, and public articles). National emissions during this time period were developed using smelter capacity data and the USAA U.S. primary aluminum production estimates, combined with the process emissions and activity data reported under the EPA's Voluntary Aluminum Industrial Partnership Program (VAIP).

For 2010–2019, the EPA used facility-specific emissions reported to the GHGRP and facility locations to allocate estimated emissions to each state. All aluminum production facilities in the U.S. report their emissions to the EPA. CF_4 emissions from LVAEs were estimated by allocating total U.S. LVAE emissions according to each state's yearly percentage of total HVAE CF_4 emissions. The percentages were calculated on a yearly basis (state total/yearly total) to account for nonreporting years.

3.3.3.3 Uncertainty

The overall uncertainties associated with the 2019 national estimates of CO_2 and PFC emissions from Aluminum production were calculated using the *2019 Refinement to the* 2006 IPCC Guidelines. As described further in Chapter 4 of the national *Inventory*, levels of uncertainty in the national estimates in 2019 were −2.3/+2.4% for CO_2 and −7.8/+7.7% for PFCs.

State-level estimates are expected to have significantly higher uncertainties in the 1990-2009 portion of the time-series due to apportioning the national emission estimates to each state based on the capacity data from the USGS Aluminum yearbooks. This approach does not reflect the volatility in actual aluminum production activities in each smelter (and thus in the different states) from year to year, and the estimated emissions in each state may therefore differ significantly from the actual emissions resulting from aluminum production activities in that state.

For the 2010 to 2019 time-series, the uncertainties associated with the state-level estimates are expected to be lower than those for the 1990-2009 time-series because emissions are estimated and reported at the facility level. Nevertheless, the 2010 to 2019 state-level uncertainties are somewhat higher than 2010 to 2019 national-level uncertainties because, for each gas, the uncertainty of each smelter's emissions is higher than the uncertainty of the emissions across all smelters.[23] The uncertainty of each smelter's CO_2 emissions is estimated at -/+6%; the uncertainty of each smelter's HVAE CF_4 emissions is estimated to range from -/+16%; and the uncertainty of each smelter's HVAE C_2F_6 emissions is estimated to range from -/+20%. The uncertainty associated with LVAE emissions is estimated based on the smelter technology type, and is estimated to range from -/+99% for each smelter. Because LVAE emissions make up a small share of total PFC emissions, this uncertainty does not have a large impact on the overall uncertainty of PFC emissions at either the smelter or the US level. For more details on national level uncertainty, see the Uncertainty discussion in Chapter 4 of the national *Inventory.*

3.3.3.4 Planned Improvements

The EPA identified a potential refinement in the approach to compile annual state estimates over 1990–2009 that would allocate emissions based on emissions data reported under EPA's VAIP. Where facility-specific data were not reported under VAIP, additional data, including technology type and estimated production, could be used to allocate data to the states from the VAIP data.

The EPA has also identified additional references that could be incorporated, where possible, to confirm whether individual smelters were producing aluminum each year from 1990–2009, because facility capacity data are available from USGS but not production data.

Additional improvements include evaluating the LVAE emissions calculations method by state for the 2010-2019 time series. Currently, the LVAE CF_4 emissions are based on each state's yearly percentage of total HVAE CF4 emissions. Future iterations of the state disaggregation estimates of LVAE CF_4 emissions will be based on estimates of aluminum production, consistent with the Tier 1 LVAE method and the national *Inventory.*

3.3.3.5 References

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U.S. Geological Survey. (1996). Minerals Yearbook: Aluminum. U.S. Geological Survey, Reston, VA.

U.S. EPA Greenhouse Gas Reporting Program (GHGRP). Envirofacts. Subpart F: Aluminum Production. Available online at: http://www.epa.gov/enviro/facts/ghg/search.html

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[23] Note that this holds true generally for the sum of variables with independent errors: the error of the sum tends to be lower than the error of each variable.

3.3.4 Magnesium Production and Processing (NIR Section 4.20)

3.3.4.1 Background

The magnesium metal production and casting industry uses sulfur hexafluoride (SF_6) and other greenhouse gases (i.e., HFC-134a and Novec 612) to prevent the rapid oxidation of molten magnesium in the presence of air. A dilute gaseous mixture of these gases with dry air and/or CO_2 is blown over molten magnesium metal to induce and stabilize the formation of a protective crust. A small portion of the cover gas reacts with the magnesium to form a thin molecular film of mostly magnesium oxide and magnesium fluoride. The amount of cover gas reacting in Magnesium Production and Processing is considered to be negligible; thus, all cover gas used is assumed to be emitted into the atmosphere. Magnesium production occurs or has occurred previously in the following states: California, Illinois, Indiana, Michigan, Minnesota, Missouri, Ohio, Tennessee, Utah, and Washington.

3.3.4.2 Methods/Approach

National emissions of SF_6, HFC-134a, Novec 612, and CO_2 from magnesium production and processing are estimated using a combination of IPCC Tier 2 and Tier 3 methods over the time series as discussed in Chapter 4, Section 4.20 (on pages 4-100 through and 4-102) of the national *Inventory.*

National magnesium processing and production emissions were allocated to the state-level using a Hybrid approach due to a lack of facility-level data for some years and for some facilities. For 2011-2019, the EPA used facility-specific emissions data from the EPA's GHGRP for primary and secondary production, die casting, and sand casting. For these same years estimates of national emissions from permanent mold, wrought, and anode production were allocated to the state-level based on state emissions percentages developed using data reported to the GHGRP. No producers of permanent mold, wrought, and anode Mg products report to the GHGRP. The EPA assumed that nonreporting facilities were located in the same states as reporting facilities.

For 1999–2010, the EPA used company-specific reported cover gas emissions data reported to the EPA through the SF_6 Emission Reduction Partnership for the Magnesium Industry to both allocate emissions to the states and process types with reporting partner companies, as well as derive a percentage of emissions by state. These percentages by state were applied to the remaining non-Partner emissions such that the full complement of national magnesium emission could be apportioned to the state-level, similar to the approach used for later years when GHGRP data became available. For 1990–1998, where GHGRP and Partnership data are not available, a simplified assumption of national to state-level apportionment based on 1999 data was used to estimate emissions from all magnesium production and processes.

Table 3-13 provides additional specifics on the approaches taken to compile state-level estimates of emissions for magnesium production consistent with national totals.

Table 3-13. Summary of Approaches to Disaggregate the National *Inventory* for Magnesium Production Across Time Series

Time Series Range	Summary of Method
1990–1998	• Percentage of emissions by state and process type in 1999 was used to allocate national emissions across states from 1990-1998 and included all process types (Approach 2, please refer to the national *Inventory* for more details).
1999–2010	• For primary, secondary, die casting, and sand casting, emissions were allocated by company and facility locations based on cover gas usage reported to the EPA Partnership Program (Approach 1). • For permanent, wrought, and anode, emissions were allocated proportionally to states with reported emissions for secondary, die casting, and sand casting, excluding the primary production company (Approach 2).

2010–2019	• For primary, secondary, die casting, and sand casting, emissions were allocated by facility locations based on information reported to the GHGRP (Approach 1). • For permanent, wrought, and anode, emissions were allocated proportionally to states with reported emissions (Approach 2).

All Processes

The methodology used for all process for 1990–1998 was based on disaggregating 1999 national emissions by process type and by state and then using that to develop shares of state emissions as a portion of total national emissions. These 1999 state emissions shares by process type were used to allocate estimated total U.S. emissions by process type to states for 1990–1998.

Primary, Secondary, Die Casting, and Sand Casting

The methodology used for 1999–2010 relied on emissions reported to the EPA as under EPA's SF6 Emission Reduction Partnership for the Magnesium Industry. The EPA allocated emissions from partners to the state in which facilities are located as reported through the GHGRP or identified through online research. Note that the national *Inventory* assumes that all U.S. emissions from primary and secondary production in 1999–2010 were from partners. This is not the case for die casting and sand casting. For nonreported estimated emissions, the EPA allocated emissions associated with the nonreporting population proportionally to states with reported emissions for the appropriate process type.

The methodology used for 2011–2019 relied on GHGRP-reported emissions. The EPA allocated emissions from GHGRP reporting facilities to the state in which the reporting facilities are located. For nonreported estimated emissions or emissions estimated from smaller casting facilities falling under the GHGRP reporting threshold, the EPA allocated emissions associated with the nonreporting population proportionally to states with reported emissions. For example, if state A had X% of total reported GHGRP emissions for a particular process type, state A got X% of total U.S. estimated nonreported emissions for that particular process type.

Permanent, Wrought, and Anode

For 1999–2010, emissions associated with these processes were not reported through the Partnership Program. Total U.S. production is reported through the USGS Yearbook. Therefore, the EPA used the same methodology for allocating nonreported emissions for primary, secondary, die, and sand casting to the states. The EPA allocated total U.S. emissions associated with these types of processes proportionally to states with reported emissions for secondary, die casting, and sand casting, excluding the primary production facility, assuming that these states were the most likely to contain facilities that produced magnesium products via permanent, wrought, and anode processes; however, it is possible that other states have emissions from these production processes.

For 2011–2019, emissions associated with these processes are not reported through the GHGRP. Total U.S. production is reported through the USGS Yearbook. Therefore, the EPA used the same methodology that is proposed for the nonreported emissions state allocation for primary, secondary, die, and sand casting. Emissions associated with these types of processes were allocated proportionally to states with reported emissions, with the exclusion of primary production facilities because there is only one facility and it is not in a state that has other magnesium facilities.

3.3.4.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of SF_6, HFC-134a, CO_2, and Novec 612 emissions from magnesium production and processing were calculated using the were calculated using the *2019 Refinement to the 2006 IPCC Guidelines*. As described further in Chapter 4 of the national *Inventory*, levels of uncertainty in the national estimates in 2019 for all gases in aggregate were −8%/+8%.

Overall, the state-level estimates of emissions for magnesium are expected to have a higher uncertainty than the national estimates; however, the variability in uncertainty levels between state-level estimates and national estimates differs throughout the time series. For the years 1990–1998, state-level estimates are expected to have a significantly higher level of uncertainty because no facility-specific emissions are available and because emissions have been allocated to states based on a single year of state-level data, which does not account for changes in emitters over the time period, such as plant openings and closures or process changes. These assumptions were required due to lack of available state- or regional-level data. For the years 1999–2010, state-level estimates, while still having a higher uncertainty that national estimates in the same time period, are more certain that the state-level estimates for 1990–1998. This is due to more accurate, facility data becoming available through the EPA Partnership for each year; however, allocation of national estimates for specific process types (i.e., sand casting, die casting, permanent, wrought, and anode) is still occurring leading to application of uncertainty. For the 2010–2019 time series, the uncertainties associated with the state-level estimates are expected to be lower than those for the 1990–2009 time-series because emissions are estimated and reported at the facility level for the most part. Nevertheless, the 2010–2019 state-level uncertainties are somewhat higher than 2010–2019 national-level uncertainties because for some process types facility-reported data are not available (i.e., permanent, wrought, and anode). For more details on national-level uncertainty, see the Uncertainty discussion in Chapter 4 of the national *Inventory*.

3.3.4.4 Planned Improvements

Planned improvements are the same as those planned for improving national estimates, given that the underlying methods for state GHG estimates are the same as those in the national *Inventory* given improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well. For more information, see Chapter 4, Section 4.20 of the national *Inventory*.

3.3.4.5 References

U.S. EPA Greenhouse Gas Reporting Program (GHGRP). Envirofacts. Subpart T: Magnesium Production. Available online at: http://www.epa.gov/enviro/facts/ghg/search.html

U.S. Geological Survey. (2020, 2017, 2016, 2015, 2014, 2013, 2012, 2011, 2010, 2009, 2008, 2007, 2006, 2005a, 2003, 2002) *Minerals Yearbook: Magnesium Annual Report*. U.S. Geological Survey, Reston, VA. Available online at: http://minerals.usgs.gov/minerals/pubs/commodity/magnesium/index.html#mis

3.3.5 Lead Production (NIR Section 4.21)

3.3.5.1 Background

Primary production of lead through the direct smelting of lead concentrate produces CO_2 emissions as the lead concentrates are reduced in a furnace using metallurgical coke. Similar to primary Lead Production, CO_2 emissions from secondary lead production result when a reducing agent, usually metallurgical coke, is added to the smelter to aid in the reduction process. CO_2 emissions from secondary production also occur through the treatment of secondary raw materials. Emissions from fuels consumed for energy purposes during the production of lead are accounted for in the energy sector. In 2019, emissive lead production occurred in nine states: Alabama, Minnesota, Indiana, Missouri, New York, Florida, California, South Carolina, and Pennsylvania. The last primary lead production facility in the United States closed at the end of 2013.

3.3.5.2 Methods/Approach

To compile emissions by state from lead production using available data, this state-level inventory disaggregated national emissions from the national *Inventory* with an Approach 2 method as defined in the Introduction chapter, using a combination of the number of facilities in a state and process emissions reported to the GHGRP to calculate process emissions (see Table 3-14). See Appendix H, Table H-7 through Table H-9 in the "Lead" Tab for more details on the data used.

The national *Inventory* methodology was adapted to calculate state-level GHG emissions to ensure consistency with national estimates. National estimates were downscaled across states because of limitations in availability of state-specific data across the time series to use national methods (i.e., IPCC Tier 1 methods) at the state level. The sum of emissions by state are consistent with national process emissions as reported in the national *Inventory*.

Table 3-14. Summary of Approaches to Disaggregate the National *Inventory* for Lead Production Across Time Series

Time Series Range	Summary of Method
1990–2009	• Data on number of lead facilities were used to estimate the percentage of production by state, multiplied by the national emissions (IPCC 2006 Tier 1).
2010–2019	• GHGRP process emissions data were used to estimate the percentage of emissions by state, multiplied by the national emissions (IPCC 2006 Tier 1).

The methodology used for 1990–2009 was based on the number of facilities in each state divided by the number of facilities nationally to calculate a percentage of facilities in each state for each year. This percentage was applied to the national CO_2 emissions from lead production per year (EPA 2021) to calculate disaggregated CO_2 emissions by state for each year. For 1995–2009, the number of facilities per state was compiled from the USGS Minerals Yearbooks for lead, as available (USGS 1995–2009), and locations were estimated based on available information. For 1990–1994, the number of facilities from the 1995 USGS Minerals Yearbook for lead was used because the Mineral Yearbooks for those years did not contain the number of facilities.

The methodology used for 2010–2019 was based on process emissions reported to the GHGRP summed by state (EPA 2010–2019) to calculate a percentage of emissions from each state. The GHGRP has a reporting threshold of 25,000 metric tons of CO_2 equivalent for lead production, so these emissions data are representative of the larger facilities in the industry. Using GHGRP emissions data means that emissions from states with smaller facilities were possibly underestimated. That percentage was then applied to the national emissions from lead production per year to calculate disaggregated gross CO_2 emissions by state.

The USGS Mineral Commodity Summaries for lead (1990–2019) only provide primary and secondary lead production as total national values, with no breakdown by state. The USGS Mineral Yearbooks for lead also did not have any state-specific production data. As such, these sources could not be used for state-level data in the state disaggregation estimates.

Primary vs. Secondary Adjustment

In general, CO_2 emissions from primary lead production facilities are about two times the CO_2 emissions from secondary lead facilities on a per-unit or production basis. To account for the difference between primary and secondary lead facilities from 1990–2013 when primary lead production took place in the United States, an adjustment was made to the state primary and secondary facility counts. The GHGRP CO_2 emissions for the one primary facility and the secondary facilities for reporting years 2010–2013 were compiled. Next, from the USGS Mineral Yearbooks, the production for the primary facility and secondary facilities was compiled for 2010–2013. The ratio of CO_2 emissions to production for each year for the primary facility and secondary facilities was calculated and then averaged across those years. Primary facilities have, on average, a 1:1 ratio of CO_2 emissions to production tons. Secondary facilities have, on average, a 1:2 ratio of CO_2 emissions to production tons. The average ratios for primary and secondary facilities were applied to each state's primary and secondary facility count to calculate a weighted percentage of emissions per state for primary and secondary facilities.

CEMS Adjustment for 2010–2019

Starting in 2010, facilities producing lead with emissions over the GHGRP reporting threshold reported both process and combustion emissions to the GHGRP. One facility started using a CEMS to measure and report CO_2 emissions in 2016. For this facility starting in 2016, process and combustion emissions were reported together under subpart C per the GHGRP requirements. All other facilities not using a CEMS reported process emissions under subpart R and combustion emissions under subpart C.[24] To disaggregate process emissions for the facility using a CEMS, a facility-specific default ratio of process emissions to total emissions was calculated for each year from 2010–2015 and averaged. Emissions reported to subparts R and C were compiled for the one facility, and the percentage of process emissions to total emissions for the non-CEMS years was applied to the total CO_2 emissions for each year the facility used CEMS in order to calculate process emissions for each year. The results were an estimated process CO_2 emissions value for that CEMS facility for 2016–2019.

Because the methodology for 1990–2009 does not use GHGRP emissions data to calculate the state emissions and the facility did not begin using a CEMS to report emissions until 2016, there is no need to adjust for CEMS facilities for those years.

3.3.5.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from Lead Production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −14%/+16% for CO_2.

State-level estimates are expected to have an overall higher uncertainty because the national emissions estimates were apportioned to each state based on a combination of the estimated number and location of facilities for 1990–2009 and GHGRP emissions data for 2010–2019. For 1990–2009, this allocation method does not address facilities' production capacities or utilization rates, which vary from facility to facility and from year to year. While this approach does assume differences in primary and secondary production processes, it implicitly assumes emissions from those primary and secondary facilities, respectively, are equal regardless of production capacity or utilization rates, which could overestimate emissions in states with smaller facilities and underestimate emissions in states with larger facilities.

For 2010–2019, uncertainty is expected to be lower because of the use of GHGRP emissions data by state to allocate national GHG emissions by state, which is a surrogate for using lead production data by state to calculate emissions. National *Inventory* estimates, however, have been 6 to 38% lower than GHGRP estimates for 2010–2019. state-level inventory estimates are derived from the national *Inventory* figures and, therefore, are lower than the corresponding totals for facilities from a given state that reports to the GHGRP.

Primary lead production occurred in the United States from 1990–2013. To minimize uncertainty, methods were adjusted to account for differences in emissions from primary and secondary lead production.

3.3.5.4 Planned Improvements

Data gaps to calculate emissions from lead production include lead production by state for the full time series. For example, the estimated number and location of facilities producing lead per state for 1990–2009 need to be confirmed, especially for 1990–1994. More information to quantify the combustion CO_2 emissions from smelting furnaces is needed to disaggregate combustion and process emissions from the facility reporting CO_2 with a CEMS to the GHGRP in 2016–2019.

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[24] For more information on the GHGRP, see 74 FR 56374, Oct. 30, 2009. Available online at: <https://www.govinfo.gov/content/pkg/FR-2009-10-30/pdf/E9-23315.pdf>

The EPA will review time-series consistency issues due to the two methodologies for 1990–2009 and for 2010–2019. Surrogate data (number of primary and secondary lead production facilities) were used in place of activity data for the 1990–2009 portion of the time series, and more research is needed so that calculations more closely reflect state trends in emissions.

3.3.5.5 References

U.S. Environmental Protection Agency. (2010-2019). Greenhouse Gas Reporting Program (GHGRP). Envirofacts GHGRP subpart S and subpart C data. Accessed February 10, 2021. Available online at: https://www.epa.gov/enviro/greenhouse-gas-customized-search

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019 (EPA 430-R-21-005), Chapter 4: References. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

U.S. Geological Survey. (1995 through 2009). Minerals Yearbook: Lead Annual Report. U.S. Geological Survey, Reston, VA.

3.3.6 *Zinc Production (NIR Section 4.22)*

3.3.6.1 Background

Zinc Production in the United States consists of both primary and secondary processes. Of the primary and secondary processes used in the United States, only the electrothermic and Waelz kiln secondary processes result in nonenergy CO_2 emissions. Emissions from fuels consumed for energy purposes during the production of zinc are accounted for in the energy sector. In 2019, emissive zinc production occurred in five states: Alabama, Pennsylvania, South Carolina, Tennessee, and Illinois.

3.3.6.2 Methods/Approach

To compile emissions by state from zinc production using available data, this state-level inventory disaggregated national emissions from the national *Inventory* with an Approach 2 method as defined in the Introduction chapter, using a combination of the number of facilities in a state and process emissions reported to the GHGRP (see Table 3-15). See Appendix H, Table H-10 through Table H-14 in the "Zinc" Tab for more details on the data used.

The national *Inventory* methodology was adapted to calculate state-level GHG emissions to ensure consistency with national estimates. National estimates were downscaled across states because of limitations in the availability of state-specific data across the time series to use national methods at the state level (e.g., IPCC Tier 2 methods). The sum of emissions by state is consistent with national process emissions as reported in the national *Inventory*.

Table 3-15. Summary of Approaches to Disaggregate the National *Inventory* for Zinc Production Across Time Series

Time Series Range	Summary of Method
1990–2009	• Data on number of zinc facilities were used to estimate the percentage of production by state, multiplied by the national emissions (IPCC 2006 Tier 2).
2010–2019	• GHGRP process emissions data were used to estimate the percentage of emissions by state, multiplied by the national emissions (IPCC 2006 Tier 2).

The methodology used for 1990–2009 was based on the number of facilities in each state divided by the number of facilities nationally to calculate a percentage of facilities in each state for each year. This percentage was applied to the national CO_2 emissions from zinc production per year (EPA 2021) to calculate disaggregated CO_2 emissions by state for each year. This method is implicitly the same as multiplying by the national emissions and other factors used in the national *Inventory.* The number of facilities per state was determined from reviewing the number of facilities reporting to the GHGRP and using company websites to confirm when facilities opened and closed and the number of electrothermic furnaces, Waelz kilns, other furnaces, and flame reactor units.

The methodology used for 2010–2019 was based on process emissions reported to the GHGRP summed by state and nationally (EPA 2010–2019) to calculate a percentage of emissions from each state. That percentage was then applied to the national emissions from zinc production per year to calculate disaggregated gross CO_2 emissions by state. The GHGRP has a reporting threshold of 25,000 metric tons of CO_2 equivalent for zinc production, so these emissions data are representative of the larger facilities in the industry. Using GHGRP emissions data means that emissions from states with smaller facilities were possibly underestimated.

Of the primary and secondary production processes used in the United States, only the electrothermic furnace and Waelz kiln secondary production processes result in CO_2 process emissions (Viklund-White 2000). Primary production processes in use in the United States are not emissive.

The USGS Mineral Commodity Summaries for zinc (1990–2019) only had U.S. zinc production as total national values with no breakdown by state. The USGS Mineral Yearbooks for zinc also did not have any state-specific production data. As such, these sources could not be used for state-level data in the state disaggregation estimates.

EAF Dust Consumption Facility Accounting for 2010–2019

Since 2010, the GHGRP has required zinc manufacturing facilities that operate electrothermic furnaces or Waelz kilns to report CO_2 emissions. The national *Inventory* includes emissive facilities that operate electrothermic furnaces or Waelz kilns and other facilities that process EAF dust. Two additional facilities that process EAF dust do not have electrothermic furnaces or Waelz kilns and do not report to the GHGRP, but they are accounted for in the national *Inventory*: PIZO in Blytheville, AR, and American Zinc Recycling Corp. (Horsehead Corp.) in Beaumont, TX.

The PIZO Blytheville, AR, facility was in operation from 2009 to 2012 (PIZO 2021). The national *Inventory* methodology of using estimated EAF dust consumed values and an emissions factor of 1.24 mton CO_2 per mton EAF dust consumed was used to calculate CO_2 emissions for each year.

The American Zinc Recycling Corp. (Horsehead) Beaumont, TX, facility was in operation from around 1993 to 2009 (AZR 2021). The EAF dust recycling and processing capacity for the Beaumont, TX, facility for 2009 was obtained from the U.S. Securities and Exchange Commission (Horsehead 2010). The CO_2 emissions for the Beaumont, TX, facility were calculated using the national *Inventory* methodology, using estimated EAF dust consumed values and an emissions factor of 1.24 mton CO_2 per mton EAF dust consumed.

Electrothermic Furnace, Waelz Kiln, Other Furnaces, and Flame Reactor Unit Adjustment for 1990–2009

Per-unit production CO_2 emissions from Waelz kilns are about 2 times the CO_2 emissions from electrothermic furnaces (EPA 2010–2019). To account for the difference in the quantity of CO_2 emissions from electrothermic furnaces and Waelz kilns, an adjustment was made to the number of electrothermic furnaces and Waelz kilns per state. The 2010–2019 GHGRP CO_2 emissions for electrothermic furnaces and Waelz kilns and number of units by type (i.e., electrothermic furnaces, Waelz kilns) per facility were compiled to calculate the average CO_2 emissions per facility and average CO_2 emissions per unit per facility. Only one facility had electrothermic furnaces. The average CO_2 emissions per unit per facility were calculated across the five facilities with Waelz kilns.

The 2009 CO_2 emissions value for the PIZO Blytheville, AR, facility was used to estimate CO_2 emissions for other furnaces, while the 2009 CO_2 emissions value for the American Zinc Recycling Corp. (Horsehead) Beaumont, TX, facility was used to estimate CO_2 emissions for flame reactor units.

The average CO_2 per unit for electrothermic furnaces and Waelz kilns and the 2009 CO_2 per unit value for other furnaces and flame reactor units were applied to calculate a weighted percentage of emissions per state for electrothermic furnaces, Waelz kilns, other furnaces, and flame reactor units. Each percentage of emissions per state was applied to the national CO_2 emissions from the national *Inventory* to calculate CO_2 emissions per state.

3.3.6.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from Zinc Production was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −19%/+21% for CO_2.

State-level estimates are expected to have an overall higher uncertainty because the national emissions estimates were apportioned to each state based on the number of facilities and production processes for 1990–2009 and GHGRP emissions data for 2010–2019.

For 1990–2009, this allocation method does not address production capacity or utilization rate at a facility-specific level. This approach could overestimate emissions in states with smaller capacity or less used production units and underestimate emissions in states with larger capacity or high utilization production units.

For 2010–2019, uncertainty is expected to be lower than the period from 1990–2009 because of the use of GHGRP emissions data by state to calculate emissions. Smaller facilities do not report to GHGRP, however, and were excluded from these estimates, affecting the completeness of these estimates.

3.3.6.4 Planned Improvements

Data gaps to calculate emissions from zinc production include zinc production by unit type by state for the full time series. The estimated number of facilities producing zinc per state for 1990–2009 needs to be confirmed, including the zinc production methodology (e.g., electrothermic furnaces, Waelz kilns, other facilities processing EAF dust).

3.3.6.5 References

American Zinc Recycling (AZR). (2021). Summary of Company History. Available online at: https://azr.com/our-history/

Horsehead Corp. (2010). 10-k Annual Report for the Fiscal Year Ended December 31, 2009. Submitted on March 16, 2010. Available online at: https://last10k.com/sec-filings/zincq/0000950123-10-025167.htm#link_fullReport

PIZO. (2021). Personal communication. Thomas Rheaume, Arkansas Department of Environment and Environment and Amanda Chiu, U.S. Environmental Protection Agency. February 16, 2021.

U.S. Environmental Protection Agency. (2010-2019). Greenhouse Gas Reporting Program (GHGRP). Envirofacts GHGRP subpart S and subpart C data. Accessed February 10, 2021. Available online at: https://www.epa.gov/enviro/greenhouse-gas-customized-search

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019 (EPA 430-R-21-005), Chapter 4: References. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

Viklund-White. (2000). The use of LCA for the environmental evaluation of the recycling of galvanized steel. ISIJ International, Vol. 40, No. 3, pp 292-299.

3.4 Product Use (Fluorinated Sources, N_2O)

The Product Use portion of IPPU emissions is a catchall category that consists of the following:

- Electronics industry (HFCs, PFCs, SF_6, NF_3, N_2O)
- Substitution of ozone-depleting substances (ODSs) (HFCs, PFCs)
- Electrical transmission and distribution (SF_6)
- Nitrous oxide from product uses (N_2O)

3.4.1 Electronics Industry (NIR Section 4.23)

3.4.1.1 Background

The Electronics Industry uses multiple greenhouse gases in its manufacturing processes. In semiconductor manufacturing, these include long-lived fluorinated greenhouse gases used for plasma etching and chamber cleaning (CRF Source Category 2E1), fluorinated heat transfer fluids (CRF Source Category 2E4) used for temperature control and other applications, and nitrous oxide (N_2O) used to produce thin films through chemical vapor deposition (reported under CRF Source Category 2H3). Similar to semiconductor manufacturing, the manufacturing of micro-electro-mechanical systems (MEMS) devices (reported under CRF Source Category 2E5 Other) and photovoltaic cells (CRF Source Category 2E3) requires the use of multiple long-lived fluorinated greenhouse gases for various processes. Electronics manufacturing occurs in the following states: Arizona, California, Colorado, Florida, Georgia, Hawaii, Idaho, Indiana, Maine, Maryland, Massachusetts, Minnesota, Mississippi, Missouri, New Jersey, New Mexico, New York, North Carolina, Oregon, Pennsylvania, Texas, Utah, Vermont, Virginia, and Washington.

For semiconductors, a single 300 mm silicon wafer that yields between 400 to 600 semiconductor products (devices or chips) may require more than 100 distinct fluorinated-gas-using process steps, principally to deposit and pattern dielectric films. Plasma etching (or patterning) of dielectric films, such as silicon dioxide and silicon nitride, is performed to provide pathways for conducting material to connect individual circuit components in each device. The patterning process uses plasma-generated fluorine atoms, which chemically react with exposed dielectric film to selectively remove the desired portions of the film. The material removed as well as undissociated fluorinated gases flow into waste streams and, unless emission abatement systems are employed, into the atmosphere. Plasma enhanced chemical vapor deposition chambers, used for depositing dielectric films, are cleaned periodically using fluorinated and other gases. During the cleaning cycle the gas is converted to fluorine atoms in plasma, which etches away residual material from chamber walls, electrodes, and chamber hardware. Undissociated fluorinated gases and other products pass from the chamber to waste streams and, unless abatement systems are employed, into the atmosphere.

In addition to emissions of unreacted gases, some fluorinated compounds can also be transformed in the plasma processes into different fluorinated compounds which are then exhausted, unless abated, into the atmosphere. For example, when C_2F_6 is used in cleaning or etching, CF_4 is typically generated and emitted as a process by-product. In some cases, emissions of the by-product gas can rival or even exceed emissions of the input gas, as is the case for NF_3 used in remote plasma chamber cleaning, which often generates CF_4 as a by-product.

Nitrous oxide is used in manufacturing semiconductor devices to produce thin films by CVD and nitridation processes as well as for N-doping of compound semiconductors and reaction chamber conditioning (Doering 2000).

Liquid perfluorinated compounds are also used as heat transfer fluids (F-HTFs) for temperature control, device testing, cleaning substrate surfaces and other parts, and soldering in certain types of semiconductor manufacturing production processes. Leakage and evaporation of these fluids during use is a source of fluorinated gas emissions (EPA 2006).

3.4.1.2 Methods/Approach

Emissions associated with the electronics industry include emissions from MEMS, heat transfer fluids, and PV. National emissions were estimated using IPCC Tier 2 methods as discussed further in Chapter 4, Section 4.23 (on page 4-124) of the national *Inventory*. In general, the EPA used a Hybrid approach to disaggregate national estimates as data to apply Approach 1 are unavailable.

Semiconductor and Micro-electro-Mechanical Systems (MEMS) Manufacturing

To disaggregate emissions by state for semiconductors and MEMS, the EPA used data sources from the GHGRP and the World Fab Forecast (WFF).[25] A Hybrid Approach was used to estimate emissions from semiconductor and MEMS manufacturing, relying on a mix of state-level data derived from the GHGRP, the EPA partnership and program data, and disaggregation of national-level emission estimates, where facility-level data was not available. For years prior to the GHGRP data being available (i.e., before 2011), a simplified assumption was used by applying the proportional state-level estimates for total manufactured layer area (TMLA) to the national semiconductor emissions estimate. For MEMS emissions, a linear interpolation was used between 1990 (assuming zero emissions from MEMS manufacturing) and 2011, the first year of available GHGRP data. Table 3-16 summarizes methods used to compile emissions of CF_4, C_2F_6, NF_3, SF_6, CHF_3, c-C_4F_8, C_3F_8, N_2O and unspecified mixes of HFCs and PFCs from semiconductor and MEMS manufacturing.

Table 3-16. Summary of Approaches to Disaggregate the National *Inventory* for Semiconductor and MEMS Manufacturing Across Time Series

Time Series Range	Summary of Method
1990–2007	• Emissions from semiconductor manufacturing were allocated between states from the national *Inventory* in the same proportion as they were in 2008 (Approach 2). • Emissions from MEMs were assumed to be zero in 1990. Emissions from MEMs facilities from 1991-2010 were then estimated by interpolating between 1990 emissions and the emissions estimated for 2011 for each state (Approach 2).
2008–-2010	• Emissions were allocated to states using the proportional state-level TMLA breakdowns for the respective year, which were applied to total estimates from the national *Inventory* (Approach 2).
2011–-2013	• Emissions from reported fabs, adjusted for time-series consistency in the national *Inventory*, were allocated based on the location of the GHGRP facility (Approach 1). • Emissions from nonreporting facilities were allocated by calculating the percentage of TMLA estimated for nonreporting facilities in each state using the WFF dataset and multiplying by the total estimate of nonreported emissions in the national *Inventory* (Approach 2). • Emissions from nonreporting MEMs facilities were not estimated.
2014–-2019	• Emissions from reported fabs were allocated to the state in which the reporting facility was located as reported through the GHGRP (Approach 1). • Emissions from nonreporting facilities were allocated by calculating the percentage of TMLA estimated for nonreporting facilities in each state using the WFF dataset and multiplying by the total estimate of nonreported emissions in the national *Inventory* (Approach 2). • Emissions from nonreporting MEMs facilities were not estimated.

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[25] EPA periodically purchases the World Fab Forecast from SEMI (https://www.semi.org/en/products-services/market-data/world-fab-forecast).

From 2014–2019, emissions from reported fabs were allocated to the state in which the reporting facility was located as reported through the GHGRP.

From 2011–2013, fluorinated GHGs (F-GHG) and N_2O emissions from reported fabs, adjusted for time-series consistency in the national *Inventory*, were allocated based on the location of the GHGRP facility. Emissions from nonreporters were allocated to each state as described above. There is a slight discrepancy between the sum of state-level emissions and the national totals in 2011–2019 because of an error in the methodology for estimating the share of non-GHGRP-reported emissions in the national *Inventory*. This issue will be reconciled in next year's national *Inventory*. Emissions from nonreporting facilities that manufactured semiconductors were estimated by calculating the percentage of TMLA estimated for nonreporting facilities in each state using the WFF dataset; the state's percentage of total nonreporter TMLA was then used to allocate the nonreporter portion of national emissions as calculated in the national *Inventory*. Emissions from nonreporting MEMS facilities are not estimated.

From 2008–2010, F-GHG and N_2O emissions from semiconductor manufacturing were allocated to states using the proportional state-level TMLA breakdowns for the respective year, which were applied to total estimates from the national *Inventory*.

From 1990–2007, F-GHG and N_2O from semiconductor manufacturing emissions were allocated between states in the same proportion as they were in 2008.

From 1990-2011, emissions from MEMs facilities were estimated by interpolating between 1990 emissions and the emissions estimated for 2011. Emissions from MEMs were assumed to be zero in 1990.

Only 26 states were identified to contain semiconductor fabs, six of which also reported emissions from the production of MEMS.

Fluorinated Heat Transfer Fluids (F-HTFs)

To estimate state-level emissions of F-HTFs, the EPA used a Hybrid approach to disaggregate national emissions. For the national *Inventory*, for years when GHGRP data were available, the EPA estimated state-level emissions based on facility location. For earlier years, the EPA allocated national F-HTF emissions to each state based on that state's share of national F-GHG emissions from semiconductor manufacturing. This Hybrid approach was used due to a lack of available data on reported HTF emissions or HTF consumption at the facility or state level for years prior to GHGRP's availability. Table 3-17 summarizes method used to compile HTF emissions.

Table 3-17. Summary of Approaches to Disaggregate the National *Inventory* for Fluorinated Heat Transfer Fluids Across Time Series

Time Series Range	Summary of Method
2000–2010	• National F-HTF emissions were allocated to states in the same proportion as F-GHG emissions associated with semiconductor manufacturing (Approach 2).
2010–2019	• National F-HTF emissions were allocated to the states in the same proportion as Emissions from reported fabs were allocated to the state in which the reporting facility was located as reported through the GHGRP (Approach 1). • Emissions from nonreporters were added to each state's emissions from HTFs by multiplying state emissions of HTFs by the estimated nonreporter GHGRP emissions percentage taken from the national *Inventory* (Approach 2).

From 2011–2019, emissions from reported fabs were allocated to the state in which the reporting facility was located as reported through the GHGRP. Emissions from nonreporters were added to each state's emissions from HTFs by multiplying state emissions of HTFs by the estimated nonreporter GHGRP emissions percentage taken from the national *Inventory*.

For emissions from 2000–2010, F-HTF emissions were allocated between states in the same proportion as F-GHG emissions associated with semiconductor manufacturing. Emissions data were taken directly from the national *Inventory* and the allocation was only applied to the HTF emissions that were included in the national *Inventory* totals. HTF emissions were assumed to not occur during or before 2000. A total of 23 states were identified as reporting emissions of F-HTFs.

Photovoltaics

To estimate state-level emissions from photovoltaics (PV) manufacturing, the EPA used a Hybrid approach, applying a GHGRP-derived emission factor to state-level manufacturing capacity data. For years with available GHGRP data, Approach 1 was used for manufacturers that reported PV emissions at the state-level. This Hybrid approach was used due to a lack of available data on reported emissions at the state-level for years prior to the GHGRP's availability. Table 3-18 summarizes methods used to compile state-level emissions from PV manufacturing as an unspecified mix of HFCs and PFCs.

Table 3-18. Summary of Approaches to Disaggregate the National *Inventory* for Photovoltaics Across Time Series

Time Series Range	Summary of Method
1990–2014	• State-level estimates of manufacturing capacity based on facility-level manufacturing capacity data were used to allocate emissions. Capacity was interpolated for years in which capacity data was unavailable. Capacity was assumed to be zero in 1997 (2006 Tier 1 (GHGRP-based EF)) (Approaches 1 and 2).
2014–2019	• State-level estimates of manufacturing capacity were used to allocate emissions for nonreporters (2006 Tier 1 [nonreporters; GHGRP-based EF] and Tier 2 [reporter]) (Approach 2). • Reported facility data were allocated to the state where the facility was located (Approach 1).

For 2000–2009, nonreported emissions were estimated using manufacturing capacity data from DisplaySearch (2010), which provides facility-specific data, including the facility's state. Emissions from nonreporters were calculated by multiplying the manufacturing capacity from each state by an emissions factor in MMTCO$_2$e per MW based on reported emissions from Mission Solar (the only reporter to the EPA's GHGRP). There is a discrepancy between the sum of the state-level emissions and the national total for 2003–2011 because of an error in summing the total U.S. manufacturing capacity of crystalline silicon PV from the DisplaySearch dataset that was discovered after the national *Inventory* was published. This results in a slight misrepresentation of PV manufacturing capacity at the national level, which affects the associated emissions estimates. This error will be corrected in next year's national *Inventory*.

Manufacturing capacity was assumed to be zero in 1997 based on an assessment of available industry manufacturing data (Platzer 2015). Manufacturing capacity was interpolated between 1997 and 2000 and used to estimate emissions in 1998 and 1999 using the same emissions factor described above.

For 2010–2019, nonreporter emissions were estimated using the proportion of each state's manufacturing capacity in 2009 (the most recent year of DisplaySearch data purchased) to the overall nonreporter estimate used in the national *Inventory*.

For 2014–2019, reported state-level emissions from photovoltaics (PV) manufacturing were estimated by allocating emissions from GHGRP reporters to the state in which the reporting facility is located. Only one PV facility, Mission Solar, reports to the GHGRP, so all the reported emissions were allocated to Texas (the state in which Mission Solar is located).

3.4.1.3 Uncertainty

The overall uncertainty associated with the national emissions estimates for the Electronics Industry were calculated using the 2019 Refinement to the 2006 IPCC Guidelines. As described further in Chapter 4 of the national *Inventory*, levels of uncertainty in the national estimates in 2019 were -6%/+6% across all semiconductor manufacturing. The EPA did not estimate uncertainty for other types of electronics products or HTFs.

State-level estimates are expected to have a higher uncertainty than national estimates because the uncertainty of each facility's emissions is higher than the uncertainty of emissions across all facilities, or in other words the uncertainty of a sum of independent variables is lower than the uncertainty of the variables. For years with state- and facility-level GHGRP data, state-level estimates will still be higher than national totals due to the uncertainty of many additional independent variables. State-level estimates will have the most uncertainty for years where state-level activity data were not available, namely years before the start of GHGRP data. Pre-2011 estimates are generated by apportioning the national totals by state-level TMLA estimates, which come from various sources including World Fab Watch and WFF. State-level estimates for 1990–2007 are apportioned using the most recent year of state-level TMLA data (2008), which will add significant uncertainty to those estimates. For more details on national-level uncertainty, see the Uncertainty discussion in Section 4.23 of the national *Inventory*.

3.4.1.4 Planned Improvements

Planned improvements are consistent with those planned for improving national estimates, given that the underlying methods for state GHG estimates are the same as those in the national *Inventory.* For more information, see Chapter 4, Section 4.23 of the national *Inventory*.

3.4.1.5 References

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3.4.2 Substitution of Ozone-Depleting Substances (NIR Section 4.24)

3.4.2.1 Background

Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are used as alternatives to several classes of ODSs that are being phased out under the terms of the *Montreal Protocol* and the Clean Air Act Amendments of 1990.[26] Ozone-depleting substances—chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, and hydrochlorofluorocarbons (HCFCs)—are used in a variety of industrial applications including refrigeration and air-conditioning equipment, solvent cleaning, foam production, sterilization, fire extinguishing, and aerosols. Although HFCs and PFCs are not harmful to the stratospheric ozone layer, they are potent greenhouse gases.

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[26] [42 U.S.C § 7671, CAA Title VI].

3.4.2.2 Methods/Approach

As described in the national *Inventory* report (EPA 2021), the EPA employs its Vintaging Model to estimate national use, banks, emissions, and transition of ODS-containing equipment and products to substitutes, including HFCs and perfluorocarbons (PFCs) and blends that contain such substances.). The Vintaging Model estimates ODS and ODS substitute trends in the United States based on modeled estimates of the quantity of equipment or products sold each year containing these chemicals and the amount of the chemical required to manufacture or maintain equipment and products over time. Emissions for each end use were estimated by applying annual leak rates and release profiles, which account for the lag in emissions from equipment as it leaks over time. The model uses a Tier 2 bottom-up modeling methodology to estimate emissions and hence requires extensive research, data, assumptions, and expert judgment to develop the activity levels and emissions profiles over the time series for each of the 78 end uses modeled (see Section 4.24 and Annex 3.9 of the national *Inventory* for additional description of the Vintaging Model and further details such as the end uses modeled [EPA 2021]).

An approach similar to the Vintaging Model can be used to develop state-level emissions estimates. California, for one, uses this approach (California Air Resources Board [CARB] 2016). Doing so however requires the same extensive data gathering and may be difficult to monitor given the interstate commerce that occurs for many of the products involved.

Another approach to estimate a state's emissions would be to assume the state's proportion of national emissions is the same as the state's proportion of national population. For many ODS substitute equipment types, this is a reasonable approach. For instance, the number of supermarkets, home refrigerators, and light-duty vehicles with air-conditioning, per person, is not expected to vary significantly from state to state. For some other end uses, however, this is not the case. For instance, EIA (2021) statistics confirm that the use of air-conditioning varies by region. This could lead to a significant difference that is not directly related to population. As noted in the national *Inventory*, the EPA estimates that residential unitary air-conditioning is the second largest emitting (in CO_2e terms) end use within the refrigeration and air-conditioning sector, which accounts for 78% of national emissions (EPA 2021).

The disaggregation approach used here is a combination of using population as a proxy for emissions (i.e., “Approach 2”) while incorporating data provided at a finer geographical distribution than the national emissions estimates (i.e., “Approach 1”).

Analysis by NOAA further points to the varying nature of emissions across the United States (Hu et al. 2017). The analysis incorporated data from a variety of ground- and air-level measurements of various fluorocarbons. By applying Lagrangian atmospheric transport models and a Bayesian inverse modeling technique, Hu et al. estimated emissions on a 1° × 1° grid across the contiguous states and District of Columbia. The paper estimated emissions of various fluorocarbons (ODS and HFCs) over six regions of the United States through this approach. The authors observed that spatial patterns for individual compounds agree well with qualitative expectations, pointing to examples of higher per capita emissions for chemicals used as blowing agents in building insulation foams (CFC-11, HCFC-142b, and HFC-365mfc) in the northern states and higher per capita emissions of HCFC-22, HFC-125, and HFC-32 used in residential and commercial air-conditioning in southeastern and central south states. These results agreed with recommendations for thermal insulation (DOE, 2016) in northern regions and the higher percentage of homes with air-conditioning (EIA, 2018a, b) in southern regions. Derived per capita emissions of HFC-134a displayed similar regional patterns as refrigerants used in residential air-conditioning, except in the central north region where the per capita emissions was comparable to that in southern regions. The authors surmised that this distribution may stem from additional use of HFC-134a in refrigeration and as a foam-blowing agent in building insulation in northern regions.

A population distribution was modified with data from Hu et al. (2017) to disaggregate national emissions to individual states, territories, and the District of Columbia. For this exercise, multiple references from the U.S.

Census were used to gather population estimates to distribute national-level emissions to the regions incorporated into the national emissions estimates (i.e., for the 50 states, the District of Columbia, Puerto Rico, American Samoa, Guam, Northern Mariana Islands, and the U.S. Virgin Islands) (U.S. Census 2021 a, b, c, d; U.S. Census 2015). Population estimates across the time series were not available for the Federated states of Micronesia, Marshall Islands, and Palau; therefore, none of the U.S. national emissions estimates was attributed to those territories. For years in which a population estimate was not provided, linear interpolation was used.

Annual emissions per capita for the six regions analyzed in Hu et al. (2017) were used. Specifically, emissions for HFC-125, HFC-134a, and HFC-143a from 2008–2014 and emissions for HFC-32 from 2010–2014 were available (Hu 2021). The six regions described in the paper are West (California, Oregon, and Washington), Mountain (Montana to New Mexico), Central North (North Dakota to Kansas to Ohio), Central South (Texas to Alabama to Kentucky), Southeast (North Carolina to Florida), and Northeast (West Virginia to Maine).

Because the Hu et al. (2017) estimates cover the 48 contiguous states and the District of Columbia, emissions estimates from the remaining states (Alaska and Hawaii) and the five other territories were derived strictly based on the state's or territory's population compared to the national population for the full time series 1990–2019. Likewise, the emissions of HFCs other than the four listed above were distributed to all states and territories by population. The emissions of HFC-32, HFC-125, HFC-134a, and HFC-143a were distributed to the six regions in the same ratio as the best estimate of such distribution shown in Hu et al. (2017). Error bars from Hu et al. were not applied or analyzed here. Because these data ended in 2014, the ratio from that year was used for 2015–2019 as well. Likewise, ratios from 2008 (or 2010 for HFC-32) were used for 1990–2008 (or 2010). Once regional distributions were made in this way, each region's emissions were distributed to the states within the region by population.

3.4.2.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of HFC emissions as ODS substitutes was calculated using a Monte Carlo analysis. As described further in Chapter 4, Section 4.24 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), the uncertainty of national emissions was −3.7% to +13.1% for a 95% confidence interval. State-level estimates are expected to have a higher uncertainty because of the use of population by state or territory during certain steps of the methodology, as described above, and from the use of atmospheric inversions to apportion emissions of four HFCs by state.

This analysis did not calculate the specific activity data and emissions factor (and importantly for this category, the reuse of chemicals not emitted) at each state and how the national activity data and emissions factors could vary based on conditions other than population for the different end uses that comprise the sector. For this reason, the division of emissions by sector (e.g., Refrigeration and Air Conditioning, Foams) cannot be provided at the state level under this approach. The Hu et al. (2017) paper used in these state-level emissions estimates shows that certain HFC emissions do not distribute evenly by population; hence, the steps of this methodology that use population distributions introduce uncertainty. In addition to the uncertainty introduced from population distributions, use of the Hu et al. work introduces uncertainty into the state-level estimates in two basic ways. First, there is uncertainty in the regional emissions estimated from atmospheric inversions, as described in the paper; such uncertainties would extrapolate through to the regional apportionment of HFC-32, HFC-125, HFC-134a, and HFC-143a calculated during the state-level estimate approach. Secondly, the Hu et al. analysis is limited in scope in both geography and time. Because their results cover only the contiguous 48 states (and the District of Columbia), uncertainty from the population distribution described above exists outside that area and again when distributing emissions to states within each of the six regions from the Hu et al. work. The time frame of the Hu et al. analysis is 2008–2014, so extrapolation before and after that time frame introduces additional uncertainty.

3.4.2.4 Planned Improvements

This approach combining population and atmospheric measurement information can be improved in several ways in future publications of this annual data. First, atmospherically-derived emissions estimates similar to those from Hu et al. (2017) for additional years, primarily after 2014, are anticipated. These data, when available, can then be used to redistribute the annual emissions after 2014. Also, although emissions derived from atmospheric measurements were not available before 2008, one could look at the trends, if any, in the data to see if a back-year extrapolation of the data would give better results than applying the earliest year ratios back to 1990. The Hu et al. (2017) data also include information for HFC-227ea and HFC-365mfc. While the emissions of these chemicals are much lower than the four HFCs used here, the same approach could be used. It might also be appropriate to use ODS information as a proxy for other HFCs. For instance, the paper found that emissions of CFC-11 and HCFC-142b (and HFC-365mfc) showed regional distributions expected based on their primary use as a blowing agent for insulating foam. These datasets could be used to distribute HFC-245fa and HCFO-1233zd(E) emissions, because these two chemicals are also used primarily in foams, noting that such foam use in household refrigerator foam and commercial refrigeration foam is unlikely to be affected by regional weather patterns.

Other improvements could be made by combining more bottom-up information to distribute national emissions to states or to derive separate state-level emissions estimates. Data on the number of supermarkets, car registrations, and air-conditioning use, or value added data in representative sectors, could all apply directly to modeled end uses. Other data could be used as a proxy for end uses, such as commercial real estate square footage as a proxy for commercial air-conditioning.

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3.4.3 Electrical Transmission and Distribution (NIR Section 4.25)

3.4.3.1 Background

The section describes methods used to estimate state-level SF_6 emissions consistent with the national *Inventory*. Fugitive emissions of SF_6 can escape from gas-insulated substations and switchgear through seals, especially from older equipment. The gas can also be released during equipment manufacturing, installation, servicing, and disposal. These emissions occur in all 50 states and have also been estimated for two territories (i.e., Puerto Rico, and the Virgin Islands). Future updates to the national *Inventory* will also include Guam.

3.4.3.2 Methods/Approach (Transmission and Distribution)

As discussed in Chapter 4, Section 4.25 (on page 4-141) of the national *Inventory*, the EPA used a combination of IPCC Tier 2, Tier 3, and country-specific methods to estimate national SF_6 emissions from Electrical Transmission and Distribution.

The national Inventory uses facility-level data reported to the GHGRP or the SF6 Emission Reduction Partnership for Electric Power Systems combined with information on total transmission miles in the US to develop SF6 emission estimates from electrical transmission and distribution. However, facilities, as defined in the GHGRP or the Partnership, in the electrical transmission and distribution sector, often cross multiple states. Thus, Approach 2 as described in the introduction was used to estimate emissions from electrical transmission and distribution. To disaggregate emissions by state for electrical transmission and distribution, the EPA used data sources from the GHGRP and Homeland Infrastructure Foundation Level Data (HIFLD) (U.S. Department of Homeland Security 2019). For years prior to 2011 before GHGRP data were available, state-level SF6 emissions from electrical transmission and distribution (ET&D) equipment were determined by applying the percentage of the total U.S. transmission miles for each state to the total U.S. emissions estimate for the entire time series, modified to include additional state-level or facility-level information in the years it is available. For 2011 and later, the method was modified as described below to first allocate emissions to states as reported to the GHGRP if the facility only reported one state, before applying to the above method to remaining transmission miles. See Table 3-19 for a summary of methods across the time series.

Table 3-19. Summary of Approaches to Disaggregate the National *Inventory* for Electrical Transmission and Distribution Across Time Series

Time Series Range	Summary of Method
1990–2010	• Emissions from the national *Inventory* were allocated to states by calculating the percentage of transmission miles by state. These state percentages were then applied to the national emissions estimate. State transmission miles were obtained from HIFLD data (2019). State percentages of the total transmission were held constant at the 2019 percentage. (Approach 2).
2011–2019	• For all GHGRP reporters that reported having transmission miles in only one state (according to RY 2017–RY 2019 reports, excluding California), their facility-reported emissions and transmission miles were allocated to that state. (Approach 1). • Emissions for California were obtained from the California Air Resources Board California High GWP Gases Inventory for 2000–2019 (Approach 2). • The remaining emissions from the national *Inventory* were allocated to states by calculating the percentage of remaining transmission miles by state (adjusted state transmission miles/adjusted national transmission miles). These state percentages were then applied to the adjusted national emissions estimate (national emissions excluding GHGRP-only one state emissions and California emissions). State transmission miles were obtained from HIFLD data (2019) and scaled using the transmission mile growth rate from UDI datasets. (Approach 2).

For disaggregating national ET&D estimates, state emissions (gas) were determined by multiplying the percentage of the total U.S. transmission miles for each state by the total national estimate from the *Inventory* for the entire time series. U.S. transmission miles were obtained from the EIA. Specifically, the EIA has published on their U.S. Energy Mapping System web map[27] the electric transmission lines data from Homeland Infrastructure Foundation—Level Data (HIFLD) (Department of Homeland Security 2019), which was last updated June 2020. The dataset includes mileage of transmission lines operated at relatively high voltages varying from 3 kV up to 765 kV. Geographic coverage includes the United States and the U.S. Territories.[28]

The fraction of transmission miles greater than 34.5 kV in each state was calculated using geographic information system (GIS) mapping. Figure 3-1 displays the GIS mapping of the transmission lines by state. Geographic software that identifies lines within state boundaries was used for the disaggregation because it removed the task of identifying and addressing changes to ownership of service territories as part of this methodology.

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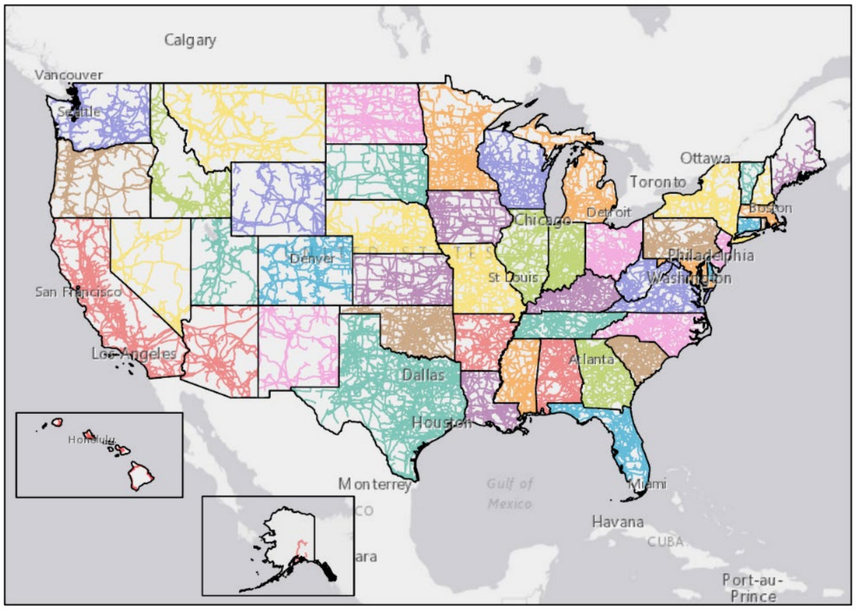
[27] https://www.eia.gov/State/maps.php

[28] Transmission miles greater than 34.5 kv in 2020 totaled 734,291 miles based on the HIFLD dataset and 749,847 miles based on the UDI dataset and GHGRP-reported transmission mileage. Despite the discrepancy, HIFLD data provide the closest match of total miles compared to other datasets previously examined, which gives us reasonable confidence on using the percentage breakdown by State that can be obtained using GIS mapping.

Figure 3-1: U.S. Transmission Lines Separated by State Using GIS Processing Tool



Source: Department of Homeland Security 2019

As described below, this method was modified to include additional state-level or facility-level information in the years for which it was available. Total emissions from 1990–1999 were disaggregated using the percentage breakdown of transmission miles by state from the HIFLD data.

For years 2011–2018, CARB provides emissions of SF_6 from California's electric power systems as reported through the Regulation for Reducing Sulfur Hexafluoride Emissions from Gas Insulated Switchgear for years 2011–2018 (CARB 2020). The EPA concluded that these reported values were a more accurate representation of state-level emissions from California. To estimate emissions for all other states and territories, the EPA removed California from the total transmission miles and adjusted the percentage breakdown of transmission miles by state accordingly. State and territory emissions were then disaggregated using the revised percentages.

For 2011–2019, for all GHGRP reporters that reported having transmission miles in only one state (according to RY 2017–RY 2019 reports), their facility-reported emissions and transmission miles were allocated to that state. Approximately 62% of reporting facilities reported having transmission miles in only one state during RY 2017–RY 2019. On average, these facilities constituted approximately 20% of the national emissions between 2011 and 2019.

For states where this scenario applied, the GHGRP-reported transmission miles for these facilities were subtracted from the state transmission mile total, as determined by the HIFLD data, to arrive at an adjusted total of state transmission miles.[29] The sum of GHGRP-reported transmission miles in only one state also was deducted from the total national transmission miles. Because the HIFLD data represent 2019 transmission miles, transmission mileage was scaled down using UDI's transmission mile growth rate for years 2011–2018 (UDI 2017, UDI 2013, UDI 2010).

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[29] California transmission miles were removed from the HIFLD transmission miles because the State-reported emissions were used in lieu of this approach. Therefore, State percentages were calculated out of the total national transmission miles minus California.

Total facility-reported emissions for cases where a facility's transmission miles are reported in only one state were summed and subtracted from the national emissions estimate.[30] To allocate the remaining national emissions by state, the percentage transmission miles by state was calculated (adjusted state transmission miles/adjusted national transmission miles). These state percentages were then applied to the adjusted national emissions estimate (national emissions excluding GHGRP-only one state emissions and California emissions).

Finally, state-level emissions for GHGRP-reported facilities that reported as being located in only one state (where applicable) were summed with the calculated state-level emissions based on the calculation above to arrive at a total state emissions estimate for electric power systems.

The approach taken to disaggregate national emissions enables the EPA to use facility-level emissions data from the reporting program starting in 2011. While this approach has limitations, it also sets up the emissions estimations for future improvements as more data become available (e.g., additional facility-level information on state locations of transmission lines obtained through research or additional reporting would facilitate greater use of GHGRP data). Additionally, using reported data for California better represents impacts of regulations on emissions in that state (e.g., California). Similarly, using data reported to the EPA can help account for any state-influenced actions (e.g., climate action planning at state and local levels).

3.4.3.3 Methods/Approach (Manufacture of Electrical Equipment)

Emissions were reported by facility from 2011–2019. The EPA determined state-level emissions using Approach 1 based on reported facility locations, which included Connecticut, Illinois, Mississippi, and Pennsylvania. In the absence of additional industry information, the EPA used Approach 2 and assumed that all nonreporting facilities are located in the same states as reporting facilities. The EPA estimates that GHGRP reporters represent about 50% of all original equipment manufacturers (OEM) emissions and for state-level estimates, applied the national scale-up factor at the state level.

For years prior to when GHGRP data were reported, using Approach 2, an average percentage state breakdown across the reporting time series (RY 2011–2019) was applied to emissions in each year to calculate state emissions from OEMs before 2011. The methods used are summarized in Table 3-20.

Additional research is required to understand 1) if the EPA's assumption about the portion of OEM emissions covered is accurate and 2) in what states these nonreporting emissions occur. Additionally, further research is necessary to determine whether the reporting facilities were in operation in all years before 2011.

Table 3-20. Summary of Approaches to Disaggregate the National *Inventory* for Manufacture of Electrical Equipment Across Time Series

Time Series Range	Summary of Method
1990–2010	• Emissions from the national *Inventory* were allocated to states by applying the average percentage state breakdown across the GHGRP reporting years (2011-2019) to national estimate for each year between 1990-2010 in the *Inventory*. (Approach 2).
2011-2019	• Emissions reported to the GHGRP were allocated based on reported facility locations (Approach 1). Nonreporters were assumed to be located in the same states with emissions allocated at the same state percentage of the total nonreporting emissions as for the emissions reported to the GHGRP. (Approach 2).

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[30] The national emissions estimate was adjusted by deducting California's CARB-reported emissions.

3.4.3.4 Uncertainty

The overall uncertainty associated with the national *Inventory* of SF_6 emissions from electric transmission and distribution source category were calculated using the *2019 Refinement to the 2006 IPCC Guidelines*. Partner reported emissions uncertainty was estimated to be -/+ 10% and GHGRP reporter emissions uncertainty was estimated to be -/+ 20%. As described further in Chapter 4 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 of the source category were −16%/+18%.

State-level estimates are expected to have a higher uncertainty across the time series due to the use of HIFLD transmission mileage data to apportion the emissions of facilities that either do not report to the GHGRP or that operate in multiple states. This allocation method introduces additional uncertainty due to the potential inaccuracy of transmission mile locations and the variability of emission rates per transmission mile across reporting facilities. As with the national *Inventory*, the state-level uncertainty estimates for this category may change as the understanding of the uncertainty of estimates and underlying datasets and methodologies improve.

3.4.3.5 Planned Improvements

The EPA plans to incorporate facility-specific reported data from the SF_6 Emission Reduction Partnership into the inventory for 1999–2010 based on historical emissions estimates collected under the EPA's SF_6 Emission Reduction Partnership for Electric Power Systems. Additional considerations will be given to whether any other state-level reported data, such as that reported by California, should be used to determine allocation of national estimates. The EPA will consider smoothing emissions for states where reported emissions cause an unexpected trend in overall state emissions of SF_6. Improvements will be incorporated as more data becomes available (e.g., additional facility-level information on state locations of transmission lines obtained through research or additional reporting would facilitate greater use of GHGRP and/or Partnership data). Additional research into regional or state level trends will also be conducted to refine the estimates where possible. In line with planned improvements to the national *Inventory,* the EPA plans to incorporate estimates for additional US Territories.

Additional research into state distribution of OEMs will also be conducted to 1) confirm or revise the 50% assumption of nonreported emissions and 2) understand the states in which these emissions take place for nonreporters.

3.4.3.6 References

California Air Resources Board. (2007). Sulfur Hexafluoride (SF_6) Emission Reductions from Gas Insulated Switchgear Chapter 10, sections 95350 to 95359, title 17.

California Air Resources Board. (2020). California High GWP Gases Inventory for 2000-2019 — by IPCC Category. Available at https://ww3.arb.ca.gov/cc/inventory/data/tables/ghg_inventory_ipcc_sum_2000-18.pdf

UDI (2017) *2017 UDI Directory of Electric Power Producers and Distributors,125th Edition*, Platts.

UDI (2013) *2013 UDI Directory of Electric Power Producers and Distributors,121st Edition*, Platts.

UDI (2010) *2010 UDI Directory of Electric Power Producers and Distributors, 118th Edition*, Platts.

UDI (2007) *2007 UDI Directory of Electric Power Producers and Distributors, 115th Edition*, Platts.

UDI (2004) *2004 UDI Directory of Electric Power Producers and Distributors, 112th Edition*, Platts.

UDI (2001) *2001 UDI Directory of Electric Power Producers and Distributors, 109th Edition*, Platts.

U.S. Department of Homeland Security. (2019). Homeland Infrastructure Foundation Level Data (HIFLD). Electric Substations. Accessed December 2020. Available online at: https://hifld-geoplatform.opendata.arcgis.com/datasets/electric-substations?geometry=-140.536%2C18.765%2C126.476%2C62.489

3.4.4 Nitrous Oxide from Product Uses (NIR Section 4.26)

3.4.4.1 Background

N_2O is primarily used in carrier gases with oxygen to administer more potent inhalation anesthetics for general anesthesia, and as an anesthetic in various dental and veterinary applications. The second main use of N_2O is as a propellant in pressure and aerosol products, the largest application being pressure-packaged whipped cream. Smaller quantities of N_2O also are used in the following applications: oxidizing agent and etchant used in semiconductor manufacturing, oxidizing agent used with acetylene in atomic absorption spectrometry, production of sodium azide for use in airbags, fuel oxidant in auto racing, and oxidizing agent in blowtorches used by jewelers and others. The amount of N_2O that is actually emitted depends on the specific product use or application. Only the medical/dental and food propellant subcategories were assumed to release emissions into the atmosphere that are not captured under another source category, and therefore these subcategories were the only usage subcategories with emissions rates. N_2O product use emissions from the national *Inventory* were disaggregated across all 50 states plus the District of Columbia and Puerto Rico in 2019.

3.4.4.2 Methods/Approach

The state-level methodology for N_2O emissions from product usage is to allocate emissions to all applicable U.S. states and territories using population statistics as a surrogate for state-specific N_2O usage, consistent with Approach 2 as defined in the Introduction chapter. See Appendix I, Table I-1 in the “N2O Use” Tab for more details on the N_2O product use categories and their assumed emissions factors and Appendix G, Table G-1 in the “Population Data” Tab for details on the population data used. The national *Inventory* methodology was adapted to calculate state-level GHG emissions of N_2O to ensure consistency with national estimates. National estimates were used to disaggregate emissions by state because of limitations in the availability of state-specific data for the time series. Total emissions for each state are the sum of emissions from N_2O product use.

State-level emissions of N_2O usage for medicine/dental anesthesia, sodium azide production, food processing propellant and aerosols, and other applications (may include fuel oxidant in auto racing, oxidizing agent in blowtorches, etc.) were calculated using the same methodology in the national *Inventory* to calculate national emissions (EPA 2021). Data on the usage of N_2O by state, however, are not available. To calculate N_2O product usage by state, national N_2O usage and emissions were distributed among the 50 states, the District of Columbia, and Puerto Rico, using U.S. population statistics as a surrogate for state-specific N_2O usage (U.S. Census Bureau 2002, 2011, 2019; Instituto de Estadísticas de Puerto Rico 2021). For each year in the 1990–2019 time series, the fraction of the total U.S. population in each state, as well as the District of Columbia and Puerto Rico, was calculated by dividing the state population by the total U.S. population.

To estimate N_2O emissions for each year by state, total national *Inventory* N_2O production was multiplied by the share of national usage and emissions rate for each respective application and then multiplied by each state’s fraction of the total population for that year. The calculated emissions by application and by state were then summed by state. Use of state populations to calculate the N_2O use and emissions by state assumed that N_2O use is consistent across all states.

3.4.4.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of N_2O from N_2O product use was calculated using the 2006 IPCC Guidelines Approach 2 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 and Annex 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −24%/+24% for N_2O.

State-level estimates are expected to have a higher uncertainty because the national emissions estimates were apportioned to each state based solely on state population for some subcategories. This assumption was required because of a general lack of more granular state-level data. Use of state population for medical/dental anesthesia and for food propellant in the state-level estimates may have lower uncertainty because these uses tend to be related to population. Use of state population for other uses (e.g., fuel oxidant in auto racing, oxidizing agent in blowtorches) introduces higher uncertainty because state-level activities are not known and less likely to be related to population. This allocation method introduces additional uncertainty due to limited data on the quantity of N_2O used by state or nationally for the full time series. The sources of uncertainty for this category are also consistent over time because the same surrogate data are applied across the entire time series.

3.4.4.4 Planned Improvements

Data gaps include the actual usage of N_2O from products by state for each application for the entire time series. Research is also needed to better characterize each application's N_2O usage.

3.4.4.5 References

Instituto de Estadísticas de Puerto Rico. (2021). Population of Puerto Rico from 1990-1999 from "Estimados anuales poblacionales de los municipios desde 1950." Accessed February 2021. Available online at: https://censo.estadisticas.pr/EstimadosPoblacionales

U.S. Census Bureau, Population Division. (2002). Table CO-EST2001-12-00 - Time Series of Intercensal State Population Estimates: April 1, 1990 to April 1, 2000, Release Date: April 11, 2002.

U.S. Census Bureau, Population Division. (2011). Table 1. Intercensal Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2010 (ST-EST00INT-01), Release Date: September 2011.

U.S. Census Bureau, Population Division. (2019). Table 1. Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2019 (NST-EST2019-01), Release Date: December 2019.

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

4 Agriculture (NIR Chapter 5)

For this methodology report, the Agriculture chapter consists of two subsectors: livestock management and other agriculture activities. More information on national-level emissions and methods is available in Chapter 5 of the national *Inventory*. See Table 4-1 summarizes the different approaches used to estimate state-level agriculture emissions. The sections below provide more detail on each category.

Table 4-1. Overview of Approaches for Estimating State-Level Agriculture Sector GHG Emissions

Category	Gas	Approach	Completeness
Enteric Fermentation	CH_4	Approach 1	Includes emissions from all states. [1]
Manure Management	CH_4, N_2O	Approach 1	Includes emissions from all states. [1]
Agricultural Soil Management	N_2O	Hybrid: (see section *4.2.2.2 Methods/Approach*)	Includes emissions from all states, Washington D.C, and territories[1], but some components of Alaska and Hawaii were not estimated.
Rice Cultivation	CH_4	Hybrid: • 1990–2015: Approach 1 • 2016–2019: Approach 2	Includes emissions from all 13 states cultivating rice.[1]
Liming	CO_2	Hybrid: • 1990–2018: Approach 1 • 2019: Approach 2	Includes emissions from all states for which USGS (through *Minerals Yearbook* and *Mineral Industry Survey*) reports limestone and dolomite consumption for agriculture in current and historical yearbooks and surveys.[1]
Urea	CO_2	Approach 1	Includes emissions from all states and territories[1] (i.e., Puerto Rico) were estimated.
Field Burning of Agricultural Residues	CH_4, N_2O	Hybrid: • 1990–2014: Approach 1 • 2015–2019: Approach 2	Includes emissions from all states except Alaska and Hawaii[1].

[1] Emissions are likely occurring in other US territories; however, due to a lack of available data and the nature of this category, this analysis includes emissions for only the territories indicated. Territories not listed are not estimated. See planned improvements.

4.1 Livestock Management

This section presents the methodology applied to estimate the livestock management emissions, which consist of the following sources:

- Enteric fermentation (CH_4)
- Manure management (CH_4, N_2O)

4.1.1 *Enteric Fermentation (NIR Section 5.1)*

4.1.1.1 Background

Methane is produced as part of normal digestive processes in animals. During digestion, microbes resident in an animal's digestive system ferment food consumed by the animal. This microbial fermentation process, referred to as Enteric Fermentation, produces CH_4 as a by-product, which can be exhaled or eructated by the animal. The amount of CH_4 produced and emitted by an individual animal depends primarily upon the animal's digestive system, and the amount and type of feed it consumes.

4.1.1.2 Methods/Approach

The EPA compiles state-level CH_4 emissions from enteric fermentation using the same methods applied in the national *Inventory* available online at: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-5-agriculture.pdf. The methods applied in the national *Inventory* are summarized below in Table 4-2. Estimates are available for all 50 States.

Table 4-2. Approaches to Estimate Enteric Fermentation Methane Across Time Series

Time Series Range	Method
1990–2017	• Cattle: IPCC Tier 2, CEFM model • Noncattle: IPCC Tier 1 (population * default emission factor)
2018, 2019	• Cattle: Multiplied 2018 and 2019 animal populations by implied emission factors developed from the CEFM for 1990–2017 • Noncattle: IPCC Tier 1 (population * default emission factor)

Please reference the national *Inventory* Section 5.1 and Annex 3.10 to the enteric fermentation methodology for additional details on estimating state-level emissions for the years 1990–2017.

- For the 1990–2017 national *Inventory*, please refer to the national *Inventory* Section 5.1 and Annex 3.10 on enteric fermentation for additional details on methods applied to estimate state-level emissions (EPA 2019).
- For noncattle animals, USDA state population estimates (from USDA *QuickStats* and the U.S. Census of Agriculture) were multiplied by the corresponding default IPCC emissions factors (IPCC 2006).
- For cattle, USDA state population data and other USDA state-level activity data (e.g., number of cattle born and slaughtered) were used as inputs to the Cattle Enteric Fermentation Model (CEFM). For 2018 and 2019 (EPA 2020, 2021), the latest national *Inventories* applied a simplified approach to estimate emissions for enteric fermentation to focus on improvements that will be included in the forthcoming national *Inventory* covering 1990–2020 to be published in April 2022. Therefore, only national-level data were updated and the CEFM was not rerun. This simplified approach was developed to adhere to IPCC good practice guidance to ensure time series consistency.

4.1.1.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CH_4 from Enteric Fermentation was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 5 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), levels of uncertainty in the national estimates in 2019 were CH_4 (−11/+18%). State-level estimates have a higher uncertainty due to apportioning the national or default emission estimates to each state. This approach does not address state-level differences in uncertainty when applying regional diet data or factors. It is important to note that beef and dairy cattle diets can vary significantly even between states that are in similar regions because of the wide variety of forage types being grown on range and pastureland. Additionally, producers often develop unique feed for their livestock based on the availability of specific feed inputs in their area. Regionally derived data were applied at the state level because state-level data were limited or unavailable for many parameters. For more details on national-level uncertainty, see the Uncertainty discussion in Section 5.1 of the national *Inventory* (see link included above).

4.1.1.4 Planned Improvements

Planned improvements to the state-level estimates are the same as those presented in Section 5.1 of the national *Inventory* (page 5-10) given improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well. In particular, state-level livestock diet data would be of value for improving estimates of enteric fermentation. Enteric fermentation emissions in the next national *Inventory* will include use of an updated CEFM model for all years (i.e., 1990 to 2020) and incorporate additional methodological refinements and not require use of a simplified approach to extend the time series.

4.1.1.5 References

IPCC (2006). Emissions from Livestock and Manure Management, Volume 4, Chapter 10, in 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The National Greenhouse Gas Inventories Programme, The Intergovernmental Panel on Climate Change. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Hayama, Kanagawa, Japan. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

U.S. Environmental Protection Agency. (April 2019). Annexes to the *Inventory* of the U.S. GHG Emissions and Sinks: Annex 3.10 Methodology for Estimating CH_4 Emissions from Enteric Fermentation. (EPA 430-R-19-001). Washington, DC. Available online at: https://www.epa.gov/sites/production/files/2019-04/documents/us-ghg-inventory-2019-annexes.pdf

U.S. Environmental Protection Agency. (April 2020). Annexes to the *Inventory* of the U.S. GHG Emissions and Sinks: Annex 3.10 Methodology for Estimating CH_4 Emissions from Enteric Fermentation. (EPA 430-R-20-002). Washington, DC. Available online at: https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-annexes.pdf

U.S. Environmental Protection Agency. (April 2021). Annexes to the *Inventory* of the U.S. GHG Emissions and Sinks: Annex 3.10 Methodology for Estimating CH_4 Emissions from Enteric Fermentation. (EPA 430-R-21-005). Washington, DC. Available online at: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-annexes.pdf

4.1.2 Manure Management (NIR Section 5.2)

4.1.2.1 Background

The treatment, storage, and transportation of livestock manure can produce anthropogenic CH_4 and N_2O emissions. Methane is produced by the anaerobic decomposition of manure and nitrous oxide is produced from direct and indirect pathways through the processes of nitrification and denitrification, volatilization, and runoff and leaching. In addition, there are many underlying factors that can affect these resulting emissions from Manure Management. For CH_4, the type of manure management system, ambient temperature, moisture, and residency (storage) time of the manure affect influence bacteria growth and therefore subsequent emissions. For N_2O, the composition of the manure (manure includes both feces and urine), the type of bacteria involved in the process, and the amount of oxygen and liquid in the manure system affect the resulting emissions.

4.1.2.2 Methods/Approach

The EPA compiles state-level emissions from manure management using the same methods applied in the national *Inventory* as summarized in Table 4-3.

Table 4-3. Approaches to Estimate Manure Management Methane and Nitrous Oxide Across Time Series

Time Series Range	Method
1990–2018	• Combination of IPCC Tier 1 and 2 approaches as described in the national *Inventory*

2019	- 2019 animal populations were multiplied by CH_4 and N_2O implied emission factors that were calculated based on 2018 estimates

For years 1990–2018, please refer to the national *Inventory* Chapter 5, Section 5.2 and Annex 3.11, which provides additional detail on the methods to estimate state-level manure management emissions (EPA 2021) available online at: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-5-agriculture.pdf. As noted in that section, the basic approach applies a combination of IPCC Tier 1 and Tier 2 methodologies. The EPA applies Tier 1 default N_2O emission factors and methane conversion factors (MCF) for dry systems from the IPCC (2006), U.S.-specific MCFs for liquid systems, and U.S.-specific values for the volatile solids production rate and the nitrogen excretion rate for some animal types, including cattle values from the CEFM (see Enteric Fermentation).

For the year 2019 *Inventory*, manure management (CH_4 and N_2O) emissions were calculated at the state level using a simplified approach. The national *Inventory* applied a simplified approach to extend the time series to 2019 for manure management to focus on improvements that would be used for the forthcoming national *Inventory* including 1990–2020 to be published in April 2022. While 1990–2018 emissions values were the same, and 2019 state-level emissions were estimated based on national-level emissions and 2018 percentage emissions distribution to states. This simplified approach adheres to IPCC good practice guidance to ensure time series consistency. Estimates are available for all 50 States.

4.1.2.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CH_4 and N_2O from Manure Management were calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 5 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were CH_4 (−18/+20%) and N_2O (−16/+24%). State-level estimates have a higher uncertainty due to apportioning the national or default emission estimates to each state. This approach does not address state-level differences in uncertainty when applying regional waste management system distributions or factors. These assumptions were applied because state-level data is limited or unavailable for many parameters. For more details on national-level uncertainty see the Uncertainty discussion in Section 5.2 of the national *Inventory* (see link included above).

4.1.2.4 Planned Improvements

Planned improvements to the state-level estimates are the same as those presented in Chapter 5, Section 5.2 of the national *Inventory* given improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well. Manure Management estimates in the next national *Inventory* including 1990–2020 will use a full manure model run and therefore state-level estimates will not be developed using the simplified approach.

4.1.2.5 References

U.S. Environmental Protection Agency. (2020). Annexes to the *Inventory* of the U.S. GHG Emissions and Sinks: Annex 3.11 Methodology for Estimating CH_4 and N_2O Emissions from Manure Management. (EPA 430-R-20-002). Washington, DC. Available online at: https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-annexes.pdf

U.S. Environmental Protection Agency. (April 2021). Annexes to the *Inventory* of the U.S. GHG Emissions and Sinks: Annex 3.11 Methodology for Estimating CH_4 and N_2O Emissions from Manure Management. (430-R-21-005). Washington, DC. Available online at: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-annexes.pdf

4.2 Other (Agriculture)

This section presents the methodology applied to estimate the other agricultural activity emissions, which consist of the following source categories:

- Rice cultivation (CH_4)
- Agricultural soil management (N_2O)
- Liming (CO_2)
- Urea fertilization (CO_2)
- Field burning of agricultural residues (CH_4, N_2O)

4.2.1 Rice Cultivation (NIR Section 5.3)

4.2.1.1 Background

Most of the world's rice is grown on flooded fields that create anaerobic conditions leading to CH_4 production through a process known as methanogenesis. Approximately 60 to 90% of the CH_4 produced by methanogenic bacteria in flooded rice fields is oxidized in the soil and converted to CO_2 by methanotrophic bacteria. The remainder is emitted to the atmosphere (or transported as dissolved CH_4 into groundwater and waterways. Methane is transported to the atmosphere primarily through the rice plants, but some CH_4 also escapes via ebullition (i.e., bubbling through the water) and to a much lesser extent by diffusion through the water.

4.2.1.2 Methods/Approach

The EPA compiles state-level CH_4 emissions from Rice Cultivation using the same methods applied in the national *Inventory*. Rice is currently cultivated in 13 states: Arkansas, California, Florida, Illinois, Kentucky, Louisiana, Minnesota, Mississippi, Missouri, New York, South Carolina, Tennessee, and Texas. This is described in Chapter 5, Section 3 of the national *Inventory* available online at: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-5-agriculture.pdf. Additional information on the methodologies and data is also provided in Annex 3.12.

The most recent national *Inventory* includes State-level emissions for the 13 states mentioned above for the years 1990–2015, which were used for this report, Approach 1. See Appendix E for time series information underlying the estimates . Within the national *Inventory*, the EPA does not currently estimate State-level emissions from rice cultivation for the years 2016–2019 because the NRI data are not available for the 2016–2019 time period, so it is not possible to develop state-level estimates for those years using the same approach. The national-level emissions for 2016–2019 are estimated using a surrogate data method. For this report, the national totals for 2016–2019 were disaggregated to the State level in a two-step process, Approach 2. First, the average proportion of the total national emissions was computed for each state from 2013–2015, which are the last 3 years for which state-level emissions have been estimated. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state from 2016–2019.

4.2.1.3 Uncertainty

The overall uncertainty associated with national estimates of CH_4 from rice cultivation was calculated using the IPCC Approach 2 (i.e., Monte Carlo simulation). As described in Chapter 5 of the *national Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), sources of uncertainty include incomplete information on management practices, uncertainties in model structure (i.e., algorithms and parameterization), emission***s*** factors***,*** and variance associated with the NRI sample. Levels of uncertainty in the national CH_4 rice cultivation estimates in 2019 were **−**89/+89% for the Tier 1 method and −48/+48% for the Tier 3 method, with a combined uncertainty of **−**75/+149%. For the years 2016–2019 in which the national *Inventory* did not previously estimate state emissions but were developed for this report, uncertainty estimates will be greater.

4.2.1.4 Planned Improvements

Planned improvements to the state-level estimates are anticipated to be the same as those presented in Section 5.3 of the national *Inventory* given improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.2.1.5 References

Full citations of references included in Chapters 5.3 (Rice Cultivation) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf and https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-annex-3-additional-source-or-sink-categories-part-b.pdf.

4.2.2 Agricultural Soil Management (NIR Section 5.4)

4.2.2.1 Background

Nitrous oxide (N_2O) is naturally produced in soils through the microbial processes of nitrification and denitrification that is driven by the availability of mineral nitrogen (N). Mineral N is made available in soils through decomposition of soil organic matter and plant litter, asymbiotic fixation of N from the atmosphere, and agricultural management practices, which are discussed below.

Several agricultural activities increase mineral N availability in soils that lead to direct N_2O emissions at the site of a management activity. These activities include synthetic N fertilization; application of managed livestock manure; application of other organic materials such as biosolids (i.e., treated sewage sludge); deposition of manure on soils by domesticated animals in pastures, range, and paddocks (PRP) (i.e., unmanaged manure); retention of crop residues (N-fixing legumes and non-legume crops and forages); and drainage of organic soils (i.e., Histosols) (IPCC 2006). Additionally, Agricultural Soil Management activities, including irrigation, drainage, tillage practices, cover crops, and fallowing of land, can influence N mineralization from soil organic matter and plant litter in addition to levels of asymbiotic N fixation.

Indirect emissions of N_2O occur when N is transported from a site and is subsequently converted to N_2O; there are two pathways for indirect emissions: (1) volatilization and subsequent atmospheric deposition of applied/mineralized N and (2) surface runoff and leaching of applied/mineralized N into groundwater and surface water.

4.2.2.2 Methods/Approach

The EPA compiles state-level N_2O emissions from Agricultural Soil Management using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 5, Section 5.4 (pages 5-27 through 5-45) of the national *Inventory* available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-5-agriculture.pdf.

For this report, a hybrid of Approach 1 and 2 was applied in developing state-level estimates. Estimates are available for all 50 states and the District of Columbia; however, some components of this category are not estimated for Alaska and Hawaii, as described in the national *Inventory*. The EPA currently estimates N_2O emissions from mineral fertilizer and PRP N additions in Alaska and Hawaii, and drained organic soils in Hawaii. For the state-level estimates, the EPA extracted soil N_2O emissions data that were compiled at the state level for drained organic soils across the entire time series; for crop residue N for 1990–2018; and for synthetic fertilizer, managed manure N, PRP manure N, and mineralization of soil organic matter from 1990–2015. The remaining years in the time series for these N sources were only estimated at the national scale using a surrogate data method. A two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from the last 3 years in the time series with state-level data (e.g., 2013–2015 for synthetic fertilizer). Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for the years with only national-level estimates in the national *Inventory*. Soil N_2O emissions for additions of biosolid N and other organic amendment N to soils are only estimated at the national scale for the entire time series. For these two sources of N, soil N_2O emissions were disaggregated to the state level based on the proportion of the U.S. population occurring in each state.

Additional information on methodologies and data is also provided in Annex 3.12 available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-annex-3-additional-source-or-sink-categories-part-b.pdf.

4.2.2.3 Uncertainty

The overall uncertainty associated with national estimates of N_2O from agricultural soil management is described in Chapter 5 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021). Uncertainty is estimated for each of the following five components of N_2O emissions from agricultural soil management: (1) direct emissions simulated by DayCent, (2) the components of indirect emissions (N volatilized and leached or runoff) simulated by DayCent, (3) direct emissions estimated with the IPCC Tier 1 method, (4) the components of indirect emissions (N volatilized and leached or runoff) estimated with the IPCC (2006) Tier 1 method, and (5) indirect emissions estimated with the IPCC Tier 1 method.

Levels of uncertainty in the national N_2O agricultural soil management estimates in 2019 were direct N_2O (−31/+31%) and indirect N_2O (−71/+154%).

4.2.2.4 Planned Improvements

Planned improvements to the state-level estimates are anticipated to be the same as those presented in Section 5.4 of the national *Inventory* given improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.2.2.5 References

Full citations of references included in Chapters 5.4 (Agricultural Soil Management) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf and https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-annex-3-additional-source-or-sink-categories-part-b.pdf.

4.2.3 Liming (NIR Section 5.5)

4.2.3.1 Background

Crushed limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) are added to soils by land managers to increase soil pH (i.e., to reduce acidification). Carbon dioxide emissions occur as these compounds react with hydrogen ions in soils. The rate of degradation of applied limestone and dolomite depends on the soil conditions, soil type, climate regime, and whether limestone or dolomite is applied. Emissions from limestone and dolomite that are used in industrial processes (e.g., cement production, glass production, etc.) are reported under the IPPU chapter.

4.2.3.2 Methods/Approach

The EPA compiles state-level CO_2 emissions from Liming using the same methods applied in the national *Inventory*. The national method is a Tier 2 approach based on the amount of limestone and dolomite applied to agricultural soils, multiplied by a country-specific emissions factor. This is described in Chapter 5, Section 5.5 (pages 5-45 through 5-48) of the national *Inventory* available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-5-agriculture.pdf.

The current national *Inventory* includes state-level emissions for the years 1990–2018. See Appendix E for time series information underlying the estimates. It did not include state-level emissions from liming for the year 2019 because state-level activity data were not available. For this report, a hybrid Approach 1 and Approach 2 was used. The national estimate for 2019, which was estimated using a linear extrapolation method, is disaggregated to the state level based on the proportion of total CO_2 emissions from carbonate lime application occurring in each state for 2018. Estimates are currently available for states other than Alaska, Arizona, Colorado, Delaware, Hawaii, Louisiana, Maryland, and New Hampshire, because USGS data did not indicate consumption of crushed limestone and dolomite; however, the District of Columbia is currently estimated.

4.2.3.3 Uncertainty

The overall uncertainty associated with national estimates of CO_2 from liming is described in Chapter 5 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021). A Monte Carlo uncertainty analysis was applied. Uncertainty analysis was performed on the amount of limestone and dolomite applied to soils, the emission factors included the fraction of lime dissolved by nitric acid versus the fraction that reacts with carbonic acid, and the portion of bicarbonate that leaches through the soil and is transported to the ocean. Uncertainty regarding the time associated with leaching and transport is not addressed in the national *Inventory* uncertainty analysis. The overall level of uncertainty in the national CO_2 liming estimates in 2019 was −111/+88%.

4.2.3.4 Planned Improvements

Planned improvements to the state-level estimates are anticipated to be the same as those presented in Section 5.5 of the national *Inventory* given improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.2.3.5 References

Full citations of references included in Chapters 5.5 (Liming) of the national *Inventory* are available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf.

4.2.4 Urea Fertilization (NIR Section 5.6)

4.2.4.1 Background

The use of urea ($CO(NH_2)_2$) as a fertilizer leads to greenhouse gas emissions through the release of CO_2 that was fixed during the production of urea. In the presence of water and urease enzymes, urea that is applied to soils as fertilizer is converted into ammonium (NH_4+), hydroxyl ion (OH), and bicarbonate (HCO_3-). The bicarbonate then evolves into CO_2 and water.

4.2.4.2 Methods/Approach

The EPA compiles state-level CO_2 emissions from Urea Fertilization using the same IPCC Tier 1 methods applied in the national *Inventory*, Approach 1. With this approach, state-level fertilizer sales data are multiplied by the default IPCC emissions factor. See Appendix E for time-series information underlying the estimates. This is described in Chapter 5, Section 5.6 (pages 5-48 through 5-50) of the national *Inventory* available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-5-agriculture.pdf. Estimates are currently available for all 50 states and Puerto Rico.

4.2.4.3 Uncertainty

The overall uncertainty associated with national estimates of CO_2 from urea fertilization is described in Chapter 5 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021). A Monte Carlo uncertainty analysis was applied. The largest source of uncertainty is the default emission factor, which assumes that 100% of the C in $CO(NH_2)_2$ applied to soils is emitted as CO_2. The overall level of uncertainty in the national CO_2 urea fertilization estimates in 2019 was −43%/+3%.

4.2.4.4 Planned Improvements

Planned improvements to the state-level estimates are anticipated to be the same as those presented in Section 5.6 of the national *Inventory* given improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.2.4.5 References

Full citations of references included in Chapters 5.6 (Urea Fertilization) of the national *Inventory* are available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf.

4.2.5 Field Burning of Agricultural Residues (NIR Section 5.7)

4.2.5.1 Background

Crop production creates large quantities of agricultural crop residues, which farmers manage in a variety of ways. For example, crop residues can be left in the field and possibly incorporated into the soil with tillage; collected and used as fuel, animal bedding material, supplemental animal feed, or construction material; composted and applied to soils; transported to landfills; or burned in the field. Field Burning of Crop Residues is not considered a net source of CO_2 emissions because the C released to the atmosphere as CO_2 during burning is reabsorbed during the next growing season by the crop. However, crop residue burning is a net source of CH_4, N_2O, CO, and NO_x, which are released during combustion.

In the United States, field burning of agricultural residues is more common in southeastern states, the Great Plains, and the Pacific Northwest. The primary crops that are managed with residue burning include corn, cotton, lentils, rice, soybeans, sugarcane, and wheat.

4.2.5.2 Methods/Approach

The EPA compiles state-level CH_4 and N_2O emissions from field burning of agricultural residues using the same methods applied in the national *Inventory*. The national *Inventory* applies a country-specific Tier 2 methodology. This is described in Chapter 5, Section 5.7 (pages 5-51 through 5-59) of the national *Inventory* available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-5-agriculture.pdf.

The most recent national *Inventory* includes state-level emissions for the years 1990–2014, but not for the years 2015 through 2019. state estimates were developed using Approach 1 for 1990–2014 and Approach 2 for disaggregating 2015–2019 national estimates. National-level emissions for 2015–2019 are estimated using a linear extrapolation of the pattern from the previous years in the *Inventory*. For this report, these national totals were disaggregated to the state level in a two-step process. First, the average proportion of the total national emissions was computed for each state from 2012–2014, which are the last 3 years in which state-level emissions had been estimated. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state from 2015–2019. Estimates are currently available for all states excluding Alaska and Hawaii, consistent with the national *Inventory*, because these two states are not captured in the current analysis.

4.2.5.3 Uncertainty

The overall uncertainty associated with national estimates of CH_4 and N_2O from field burning of agricultural residues is described in Chapter 5 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021).

As described in the national *Inventory*, emissions are estimated using a linear regression model with autoregressive moving-average (ARMA) errors for 2019. The linear regression ARMA model also produced estimates of the upper and lower bounds to quantify uncertainty.

Because of data limitations, there are additional uncertainties in agricultural residue burning, particularly the potential omission of burning associated with Kentucky bluegrass (produced on farms for turf grass installation) and sugarcane. The EPA is aware that some agricultural residue burning is not currently captured in the national *Inventory* analysis; please see planned improvements information. Overall levels of uncertainty in the national CH_4 and N_2O field burning of agricultural residue estimates in 2019 were: CH_4 (−18/+18%) and N_2O (−17/+17%).

4.2.5.4 Planned Improvements

Planned improvements to the state-level estimates are anticipated to be the same as those presented in Section 5.7 of the national *Inventory* given improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.2.5.5 References

Full citations of references included in Chapters 5.7 (Field Burning of Agricultural Residues) of the national *Inventory* are available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf.

5 Land Use, Land-Use Change, and Forestry (NIR Chapter 6)

This chapter describes the methods applied to estimate state-level GHG fluxes resulting from land use and land-use change within states according to changes within and conversions between all land-use types, including Forest Land, Cropland, Grassland, Wetlands, and Settlements (as well as Other Land). The EPA works closely with the USDA-USFS, and NOAA on estimates for the national *Inventory*. USFS[31] and NOAA develop state-level estimates for the forest land and wetlands land use and land-use change categories, which are used for the national *Inventory* and this state-level report. Table 5-1 summarizes the different approaches used to estimate state-level land Use, land-Use Change, and forestry emissions and sinks completeness. State completeness is consistent with the national *Inventory*. The sections below provide more detail on each category.

See also the national *Inventory* report Chapter 6.1 for a description of how the U.S. land base is represented to identify land areas consistent with IPCC Guidelines. Work is underway to provide additional spatial and temporal resolution to the representation of the U.S. land base and will help refine methods for state-level estimates in subsequent annual publications of this data.

Table 5-1. Overview of Approaches for Estimating State-Level Land Use, Land Use Change and Forestry Sector Greenhouse Gas Emissions and Sinks

Category	Gas	Approach	Geographic Completeness
Forest Land Remaining Forest Land and Lands Converted to Forest Land	Carbon	Approach 1	Includes estimates from all states except Hawaii.[1] For Alaska, *Lands Converted to Forest* are included in the *Forest Land Remaining Forest Land* data.
Cropland and Lands Converted to Cropland	Carbon	Hybrid: • 1990–2015: Approach 1 • 2016–2019: Approach 2	Includes estimates from all states except Alaska. [1]
Grassland and Lands Converted to Grassland			
Carbon Stock Changes	Carbon	Hybrid: • 1990–2015: Approach 1 • 2016–2019: Approach 2	Includes estimates from all states except Alaska. [1]
Non-CO_2 Emissions from Grassland Fires	CH_4, N_2O	Hybrid: • 1990–2014: Approach 1 • 2015–2019: Approach 2	Includes estimates from all states except Alaska.
Wetlands and Lands Converted to Wetlands			
Coastal Wetlands	Carbon, CH_4	Approach 1	Includes estimates from all states and Washington, D.C. with coastal wetlands except Alaska and Hawaii.[1]
Peatlands	CO_2, CH_4, N_2O	Approach 2	Includes estimates from all states except Hawaii.
Settlements and Land Converted to Settlements			

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[31] U.S. Forest Service Resource Update FS–307 (Domke, 2021): https://www.nrs.fs.fed.us/pubs/62418.

Soil C	Carbon	Hybrid: • 1990–2015: Approach 1 • 2016–2019: Approach 2	Includes estimates from all states except Alaska. [1]
Settlement Trees	Carbon	Hybrid: • 1990–2015: Approach 1 • 2016–2019: Approach 2	Includes estimates from all states and Washington D.C. [1]
Soil N_2O	N_2O	Hybrid: • 1990–2015: Approach 1 • 2016–2019: Approach 2	Includes estimates from all states except Alaska. [1]
Landfilled Yard Trimmings and Food Scrap (LFYTFS)	Carbon	Approach 2	Includes estimates from all states, Washington D.C., and territories[1] (i.e., Puerto Rico).

[1] Emissions are likely occurring in other US territories; however, due to a lack of available data and the nature of this category, this analysis includes emissions for only the territories indicated. Territories not listed are not estimated. See planned improvements.

5.1.1 Forest Land Remaining Forest Land (NIR Section 6.2)

5.1.1.1 Background

Carbon is continuously cycled among the forest ecosystem carbon storage pools (i.e., aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon) and the atmosphere because of biogeochemical processes in forests (e.g., photosynthesis, respiration, decomposition, and disturbances such as fires or pest outbreaks) and anthropogenic activities (e.g., harvesting, thinning, and replanting). The net change in forest carbon, however, is not equivalent to the net flux between forests and the atmosphere because timber harvests do not cause an immediate flux of all harvested biomass carbon to the atmosphere. Instead, harvesting transfers a portion of the carbon stored in wood to a "product pool." Once in a product pool, the carbon is emitted over time as CO_2 in the case of decomposition and as CO_2, CH_4, N_2O, CO, and NO_x when the wood product combusts. Emissions of non-CO_2 gases from forest fires, both wild and prescribed, along with N_2O emissions from nitrogen additions to the soil and CO_2, CH_4, and N_2O emissions from drained organic soils also occur.

5.1.1.2 Methods/Approach

To compile national estimates of carbon stock changes from forest ecosystem carbon pools on Forest Land Remaining Forest Land, and non-CO_2 emissions from fires, along with non-CO_2 emissions from drained organic soils, on forest land remaining forest land and land converted to forest land for the national *Inventory*, estimates for each state were produced and summed into a national total. This is described in Chapter 6, Section 6.2 (pages 6-23 through 6-45) of the national *Inventory* available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf. Additional information on the methodologies and data are also provided in Annex 3.13.

Please note that N_2O emissions from nitrogen additions to the soil are not included in the state-level estimates and that Hawaii are not included in the national total or available at the state level at this time. Emissions of non-CO_2 gases from forest fires, non-CO_2 emissions from drained organic soils, and N_2O emissions from nitrogen additions to the soil include emissions from both forest land remaining forest land and land converted to forest land because it is not possible to report them separately at this time. Additionally, the estimates of the carbon stock change in harvested wood are not currently available at the state level. Work is underway to develop and approach for disaggregating the national estimates down to state level.

5.1.1.3 Uncertainty

The subcategories included in this state-level report include the carbon stock changes in forest ecosystem carbon storage pools, non-CO_2 gases from forest fires and non-CO_2 emissions from drained organic soils. A brief overview of the uncertainty analyses for each of the subcategories included in the national *Inventory* is provided below. In addition, quantitative uncertainty estimates for individual states (2019) for the carbon stock changes in forest ecosystem carbon storage pools and non-CO_2 gases from forest fires are provided in the Appendix 2 of the USFS Resource Update FS–307 (Domke, 2021), and can be found online here: https://www.fs.fed.us/nrs/pubs/download/ru_fs307_Appendix2.pdf.

- Carbon stock changes in forest ecosystem carbon storage pools: The overall uncertainty associated with the 2019 national estimate of the carbon stock changes in forest ecosystem carbon storage pools was calculated through a combination of sample-based and model-based approaches to uncertainty for forest ecosystem CO_2 flux using IPCC Approach 1 (IPCC 2006). As described further in Chapter 6.2 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), levels of uncertainty in the national estimates in 2019 were (−11.7/+11.7%). State-level estimates of uncertainty vary significantly among the states but, in general, tend to have a higher uncertainty than those provided for the United States in the national *Inventory*. These higher uncertainties can occur when the models and factors developed from studies done at a larger geographical scale are used to generate estimates at smaller geographic scales, such as state-level, the potential for unique circumstances occuring within a state can potentially reduce the accuracy and precision of the flux estimates and increase the overall uncertainty. For more details on national-level uncertainty, see the Uncertainty discussion in Section 6.2 and Annex 3.13 of the national *Inventory*.

- Non-CO_2 gases from forest fires (includes both forest land remaining forest land and land converted to forest land): The overall uncertainty associated with the 2019 national estimate of non-CO_2 gases from forest fires was calculated through a Monte Carlo (IPCC Approach 2 [IPCC 2006]) sampling approach employed to propagate uncertainty based on the model and data applied for US forest land. As shown in Chapter 6 of the national *Inventory*, levels of uncertainty in the national estimates in 2019 were CH_4 (−16/+18%) and N_2O (−13/+14%). state-level estimates of uncertainty vary significantly among the states, but, in general, tend to have a higher uncertainty than those provided in the national *Inventory*. These higher uncertainties can occur when the models and factors developed from studies done at a larger geographical scale are used to generate estimates at smaller geographic scales, such as state-level, the potential for unique circumstances occuring within a state can potentially reduce the accuracy and precision of the flux estimates and increase the overall uncertainty. For more details on national-level uncertainty and the quantities and assumptions employed to define and propagate uncertainty, see the Uncertainty discussion in Section 6.2 and Annex 3.13 of the national *Inventory.*
- Non-CO_2 gases from drained organic soils (includes both forest land remaining forest land and land converted to forest land): The overall uncertainty associated with the 2019 national estimate of non-CO_2 gases from drained organic soils was calculated through IPCC Approach 1 (IPCC 2006). As described further in Chapter 6 of the national *Inventory*, levels of uncertainty in the national estimates in 2019 were CH_4 (−70/+80%) and N_2O (−100/+128%). State-level estimates of uncertainty vary significantly among the states but, in general, tend to have a higher uncertainty than those provided in the national *Inventory*. For more details on national-level uncertainty and the quantities and assumptions employed to define and propagate uncertainty, see the Uncertainty discussion in Section 6.2 and Annex 3.13 of the national *Inventory.*
- Non-CO_2 gases from drained organic soils (includes both forest land remaining forest land and land converted to forest land): The overall uncertainty associated with the 2019 national estimate of non-CO_2 gases from drained organic soils was calculated through IPCC Approach 1 (IPCC 2006). As described further in Chapter 6 of the national *Inventory*, levels of uncertainty in the national estimates in 2019 were CH_4 (-70/+80%) and N_2O (-100/+128%). State-level estimates of uncertainty will vary significantly among the States, but in general will tend to have a higher uncertainty than those provided in the national *Inventory*. These higher uncertainties can occur when the models and factors developed from studies done at a larger geographical scale are used to generate estimates at smaller geographic scales, such as state-level, the potential for unique circumstances occuring within a state can potentially reduce the accuracy and precision of the flux estimates and increase the overall uncertainty. For more details on national level uncertainty and the quantities and assumptions employed to define and propagate uncertainty, see the Uncertainty discussion in section 6.2 and Annex 3.13 of the national *Inventory.*

5.1.1.4 Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state-level GHG estimates are the same as those in the national *Inventory*. To view the planned improvements to the methods and data for estimating emissions and removals from forest land remaining forest land, see the planned improvements discussion on pp. 6-37 through 6-38 and 6-40 of Chapters 6.2, respectively, in the national *Inventory* for a description of future work to improve these estimates. In addition, as noted by the USFS Resource Update FS–307 (Domke, 2021), investments are being made to leverage existing state-level forest products information to allow for the disaggregation of HWP estimates at the state level in the future.

5.1.1.5 References

Domke, G.M., Walters, B.F., Nowak, D.J., Smith, J.E., Nichols, M.C., Ogle, S.M., Coulston, J.W., and Wirth, T.C. 2021. Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990–2019. Resource Update FS–307. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 5 p. [plus 2 appendixes]. Available online at: https://doi.org/10.2737/FS-RU-307

Full citations of all references included in Chapters 6.2 (Forest Land Remaining Forest Land) of the national *Inventory* are found on pages 10-63 to 10-68 of Chapter 10 and available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf.

5.1.2 Land Converted to Forest Land (NIR Section 6.3)

5.1.2.1 Background

Land use conversions into forest land can result in carbon stock changes to all forest ecosystem carbon pools (i.e., aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon). This Section 5.1.2 provides estimates of carbon stock changes resulting from conversion of cropland, grassland, wetlands, settlements, and other lands to forest land.

5.1.2.2 Methods/Approach

The methods applied for estimating carbon stock changes in Land Converted to Forest Land are the same as those applied for forest land remaining forest land. This is described in Chapter 6, Section 6.3 (pages 6-46 through 6-53) of the national *Inventory* available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf. Additional information on the methodologies and data is also provided in Annex 3.13 of the national *Inventory*. Please note that estimates for Hawaii are not included in the national total or available at the state level at this time. Forest ecosystem carbon stock changes from land conversion in Alaska are currently included in the forest land remaining forest land because there is insufficient data to separate the changes at this time.

5.1.2.3 Uncertainty

The overall uncertainty associated with the 2019 national estimate of the carbon stock changes in forest ecosystem carbon storage pools for land converted to forest land is described in Chapter 6.3 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021). The uncertainty estimates were calculated through a combination of sample-based and model-based approaches to uncertainty for non-soil forest ecosystem CO_2 flux using IPCC Approach 1 (IPCC 2006), in combination with IPCC Approach 2 for mineral soils (described in Section 6.4 Cropland Remaining Cropland of the *Inventory* report). Uncertainty estimates are provided for each land conversion category and carbon pool. The combined level of uncertainty in the national estimates in 2019 was −11/+11%. State-level estimates of uncertainty are not available but are likely to vary significantly from the national estimates and, in general, tend to have a higher uncertainty than those provided for the United States in the national *Inventory*. These higher uncertainties can occur when the models and factors developed from studies done at a larger geographical scale are used to generate estimates at smaller geographic scales, such as state-level, the potential for unique circumstances occuring within a state can potentially reduce the accuracy and precision of the flux estimates and increase the overall uncertainty. For more details on national-level uncertainty, see the Uncertainty discussion in Section 6.4 and Annex 3.13 of the national *Inventory.*

5.1.2.4 Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from land converted to forest land, see the planned improvements discussion on page 6-53 of Chapter 6.3, in the national *Inventory*.

5.1.2.5 References

Full citations of references included in Chapter 6.3 (Land Converted to Forest Land) of the national *Inventory* are found on pages 10-68 to 10-69 of Chapter 10 and available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf.

5.1.3 Cropland Remaining Cropland (NIR Section 6.4)

5.1.3.1 Background

Carbon in cropland ecosystems occurs in biomass, dead organic matter, and soils. However, carbon storage in cropland biomass and dead organic matter is relatively ephemeral and does not need to be reported according to the IPCC (2006), with the exception of carbon stored in perennial woody crop biomass, such as citrus groves and apple orchards, in addition to the biomass, downed wood and dead organic matter in agroforestry systems. Within soils, carbon is found in organic and inorganic forms of carbon, but soil organic carbon is the main source and sink for atmospheric CO_2 in most soils.

The IPCC (2006) recommends reporting changes in soil organic carbon stocks due to agricultural land-use and management activities for mineral and organic soils. Management of croplands and cropland soils has an impact on organic matter inputs and microbial decomposition, and thereby result in a net carbon stock change.

Cropland Remaining Cropland includes all cropland in an inventory year that has been cropland for a continuous time period of at least 20 years. This determination is based on the USDA NRI for nonfederal lands and the National Land Cover Dataset for federal lands. Cropland includes all land that is used to produce food and fiber, forage that is harvested and used as feed (e.g., hay and silage), in addition to cropland that has been enrolled in the Conservation Reserve Program (i.e., considered set-aside cropland).

5.1.3.2 Methods/Approach

The EPA compiles state-level emissions from Cropland Remaining Cropland using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6, Section 6.4 (pages 6-53 through 6-65) of the national *Inventory* available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf. For this report, estimates were developed using a hybrid of Approach 1 and Approach 2. The current national *Inventory* includes state-level emissions for the years 1990–2015 for soil organic C stock changes. The remaining years in the time series were only estimated at the national scale using a surrogate data method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2019. Estimates are included for all states with the exception of Alaska.

Additional information on methodologies and data is also provided in Annex 3.12 available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-annex-3-additional-source-or-sink-categories-part-b.pdf.

5.1.3.3 Uncertainty

The overall uncertainty associated with national estimates from Cropland Remaining Cropland is described in Chapter 6 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021) and in further detail in Annex 3.12. Uncertainty for the Tier 2 and 3 approaches is derived using a Monte Carlo approach. The combined uncertainty for soil organic C stocks in Cropland Remaining Cropland in 2019 ranges from −601% to +601%.

5.1.3.4 Planned Improvements

The planned improvements are anticipated to be the same as those planned for improving the national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory* and will lead directly to improvements in the quality of state-level estimates as well. To review the planned improvements to the methods and data for estimating emissions and removals from Cropland Remaining Cropland, see the planned improvements discussion on pages 6-63 and 6-65 of Chapter 6, Section 4 in the national *Inventory*.

5.1.3.5 References

Full citations of references included in Chapters 6.4 (Cropland Remaining Cropland) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf and https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-annex-3-additional-source-or-sink-categories-part-b.pdf.

5.1.4 Land Converted to Cropland (NIR Section 6.5)

5.1.4.1 Background

Land-use change can lead to large losses of C to the atmosphere, particularly conversions from forest land. Moreover, conversion of forest to another land use (i.e., deforestation) is one of the largest anthropogenic sources of emissions to the atmosphere globally.

Land Converted to Cropland includes all cropland in an inventory year that had been in another land use(s) during the previous 20 years, and used to produce food or fiber, or forage that is harvested and used as feed (e.g., hay and silage). For example, grassland or forest land converted to cropland during the past 20 years would be reported in this category. Recently converted lands are retained in this category for 20 years as recommended by IPCC (2006).

5.1.4.2 Methods/Approach

The EPA compiles state-level emissions from Land Converted to Cropland using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6, Section 6.5 (pages 6-65 through 6-71) of the national *Inventory* available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf. For this report, estimates were developed using a hybrid of Approach 1 and Approach 2. The current national *Inventory* includes state-level emissions for the years 1990–2019 for biomass, standing dead, deadwood, and litter and for the years 1990–2015 for soil organic C stock changes. The remaining years in the time series for soil organic C stock changes were only estimated at the national scale using a surrogate data method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2019. Estimates are included for all states with the exception of Alaska.

Additional information on methodologies and data is also provided in Annex 3.12 available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-annex-3-additional-source-or-sink-categories-part-b.pdf.

5.1.4.3 Uncertainty

The overall uncertainty associated with national estimates from Land Converted to Cropland is described in Chapter 6 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021) and in further details in Annex 3.12 and Annex 3.13 (Forestland Converted to Cropland). The uncertainty analyses for mineral soil organic C stock changes using the Tier 3 and Tier 2 methodologies are based on a Monte Carlo approach that is used in Cropland Remaining Cropland analysis. The combined uncertainty for total C stocks in Land Converted to Cropland in 2019 ranged from −102% to +103%.

5.1.4.4 Planned Improvements

The planned improvements are anticipated to be the same as those planned for improving the national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory* and will lead directly to improvements in the quality of state-level estimates as well. To review the planned improvements to the methods and data for estimating emissions and removals from Land Converted to Cropland, see the planned improvements discussion on pages 6-70 and 6-71 of Chapter 6, Section 5 in the national *Inventory*.

5.1.4.5 References

Full citations of references included in Chapters 6.5 (Land Converted to Cropland) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf and https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-annex-3-additional-source-or-sink-categories-part-b.pdf.

5.1.5 Grassland Remaining Grassland (NIR Section 6.6)

5.1.5.1 Background

Carbon in grassland ecosystems occurs in biomass, dead organic matter, and soils. Soils are the largest pool of carbon in grasslands and have the greatest potential for longer-term storage or release of carbon. Biomass and dead organic matter carbon pools are relatively ephemeral compared to the soil carbon pool, with the exception of carbon stored in tree and shrub biomass that occurs in grasslands.

The 2006 IPCC Guidelines recommend reporting changes in biomass, dead organic matter and soil organic carbon stocks with land use and management. Carbon stock changes for aboveground and belowground biomass, dead wood and litter pools are reported for woodlands (i.e., a subcategory of grasslands), and may be extended to include agroforestry management associated with grasslands in the future. For soil organic carbon, the 2006 IPCC Guidelines (IPCC 2006) recommend reporting changes due to (1) agricultural land-use and management activities on mineral soils, and (2) agricultural land-use and management activities on organic soils.

Grassland Remaining Grassland includes all grassland in an inventory year that had been grassland for a continuous time period of at least 20 years. Grassland includes pasture and rangeland that are primarily, but not exclusively used for livestock grazing. Rangelands are typically extensive areas of native grassland that are not intensively managed, while pastures are typically seeded grassland (possibly following tree removal) that may also have additional management, such as irrigation or inter-seeding of legumes. Woodlands are also considered grassland and are areas of continuous tree cover that do not meet the definition of forest land.

Non-CO_2 emissions from Grassland Fires are also included. Non-CO_2 emissions from grassland fires do not include emissions from burning perennial biomass (a national *Inventory* planned improvement).

5.1.5.2 Methods/Approach

The EPA compiles state-level emissions from Grassland Remaining Grassland using the same methods applied in the national *Inventory*. Please see the methodologies are described in Chapter 6, Section 6.6 (pages 6-71 through 6-82) of the national *Inventory* available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf. For this report, estimates were developed using a hybrid of Approach 1 and Approach 2. The current national *Inventory* includes state-level emissions for the years 1990–2019 for biomass, standing dead, deadwood, and litter and for the years 1990–2015 for soil organic C stock changes. The remaining years in the time series for soil organic C stock changes were only estimated at the national scale using a surrogate data method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2019. Estimates are included for all states with the exception of Alaska.

Additional information on national *Inventory* methodologies and data is also provided in Annex 3.12 available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-annex-3-additional-source-or-sink-categories-part-b.pdf.

5.1.5.3 Uncertainty

The overall uncertainty associated with national estimates from Grassland Remaining Grassland is described in Chapter 6 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021) and in further details in Annex 3.12. The uncertainty analyses for mineral soil organic C stock changes using the Tier 3 and Tier 2 methodologies are based on a Monte Carlo approach that is used in Cropland Remaining Cropland analysis. Uncertainty estimates are also developed for Biomass Burning in Grassland using a linear regression ARMA model to estimate the upper and lower bounds of the emission estimate. The combined uncertainty for total C stocks in Grassland Remaining Grassland in 2019 ranged from −1,066% to +1,066%.

5.1.5.4 Planned Improvements

The planned improvements are anticipated to be the same as those planned for improving the national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory* and will lead directly to improvements in the quality of state-level estimates as well. To review the planned improvements to the methods and data for estimating emissions and removals from Grassland Remaining Grassland, see the planned improvements discussion on pages 6-81 and 6-82 of Chapter 6, Section 6 in the national *Inventory.*

5.1.5.5 References

Full citations of references included in Chapters 6.6 (Grassland Remaining Grassland) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf and https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-annex-3-additional-source-or-sink-categories-part-b.pdf.

5.1.6 Land Converted to Grassland (NIR Section 6. NIR Section 6.7)

5.1.6.1 Background

Land-use change can lead to large losses of C to the atmosphere, particularly conversions from forest land. Moreover, conversion of forest to another land use (i.e., deforestation) is one of the largest anthropogenic sources of emissions to the atmosphere globally.

Land Converted to Grassland includes all grassland in an inventory year that had been in another land use(s) during the previous 20 years. For example, cropland or forest land converted to grassland during the past 20 years would be reported in this category. Recently converted lands are retained in this category for 20 years as recommended by IPCC (2006).

5.1.6.2 Methods/Approach

The EPA compiles state-level emissions from Land Converted to Grassland using the same methods applied in the national *Inventory*. Please see the methodologies are described in Chapter 6, Section 6.7 (pages 6-82 through 6-89) of the national *Inventory* available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf. For this report, estimates were developed using a hybrid of Approach 1 and Approach 2. The current national *Inventory* includes state-level emissions for the years 1990–2019 for biomass, standing dead, deadwood, and litter and for the years 1990–2015 for soil organic C stock changes. The remaining years in the time series for soil organic C stock changes were only estimated at the national scale using a surrogate data method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2019. Estimates are included for all states with the exception of Alaska.

Additional information on methodologies and data is also provided in Annex 3.12 available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-annex-3-additional-source-or-sink-categories-part-b.pdf.

5.1.6.3 Uncertainty

The overall uncertainty associated with national estimates from Land Converted to Grassland is described in Chapter 6 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021) and in further details in Annex 3.12. The uncertainty analyses for mineral soil organic C stock changes using the Tier 3 and Tier 2 methodologies are based on a Monte Carlo approach that is used in Cropland Remaining Cropland analysis. The combined uncertainty for total C stocks in Land Converted to Grassland in 2019 ranged from −146% to +148 %.

5.1.6.4 Planned Improvements

The planned improvements are anticipated to be the same as those planned for improving the national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from Land Converted to Grassland, see the planned improvements discussion on pages 6-88 and 6-89 of Chapter 6, Section 7 in the national *Inventory*.

5.1.6.5 References

Full citations of references included in Chapters 6.7 (Land Converted to Grassland) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf and https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-annex-3-additional-source-or-sink-categories-part-b.pdf.

5.1.7 Wetlands Remaining Wetlands (NIR Section 6.8)

This section presents methods for estimating state-level CO_2, CH_4, and N_2O emissions and removals from management of wetlands consistent with the national *Inventory*, specifically:

- Coastal wetlands remaining coastal wetlands (CO_2, CH_4)

- Peatlands remaining peatlands (CO_2, CH_4, and N_2O)

5.1.7.1 Coastal Wetlands Remaining Coastal Wetlands

5.1.7.2 Background

Consistent with ecological definitions of wetlands, the United States has historically included under the category of Wetlands those coastal shallow water areas of estuaries and bays that lie within the extent of the Land Representation. The national *Inventory* includes all privately owned and publicly owned coastal wetlands (i.e., mangroves and tidal marsh) along the oceanic shores on the conterminous United States but does not include Coastal Wetlands Remaining Coastal Wetlands in Alaska or Hawaii. Soil and biomass C stocks from seagrasses are not currently included in the *Inventory* because of insufficient data on distribution, change through time, and carbon (C) stocks or C stock changes as a result of anthropogenic influence. Additionally, the estimates of N_2O emissions from aquaculture are only available at the national level because of data limitations and have not been included in the current state estimates.

Under the Coastal Wetlands Remaining Coastal Wetlands category, the following emissions and removals subcategories are quantified at the state level:

- Carbon stock changes and CH_4 emissions on Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands,
- Carbon stock changes on Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands, and
- Carbon stock changes on Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands.

5.1.7.3 Methods/Approach

To compile national estimates of carbon stock changes and CH_4 emissions from Coastal Wetlands Remaining Coastal Wetlands for the national *Inventory*, estimates for each state and the District of Columbia with coastal wetlands were produced and summed into a national total. A description of the methods and data used to estimate state-level emissions is provided in Chapter 6, Section 6.8 (pages 6-96 through 6-115) of the national *Inventory* available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf. Please note that estimates for Hawaii and Alaska are not included in the national total or available at the state level at this time.

States (plus the District of Columbia) with coastal wetlands currently included in the national *Inventory* are Alabama, California, Connecticut, Delaware, Florida, Georgia, Louisiana, Maine, Maryland, Massachusetts, Mississippi, New Hampshire, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, South Carolina, Texas, Virginia, and Washington.

5.1.7.4 Uncertainty

Uncertainty estimates for each of the emissions and removals categories are only available at the national level. A brief overview of the uncertainty analyses for each of the subcategories included in the national *Inventory* is provided below.

- Carbon stock changes and CH_4 emissions on Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands: Underlying uncertainties in the estimates of soil and biomass C stock changes and CH_4 emissions include uncertainties associated with Tier 2 literature values of soil C stocks, biomass C stocks and CH_4 flux, assumptions that underlie the methodological approaches applied and uncertainties linked to interpretation of remote sensing data. Uncertainty specific to Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands include differentiation of palustrine and estuarine community classes, which determines the soil C stock and CH_4 flux applied. Uncertainties for soil and biomass C stock data for all subcategories are not available and thus assumptions were applied using expert judgment about the most appropriate assignment of a C stock to a disaggregation of a community class. IPCC Approach 1 (IPCC 2006) was used to calculate these uncertainties. As described further in Chapter 6.8 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), levels of uncertainty in the national estimates in 2019 for biomass carbon stock change are (−24.1/+24.1%), soil carbon stock change are (−17.8/+17.8%) and CH_4 emissions are (−29.8/+29.8%). The combined uncertainty across all subsources is (−36.6/+36.6%), which is primarily driven by the uncertainty in the CH_4 estimates because there is high variability in CH_4 emissions when the salinity is less than 18 ppt. State-level estimates of uncertainty will vary significantly among the states but, in general, tend to have a higher uncertainty than those provided for the United States in the national *Inventory*. For more details on national-level uncertainty see the Uncertainty discussion in Section 6.8 of the national *Inventory*.

- Carbon stock changes on Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands: Underlying uncertainties in the estimates of soil and biomass C stock changes are associated with country-specific (Tier 2) literature values of these stocks, while the uncertainties with the Tier 1 estimates are associated with subtropical estuarine forested wetland DOM stocks. Assumptions that underlie the methodological approaches applied and uncertainties linked to interpretation of remote sensing data are also included in this uncertainty assessment. IPCC Approach 1 (IPCC 2006) was used to calculate these uncertainties. As described further in Chapter 6.8 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), levels of uncertainty in the national estimates in 2019 for biomass carbon stock change are (−24.1/+24.1%), dead organic matter carbon stock change are (−25.8/+25.8%) and soil carbon stock change are (−15/+15%). The combined uncertainty across all subsources is (−32/+32%), which is primarily driven by the uncertainty in the soil carbon stock change estimates. State-level estimates of uncertainty will vary significantly among the states but, in general, tend to have a higher uncertainty than those provided for the United States in the national *Inventory*. For more details on national-level uncertainty see the Uncertainty discussion in Section 6.8 of the national *Inventory*.
- Carbon stock changes on Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands: Underlying uncertainties in estimates of soil and biomass C stock changes include uncertainties associated with country-specific (Tier 2) literature values of these C stocks and assumptions that underlie the methodological approaches applied and uncertainties linked to interpretation of remote sensing data. Uncertainty specific to coastal wetlands include differentiation of palustrine and estuarine community classes that determines the soil C stock applied. IPCC Approach 1 (IPCC 2006) was used to calculate these uncertainties. As described further in Chapter 6.8 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), levels of uncertainty in the national estimates in 2019 for biomass carbon stock change are (−20/+20%), dead organic matter carbon stock change are (−25.8/+25.8%) and soil carbon stock change are (−17.8/+17.8%). The combined uncertainty across all subsources is (−33.4/+33.4%). state-level estimates of uncertainty will vary significantly among the states but, in general, tend to have a higher uncertainty than those provided for the United States in the national *Inventory*. For more details on national-level uncertainty see the Uncertainty discussion in Section 6.8 of the national *Inventory*.

5.1.7.5 Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from Coastal Wetlands

Remaining Coastal Wetlands, see the planned improvements discussions on pp. 6-103, 6-108, and 6-112 through 6-113 of Chapter 6.8, in the national *Inventory*.

While the N_2O flux from aquaculture has not been estimated for this initial version of the *Inventory* by state, the EPA intends to include this in future annual publications of this data.

5.1.7.6 References

Full citations of the references included in Chapters 6.8 (Coastal Wetlands Remaining Coastal Wetlands) of the national *Inventory* are listed on pages 10-80 to 10-83 in Chapter 10, References of the *Inventory* and available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf.

5.1.7.7 Peatlands Remaining Peatlands

5.1.7.8 Background

This section describes methods to estimate state-level CO_2, CH_4, and N_2O emissions from Peatlands Remaining Peatlands (managed peatlands).

Managed peatlands are peatlands that have been cleared and drained for the production of peat. The production cycle of a managed peatland has three phases: land conversion in preparation for peat extraction (e.g., clearing surface biomass, draining), extraction (which results in the emissions reported under Peatlands Remaining Peatlands), and abandonment, restoration, rewetting, or conversion of the land to another use. On-site and off-site emissions also result from managed peatlands. On-site emissions from managed peatlands occur as the land is cleared of vegetation and the underlying peat is exposed to sun and weather. Off-site CO_2 emissions from managed peatlands occur from waterborne carbon losses and the horticultural and landscaping use of peat.

5.1.7.9 Methods/Approach

State-level estimates are based on the national-level methods included in Chapter 6.8, Wetlands Remaining Wetlands of the national *Inventory.* State-level peat production was estimated using Bureau of Mines and USGS's Minerals Yearbooks from 1990–2018, covering the contiguous 48 states and the District of Columbia. For Alaska, the method is the same as the national-level method; the national *Inventory* historically breaks out peat production and emissions Separately for Alaska because of data availability. The following are not estimated:

- Hawaii and Puerto Rico: peat production data were not available, and regional data provided in the USGS yearbooks did not note these states as peat producers.

For annual state-level peat production for 1990–2019, the primary activity data used to estimate emissions were calculated as follows given that no single data source covers all years:

- For 1990–1993, state-level annual peat production data were obtained from the Bureau of Mines Minerals Yearbooks (Bureau of Mines, 1990, 1991, 1992, 1993). These data were available for only select states and The Bureau of Mines also reported a total national production value. The Bureau of Mines state peat production data were summed by year to obtain total *known* state peat production. The total known state peat production value was subtracted from the total national peat production of the conterminous 48 states available from the Bureau of Mines annual Minerals Yearbooks (Bureau of Mines, 1990, 1991, 1992, 1993) to obtain the peat production for states not accounted for in the Bureau of Mines state-level data. The peat production not accounted for in the state-level data was equally distributed among the remaining states with no Bureau of Mines data by dividing the unaccounted for peat production value by the number of remaining states. See Appendix E.
- For 1994–1997, state-level annual peat production data were obtained from the USGS Minerals Yearbooks-for those years, respectively (USGS 2020a). Regional total data became available in 1994. To

determine peat production for states within a “peat-producing region” (i.e., Northeast, Great Lakes, Southeast, West), but with no individual reported peat production data, individual state values were summed and then subtracted from the available regional total peat production value to determine the peat production not accounted for in the regional data.-The peat production for states with individual reported peat production data and peat production estimated from region-based peat production data were then summed. This value was subtracted from the total national peat production of the contiguous 48 states available from the USGS annual Minerals Commodities Summary (2020b). The remaining peat production value was then equally distributed among the remaining states that are not within a peat-producing region by dividing the unassigned peat production value by the number of remaining states. See Appendix E.

- For 1998–2018, state-level annual peat production data were obtained from the USGS Minerals Yearbooks (USGS 2020a) and 2018 tables-only (USGS 2020c) release of the USGS Minerals Yearbook or the respective years. To determine peat production for states within a “peat-producing region” (i.e., East, Great Lakes, West), but with no individual reported peat production data, individual state values were summed and then subtracted from the available regional total peat production value to determine the peat production not accounted for in the regional data. *Note that between 1997 and 1998, peat-producing regions changed from Northeast, Great Lakes, Southeast, and West to East, Great Lakes, and West. States placed within these regions varied from year to year.* The peat production for states with individual reported peat production data and peat production estimated from region-based peat production data were then summed. This value was subtracted from the total national peat production of the contiguous 48 states available from the USGS annual Minerals Commodities Summary (USGS 2020b). The remaining peat production value was then equally distributed among the remaining states that are not within a peat-producing region by dividing the remaining peat production value by the number of remaining states. Where state-level values from the USGS annual Mineral Commodities Summary summed greater than the total annual peat production (2001, 2006, 2008, 2009, 2010, 2014, 2015, 2016, and 2018), data were normalized to equal the annual peat production data for consistency. See Appendix E.
- 2019 state-level peat production was estimated as an average fraction of total peat production for the previous 10 years because 2019 USGS data were not available at the time of *Inventory* development. There is annual variability in the peat production values, which lends itself to using an average, rather than relying solely on the previous year (2018) to estimate peat production. An average percentage was estimated by calculating the average fraction of total U.S. peat production over the past 10 years for a given state. This average fraction was then multiplied by the 2019 total U.S. peat production of the conterminous 48 states available from the USGS annual Minerals Commodities Summary. See Appendix E.

Following peat production estimation, peat production area was calculated using a standard conversion factor from mass of peat production to land area required for that mass of peat production: 100 tonnes of peat per Hectare per year (Vacuum method, Canada) (Cleary et al. 2005).

To estimate state-level emissions from peatlands remaining peatlands), national assumptions were applied to estimate types of peat soil (percentage nutrient rich vs. percentage nutrient poor peat soil), which affects emissions. Six separate calculations were then performed to yield CO_2, CH_4, and N_2O emissions estimates.

- Emissions factors for off-site CO_2 emissions from horticulture use (which differentiates between rich and poor peat) and dissolved organic carbon were applied to peat production and the areas of peat production were calculated to yield off-site CO_2 emissions. Because of a lack of peat application data, off-site peat was assumed to be applied where it was produced. (The EPA acknowledges that this assumption increases uncertainty and acknowledges that although reasonable at a national level it is less reasonable at the state level. The EPA intends to review this assumption. See Planned Improvements below.)

- An emissions factor for on-site CO_2 emissions of drained organic soils was applied to peat production to yield on-site CO_2 emissions.
- Emissions factors for direct CH_4 emissions for drained land surfaces and drainage ditches created from peat extraction were applied to the peat production area to yield on-site CH_4 emissions.
- An emissions factor for on-site N_2O emissions was applied to the peat production area of nutrient-rich peat soil only to yield on-site N_2O emissions.

5.1.7.10 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2, CH_4 and N_2O from Peatlands Remaining Peatlands were calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 6 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), levels of uncertainty in the national estimates in 2019 were CO_2 (−16/+16%), CH_4 (−59/+78%) and N_2O (−56/+56%). State-level estimates have a higher uncertainty due to apportioning portions of the national or default emission estimates to states that did not have peat production data available. These assumptions were required due to a general lack of available state-level data for peat production. For more details on national-level uncertainty, see the Uncertainty discussion in Section 6.8 of the national *Inventory*.

5.1.7.11 Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for state GHG estimates are based on those used in the national *Inventory*. In addition, the methodology used to estimate state-level emissions will be reviewed and revised over time as to identify other data to update assumptions (e.g., data and approaches to proxy peat production (better refine where peat is produced) and consumption). The EPA plans to also assess estimating emissions for Hawaii and applicable Territories, pending data availability. To find information on planned improvements to refine methods for estimating emissions and removals from wetlands remaining wetlands (coastal wetlands remaining coastal wetlands and peatlands remaining peatlands), see the planned improvements discussion on pages 6-95, 6-96 described in the national *Inventory* at the link provided above.

5.1.7.12 References

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U.S. Geological Survey (USGS). (2020c). *Minerals Yearbook: Peat – Tables-only release (2018).* U.S. Geological Survey, Reston, VA. Available online at: http://minerals.usgs.gov/minerals/pubs/commodity/peat/index.html#myb

Full citations of other references relevant to Chapters 6.8 (Wetlands Remaining Wetlands) and 6.9 (Land Converted to Wetlands) of the national *Inventory* are listed on pages 10-80 to 10-83 in Chapter 10, References of the *Inventory* and available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf.

5.1.8 Land Converted to Wetlands (NIR Section 6.9)

This section describes methods to estimate state-level CO_2 and CH_4 emissions from Lands Converted to Vegetated Coastal Wetlands consistent with the national *Inventory*.

5.1.8.1 Background

Land Converted to Vegetated Coastal Wetlands occurs as a result of inundation of unprotected low-lying coastal areas with gradual sea-level rise, flooding of previously drained land behind hydrological barriers, and through active restoration and creation of coastal wetlands through removal of hydrological barriers. Land use conversions into coastal wetlands can result in carbon stock changes to all coastal wetland carbon pools (i.e., aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon) and emissions of CH_4 if inundated with fresh water. This chapter provides estimates of CO_2 and CH_4 emission and removals resulting from conversion of cropland, grassland, wetlands, settlements, and other lands to vegetated coastal wetlands.

5.1.8.2 Methods/Approach

To compile national estimates of carbon stock changes and CH_4 emissions from land converted to vegetated coastal wetlands for the national *Inventory*, estimates for each state and the District of Columbia with coastal wetlands were produced and summed into a national total. A description of the methods and data used to estimate state-level emissions is provided in Chapter 6, Section 6.9 (pages 6-115 through 6-121) of the national *Inventory* available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf. Please note that estimates for Hawaii and Alaska are not included in the national total or available at the state level at this time.

States (plus the District of Columbia) with coastal wetlands currently included in the national *Inventory* are Alabama, California, Connecticut, Delaware, Florida, Georgia, Louisiana, Maine, Maryland, Massachusetts, Mississippi, New Hampshire, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, South Carolina, Texas, Virginia, and Washington.

5.1.8.3 Uncertainty

Underlying uncertainties in estimates of soil C removal factors, biomass change, DOM, and CH_4 emissions include error in uncertainties associated with Tier 2 literature values of soil C removal estimates, biomass stocks, DOM, and IPCC default CH_4 emission factors, uncertainties linked to interpretation of remote sensing data, as well as assumptions that underlie the methodological approaches applied. IPCC Approach 1 (IPCC 2006) was used to calculate these uncertainties. As described further in Chapter 6.9 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), levels of uncertainty in the national estimates in 2019 for biomass carbon stock change are (−20/+20%), dead organic matter carbon stock change are (−25.8/+25.8%), soil carbon stock change are (−17.8/+17.8%) and CH_4 emissions are (−29.9/+29.9%). The combined uncertainty across all subcategories (−42.2/+42.2%). State-level estimates of uncertainty will vary significantly among the states but, in general, tend to have a higher uncertainty than those provided for the United States in the national *Inventory*. For more details on national-level uncertainty see the Uncertainty discussion in Section 6.9 of the national *Inventory*.

5.1.8.4 Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from Land Converted to Vegetated Coastal Wetlands, see the planned improvements discussions on page 6-121 of Chapter 6.9, in the national *Inventory*.

5.1.8.5 References

U.S. Environmental Protection Agency. (April 2021). *Inventory* of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

Full citations of the references included in Chapters 6.9 (Land Converted to Wetlands) of the national *Inventory* are listed on pages 10-82 to 10-84 in Chapter 10, References of the *Inventory* and available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf.

5.1.9 Settlements Remaining Settlements (NIR Section 6.10)

This section presents methods used to estimate state-level CO_2, CH_4, and N_2O emissions and removals from Settlement lands and Remaining Settlement lands consistent with the national *Inventory*. Settlements are land uses where human populations and activities are concentrated. The section is organized to address the following subcategories:

- Carbon dioxide emissions from drained organic soils (CO_2)
- Changes in carbon stocks in settlement trees (CO_2)
- Nitrous oxide emissions from settlement soils (N_2O)
- Changes in yard trimmings and food scrap carbon stocks in landfills (CO_2)

5.1.9.1 Soil Carbon Stock Changes

5.1.9.2 Background

Soil organic C stock changes for Settlements Remaining Settlements occur in both mineral and organic soils. However, the United States does not estimate changes in soil organic C stocks for mineral soils in Settlements Remaining Settlements. This approach is consistent with the assumption of the Tier 1 method in the 2006 IPCC Guidelines (IPCC 2006) that inputs equal outputs, and therefore the soil organic C stocks do not change. In contrast, drainage of organic soils can lead to continued losses of C for an extended period of time.

Drainage of organic soils is common when wetland areas have been developed for settlements. Organic soils, also referred to as Histosols, include all soils with more than 12 to 20% organic C by weight, depending on clay content. The organic layer of these soils can be very deep (i.e., several meters), and form under inundated conditions that results in minimal decomposition of plant residues. Drainage of organic soils leads to aeration of the soil that accelerates decomposition rate and CO_2 emissions. Due to the depth and richness of the organic layers, C loss from drained organic soils can continue over long periods of time, which varies depending on climate and composition (i.e., decomposability) of the organic matter. See Chapter 6 of the national *Inventory* for more information (EPA 2021).

5.1.9.3 Methods/Approach

The EPA compiles state-level estimates of soil carbon stock changes using the same methods applied in the national *Inventory*. Please see the methodologies are described in Chapter 6, Section 6.10 (pages 6-122 through 6-125) of the national *Inventory* available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf. The EPA used a hybrid Approach 1 and Approach 2 for State-level estimates. The current national *Inventory* includes state-level emissions for the years 1990–2015 for soil organic C stock changes. The remaining years in the time series were only estimated at the national scale using a linear extrapolation method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2019. Estimates are included for all states with the exception of Alaska.

5.1.9.4 Uncertainty

The overall uncertainty associated with national estimates from Soil Carbon Stock Changes is described in Chapter 6 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021). Uncertainty for the Tier 2 approach is derived using a Monte Carlo approach. The uncertainty for total Soil Carbon Stock Changes in 2019 ranged from −53% to +53%.

5.1.9.5 Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from Soil Carbon Stock Changes, see the planned improvements discussions on pages 6-124 and 6-125 of Chapter 6.10, in the national *Inventory*.

5.1.9.6 References

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

Full citations of the references included in Chapters 6.10 (Settlement Remaining Settlement) of the national *Inventory* are listed on pages 10-84 to 10-85 in Chapter 10, References of the *Inventory* and available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf.

5.1.10 Changes in Carbon Stocks in Settlement Trees

5.1.10.1 Background

In settlement areas, the anthropogenic impacts on tree growth, stocking and mortality are particularly pronounced (Nowak 2012) in comparison to forest lands where non-anthropogenic forces can have more significant impacts. Trees in settlement areas of the United States are a significant sink over the time series. Dominant factors affecting carbon flux trends for settlement trees are changes in the amount of settlement area (increasing sequestration due to more settlement lands and trees) and net changes in tree cover (e.g., tree losses vs tree gains through planting and natural regeneration), with percent tree cover trending downward recently. In addition, changes in species composition, tree sizes and tree densities affect base C flux estimates. Annual sequestration increased by 35% between 1990 and 2019 due to increases in settlement area and changes in tree cover. Trees in settlements often grow faster than forest trees because of their relatively open structure (Nowak and Crane 2002). Because tree density in settlements is typically much lower than in forested areas, the C storage per hectare of land is in fact smaller for settlement areas than for forest areas. Also, percent tree cover in settlement areas are less than in forests and this tree cover varies significantly across the United States (e.g., Nowak and Greenfield 2018a).

5.1.10.2 Methods/Approach

To compile national estimates of CO_2 emissions and removals from carbon stock changes from settlement trees for the national *Inventory*, estimates for all 50 states and the District of Columbia were produced and summed into a national total. In this case, the EPA is applying an Approach 1 method (i.e., using methods consistent for with the national *Inventory*). A description of the methods and data used to estimate changes in carbon stocks in settlement trees is found in Chapter 6, Section 6.10 (pages 6-125 through 6-132) of the national *Inventory* (EPA 2021) available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf.

5.1.10.3 Uncertainty

Uncertainty associated with changes in C stocks in settlement trees includes the uncertainty associated with settlement area, percent tree cover in developed land and how well it represents percent tree cover in settlement areas and estimates of gross and net C sequestration for each of the 50 states and the District of Columbia. Additional uncertainty is associated with the biomass models, conversion factors, and decomposition assumptions used to calculate C sequestration and emission estimates (Nowak et al. 2002). These results also exclude changes in soil C stocks, and there is likely some overlap between the settlement tree C estimates and the forest tree C estimates (e.g., Nowak et al. 2013). IPCC Approach 2 (IPCC 2006) was used to calculate these uncertainties. As described further in Chapter 6.10 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), levels of uncertainty in the national estimates in 2019 for carbon stock change are (−51/+52%). State-level estimates of uncertainty will vary significantly among the states but, in general, tend to have a higher uncertainty than those provided for the United States in the national *Inventory*. For more details on national-level uncertainty see the Uncertainty discussion in Section 6.10 of the national *Inventory*.

5.1.10.4 Planned Improvements

The planned improvements are consistent with those planned for improving national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory*. To review planned improvements to refine methods for estimating changes in Settlement trees carbon stocks, see the planned improvements discussion on page 6-132 of Section 6.10 in the national *Inventory* for a description of future work to further refine these estimates.

5.1.10.5 References

Nowak, D.J. and D.E. Crane (2002) Carbon storage and sequestration by urban trees in the United States. Environmental Pollution 116(3):381–389.

Nowak, D.J., E.J. Greenfield, R.E. Hoehn, and E. Lapoint (2013) Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental Pollution 178: 229-236.

Nowak, D.J. and E.J. Greenfield (2018a) U.S. urban forest statistics, values and projections. Journal of Forestry. 116(2):164–177.

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

5.1.11 N_2O Emissions from Settlement Soils

5.1.11.1 Background

Of the synthetic N fertilizers applied to soils in the United States, approximately 1 to 2% are currently applied to lawns, golf courses, and other landscaping within settlement areas, and contributes to soil N_2O emissions. The area of settlements is considerably smaller than other land uses that are managed with fertilizer, particularly cropland soils, and therefore, settlements account for a smaller proportion of total synthetic fertilizer application in the United States. In addition to synthetic N fertilizers, a portion of surface applied biosolids (i.e., treated sewage sludge) is used as an organic fertilizer in settlement areas, and drained organic soils (i.e., soils with high organic matter content, known as Histosols) also contribute to emissions of soil N_2O.

N additions to soils result in direct and indirect N_2O emissions. Direct emissions occur onsite due to the N additions in the form of synthetic fertilizers and biosolids as well as enhanced mineralization of N in drained organic soils. Indirect emissions result from fertilizer and biosolids N that is transformed and transported to another location in a form other than N_2O (i.e., ammonia [NH_3] and nitrogen oxide [NO_x] volatilization, nitrate [NO3-] leaching and runoff), and later converted into N_2O at the offsite location. The indirect emissions are assigned to settlements because the management activity leading to the emissions occurred in settlements (EPA 2021)

5.1.11.2 Methods/Approach

The EPA compiles state-level estimates of N_2O Emissions from Settlement Soils using the same methods applied in the national *Inventory*. Please see the methodologies are described in Chapter 6, Section 6.10 (pages 6-132 through 6-135) of the national *Inventory* available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf. The EPA applied a hybrid Approach 1 and Approach 2 for state-level estimates. The current national *Inventory* includes state-level emissions for the years 1990–2015 for synthetic N and N inputs from drained organic soils. The remaining years in the time series were only estimated at the national scale using a surrogate data method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2019. Soil N_2O emissions for additions of biosolid N are only estimated at the national scale for the entire time series. For this source of N, soil N_2O emissions were disaggregated to the state-level based on the proportion of the U.S. population occurring in each state. Estimates are included for all states with the exception of Alaska.

5.1.11.3 Uncertainty

The overall uncertainty associated with national estimates from N_2O emissions from Settlement Soils is described in Chapter 6 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021). As described:

- The amount of N_2O emitted from settlement soils depends not only on N inputs and area of drained organic soils, but also on a large number of variables that can influence rates of nitrification and denitrification, including organic C availability; rate, application method, and timing of N input; oxygen gas partial pressure; soil moisture content; pH; temperature; and irrigation/watering practices. The effect of the combined interaction of these variables on N_2O emissions is complex and highly uncertain. The IPCC default methodology does not explicitly incorporate any of these variables, except variation in the total amount of fertilizer N and biosolids application, which in turn, leads to uncertainty in the results.

- Uncertainties exist in both the fertilizer N and biosolids application rates in addition to the emission factors. Uncertainty in the area of drained organic soils is based on the estimated variance from the NRI survey. For biosolids, there is uncertainty in the amounts of biosolids applied to nonagricultural lands and used in surface disposal. These uncertainties are derived from variability in several factors, including: (1) N content of biosolids; (2) total sludge applied in 2000; (3) wastewater existing flow in 1996 and 2000; and (4) the biosolids disposal practice distributions to nonagricultural land application and surface disposal. In addition, there is uncertainty in the direct and indirect emission factors that are provided by IPCC (2006).

Uncertainty is propagated through the calculations of N_2O emissions from fertilizer N and drainage of organic soils based on a Monte Carlo analysis. The overall levels of uncertainty for national *Inventory* Direct N_2O Emissions from Soils and Indirect N_2O Emissions are −29/+41% and −39/+39%, respectively.

5.1.11.4 Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating N_2O emissions from settlement soils, see the planned improvements discussions on page 6-135 of Chapter 6.10 in the national *Inventory*.

5.1.11.5 References

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

Full citations of the references included in Chapters 6.10 (Settlement Remaining Settlement) of the national *Inventory* are listed on pages 10-84 to 10-85 in Chapter 10, References of the *Inventory* and available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf.

5.1.12 Changes in Yard Trimmings and Food Scrap Carbon Stocks in Landfills

5.1.12.1 Background

In the United States, yard trimmings (i.e., grass clippings, leaves, and branches) and food scraps account for a significant portion of the municipal waste stream, and a large fraction of the collected yard trimmings and food scraps are put in landfills. Carbon (C) contained in landfilled yard trimmings and food scraps can be stored for very long periods. Carbon stock changes in yard trimmings and food scraps and associated CO_2 emissions and removals are reported under Settlements Remaining Settlements because the bulk of the C, which comes from yard trimmings, originates from settlement areas. While the majority of food scraps originate from cropland and grassland, in the national *Inventory* they are reported with the yard trimmings in the Settlements Remaining Settlements section. Additionally, landfills are considered part of the managed land base under settlements and reporting these C stock changes that occur entirely within landfills fits most appropriately in the Settlements Remaining Settlements section.

5.1.12.2 Methods/Approach

State-level emissions were compiled using Approach 2, or by allocating net national changes in carbon stocks and associated emissions and removals to states, the District of Colombia, and territories based on the state’s fraction of total U.S. population. This approach was applied due to unavailability of state-level activity data on mass of yard trimmings and food scraps discarded to managed landfills. The EPA used state population estimates from the U.S. census. The total population of the 50 states, plus the population of the District of Columbia and Puerto Rico, was used as the total U.S. population.

State emissions were calculated using the following stepwise process:

Step 1. The EPA obtained U.S. census population data from the U.S Census Bureau (U.S. Census Bureau 2002, 2011, and 2019; SDC-PR 2019).

Step 2. The fraction of the total U.S. population was calculated for each state, including the District of Columbia and Puerto Rico, and calculated as a fraction of the total U.S. population.

Step 3. The fraction of the population was multiplied by the total national emissions calculated for the 1990–2019 *Inventory*. This calculation was also performed for grass, leaves, branches, and food scraps to yield total state emissions for each subcategory.

5.1.12.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CO_2 from Changes in Yard Trimmings and Food Scraps Carbon Stocks were calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 6 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), levels of uncertainty in the national estimates in 2019 were CO_2 (−61/+57%). State-level estimates have a higher uncertainty due to apportioning the national estimates to states based on population. These assumptions were required because of a general lack of available state-level data for peat production. For more details on national-level uncertainty, see the Uncertainty discussion in Section 6.10 of the national *Inventory*.

5.1.12.4 Planned Improvements

The EPA will review and revise the state-level methodology over the time series, and as appropriate, assess if other information would better reflect state-level activity (e.g., mass of yard trimmings and food scraps discarded to managed landfills) to improve the accuracy of the estimates. For example, determining states with more densely populated cities may imply lower yard trimming contributions. Additional planned improvements are consistent with those planned for improving national estimates given that the underlying methods for state GHG estimates are the derived from those in the national *Inventory*. The discussion of planned improvements to refine methods for estimating changes in carbon stocks in landfilled yard trimmings at the national level discussed starts on pp. 6-141 of Chapters 6.1 in the national *Inventory*.

5.1.12.5 References

SDC-PR. (2019). State Data Center of Puerto Rico. Population of Puerto Rico from 1990-1999 from "Estimados anuales poblacionales de los municipios desde 1950," Instituto de Estadísticas.

U.S. Census Bureau, Population Division. (April 11, 2002). Table CO-EST2001-12-00 - Time Series of Intercensal State Population Estimates: April 1, 1990 to April 1, 2000. 2002

U.S. Census Bureau, Population Division. (September 2011). Table 1. Intercensal Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2010 (ST-EST00INT-01).

U.S. Census Bureau, Population Division. (December 2019). Table 1. Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2019 (NST-EST2019-01).

U.S. Environmental Protection Agency. (April 2021). *Inventory* of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Full citations of all other relevant references to estimating Landfilled Yard Trimmings and Food Scraps Carbon Stock Changes are included in Chapter 6.10 *(Settlements Remaining Settlements)* are listed in Chapter 10 titled References of the national *Inventory* on pages 10-85 to 10-89 and available online at https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf.

5.1.13 Land Converted to Settlements (NIR Section 6.11)

5.1.13.1 Background

Land Converted to Settlements includes all settlements in an inventory year that had been in another land use(s) during the previous 20 years. For example, cropland, grassland, or forest land converted to settlements during the past 20 years would be reported in this category. Converted lands are retained in this category for 20 years as recommended by IPCC (2006). The national *Inventory* includes all settlements in the conterminous United States and Hawaii but does not include settlements in Alaska. Areas of drained organic soils on settlements in federal lands are also not included in the national *Inventory*.

Land use change can lead to large losses of carbon (C) to the atmosphere, particularly conversions from forest land. Moreover, conversion of forest to another land use (i.e., deforestation) is one of the largest anthropogenic sources of emissions to the atmosphere globally, although this source may be declining globally according to a recent assessment.

IPCC (2006) recommends reporting changes in biomass, dead organic matter, and soil organic C stocks due to land use change. All soil organic C stock changes are estimated and reported for Land Converted to Settlements, but there is limited reporting of other pools in the national *Inventory*. Loss of aboveground and belowground biomass, dead wood and litter C are reported for Forest Land Converted to Settlements, but not for other land use conversions to settlements (EPA 2021).

5.1.13.2 Methods/Approach

The EPA compiles state-level estimates of Land Converted to Settlements using the same methods applied in the national *Inventory*. Please see the methodologies are described in Chapter 6, Section 6.10 (pages 6-141 through 6-147) of the national *Inventory* available online here: https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf. The EPA used a hybrid Approach 1 and Approach 2 for state-level estimates. The current national *Inventory* includes state-level emissions for the years 1990–2019 for biomass, standing dead, deadwood, and litter, and for the years 1990–2015 for soil organic C stock changes. The remaining years in the time series for soil organic C stock changes were only estimated at the national scale using a surrogate data method, and a two-step process was used to approximate the state-level emissions for the remaining years. First, the average proportion of the total national emissions was computed for each state from 2013–2015. Second, the state-level proportions were multiplied by the total national emissions to approximate the amount of emissions occurring in each state for 2016–2019. Estimates are included for all states with the exception of Alaska.

5.1.13.3 Uncertainty

The overall uncertainty associated with national estimates from Land Converted to Settlements is described in Chapter 6 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021). As described:

- The uncertainty analysis for C losses with Forest Land Converted to Settlements is conducted in the same way as the uncertainty assessment for forest ecosystem C flux in the Forest Land Remaining Forest Land category. For additional details, see the Uncertainty Analysis in Annex 3.13.
- The uncertainty analysis for mineral soil organic C stock changes and annual C emission estimates from drained organic soils in Land Converted to Settlements is estimated using a Monte Carlo approach, which is also described in the Cropland Remaining Cropland section.

The overall level of uncertainty for national *Inventory* Land Converted to Settlements estimates is −33/+34%.

5.1.13.4 Planned Improvements

The planned improvements are consistent with those planned for improving the national estimates given that the underlying methods for the state GHG estimates are the same as those in the national *Inventory*. To review the planned improvements to the methods and data for estimating emissions and removals from Land Converted to Settlements, see the planned improvements discussions on pages 6-146 and 6-147 of Chapter 6.10, in the national *Inventory*.

5.1.13.5 References

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

Full citations of the references included in Chapters 6.10 (Settlement Remaining Settlement) of the national *Inventory* are listed on pages 10-87 to 10-89 in Chapter 10, References of the *Inventory* and available online here: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-10-references.pdf.

5.1.14 Other Land Remaining Other Land (NIR Section 6.12) and Land Converted to Other Land (NIR Section 6.13)

Other Land is a land-use category that includes bare soil, rock, ice, and all land areas that do not fall into any of the other five land-use categories (i.e., forest land, cropland, grassland, wetlands, and settlements). Following the guidance provided by the IPCC (2006), C stock changes and non-CO_2 emissions are not estimated for Other Land because these areas are largely devoid of biomass, litter, and soil C pools. However, C stock changes and non-CO_2 emissions are estimated for Land Converted to Other Land during the first 20 years following conversion to account for legacy effects. While the magnitude of these area changes is known (see Table 6-5), research is ongoing to track C across Other Land Remaining Other Land and Land Converted to Other Land. Until such time that reliable and comprehensive estimates of C across these land-use and land-use change categories can be produced, it is not possible to separate CO_2, CH_4, or N_2O fluxes on Land Converted to Other Land from fluxes on Other Land Remaining Other Land at this time. Emissions and removals from other lands and lands converted to other lands will be included in future versions of this publications when they are integrated into the national *Inventory*. See Chapter 6.13 (pg. 6-148) of the national *Inventory* (EPA 2021).

5.1.14.1 References

U.S. Environmental Protection Agency. (April 2021). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. Office of Air and Radiation, Office of Atmospheric Programs, U.S. Environmental Protection Agency, Washington, DC. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

6 Waste (NIR Chapter 7)

For this methodology report, the Waste chapter consists of two subsectors: Solid Waste Disposal and Wastewater Treatment and Discharge. More information on national-level emissions and methods is available in Chapter 7 of the national *Inventory*. Note emissions from waste incineration are discussed in Chapter 2 section 2.1.4 of this methodology report. Table 6-1 summarizes the different approaches used to estimate state-level waste emissions and completeness across states. Geographic completeness is consistent with the national *Inventory*. The sections below provide more detail on each category.

Table 6-1. Overview of Approaches for Estimating State-Level Waste Sector Greenhouse Gas Emissions and Sinks

Category	Gas	Approach	Geographic Completeness
Landfills	CH_4	Approach 2	Includes emissions from all states, Washington D.C., and territories (i.e., Guam, Puerto Rico) as applicable.
Wastewater	CH_4, N_2O	Approach 2	Includes emissions from all states, Washington D.C. and territories[1] (i.e., Guam, Puerto Rico, US Virgin Islands, and Northern Mariana Islands for domestic wastewater).
Composting	CH_4, N_2O	Approach 2	Includes emissions from all states, Washington D.C., and territories as applicable.
Standalone Anaerobic Digestion	CH_4	Approach 2	Includes emissions from all states, Washington D.C., and territories as applicable.

[1] Emissions are likely occurring in other US territories; however, due to a lack of available data and the nature of this category, this analysis includes emissions for only the territories indicated. Territories not listed are not estimated.

6.1 Solid Waste Disposal

This section presents the methodology used to estimate the emissions from solid waste disposal management activities, which consist of the following sources:

- Landfills (MSW and industrial waste) (CH_4)
- Composting (CH_4, N_2O)
- Stand-alone anaerobic digestion at biogas facilities (CH_4)

6.1.1 Landfills (NIR Section 7.1)

6.1.1.1 Background

After being placed in a landfill, organic waste (such as paper, food scraps, and yard trimmings) is initially decomposed by aerobic bacteria. After the oxygen has been depleted, the remaining waste is available for consumption by anaerobic bacteria, which break down organic matter into substances such as cellulose, amino acids, and sugars. These substances are further broken down through fermentation into gases and short-chain organic compounds that form the substrates for the growth of methanogenic bacteria. These CH_4-producing anaerobic bacteria convert the fermentation products into stabilized organic materials and biogas consisting of approximately 50% biogenic CO_2 and 50% CH_4, by volume. Methane and CO_2 are the primary constituents of landfill gas generation and emissions. Consistent with the 2006 IPCC Guidelines, net CO_2 flux from carbon stock changes in landfills are estimated and reported under the LULUCF sector (see Chapter 5 of this report) (IPCC 2006).

More information on emission pathways and national-level emissions from landfills and associated methods can be found in the Waste chapter (Chapter 7), Section 7.1 of the national *Inventory* available online at https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-7-waste.pdf?VersionId=skK.lO1zbaYrNwnmUKNiyepctaM_yV3z.

6.1.1.2 Methods/Approach (Municipal Solid Waste Landfills)

The MSW landfill state emissions inventories applied Approach 2 for disaggregating national estimates and relied heavily on the subpart HH data collected through the GHGRP. As explained in the methodology discussion of Section 7.1 of the national *Inventory*, the EPA uses an IPCC Tier 2 approach and several data sources, methods, and assumptions to estimate emissions (see pp. 7-7 through 7-12 for details on the inputs and equations). The state inventories applied a state percentage of either waste landfilled or net CH_4 emissions by state as reported to subpart HH (EPA 2019) as a proxy for each state's share of CH_4 net emissions over the time series. Table 6-2 below summarizes the methodology used to develop the state-level estimates, followed by additional detail. The annual state percentages were applied to the national estimates to retain an IPCC Tier 2 approach consistent with the national *Inventory*.

Table 6-2. Summary of Approaches to Disaggregate the National *Inventory* for MSW Landfills Across Time Series

Time Series Range	Summary of Method
1990–2009	• Applied the percentage of waste landfilled by state (aggregated total as reported by landfills in each state to subpart HH for historical years) to the national CH_4 net emissions for each year (IPCC 2006 Tier 2) • The state percentage approach accounts for all emissions, including those that were calculated in the national *Inventory* through back-casting subpart HH data and scaling up emissions to account for smaller landfills that do not report through subpart HH.
2010–2019	• Applied the percentage of net CH_4 emissions by state (aggregated total as reported by landfills in each state to subpart HH) to the national CH_4 net emissions for each year. • The state percentage approach accounts for all emissions, including those calculated by scaling up emissions to account for smaller landfills that do not report through subpart HH.

Historical waste disposed of since a facility began operating is reported using prescribed methods in the rule to maintain consistency across the facility data. The quantity of waste landfilled by subpart HH reporters was assumed to be representative of the universe of MSW landfills in the United States because subpart HH reporters include each state's highest emitting MSW landfills, which is directly tied to the quantity of waste landfilled. The national *Inventory* methodology back-casts subpart HH net CH_4 emissions and uses a scale-up factor to account for lower-emitting MSW landfills (e.g., nonreporters). The intent of the scale-up factor is to estimate CH_4 emissions from MSW landfills that do not report to the GHGRP. The national *Inventory* team has put significant effort into identifying landfills that do not report to the GHGRP, most recently in 2020. Basic landfill characteristics such as the landfill name and location, first year of operation, current operational status, and waste-in-place data have been compiled for these landfills, when available. Disaggregating the subpart HH data by state was determined to be a reasonable assumption considering the lack of historical data for landfills that do not report to the GHGRP.

The methodology used for 1990–2009 applies a state percentage of waste landfilled for this time frame as reported by landfills under subpart HH of the GHGRP to the national estimates of CH_4 emissions. Approximately 1,200 MSW landfills have reported to the GHGRP since reporting began in 2010. This approach disaggregates national net emissions values by applying the state percentage as a proxy of net emissions.

The methodology for 2010-2019 applies a state percentage of net CH_4 emissions reported by landfills under subpart HH to the national estimates of CH_4 emissions. Using net CH_4 emissions is consistent with the recent methodological refinements in the national *Inventory* to incorporate reported subpart HH net CH_4 emissions. Unlike the national *Inventory*, scale-up factors for each state were not developed. Developing state-specific scale-up factors would require significant effort; instead, the national emissions values are disaggregated by a proxy that is assumed to be generally representative of state-by-state emissions.

Emissions from managed landfills located in Puerto Rico and Guam were included because facilities in these territories report to subpart HH.

6.1.1.3 Methods/Approach (Industrial Landfills)

The EPA estimates CH_4 emissions from industrial waste landfills for two industry categories consistent with the national *Inventory*: pulp and paper and food and beverage. Data reported to the GHGRP on industrial waste landfills suggest that most of the organic waste that would result in methane emissions is disposed of at pulp and paper and food processing facilities. Information on both industry categories with respect to the amount of waste generated and disposed of in a dedicated industrial waste landfill is limited; thus, the EPA uses a Tier 1 approach to estimate CH_4 emissions. Additionally, no comprehensive list of industrial waste landfills exists. While the information is available in the Waste Business Journal (WBJ), the quality of the data is unknown and the date of data related to each waste management facility included is also unknown. Therefore, the EPA does not have information on the number of industrial waste landfills that were operational over the time series and information regarding the number of industrial waste landfills located in each state. The types and amounts of waste disposed of in the operational industrial waste landfills are also limited.

A portion of pulp and paper mills in the United States report to subpart TT (Industrial Waste Landfills) of the GHGRP. Previous analyses of the 2016 pulp and paper emissions from the GHGRP (RTI 2018) showed that total subpart TT emissions from facilities associated with a pulp and paper NAICS code generally align (within approximately 10 to 20%) of the national *Inventory*'s national estimate of emissions from the pulp and paper manufacturing sector. On the other hand, a small number of facilities associated with a food and beverage NAICS code report to subpart TT, and emissions are vastly different between subpart TT and the national *Inventory*.

Because of the data limitations described above, Approach 2 was used to disaggregate the national *Inventory* CH_4 emissions for both industry categories, rather than a more detailed facility-specific bottom-up approach.

Pulp and Paper Manufacturing

For the pulp and paper source category, we extracted a state-by-state count of mills in the United States from two sources: DataBasin for 2008 and MillsOnline for 2015–2016. The count of facilities is approximately 233 and 332 from DataBasin and MillsOnline, respectively. The count and percentage of mills by state are shown in Appendix F (Table F-1). The Industrial Resources Council states that 430 pulp and paper mills are operational in the United States, although the exact year of this data is unknown and no state-specific counts are provided. According to the Industrial Resources Council, mills are located in 41 states except Alaska, Colorado, North Dakota, Nebraska, Nevada, Rhode Island, South Dakota, Utah, and Wyoming. For comparison, the subpart TT pulp and paper facilities across the 2011–2019 reporting years represent a maximum of 92 facilities located across 21 states.

To estimate CH_4 generation and CH_4 emissions, the DataBasin 2008 percentages by state were applied to the national *Inventory* estimate for the pulp and paper manufacturing sector for 1990–2010, and the MillsOnline

2015–2016 percentages by state were applied for 2011–2019. This approach assumes broadly that each facility is generating an equal amount of waste that is landfilled and, therefore, an equal amount of CH_4 emissions. Consistent with the national *Inventory*, this assumption and approach were used in an attempt to ensure completeness in coverage of industrial waste landfills in the United States because the subpart TT pulp and paper facilities may not equal the total number of pulp and paper facilities disposing of waste in dedicated industrial waste landfills. The exact number of pulp and paper manufacturing facilities that dispose of waste in industrial waste landfills is unknown.

Methane emissions from the pulp and paper sector were disaggregated by applying the percentage of the mills by state as a proxy of facilities generating and disposing of waste in industrial waste landfills. No additional calculations were performed, and the IPCC Tier 1 methodology (IPCC 2006) used to generate the national emissions estimates was applied by default.

Food and Beverage Manufacturing

Minimal data are available to characterize the amounts and types of waste generated nationally from food and beverage manufacturers and disposed of in industrial waste landfills. Less is known about the number of facilities in each state that disposed of waste in a dedicated industrial landfill.

A similar approach using a count of assumed industrial food and beverage manufacturing facilities that dispose of waste in an industrial waste landfill by state was applied to the national food and beverage category estimates. The list of food and beverage manufacturing facilities consists of 13 NAICS codes as shown in Appendix F (Table F-2) comprising 9,175 facilities (can be shared upon request). This list was extracted from the EPA Excess Food Opportunities database (2020 update [EPA 2020a]).

The EPA Excess Food Opportunities database includes a low- and high-end estimate of the amount of excess food generated (tons/year). These data were not used in the methodology. Rather, the average percentage of the amount of excess food generated by each state across the selected NAICS codes was used as a proxy for the share of CH_4 generation and emissions estimates. The same approach used for the pulp and paper manufacturing sector was applied whereby the average percentage of excess food by state was applied to the national total amount of CH_4 generation and CH_4 emissions for each year of the time series. This is a broad assumption but allows for the calculation of emissions with limited knowledge on the location of facilities disposing of food waste into industrial waste landfills.

The percentage of excess food generated by state is presented in Appendix F (see Table F-3). Note that the Excess Food Opportunities database and map do not indicate the management pathway for the excess food. The EPA Facts & Figures methodology (EPA 2020b) also does not include an estimation of the amount of excess food being disposed of in industrial waste landfills. Therefore, the percentage of waste disposed of is likely overrepresented for some states and is why the estimates for the District of Columbia, the Virgin Islands, and Puerto Rico have been zeroed out.

6.1.1.4 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CH_4 from MSW and industrial waste landfills was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2019 were −25%/+25% of the estimated CH_4 emissions for MSW landfills and −31%/+25% of the estimated CH_4 emissions for industrial waste landfills.

State-level estimates likely have a higher uncertainty due to apportioning the national emissions estimates to each state based on assumptions made to disaggregate the national emissions estimates based on state percentages as reported to the GHGRP and the application of the scale-up factor to nationally compiled landfill gas recovery databases used in the national *Inventory*. Additionally, state-level estimates before the GHGRP began (i.e., before 2010) may have more uncertainty than state-level estimates after the GHGRP began (i.e., 2010 and afterward). For more details on national level uncertainty see the uncertainty discussion in Section 7.2 of the national *Inventory* at the link provided in the Background discussion above.

6.1.1.5 Planned Improvements

Potential refinements to landfill estimation methods include the following:

MSW Landfills

- Planned improvements to the state-level estimates are consistent with those presented in Section 7.1 of the national *Inventory*. In particular, the EPA plans to improve completeness of emissions from all waste management practices (i.e., open dumpsites) in U.S. territories by identifying data and applying methods to include emissions from open dumpsites in territories. Additionally, the 1990–2020 national *Inventory* will separately estimate CH_4 generation, CH_4 recovery, and CH_4 oxidation (activity estimates) for each year in the time series rather than just for 1990 through 2005. These national estimates will allow for state-level MSW landfill activity estimates.

Industrial Waste Landfills

- Identifying a more a complete and comprehensive list of pulp and paper facilities in the United States, including years of operation since 1990. Further quality control on this inventory will be performed by comparing the counts of industrial waste landfills by state in the WBJ Directory 2020.

6.1.1.6 References

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6.1.2 Composting (NIR Section 7.3)

6.1.2.1 Background

This section presents methods used to estimate state-Level GHGs from large-scale commercial composting facilities that typically include sections of the waste that operate in an anaerobic environment where degradable organic carbon in the waste material is broken down, generating CH_4 and N_2O. Even though CO_2 emissions are generated, they are not included in net GHG emissions for composting. Consistent with the national *Inventory*, emissions from residential (backyard) composting are not included in the scope. Additionally, the national *Inventory* assumes windrow is the composting method used, and the waste mixture is homogeneous, consisting primarily of yard waste and some food. Annual throughput data on static and in-vessel commercial composting methods were not identified in secondary (published) data. Consistent with the 2006 IPCC Guidelines, net CO_2 flux from carbon stock changes in waste material is estimated and reported under the LULUCF sector (see Chapter 5 of this report) (IPCC 2006).

More information on emission pathways and national-level emissions from composting and associated methods can be found in the Waste chapter (Chapter 7), Section 7.3 of the national *Inventory* available online at https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-7-waste.pdf?VersionId=skK.lO1zbaYrNwnmUKNiyepctaM_yV3z.

6.1.2.2 Methods/Approach

The EPA compiles national CH_4 and N_2O emissions estimates for commercial composting facilities in the United States using an IPCC Tier 1 method by which an IPCC default emissions factor is applied to the national quantity of material composted. No facility-specific information is used because it is generally unavailable over the time series.

The national *Inventory* was disaggregated to the state level using Approach 2 on the basis of data available for the proportion of material composted by state for select years. Table 6-3 summarizes published state-level estimates of material composted used in this inventory.

Table 6-3. Summary of Availability and Sources for Composting Data

Year Composting Data Available for	Reference Abbreviation (for purposes of this methodology)	Full Reference (Author Year)
2000	BioCycle 2001	Goldstein & Madtes 2001
2002	BioCycle 2004	Kaufman et al. 2004
2004	BioCycle 2006	Goldstein et al. 2006
2006	BioCycle 2008	ArSova et al. 2008
2008	BioCycle 2010	ArSova et al. 2010
2010	EREF 2016	Environmental Research & Education Foundation 2016
2011	Shin 2014	Shin, 2014
2012	ILSR 2014	Institute for Local Self-Reliance 2014
2013	EREF 2016	EREF 2016
2016	WBJ 2016	Waste Business Journal 2016
2020	WBJ 2020	Waste Business Journal 2020

The state-level data were largely compiled from voluntary surveys of state agencies that reported MSW generated and estimates by relevant management pathways (e.g., landfill, recycling, composting). Composting estimates may be directly reported by the state agencies or estimated or adjusted by the report authors using the best available information for available years. Occasionally, data for some states are not available and are indicated as such in the data sources. The WBJ is an annually updated database of which the quality is unknown, but it is used because there is a general lack of data. Both the WBJ 2016 and 2020 were used to estimate state data for 2017–2019. Completeness is one limitation with the available state data used.

The general methodology to estimate the annual quantity of waste composted per year is as follows:

$$Composted_S = \%_S \times N_C$$

where:

Composted_S = the mass of material composted by state (tons/year)

$\%_S$ = the state percentage of material composted, calculated using available state data (%)

N_C = the national estimate of material composted as reported in the EPA Advancing Sustainable Materials Facts & Figures reports (tons/year) (EPA 2020)

The state percentages of material composted were calculated by dividing each state-reported amount of waste composted by the total of all material composted for that year. The sum of all state-reported data is referred to as national estimates by the report authors, but to avoid confusion with the Facts & Figures data, we refer to this as the sum of state-reported data. Limitations with the state-reported survey data include its voluntary nature and occasional missingness of state data for states that did not provide a survey response. The report authors noted they made assumptions to estimate and adjust data to the extent possible. For years where no state data were reported in a specific survey, the EPA estimated the data using the prior or next year of available data. These gaps were minimal (i.e., five or fewer states for each survey year).

Because state data are only available for select years, interpolation and extrapolation were required to generate estimates for each year of the time series. State proportions applied to 1990–1999 are the same as those for 2000 (BioCycle 2001). No state data exist for this portion of the time series, and there is a large amount of uncertainty surrounding the number of facilities and amount of material composted. This is a conservative approach in that it is unknown when a state began compositing operations, so it is assumed if they had operations in 2000 that they did in 1990 as well. Data in between the survey data were interpolated using the prior year and next year's survey data (the state proportion of material composted). Annual state data were interpolated for 2001, 2003, 2005, 2007, 2009, 2014, 2014, 2017, 2018, and 2019. State percentages for each year are presented in Appendix F (Table F-4).

The formula used for interpolation of the state percentage for the year in question is as follows:

$$y = \left(\frac{y_2 - y_1}{x_2 - x_1}\right) \times (x) - x_1 + y_1$$

where:

y = state percentage of waste composted for the year without data, %

y_1 = state percentage of waste composted for the prior year with data, %

y_2 = state percentage of waste composted for the next year with data, %

x = the year without data

x_1 = the prior year with data

x_2 = the next year with data

The state percentage data were multiplied by the national estimate of material composted from the EPA Facts & Figures reports to cap the total quantity composted across the states and match the state totals to the national *Inventory*. The EPA Facts & Figures national estimates were directly used to estimate the national *Inventory*. The IPCC Tier 1 method used in the national *Inventory* estimates (IPCC 2006),are the product of an emissions factor and the mass of organic waste composted.

The final step in developing the state inventory was estimating the CH_4 and N_2O emissions. For simplicity, the state percentages were multiplied by the annual national emissions estimates.

6.1.2.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CH_4 and N_2O from composting (specifically large-scale, commercial composting facilities) was calculated using the 2006 IPCC Guidelines Approach 1 methodology (IPCC 2006). As described further in Chapter 7 of the national *Inventory*, levels of uncertainty in the national estimates in 2019 were CH_4 (−50%/+50%) and N_2O (−50%/+50%). State-level estimates will have a higher uncertainty than the national estimates because of apportioning the national quantity of material composted (sourced from the EPA Sustainable Materials Management reports and calculated with a mass balance methodology) to each state based on sporadically published waste management data from a voluntary state agency survey for select years. The national methodology also assumes most composting in the United States use the windrow method and treats a homogenous mixture of primarily yard trimmings, some food waste, and some paper waste. For more details on national-level uncertainty, see the uncertainty discussion in Section 7.3 of the national *Inventory,* available online at https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-7-waste.pdf?VersionId=skK.lO1zbaYrNwnmUKNiyepctaM_yV3z.

6.1.2.4 Planned Improvements

In future annual publications, the EPA plans to investigate state volumes of material composted further where the report authors (from referenced composting data sources) indicated potentially combined volumes of waste sent to composting, recycling, and anaerobic digestion. The EPA also plans to confirm annual quantities of material composted in states where data are lacking (e.g., Alaska, Guam). Planned improvements to the national estimates for composting outlined in Section 7.3 (p. 7-57) of the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

6.1.2.5 References

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6.1.3 Stand-Alone Anaerobic Digestion (NIR Section 7.4)

6.1.3.1 Background

Anaerobic digestion is a series of biological processes in the absence of oxygen in which microorganisms break down organic matter, producing biogas and soil. Stand-alone digestion is one of three main categories of anaerobic digestion facilities, which also includes on-farm digesters and digesters at water resource recovery facilities. This section focuses exclusively on stand-alone digesters, which typically manage food waste from different sources, including food and beverage processing industries. Emissions from on-farm digesters and digesters at water resource recovery facilities are reflected under Sections 4.1.2 Manure Management and 6.2.1 Wastewater Treatment and Discharge of this report. Based on available data, anerobic digestion occurs in the following 31 states: Arizona, California, Colorado, Connecticut, Florida, Georgia, Iowa, Idaho, Indiana, Kansas, Massachusetts, Maryland, Maine, Michigan, Minnesota, Missouri, North Carolina, North Dakota, New Hampshire, New Jersey, New York, Ohio, Oregon, Pennsylvania, Rhode Island, Tennessee, Texas, Virginia, Vermont, Washington, and Wisconsin.

At stand-alone digestors, methane (CH_4) emissions may result from a fraction of the biogas that is lost during the process due to leakages and other unexpected events (0 to 10% of the amount of CH_4 generated, IPCC 2006), collected biogas that is not completely combusted, and entrained gas bubbles and residual gas potential in the digested sludge. CO_2 emissions are biogenic in origin and should be reported as an informational item in the Energy Sector (IPCC 2006).

More information on emission pathways and national-level emissions and methods can be found in Section 7.4 of the national *Inventory*.

6.1.3.2 Methods/Approach

The EPA compiles national CH_4 emissions estimates for stand-alone anaerobic digester facilities in the United States using an IPCC Tier 1 method, where an IPCC default emissions factor is applied to the estimated national quantity of material digested. A default CH_4 emissions factor (IPCC 2006) was multiplied by a weighted average annual quantity of material digested by stand-alone digesters from two voluntary EPA data collection surveys (EPA 2018, 2019) and an estimated number of operating facilities per year (see Table 7-47 and Table 7-48, respectively, of the national *Inventory*). No facility-specific quantities of material digested were directly used because of a general lack of facility-specific data over the time series. The methodology applied to generate the national *Inventory* was based on two large assumptions—the number of operational facilities and the weighted average of material digested for two of the 29 years in the time series (1990–2019). The state inventory further takes these assumptions to a state level by assuming that the same percentage of total operational facilities is the same for each year of the time series because of a general lack of data on total operational facilities by state across the time series. Therefore, the state-level inventories are a gross estimate that may be refined in future years if available information by state is obtained.

In the national *Inventory*, the EPA calculated a weighted average of material digested using masked survey data from the two available survey reports for years 2015 and 2016 (EPA 2018, 2019). The weighted average was applied to an estimated number of operational facilities per year to estimate the annual quantity of material digested. The first step to calculating the state inventory was to disaggregate the annual estimates of the material digested. This was disaggregated by applying a state percentage of operational facilities as reported to the two published EPA survey reports (EPA 2018, 2019). The state proportions of operational facilities in 2015 and 2016 are presented in Appendix F (Table F-5).

The state proportions were multiplied by the national quantity digested for each year in the time series, which forced the total quantities across the states to match the national *Inventory* estimates. The same state percentage was used for each year in the time series because of a lack of compiled data on the number of stand-alone digesters by state between 1990 and 2019.

The equation used to estimate the annual quantity of material digested per year by state is presented as Equation 1.

$$Digested_S = \%_S \times N_D \qquad \textit{Equation 1}$$

where:

$Digested_S$ = the quantity of material digested by state (kilotons/year)

$\%_S$ = the state proportion of operational facilities, calculated from the number of operational stand-alone digesters as reported in the EPA surveys (EPA 2018, 2019) for 2015 and 2016; the same state percentage was applied to each year in the time series (%, see Appendix F [Table F-5])

N_D = the annual national estimate of material digested (kilotons/year).

The state-specific annual CH_4 generation estimates were calculated using Equation 2:

$$G_{CH4} = Digested_S \times EF_{CH4} \times \frac{1}{1000} \qquad \textit{Equation 2}$$

where:

G_{CH4} = CH_4 generation from stand-alone anaerobic digesters, kt CH_4

$Digested_S$ = mass (quantity) of material digested by state, kt

EF_{CH4} = CH_4 emissions factor, 0.8 Megagram/Gigagram (Mg/Gg, wet basis) (IPCC 2006)

1/1,000 = conversion factor, Gg/Mg

The national *Inventory* estimates for CH_4 recovery were estimated using the 2 years of available EPA survey data (EPA 2018, 2019). The state-specific CH_4 recovery estimates were calculated using Equation 3:

$$R_{CH4} = \%_S \times \ National\ R_{CH4} \qquad \textit{Equation 3}$$

where,

R_{CH4} = CH_4 recovery from stand-alone anaerobic digesters, kt CH_4

$\%_S$ = state percentage of operational facilities, % (see Appendix F [Table F-5])

National R_{CH4} = national amount of recovered CH_4, kt

Lastly, the state estimates of net CH_4 emissions were calculated by summing the CH_4 generation and CH_4 recovery estimates:

$$Emiss_{CH4} = G_{CH4} - \ R_{CH4} \qquad \textit{Equation 4}$$

where,

$Emiss_{CH4}$ = CH_4 emissions by state, kt

G_{CH4} = CH_4 generation from stand-alone anaerobic digesters, kt CH_4

R_{CH4} = CH_4 recovery from stand-alone anaerobic digesters, kt CH_4

6.1.3.3 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CH_4 from Stand-Alone Anaerobic Digesters was calculated using the 2006 IPCC Guidelines Approach 1 methodology (IPCC 2006). As described further in Chapter 7 of the national *Inventory*, levels of uncertainty in the national estimates in 2019 were CH_4 (−50%/+50%). State-level estimates will have a higher uncertainty because of apportioning the national emissions estimates to each state based solely on the number of stand-alone anerobic digester facilities from EPA survey data collected between 2015 and 2018. Emissions estimates before 2015 will have a higher uncertainty than those in 2015 and later years. These assumptions were required because of limited facility-specific data presented in secondary resources. No attempt was made to collect state-maintained permitting data on annual throughput because the EPA is collecting this information under an Information Collection Request. For more details on national level uncertainty see the uncertainty discussion in Section 7.4 of the national *Inventory*.

6.1.3.4 Planned Improvements

The planned improvements are consistent with those planned for improving national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory*. To find information on planned improvements to refine methods for estimating emissions stand-alone anaerobic digestion, see the planned improvements discussion starting on pp. 7-62 of Section 7.3 in the national *Inventory* for a description of future work to further improve these estimates.

6.1.3.5 References

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6.2 Wastewater Management

This section presents the methodology used to estimate the emissions from wastewater treatment and discharge, which consists of the following source category:

- Wastewater treatment and discharge (domestic and industrial) (CH_4, N_2O)

6.2.1 Wastewater Treatment and Discharge (NIR Section 7.2)

6.2.1.1 Background

Consistent with the national *Inventory* and international guidance, the EPA has developed disaggregated state estimates for both domestic and industrial wastewater treatment and discharge as discussed below.

- Domestic wastewater CH_4 and N_2O emissions originate from both septic systems and from centralized treatment plants. Within these centralized plants, CH_4 emissions can arise from aerobic systems that liberate dissolved CH_4 that formed within the collection system or that are designed to have periods of anaerobic activity, from anaerobic systems, and from anaerobic sludge digesters when the captured biogas is not completely combusted. N_2O emissions can result from aerobic systems. Methane emissions will also result from the discharge of treated effluent from centralized treatment plants to waterbodies where carbon accumulates in sediments while N_2O emissions will also result from discharge of centrally treated wastewater to waterbodies with nutrient-impacted/eutrophic conditions.

- Industrial wastewater CH_4 emissions originate from in-plant treatment systems, typically comprising biological treatment operations in which some are designed to have anaerobic activity or may periodically have anaerobic conditions form. N_2O emissions are primarily expected to occur from aerobic treatment systems. Emissions will also result from discharge of treated effluent to waterbodies.

6.2.1.2 Methods/Approach (Domestic Wastewater)

The EPA estimated state-level domestic wastewater treatment and discharge emissions (CH_4) using a simplified approach to apportion the national emission estimates to each state based on population (i.e., Approach 2 as defined in the Introduction to this report). In this method, the EPA accessed historic U.S. Census data to compile state-level population data for each year of the inventory (1990–1999: U.S. Census Bureau 2017; 2000–2009: U.S. Census Bureau 2016; 2010–2019: U.S. Census Bureau 2019). For the years 2010–2019, there were small discrepancies in the sum of the state-level populations and the national-level data collected in May 2020 for the 1990–2019 *Inventory* perhaps because the state-level population data were last updated in December 2019 and may not be mid-year estimates (like the national population). The sum of the state populations differed from the national population by less than 0.6% and in most cases by less than 0.05%. Because these differences are so small, the state-level population data from 2010–2019 were still used to estimate the relative percentage of the U.S. population in each state. The EPA then calculated state-level emissions by multiplying the percentage of the U.S. population in each state by the CH_4 and N_2O national emissions for each year of the time series.

This simplified approach assumes the following:

- Every state has the same wastewater treatment system usage as the national *Inventory.*
- Every state has same distribution of discharge to various waterbody types as the national *Inventory.*
- Kitchen disposal usage is the same in every state, and wastewater biochemical oxygen demand (BOD) produced per capita, with and without kitchen scraps, is the same in every state (i.e., assumes total wastewater BOD produced per capita is the same as national production).
- Per capita protein consumption in the United States is the same in every state (i.e., assumes per capita consumption is the same as national consumption).

The EPA did not perform a more detailed approach that would account for the types of treatment (e.g., on-site such as septic systems and centralized systems such as publicly owned treatment works [POTWs]) used in each state (see planned improvements below in Section 6.2.1.4). Similarly, there are insufficient readily available data sources to allow classification of the type of specific waterbodies within each state so the EPA did not consider the type of waterbody receiving wastewater discharges within each state.

6.2.1.3 Methods/Approach (Industrial Wastewater)

Consistent with the national *Inventory* and national estimates, both CH_4 and N_2O emissions were estimated for treating industrial wastewater from pulp and paper manufacturing; meat and poultry processing; petroleum refining; and breweries, while CH_4 emissions were also estimated for treating industrial wastewater from vegetables, fruits, and juices processing, and for starch-based ethanol production. These are the Industry categories that are likely to produce significant GHG emissions from wastewater treatment. Data on industrial production by state are available or can be estimated from other readily available data for at least some of the time series of the inventory.

The EPA estimated state-level emissions by estimating the percentage of the industry production that occurs in each state (i.e., using Approach 2 as described in the Introduction to this report). Where data were readily available, the EPA estimated the distribution of production for each year of the time series and multiplied that by the national emissions estimate for each year of the time series. In some cases, due to time and resources, the EPA was able to estimate the distribution of production for a subset of years in the time series, as discussed by industry, below.

For pulp and paper manufacturing, state-level production data are not available, so the EPA estimated state-level emissions by estimating the percentage of wastewater directly discharged in that state compared to the total flow of wastewater directly discharged for that industry, using data reported to the EPA's ICIS-NPDES database. The EPA then multiplied that percentage by the national emissions estimate to obtain a state-level emissions estimate. Because of the limitation of data resources for this effort, the EPA accepted the ICIS-NPDES data as is and did not conduct further outlier or data gap analyses (see planned improvements below in Section 6.2.1.4).

Both approaches assume the following:

- All facilities in an industry within a state have the same distribution of wastewater treatment operations as the national distribution.
- Every state has the same BOD and total nitrogen in untreated industry wastewater as the national-level estimates.
- Every state has the same nitrogen removal factor as the national-level estimates.
- The percentage of wastewater directly discharged by the state represents the distribution of all pulp and paper production by the state.

Further details on methods and data sources assumptions for each industry treating wastewater are described below.

Pulp and Paper Manufacturing

- Industrial production data for pulp and paper are highly confidential and are not available by state.
- The EPA used the amount of wastewater directly discharged by pulp mills by state (reported to ICIS-NPDES from Enforcement Compliance History Online [ECHO]; ECHO 2021) to proportion U.S. national emissions estimates to a state (as shown in Appendix F (Table F-6). Because wastewater flow data housed in ECHO changed in 2016, using older data may cause discontinuities in the time series. The EPA determined the distribution of discharge flow by state for 2019 using 2019 ECHO data and applied this distribution to all years of the national *Inventory*. There was no wastewater flow reported for the District of Columbia or the territories for this industry.
  - Downloaded the total pulp and paper facility universe in ECHO, focusing on facilities that have actual discharge monitoring report data, not just facility information (e.g., address). In 2019, 343 facilities made up the industry universe based on this criterion.
  - Downloaded 2019 flow data where available (ECHO 2021). Not all facilities report total flow if it is not required by their permit.
  - For facilities without flow data, downloaded all solids discharge data for the industry universe and estimated total flow by using average daily flow per concentration of solids by state.
    - For facilities that have both an average daily flow (MGD) and an average concentration of solids (mg/L), calculated the average flow per average concentration (MGD/mg/L).
    - Averaged these values by state.
    - For facilities with missing flow data but with solids concentration data, multiplied the average solids concentration (m/L) by the calculated state average concentration per flow (MGD/mg/L) to get an estimated daily flow rate (MGD).
    - Multiplied the daily flow rate by 365.25 days to estimate a total yearly flow.
  - For facilities without flow or solids concentration data, applied the same methodology above using ECHO's "Organic Enrichment" pollutant category.

  - If a facility did not have data for flow, solids, or organic enrichment, estimated total flow as zero. This assumption of zero flow was applied to 11 facilities.
- Calculated the percentage of national flow by state:
  - Some states are missing from these calculations, such as Washington, because of a lack of reported data. The EPA assumed some of these states have nonzero emissions, but they do not have the data to estimate them, so they are reported as not applicable.
- Calculated the state-level emissions by multiplying national emissions by the percentage of national flow by state.
- Example: 2019 California Emissions
  - California has two facilities in the facility universe with reported data. In 2019, one reported a total annual flow of 589.4 MMGal and the other 0 MMGal.
  - The total flow based on the sum of reported flows and calculated flows for all reporting facilities was 1,931,834 MMGal in 2019.
  - California's flow was 0.04% of this total flow.
  - Pulp and paper's national methane emissions in 2019 was 29 Gg CH_4, so California's 2019 emissions were estimated to be (29 Gg CH_4 * 0.04% = 0.011 Gg CH_4).

Meat and Poultry Processing

- Annual U.S. and state-level production data for red meat processing and poultry processing data are available from USDA-NASS (as shown in Appendix F (Table F-7). Depending on the commodity, limited state-level data are available. Typically, the USDA reports only break out the primary states where the commodity is processed and then present production in "other states."
- For red meat processing:
  - The EPA gathered state-level 2019 average live weight and total head slaughtered for the following commodities: beef, calves, hogs, and lamb/mutton (USDA 2020a).
    - Territories and Washington, DC, are not included in USDA-reported data.
  - For total head slaughtered (thousand head):
    - To populate states for which specific production data are not disclosed by USDA ("D" states), the EPA evenly divided the difference between the sum of the state-level data and the reported national-level total to those D states.
    - Similarly, USDA provided a total for New England states that was evenly distributed to those states noted (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont).
  - For average live weight (pounds):
    - The EPA used the average of available state-level data and the national average to determine the appropriate average live weight for the remaining states (D states). This calculated value was applied to all D states.
    - Similarly, the reported average live weight value for New England states was applied to those states.
  - As with the national *Inventory*, the EPA determined live weight killed (LWK) by multiplying the average live weight by the total head/1,000 to get to million pounds LWK.
  - The EPA added the disaggregated red meat processing data by state and divided the data by the reported national production to determine the proportion distributed to states. Because of the estimated nature of the calculated values, the total state-level LWK is estimated as about 95% of the national total so the percentages were normalized to 100%.
- For poultry processing:

    - The EPA gathered state-level 2019 poultry live weight data. Only broilers had state-level data available. Turkeys and mature chickens did not.
        - Young turkey data were available by state. The EPA assumed that states with young turkeys would be representative of turkey processing production; therefore, young turkey data were used as a proxy for total turkeys (USDA 2020a).
        - Broilers (or young chickens) were used to represent mature chicken processing production by state (USDA 2020a).
    - To populate D states, the EPA evenly divided the difference between the sum of the state-level data and the reported national-level total to those D states.
    - For turkeys and mature chickens, the proportion of young turkeys and young chickens, respectively, was multiplied by the national-level value to determine the pounds of processing production per state.
    - Those values were added together and then divided by the total poultry (broilers, mature chickens, turkeys) values to determine the proportion of poultry LWK for states.
- To calculate CH_4 emissions, the EPA:
    - Multiplied national red meat plant CH_4 emissions by the percentage of U.S. total meat processing and added that to the national poultry plant CH_4 emissions multiplied by the percentage of U.S. total poultry processing by state.
    - Multiplied the 2019 state-level proportion of U.S. meat and poultry BOD treated on-site by the national effluent CH_4 emissions from meat and poultry.
    - Added plant and effluent emissions for total state-level emissions.
- To calculate N_2O emissions, the EPA:
    - Multiplied the 2019 state-level proportion of U.S. total nitrogen in aerobically treated meat and poultry wastewater by the N_2O emissions from meat and poultry processing wastewater treatment for each year in the time series.
    - Multiplied the 2019 state-level proportion of U.S. total nitrogen in discharged meat and poultry wastewater by the N_2O emissions from meat and poultry processing wastewater treatment effluent for each year in the time series.
    - Added plant and effluent emissions for total state-level emissions.

Vegetables, Fruits, and Juices Processing

- Annual U.S. production data for vegetables, fruits, and juices processing are available from USDA. Depending on the commodity, state-level data are available (as shown in Appendix F (Table F-8). Typically, the USDA reports only identify the primary states where the commodity is processed. For example, production data on broccoli are provided for California and "other states," while production data on asparagus are provided for Michigan, Washington, and "other states."
    - Territories and Washington, DC, are not included in the USDA-reported data.
- The EPA determined that the year with the most complete state-level production values is 2017 because USDA suspended the reporting of some state-level production values in 2018 and more notably in 2019.
- For processing production data:
    - Potatoes: State-level data for potato processing were not available. Instead, the EPA used state-level potato production (i.e., the production of potatoes grown not processed) as a proxy to determine the states to include (USDA 2020a).
    - Other vegetables: The EPA gathered data for asparagus, broccoli, carrots, cauliflower, sweet corn, cucumber (for pickles), lima beans, green peas, snap beans, spinach, and tomatoes (USDA 2020b). Where USDA reported data for "other states" those data were distributed equally among the

    commodities. The EPA added the production for these commodities to determine the percentage of the U.S. total for all “other vegetables,” which is the production value used in the national *Inventory* (not the individual commodities).
  - Processed apples, grapes used for wine, and citrus fruits were also determined at a state level. For apples, where USDA reported data for “other states,” those data were distributed equally (USDA 2020a).
  - Noncitrus fruits are split out into separate commodities (e.g., blueberries, sweet cherries[32]); no state-level data are available for the aggregated “noncitrus fruit” category. Therefore, the EPA gathered the state-level “utilized production” data for these separate commodities to determine the appropriate states and relative percentage of utilized production for noncitrus fruits (USDA 2020a).
  - For processed noncitrus fruit data, the data used for *Inventory* calculations, are typically calculated in the national *Inventory* (utilized production minus fresh minus apples minus grapes for wine); however, because of the intensive nature of gathering data for the separate commodities, “utilized production” was used as a proxy for processed production data.
- To calculate emissions, the EPA calculated the 2017 percentage of U.S. total BOD by state and multiplied that by the national vegetables and fruits emissions for each year in the time series.

Petroleum Refining

- Annual production data are available from the EIA within DOE (EIA 2021a) (as shown in Appendix F [Table F-9].
- Because state-level data may reveal confidential data, production data are aggregated by Petroleum Administration for Defense Districts, or PADDs. Production data for the following PADDs and subdistricts are available:
  - PADD I (East Coast)
    - Subdistrict A (New England): Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont
    - Subdistrict B (Central Atlantic): Delaware, District of Columbia, Maryland, New Jersey, New York, and Pennsylvania
    - Subdistrict C (Lower Atlantic): Florida, Georgia, North Carolina, South Carolina, Virginia, and West Virginia
  - PADD II (Midwest): Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Ohio, Oklahoma, Tennessee, and Wisconsin
  - PADD III (Gulf Coast): Alabama, Arkansas, Louisiana, Mississippi, New Mexico, and Texas
  - PADD IV (Rocky Mountain): Colorado, Idaho, Montana, Utah, and Wyoming
  - PADD V (West Coast): Alaska, Arizona, California, Hawaii, Nevada, Oregon, and Washington
- Operating capacity by state are available from EIA (EIA 2021b).
- The EPA created state-level annual production data for each year of the time series by dividing the annual production for each PADD subdistrict by the percentage of operating capacity each state provided in that year.
- Petroleum operating capacity values were not available for 1996 and 1998. These values were linearly interpolated.
- Example: 2019 California Emissions
  - California data are included in PADD V.

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[32] The EPA gathered 2017 used production for apricots, avocados, blueberries, and wild blueberries; sweet and tart cherries; coffee; cranberries; dates; nectarines; olives; papaya; peaches; pears; plums; prunes; raspberries; and strawberries.

  - PADD V has a total of 27 refineries with an operating capacity of 2,875,071 barrels.
  - California has a total of 15 refineries with an operating capacity of 1,909,671 barrels (or 66.4% of PADD V capacity).
  - PADD V produced 1,122,935 barrels in 2019.
  - Estimate California production as (1,122,935 barrels * 66.4%=) 745,629 barrels.
  - Calculate percentage of national production that is California (745,629 barrels/7,460,380 barrels = 10%).
  - Calculate California emissions as national emissions * percentage of national production (4.6 Gg CH_4 * 10% = 0.46 Gg CH_4).

Starch-based Ethanol Production

- State-level ethanol production data are available from SEDS (https://www.eia.gov/state/seds/) (as shown in Appendix F [Table F-10].
  - Fuel ethanol production data, including denaturant, in thousand barrels are available for years 1960–2018 (EIA 2018).
  - The EPA checked the difference between SEDS national production and the reported production in the national *Inventory* and found small differences—at most a 1.8% difference in 2017—further confirming this is a good source of state-level production.
  - The calculated 2018 percentage of national production by state was used for 2019 values.
- Calculated the percentage of national production by state for 1990–2018.
- Calculated the state-level emissions by multiplying national emissions by percentage production by state.
- Example: 2019 California Emissions
  - 2018 California production value is 5,242 thousand barrels.
  - National production for 2018 is 383,128 thousand barrels.
  - California produced 1.4% of the national production in 2018, and this value is used for 2019.
  - Calculate 2019 California emissions as national emissions * percentage of national production (6.4 Gg CH_4 * 1.4% = 0.09 Gg CH_4).

Breweries

- Annual production data by state are available from the Alcohol and Tobacco Tax and Trade Bureau (TTB 2020) (as shown in Appendix F [Table F-10].
  - Data are available for years 2008–2019. Therefore, the calculated percentage of national production for 2008 was used for years 1990–2007.
  - These data are for taxable production values only, which accounts for 93% of total production. Approach assumes that this portion of production is still representative of relative production percentages for each state.
  - Data are not available broken out between craft and noncraft production, so the approach assumes each state has the same distribution of craft and noncraft production as the national distribution.
- Calculated the percentage of national production by state.
- Calculated the state-level emissions by multiplying national emissions by percentage production by state.
- Example: 2019 California Emissions
  - California production is 17,872,597 barrels.
  - National production is 167,077,233 barrels.
  - California produces 10.7% of national production.
  - Calculate California emissions as national emissions * percentage of national production (5.6 Gg CH_4 * 10.7% = 0.599 Gg CH_4).

6.2.1.4 Uncertainty

The overall uncertainty associated with the 2019 national estimates of CH_4 and N_2O from wastewater treatment and discharge were calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As described further in Chapter 7 of the national *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA 2021), levels of uncertainty in the national estimates in 2019 were CH_4 (−28/+38%) and N_2O (−37/+209%). State-level estimates have a higher uncertainty due to apportioning the national emissions estimates to each state based solely on state population (for domestic) or state industry sector production (for industrial). This approach does not address state-level differences in the type of wastewater treatment systems in use or in the conditions of the state's receiving waterbodies. For all sectors other than domestic, petroleum refining, starch-based ethanol, and breweries, state-level emissions for the time series were estimated based on a single year of state-level data, which also results in higher uncertainty for the state estimates. These assumptions were required due to the general lack of readily available state- or regional-level data. For more details on national-level uncertainty, see the Uncertainty discussion in the Waste chapter (Chapter 7), Section 7.2 of the national *Inventory*, available online at https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-7-waste.pdf?VersionId=skK.lO1zbaYrNwnmUKNiyepctaM_yV3z.

6.2.1.5 Planned Improvements

Generally, the EPA plans to review and assess recommendations on potential comparable datasets provided during review of the inventory methods. These sources may inform the following potential improvements for both domestic and industrial state-level emissions estimates.

- Determine state-level sources for the type of wastewater treatment systems in use for municipal or domestic or for industrial wastewater (by industrial sector).
- Determine state-level sources for BOD or total nitrogen data in municipal or domestic wastewater or industrial wastewater (by industrial sector).
- As stated in Section 7.2 of the national *Inventory*, investigate additional sources for estimating wastewater volume discharged and discharge location for both domestic and industrial sources.
- Investigate sources to better define a state-level breakdown of centralized and septic systems.

For individual industries, the EPA notes the following potential improvements:

Pulp and Paper Manufacturing

- Determine state-level sources for the production of pulp, paper, and paperboard.
- Investigate additional years of ECHO data to improve the time series.
- Confirm whether facilities with no reported flow or the investigated discharge parameter data did not operate in 2019. If operated, the EPA could determine other appropriate methods to estimate flow.
- Investigate states where data are reported as not applicable and confirm emissions estimates do not apply. Pending findings, determine another source to estimate wastewater flow for these states.

Meat and Poultry Processing

- Investigate additional years of available USDA data for inclusion to improve the time series.
- Investigate the presence of meat and poultry processing in the U.S. territories or the District of Columbia and, pending findings, additional sources for estimating those emissions. For the District of Columbia, reach out to USDA NASS to confirm if the District of Columbia is already included in reporting.

Vegetables, Fruits, and Juices Processing

- Investigate other years of available USDA data for inclusion. The EPA would focus its efforts on years prior to 2017 due to the changes in data reported by USDA, noted above.

- Investigate the presence of vegetables, fruits, and juices processing in the U.S. territories or the District of Columbia and, pending findings, additional sources for estimating those emissions. For the District of Columbia, reach out to USDA NASS to confirm if the District of Columbia is already included in reporting.

Starch-based Ethanol Production

- Investigate sources to break down wet and dry milling by state over the time series.

Breweries

- Investigate sources to break down craft and noncraft breweries by state over the time series.

6.2.1.6 References

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Appendix

A: Energy Sector Combustion Estimates

Please see separate xlsx file.

B: Energy Sector Fugitive Estimates

Please see separate xlsx file.

C: IPPU Minerals Sector Estimates

Please see separate xlsx file.

D: IPPU Chemicals Sector Estimates

Please see separate xlsx file.

E: Agriculture LULUCF Estimates

Please see separate xlsx file.

F: Waste Estimates

Please see separate xlsx file.

G: Population Data used in Estimates

Please see separate xlsx file.

H: IPPU Metals Sector Estimates

Please see separate xlsx file.

I: IPPU Product Use Sector Estimates

Please see separate xlsx file.