Methodology Report for Inventory of U.S. Greenhouse Gas Emissions and Sinks by State: 1990–2021

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1 Introduction

This report describes methods used to compile the annual publication of U.S. anthropogenic greenhouse gas (GHG) emissions and sinks disaggregated by U.S. state and 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 1990–2021 and is available here: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks. This state-level report is complementary publication released annually after the national *Inventory* report.

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 EPA provides users information on where they can find official state-level data from EPA's website here: https://www.epa.gov/ghgemissions/learn-more-about-official-state-greenhouse-gas-inventories. In addition, for states where an official inventory is available, EPA's GHG Data Explorer provides links along with the published state-level data 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 and 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. The emissions and removals presented in this 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., 2021).
- 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.
- Use estimates that were compiled to avoid double counting or gaps in emissions coverage between states, ensuring 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.

This 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

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

countries for UNFCCC reporting. The chapter and category section titles all include a reference to the corresponding section in the national *Inventory* report (NIR), such as NIR Section 3.1., to facilitate understanding national inventory methods in relation to approaches applied to allocate national emissions to the state level. For each category, we recommend reading this report in conjunction with the referenced 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

EPA recognizes that there will be differences between 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." EPA has strived to ensure the coverage, methodological, and accounting approaches are clearly described so users can understand differences with how states may compile their inventories. The results should be viewed as complementary and supplement existing state data. Differences between EPA and official state estimates include:

- **Organization of sectors.** 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 allows countries to compare data and supports cooperation on climate action. States may use alternate organization of data for presenting emissions and sinks, such as economic sectors, 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 IPPU 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, EPA may be using different methodologies, activity data, and emissions factors, or may have access to the latest facility-level information through EPA's Greenhouse Gas Reporting Program (GHGRP). EPA used as a basis, or starting point, either 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, 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 2 or 3"), or they 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 the methodological framework in the IPCC guidelines.[2] Differences in accounting approaches also include differences in the approach to

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[2] Per the 2006 IPCC Guidelines, national inventories include GHG emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction with some minor exceptions. For example, one exception is "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

estimating transportation, cross-border aviation and marine emissions, or treatment of biogenic CO_2. For example, 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 (C stock) changes of the relevant land use category of the agriculture and LULUCF sectors, where the biomass originates, and including 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 are based on an equivalent or an apples to apples comparison of estimates.

- **Time series.** EPA has developed state-level estimates for 1990–2021 consistent with the national *Inventory* published in April 2023 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 previously published estimates for earlier years, but not recalculated or otherwise updated these estimates 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 CO_2 equivalency of non-CO_2 gases, such as different values for GWPs. Consistent with the national *Inventory,* in this report EPA is using 100-year GWPs from IPCC's Fifth Assessment Report (AR5) to calculate CO_2 equivalency of non-CO_2 emissions, as required in reporting annual inventories to the UNFCCC. EPA shifted to using 100-year GWPs from AR5 in 2023. Recent decisions[4] under the UNFCCC require members of the Conference of Parties to use 100-year GWP values from AR5 for calculating CO_2-equivalents in their national reporting (IPCC 2013) by the end of 2024. This requirement reflects updated science and ensures that national GHG inventories reported by all nations are comparable.

1.2 Institutional Arrangements for Compiling State-Level Inventory Estimates

In preparing the state-level inventory, EPA took advantage of existing data arrangements used to compile the national *Inventory* (see Chapter 1.2 of the national *Inventory*). 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[5] 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. EPA also acknowledges additional effort from USDA's National Agricultural Statistics Service (NASS) and Office of Chief Economist (OCE) for providing state-level data on energy use in agriculture and from the Department of Energy's Energy Information Administration (EIA) for providing state-level energy use data. Finally, EPA acknowledges contributions and investments from USDA-OCE that will facilitate addressing some of the planned improvements outlined in Chapters 4 and 5 of this report.

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.

[4] See paragraphs 1 and 2 of the decision on common metrics adopted at the 27th UNFCCC Conference of Parties (COP27), available online at https://unfccc.int/sites/default/files/resource/cp2022_10a01_adv.pdf

[5] https://www.fs.fed.us/nrs/pubs/download/ru_fs307_Appendix2.pdf.

EPA also collects GHG emissions data from individual facilities and suppliers of certain fossil fuels and industrial gases through its GHGRP.[6] The GHGRP does not provide full economywide coverage of total annual U.S. GHG 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 national *Inventory*. In general, the threshold for reporting is 25,000 metric tons or more of CO_2 equivalent per year. Facilities in most source categories subject to GHGRP began reporting for the reporting year (RY) 2010, while additional types of industrial operations began reporting for RY 2011. When incorporating these data from GHGRP, consistent with the national *Inventory*, EPA considers good practice guidance from the 2019 Refinement to the 2006 IPCC Guidelines (Volume 1, Chapter 2)[7] and IPCC's Technical Bulletin on Use of Facility-Specific Data in National GHG Inventories[8] to ensure, completeness, time series consistency, and transparency in state-level methods and associated estimates.

Data presented in this state-level inventory report and 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 emissions 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*, 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 of lands converted to forest land 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 (e.g., population, production capacity, GHGRP). 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 a 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 EPA's GHGRP, which began collecting data in 2010, as a basis for national- and state-level estimates. For these categories, EPA uses Approach 1 for 2010–2021 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

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

[7] https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/1_Volume1/19R_V1_Ch02_DataCollection.pdf

[8] https://www.ipcc-nggip.iges.or.jp/public/tb/TFI_Technical_Bulletin_1.pdf

approach is used to estimate state-level CO_2 and PFC emissions from aluminum production (see Section 3.3.3).

Across this report, in addition to a sector-level summary, under each category, 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, EPA has included equations to enhance understanding of the implementation of disaggregation methods. EPA has also included data appendices to provide underlying data to estimate emissions and sinks.

1.4 Summary of Updates Since Previous Report

Each year, many emission and sink estimates in the national *Inventory* are recalculated and revised, as efforts are made to improve the estimates through the use of better methods and/or data with the goal of improving inventory quality and reducing uncertainties, including the transparency, completeness, consistency, and overall usefulness of the report. The same is the case with state-level estimates where updates were made to improve inventory quality. In general, when methodological changes have been implemented, the previous national *Inventory's* time series (i.e., 1990–2020) was recalculated to reflect the change. Note that the most common reason for recalculating national GHG emission estimates is to update recent historical activity data. Changes in historical data are generally the result of changes in statistical data supplied by other U.S. government agencies, and do not necessarily impact the entire time series.

A summary of methodological changes and historical data updates made to the state-level data is presented below by category. Table 1-1 notes whether changes are due to refinements in the national *Inventory* methods and data, including new categories, and/or due to an update that refined the approach and data used to disaggregate national estimates to the state level. Note that when category-level changes in absolute state-level emissions or removals for a state between this version and the previous state report are due to recalculations and improvements implemented in the national *Inventory*, changes are indicated only in the national-level column in Table 1-1 below, as the approach to disaggregation of the updated national estimates to the state level remains unchanged. Categories not listed had no changes for either the national or state-level estimates. See the recalculations sections of each category for more detail on the updates within this report.

Table 1-1. Category Estimates Updated Since Release of Previous Inventory by U.S. State

IPCC Sector	Category	Changes to Inventory (i.e., Refined Method/Data or New Category)	
		National-Level	State-Level
E	Fuel Combustion	●	●
E	Non-Energy Use of Fuels	●	●
E	Oil and Gas Systems (revision of methodology to use basin level data for certain segments), Abandoned Oil and Gas Wells	●	●
I	Glass Production	●	
I	Other Process Uses of Carbonates	●	●
I	CO_2 Emissions from CO_2 Consumption		●
I	Ammonia Production	●	
I	CO_2 from Urea Use		●
I	Adipic Acid	●	●
I	CO_2 from Carbide Production		●
I	Titanium Dioxide Production		●
I	Petrochemicals		●
I	Phosphoric Acid Production		●

IPCC Sector	Category	Changes to Inventory (i.e., Refined Method/Data or New Category)	
		National-Level	State-Level
I	Iron and Steel Production	●	
I	Aluminum Production	●	
I	Magnesium Production	●	●
I	Lead Production		●
I	Zinc Production	●	
I	Electronics Industry	●	●
I	ODS Substitutes	●	
I	Electrical Transmission and Distribution	●	●
I	N_2O from Product Use		●
A	Enteric Fermentation	●	
A	Manure Management	●	
A	Agricultural Soil Management	●	
A	Liming	●	
A	Urea Fertilization	●	
L	Forest Land Remaining Forest Land	●	
L	Land Converted to Forest Land	●	
L	Land Converted to Cropland	●	
L	Grassland Remaining Grassland	●	
L	Land Converted to Grassland	●	
L	Wetlands Remaining Wetlands	●	●
L	Land Converted to Wetlands	●	
L	Settlements Remaining Settlements (subcategory landfilled yard trimmings and food scraps)	●	●
L	Land Converted to Settlements	●	
W	Landfills	●	
W	Composting	●	
W	Anerobic Digestion at Biogas Facilities	●	
W	Wastewater Treatment and Discharge	●	●

E = Energy Sector; I = Industrial Processes and Product Use; A = Agriculture; L = Land Use Change, Land Use Change and Forestry; W = Waste

1.5 QA/QC Procedures

In disaggregating emissions and sinks from the national *Inventory*, EPA implemented QC procedures during the compilation process to ensure quality, transparency, and credibility of the state GHG data. EPA implemented general QC procedures adapted from the existing QA/QC plan[9] 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). 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 and resulting 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, the procedure and findings are discussed in the respective category section.

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[9] 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.

EPA also implemented QA procedures outlined by EPA and IPCC as QA good practices (i.e., external review by experts not directly involved in compiling the data). EPA conducted a peer review in fall 2021, and an annual 30-day state expert review in summer 2023. 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.

1.5.1 Peer Review

The methodology report and the resulting state-level estimates for the 1990–2019 data were independently peer reviewed from September 17 to November 1, 2021. Seventeen external experts participated in a process independently coordinated by RTI International and an EPA peer-review coordinator.

EPA gratefully acknowledges all the peer reviewers for their useful comments. The peer review report and responses from EPA are 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 the report followed the procedures in 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, the 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 a 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.

1.5.2 State Expert Review

Technical staff from each state (e.g., environmental agencies, other state agencies, institutions) were provided with an opportunity to review the draft data and a draft of this methodology report from July 17–August 16, 2023. The methodology report and state-level estimates were shared with state experts from all 50 U.S. states and the District of Columbia for review.

EPA gratefully acknowledges all the state experts for their review. EPA asked state experts for feedback on this methodology report, its data appendices, and the resulting estimates.

No additional technical comments were received on the draft report. Responses to comments from the previous review are available at https://www.epa.gov/ghgemissions/state-ghg-emissions-and-removals. See category-specific planned improvement discussions throughout this report reflecting updates planned for future publications of these data.

1.6 Uncertainty

EPA has not assessed state-specific or category-level quantitative uncertainties for the activity data and other parameters used to estimate state-level emissions and removals for this current publication but has included qualitative information on how uncertainties compare to those assessed quantitively for each category in the national *Inventory.*[10]

The uncertainties of state-level emissions estimates are generally expected to be comparable to 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 U.S. production is multiplied by an emissions factor to obtain total national-level emissions, but production capacity rather than production is used to allocate the U.S. 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 national-level uncertainties (in percentage terms), assuming the uncertainties in the estimates for each facility and state are independent of each other. For example, EPA estimates the uncertainties in emissions from aluminum production at individual smelters to be +6/−6%, +16/−16%, and +20/−20% for CO_2, perfluoromethane and perfluoroethane emissions, respectively. When propagated to the national level across the seven smelters that operated in 2021, these uncertainties decline to −2%/+3% for CO_2 and +8/−8% 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 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.

1.7 Planned Improvements

Across this report, per EPA's QC and feedback from the previous peer and state reviews, EPA has outlined areas for improving future annual publications of these data at the category level across the report. Based on feedback, EPA continues to prioritize the following cross-cutting improvements for future annual publications of these data:

- Finalize state-level key category analyses consistent with IPCC guidance and international reporting guidelines to help identify categories that are more significant at the state level and publish in fall of 2023.
- Disaggregate estimates further for U.S. territories (in GHG Inventory Data Explorer) and tribal lands, where feasible.
- Publish additional state-level activity data/factors underlying estimates where feasible and not previously included.

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[10] Within the forest land remaining forest land and lands converted to forest land categories, USFS has quantified uncertainties for state-level estimates for net CO_2 flux from forest ecosystem carbon 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 USDA-USFS Resource Bulletin WO–101 (Domke et al., 2023), available at: https://www.fs.usda.gov/research/treesearch/66035.

1.8 References

IPCC (Intergovernmental Panel on Climate Change) (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M.B. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

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)—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 international bunker fuels (IBFs)[11] and biomass emissions,[12] 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[a]
FFC	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, the District of Columbia, tribal lands, and territories (i.e., American Samoa, Guam, Puerto Rico, , Northern Mariana Islands, U.S. Virgin Islands and other outlying minor islands) as applicable.
NEUs of Fossil Fuels	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories (i.e., American Samoa, Guam, Puerto Rico, , Northern Mariana Islands, U.S. Virgin Islands and other outlying minor islands) as applicable.
Geothermal Emissions	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, and tribal lands as applicable.[a]
Incineration of Waste	CO_2, CH_4, N_2O	Hybrid approach • 2011–2021: Approach 1 • 1990–2010: Approach 2	Includes emissions from all states, the District of Columbia, and tribal lands as applicable.[a]
IBFs (memo item)	CO_2, CH_4, N_2O	Approach 2	Includes emissions from all states, the District of Columbia, and tribal lands as applicable.
Wood Biomass and Biofuels Consumption (memo item)	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, and tribal lands as applicable.[a]
Coal Mining	CH_4	Approach 1: Active Underground Mines	Includes emissions from all states and the District of Columbia as applicable.[a]

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[11] Emissions from IBFs 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.

[12] 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.

Category	Gas	Approach	Geographic Completeness [a]
		Approach 1: Surface Mining and Post-mining Activities	
Abandoned Underground Coal Mines	CH_4	Hybrid	Includes emissions from all states and the District of Columbia as applicable.[a]
Petroleum and Natural Gas Systems	CO_2, CH_4, N_2O	Approach 2	Includes emissions from all states, the District of Columbia, and territories (i.e., American Samoa, Guam, Puerto Rico, U.S. Virgin Islands, Northern Mariana Islands, and other outlying minor islands) as applicable.[a]
Abandoned Oil and Gas Wells	CO_2, CH_4	Approach 2	Includes emissions from all states, the District of Columbia, and territories (i.e., American Samoa, Guam, Puerto Rico, U.S. Virgin Islands, Northern Mariana Islands, and other outlying minor islands) as applicable.[a]

[a] Emissions are not likely occurring in U.S. 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)
- IBFs (CO_2, CH_4, N_2O)
- Wood biomass and biofuels consumption (CO_2)

2.1.1 Fossil Fuel Combustion (NIR Section 3.1)

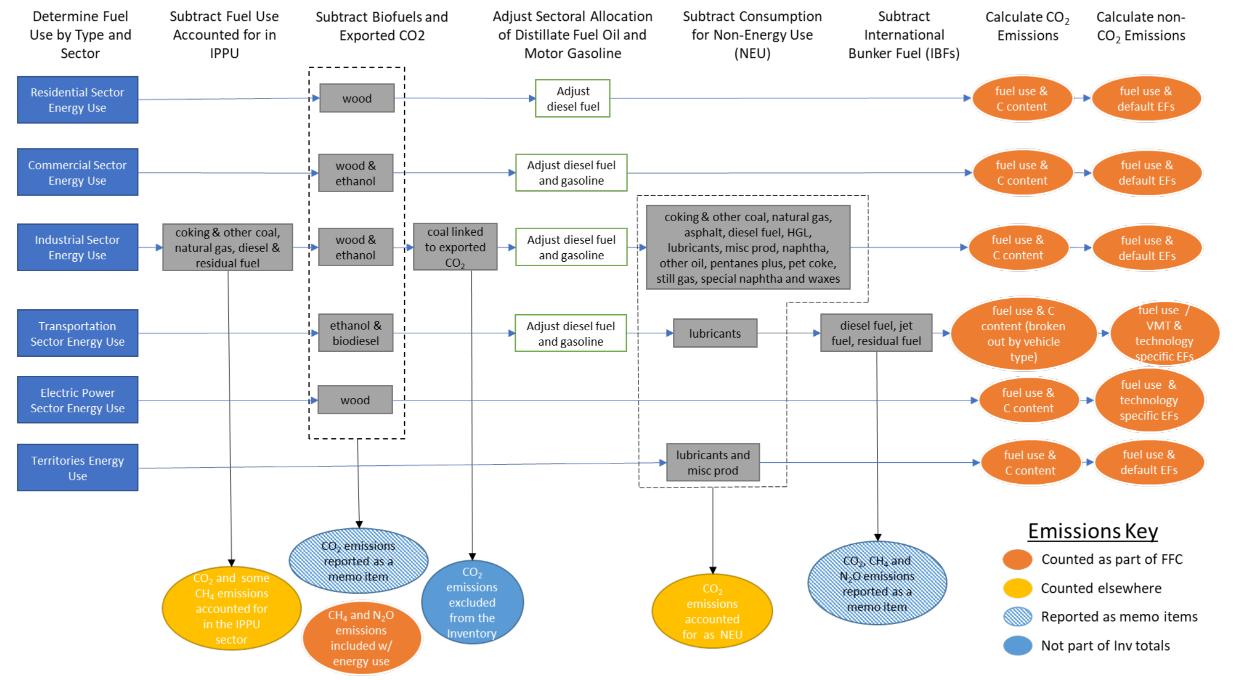
2.1.1.1 Background

Emissions from FFC 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 to estimate CO_2 emissions from FFC and the methods 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 were taken from national-level energy balances prepared for EIA's *Monthly Energy Review* (MER) estimates (EIA 2023a). 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.[13] The approach starts with determining fuel use by fuel type because different types of fuels have different carbon content (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 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:

- For energy used in the IPPU sector, see Chapter 3.
- For biofuel use, see Section 2.1.6.
- For NEUs of fuels, see Section 2.1.2.

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

- For IBFs, see Section 2.1.5.

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 1.3 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.

2.1.1.2.1. 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 below. 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 2021 FFC CO_2” 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 2021. Three additional steps (Steps 8–10 in Table 2-2) 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 the “National 2021 FFC CO_2” Tab of Appendix A, 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. 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 2-2 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

Calculation Step	National-Level Estimates	State-Level Estimates
		state-level fuel use data (not vehicle specific)
Step 6: Subtract Consumption for 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

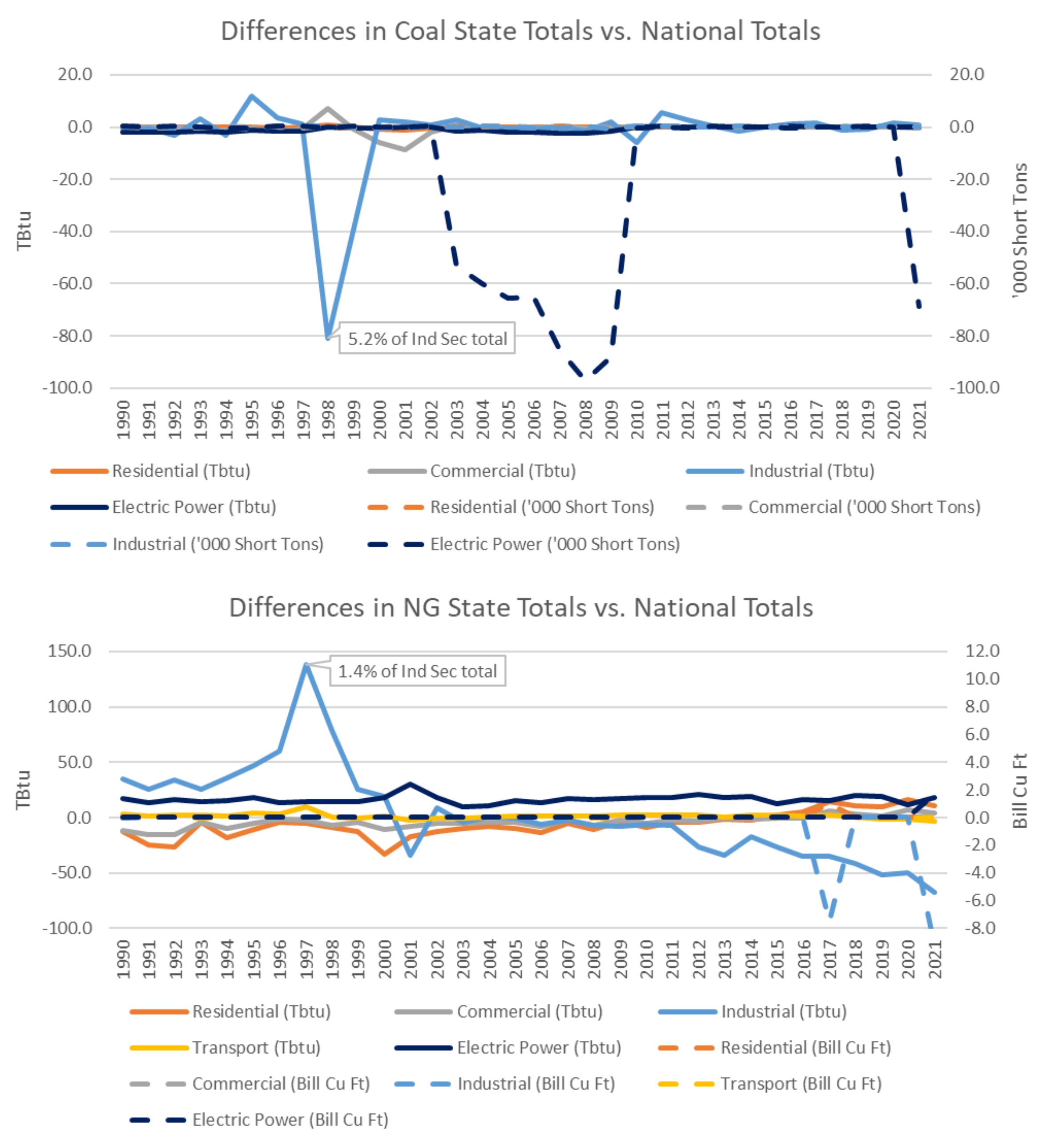
The following discussion details what data were used for each step in Table 2-2 to determine national- and state-level FFC emissions. Appendix A, Table A-1 in the "State FCC CO_2" Tab, provides more details on where state-level data were used directly and where other data were used to make adjustments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

2.1.1.2.2. 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 MER. Because not all fuel supplied/consumed directly results in GHG emissions, or it could be included as part of other emissions reporting in the national *Inventory*, adjustments have to be made as shown above in Table 2-2 and described in the following steps. State-level energy data are available from 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 1960–2021 (EIA 2023b). SEDS estimates energy consumption using data from surveys of energy suppliers that report consumption, sales, or distribution of energy at the state level. Most 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 data sets rely largely on the same survey returns for producers and consumers.

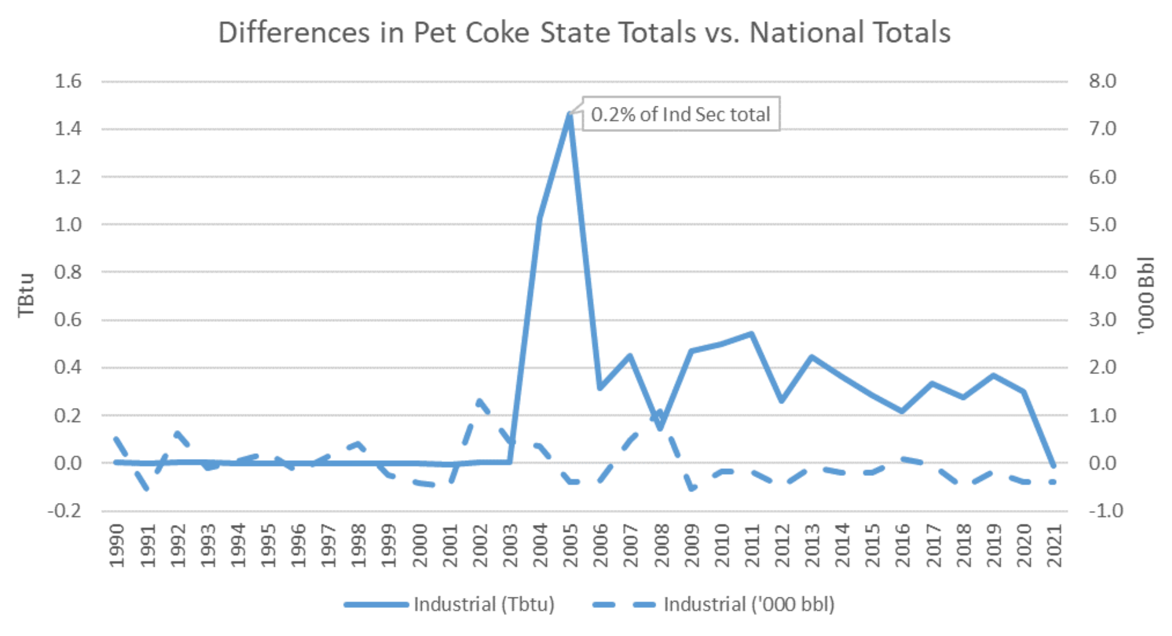
However, the totals across all states (and the District of Columbia) from SEDS do not always match the U.S. total energy data used in the national *Inventory*, which is based on the EIA February 2023 MER estimates (EIA 2023b). The main differences are for coal and natural gas and primarily in the industrial sector, as shown in Figure 2-2 below. 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. These different calculations sometimes cause the sums of the SEDS states to be different than the MER values. Although the percentage differences are not large (max 5.2% for coal and 1.4% for natural gas 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 below. 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. Since 2004, the MER has used 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.

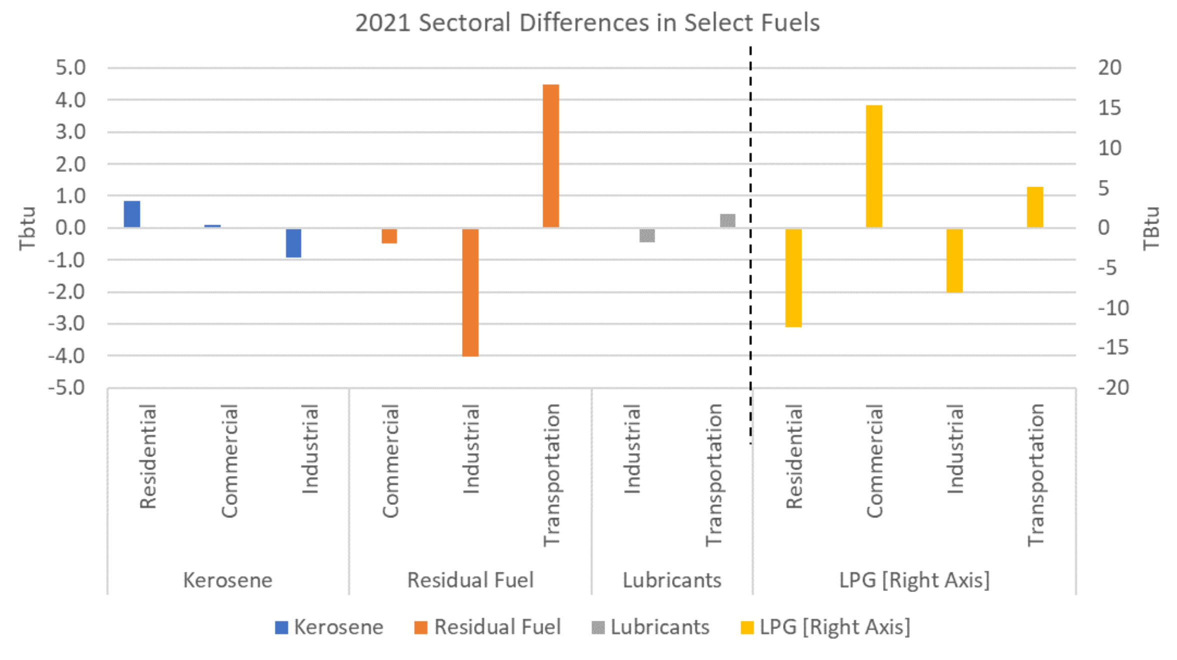
Figure 2-3. Differences Between State-Level and National Total Energy Use for Petroleum Coke



For diesel fuel and gasoline, the totals generally line up, but there are differences across sectors. These differences are 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 2021. This is because the SEDS represents the latest data from EIA in terms of sector breakouts that were not reflected in the national *Inventory* 2021 values that relied on older EIA data. Again, the totals for the fuels line up, but there are differences across sectors, as shown in Figure 2-4 below. The updated SEDS data were used in the state-level breakout because they represent the latest data available. This results in differences in 2021 results across sectors for the state totals versus the national *Inventory*. However, the national *Inventory* numbers will be updated to match the 2021 SEDS data during the next national *Inventory* cycle.

Figure 2-4. 2021 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 supplemental gas in state level results 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 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, biodiesel and 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.

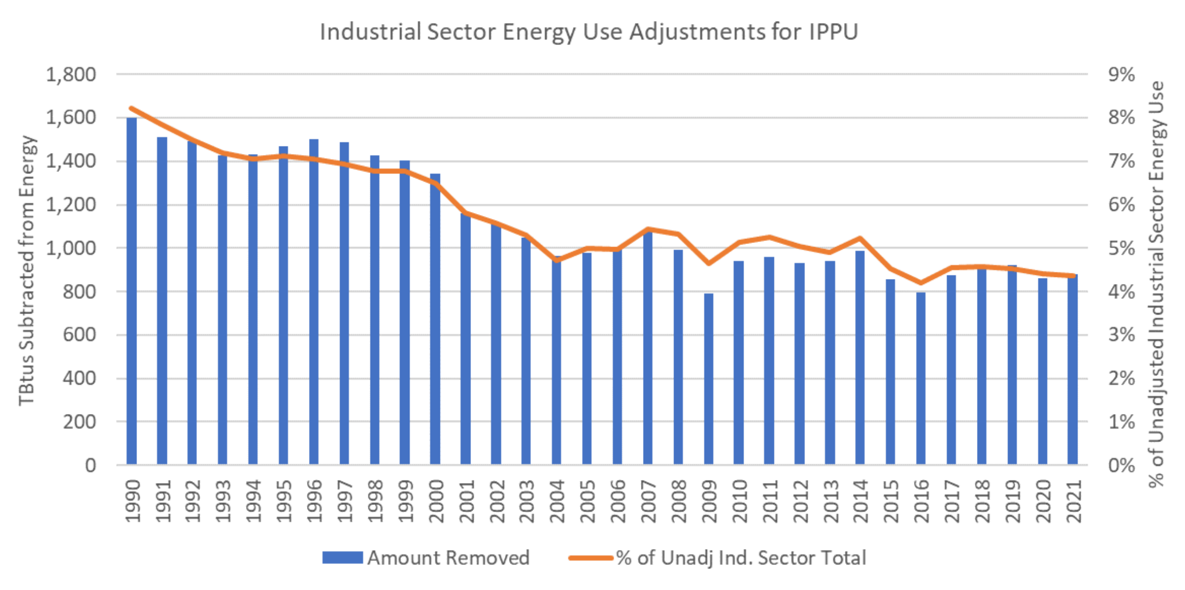
Appendix A has details on how the SEDS data were adjusted to determine state-level energy use by fuel type and sector. Tables A-2 through A-6 in the “FFC CO_2 Residential” Tab describe the residential sector adjustments. Tables A-9 through A-13 in the “FFC CO_2 Commercial” Tab describe the commercial 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 through A-56 in the “FFC CO_2 Electricity” Tab describe the electricity production sector adjustments.

2.1.1.2.3. 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 the energy sector to the sector 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, emissions from fuels used as raw materials are presented as part of IPPU and are removed from the energy use estimates (IPCC 2006, Volume 3, Chapter 1). Portions of fuel use were therefore subtracted from the industrial sector fuel consumption data before determining combustion emissions. Note that 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 (approximately 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 CO_2 Industrial” Tab, describe the coking coal used 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 the 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 CO_2 Industrial” Tab, describe this adjustment. The second adjustment was to subtract coal directly used 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 that this does not include coal combusted at I&S facilities to produce power. Other national-level 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 CO_2 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 CO_2 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 CO_2 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 content 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 CO_2 Industrial” Tab, describe this adjustment. The second adjustment was to subtract natural gas directly used 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 CO_2 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 CO_2 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 CO_2 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 CO_2 Industrial" Tab, describe this adjustment. An IPPU-adjusted residual fuel total was then calculated. Appendix A, Table A-35 in the "FFC CO_2 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. 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 CO_2 Industrial" Tab, describes this adjustment.
- **Distillate fuel.** Distillate fuel use was adjusted to subtract the amount of distillate fuel directly used 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 CO_2 Industrial" Tab, describe this adjustment. An IPPU-adjusted distillate fuel total was then calculated. Appendix A, Table A-39 in the "FFC CO_2 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.

2.1.1.2.4. 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 non-biogenic components of those fuels only (which also include any adjustments for denaturant), as described in Step 5 below. 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 2.1.6 for more detail on biofuel use at the state level used to calculate biomass CO_2 as a memo item.

2.1.1.2.5. 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 CO_2 Industrial" Tab, describes this adjustment.

2.1.1.2.6. 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 in the U.S. Department of Transportation's Federal Highway Administration (FHWA) highway statistics data (FHWA 1996–2021).[14] 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. Through 2020, the allocation was based on data from EIA's fuel oil and kerosene sales (FOKS) data (EIA 2022). EIA suspended the FOKS report after data year 2020. Starting in 2021, diesel fuel use is allocated to sectors based on data from SEDS. For 2021 forward, SEDS uses several external sources, regressions, and historical sector and state shares to estimate the data that were in the FOKS report. 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 data and outputs from EPA's MOtor Vehicle Emissions Simulator (MOVES) model (EPA 2022). 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 below in Figure 2-6 and Figure 2-7, including information on the categories of use included in each sector and data for 2021 as an example.

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[14] FHWA forms MF-21 and MF-24 are used in the calculations. For 2021, form MF-24 is not available yet, so values for 2020 were used in the calculations shown.

Figure 2-6. Comparison of Gasoline Sector Allocation

EIA National Energy Balance

Total Supply	2021 ('000 Gal)
Motor Gasoline	135,149,280

Commercial Sector	2021 ('000 Gal)	% of Total
Public non-highway	100,136	
Lawn and garden*	3,028,675	
Misc.	27,062	
Sector Total:	**3,155,873**	**2.3**

Industrial Sector	2021 ('000 Gal)	% of Total
Ag	134,866	
Construction	389,428	
Ind. & comm.	1,766,839	
Sector Total:	**2,291,133**	**1.7**

Transportation Sector	2021 ('000 Gal)	% of Total
Highway	128,909,697	
Boating	2,326,171	
Rec. vehicles*	1,691,428	
Sector Total:	**132,927,296**	**96.1**

Total	2021 ('000 Gal)
Motor Gasoline	138,374,302

Commercial Sector	2021 ('000 Gal)
Motor Gasoline	3,111,990

Industrial Sector	2021 ('000 Gal)
Motor Gasoline	2,207,520

Transportation Sector	2021 ('000 Gal)
Motor Gasoline	129,829,770

* 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

Total Supply	2021 ('000 Gal)
Motor Gasoline	135,149,280

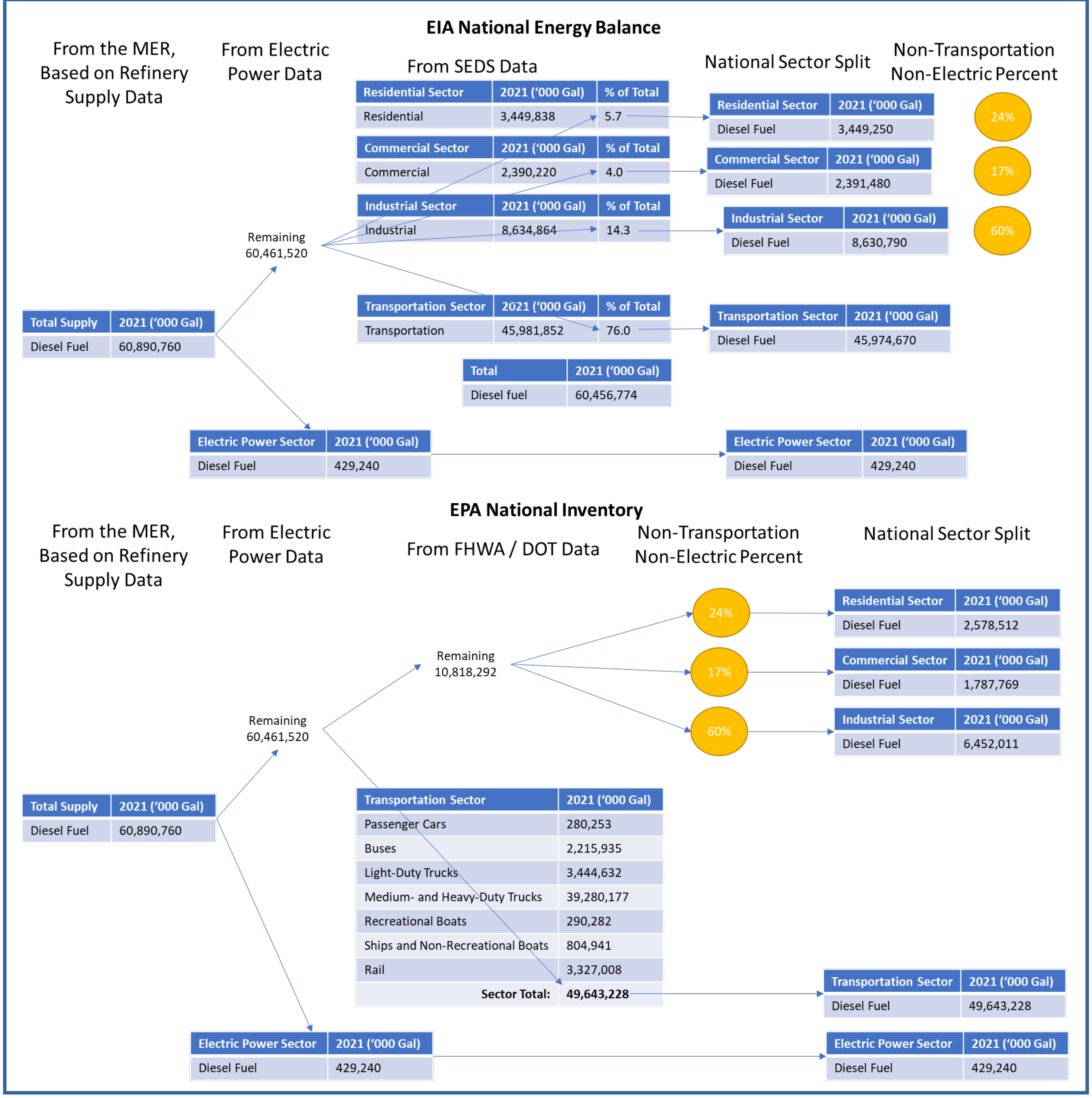
Transportation Sector	2021 ('000 Gal)
Automobiles	45,646,648
Motorcycles	937,387
Buses	361,098
Light Trucks	78,495,932
Other Trucks	3,468,633
Boats (Recreational)	1,336,671
Sector Total:	**130,246,368**

Commercial Sector	2021 ('000 Gal)
Motor Gasoline	2,868,274

Industrial Sector	2021 ('000 Gal)
Motor Gasoline	2,034,638

Transportation Sector	2021 ('000 Gal)
Motor Gasoline	130,246,368

Figure 2-7. Comparison of Diesel Fuel Sector Allocation



EIA National Energy Balance

Total Supply	2021 ('000 Gal)
Diesel Fuel	60,890,760

Electric Power Sector	2021 ('000 Gal)
Diesel Fuel	429,240

Residential Sector	2021 ('000 Gal)	% of Total
Residential	3,449,838	5.7

Commercial Sector	2021 ('000 Gal)	% of Total
Commercial	2,390,220	4.0

Industrial Sector	2021 ('000 Gal)	% of Total
Industrial	8,634,864	14.3

Transportation Sector	2021 ('000 Gal)	% of Total
Transportation	45,981,852	76.0

Total	2021 ('000 Gal)
Diesel fuel	60,456,774

Residential Sector	2021 ('000 Gal)
Diesel Fuel	3,449,250

Commercial Sector	2021 ('000 Gal)
Diesel Fuel	2,391,480

Industrial Sector	2021 ('000 Gal)
Diesel Fuel	8,630,790

Transportation Sector	2021 ('000 Gal)
Diesel Fuel	45,974,670

Electric Power Sector	2021 ('000 Gal)
Diesel Fuel	429,240

EPA National Inventory

Total Supply	2021 ('000 Gal)
Diesel Fuel	60,890,760

Electric Power Sector	2021 ('000 Gal)
Diesel Fuel	429,240

Transportation Sector	2021 ('000 Gal)
Passenger Cars	280,253
Buses	2,215,935
Light-Duty Trucks	3,444,632
Medium- and Heavy-Duty Trucks	39,280,177
Recreational Boats	290,282
Ships and Non-Recreational Boats	804,941
Rail	3,327,008
Sector Total:	**49,643,228**

Residential Sector	2021 ('000 Gal)
Diesel Fuel	2,578,512

Commercial Sector	2021 ('000 Gal)
Diesel Fuel	1,787,769

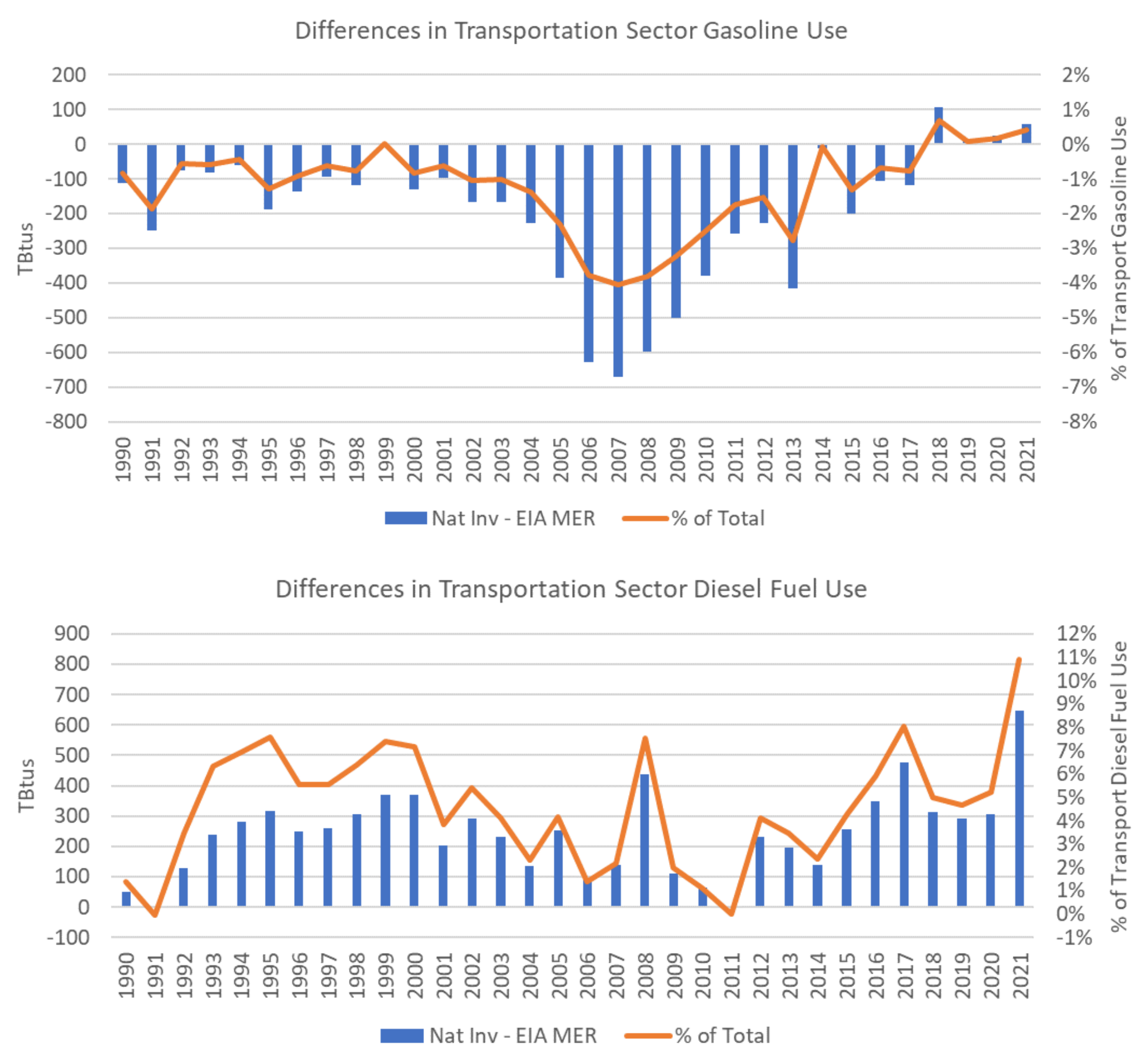
Industrial Sector	2021 ('000 Gal)
Diesel Fuel	6,452,011

Transportation Sector	2021 ('000 Gal)
Diesel Fuel	49,643,228

Electric Power Sector	2021 ('000 Gal)
Diesel Fuel	429,240

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 below in Figure 2-8.

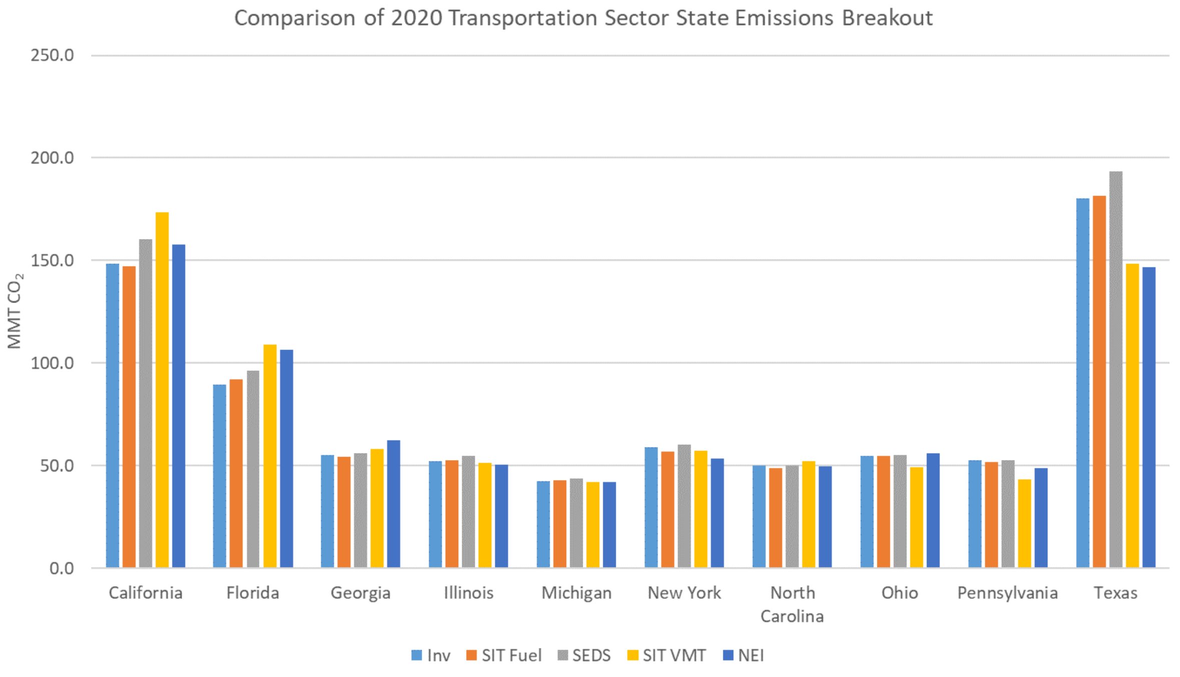
Figure 2-8. Comparison of Transportation Sector Fuel Use



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 2021a, 2021b). 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 CO_2 Transportation" Tab, describe this adjustment. The FHWA data reflect on-highway fuel use, but, as seen in Figure 2-6 and Figure 2-7 above, 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. EPA will consider alternative or complementary approaches to allocate transportation fuel across states, including VMT data and other sources. For example, the National Emissions Inventory (NEI) uses county-level fleet and activity data to generate a bottom-up inventory (EPA 2017).[15] Figure 2-9 shows the transportation sector emissions in 2020[16] 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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[15] 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 at the county level through the MOVES model. However, applying that approach 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.

[16] 2020 is shown because that is the latest year of NEI data that are produced every three 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 CO_2 Residential" Tab, describe 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 CO_2 Commercial" Tab, describe 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 the exact 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 CO_2 Industrial" Tab, describe 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 the exact 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 CO_2 Electricity" Tab, describe 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.

2.1.1.2.7. 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 NEU as construction materials, chemical feedstocks, lubricants, solvents, and waxes.[17] 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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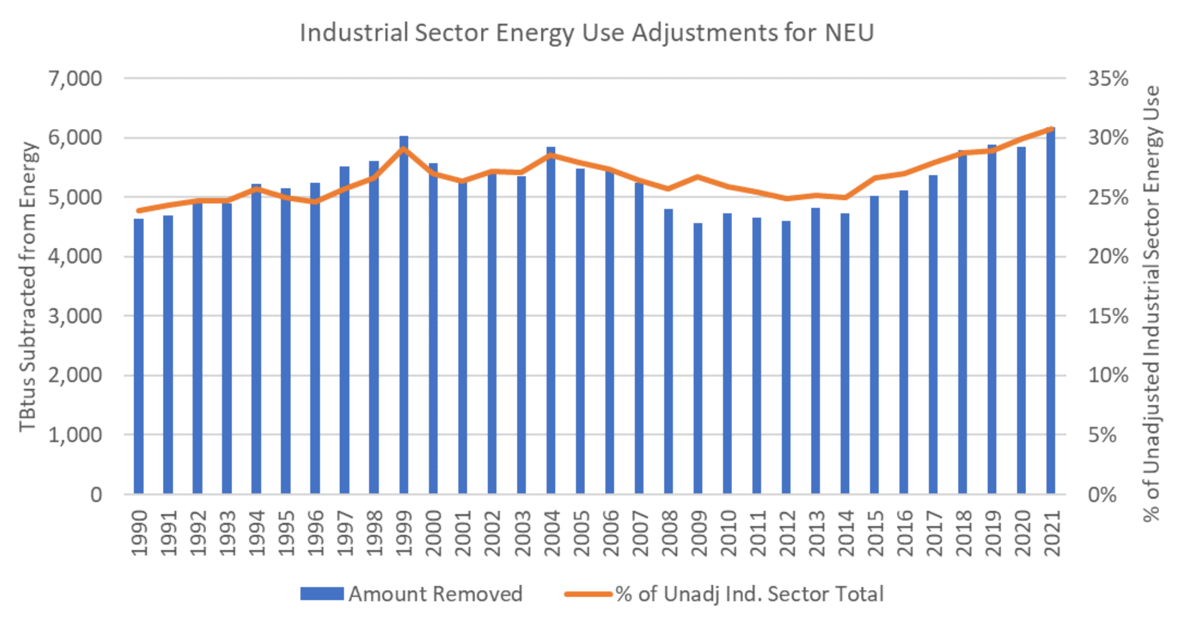
[17] Under IPCC Inventory guidance, emissions from these nonenergy sources should be reported as part of IPPU. However, because of national circumstances and the inability to separate these uses from the national energy balance, the United States reports these emissions as part of energy. This is an 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 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 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 2021 NEU CO_2” 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. The fuels requiring subtraction are:

- **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, 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.

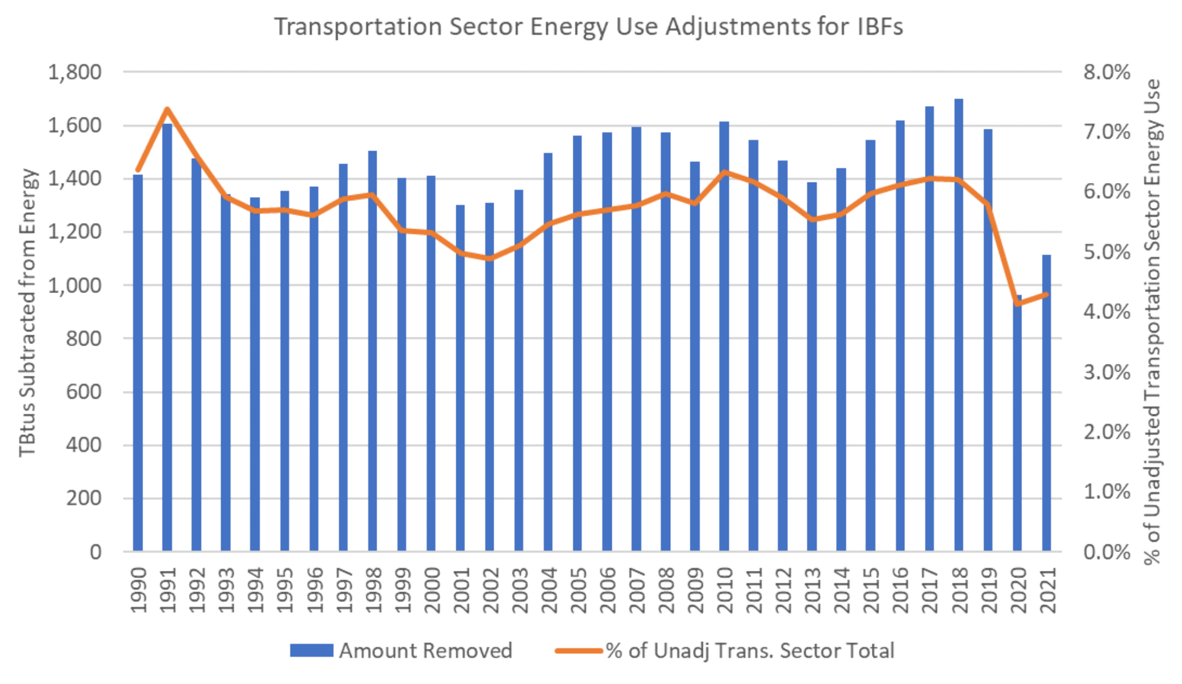
- **LPG, pentanes plus, still gas, and petroleum coke.** The national-level amount of each of these fuels used for NEUs was taken from the national *Inventory* (from EIA data) and assumed to be used primarily as chemical feedstocks. The amount of NEUs for each fuel was allocated across states based on the percentage of each total fuel use in the industrial sector per the original state-level data from SEDS. The SEDS data includes NEU and fuel combustion uses of fuel so this approach assumes that the percentage of these fuel products used in NEU applications per state are proportional to the fuel combustion uses of these fuel products in a given state. This assumption was considered reasonable as the fuel combustion and NEU applications of these fuel products are likely to be in the same types of chemical facilities. Appendix A, Tables A-63 through A-65 and Tables A-69 through 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 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 fuel or other 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%). 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 the industrial and transportation sectors), naphtha (<401 °F), other oil (>401 °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, Tables A-62, A-66 through A-68, A-73, and A-75 through 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, and carbon factors were applied; see further discussion in Section 2.1.2 below.

2.1.1.2.8. Step 7: Subtract Consumption of IBFs

The energy statistics include consumption of fossil fuels that are ultimately used for international bunkers. In the national *Inventory*, emissions from IBF 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 and the International Maritime Organization, 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 4% 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 2021 FFC CO_2" Tab.

The following approaches were taken to determine the state-level amounts 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 2022). This approach was considered reasonable because the FOKS data have information directly on bunker fuel used at the state level.[18] 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 that 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 IBFs by state based on the total amount of jet fuel used by state could potentially lead to an overestimation of IBF 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

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[18] Note that the FOKS data publication was suspended with the 2020 data release; for this cycle, the same percentage by state for 2020 was applied to 2021.

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 2-21adjusted 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, as discussed further below.

2.1.1.2.9. Step 8: Determine the C 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 carbon estimate defines the maximum amount of C that could potentially be released to the atmosphere if all of the carbon in each fuel was converted to CO_2. Fuel-specific C 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 C contents within the United States do not vary appreciably. Two possible exceptions to this are coal and gasoline where state-specific C 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, EPA will look into using specific state-level factors in the state-level estimates in future reports.

2.1.1.2.10. 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 C content of the fuels consumed (from Step 8), and the fraction of carbon that is oxidized. Carbon emissions were multiplied by the molecular-to-atomic weight ratio of CO_2 to carbon (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.

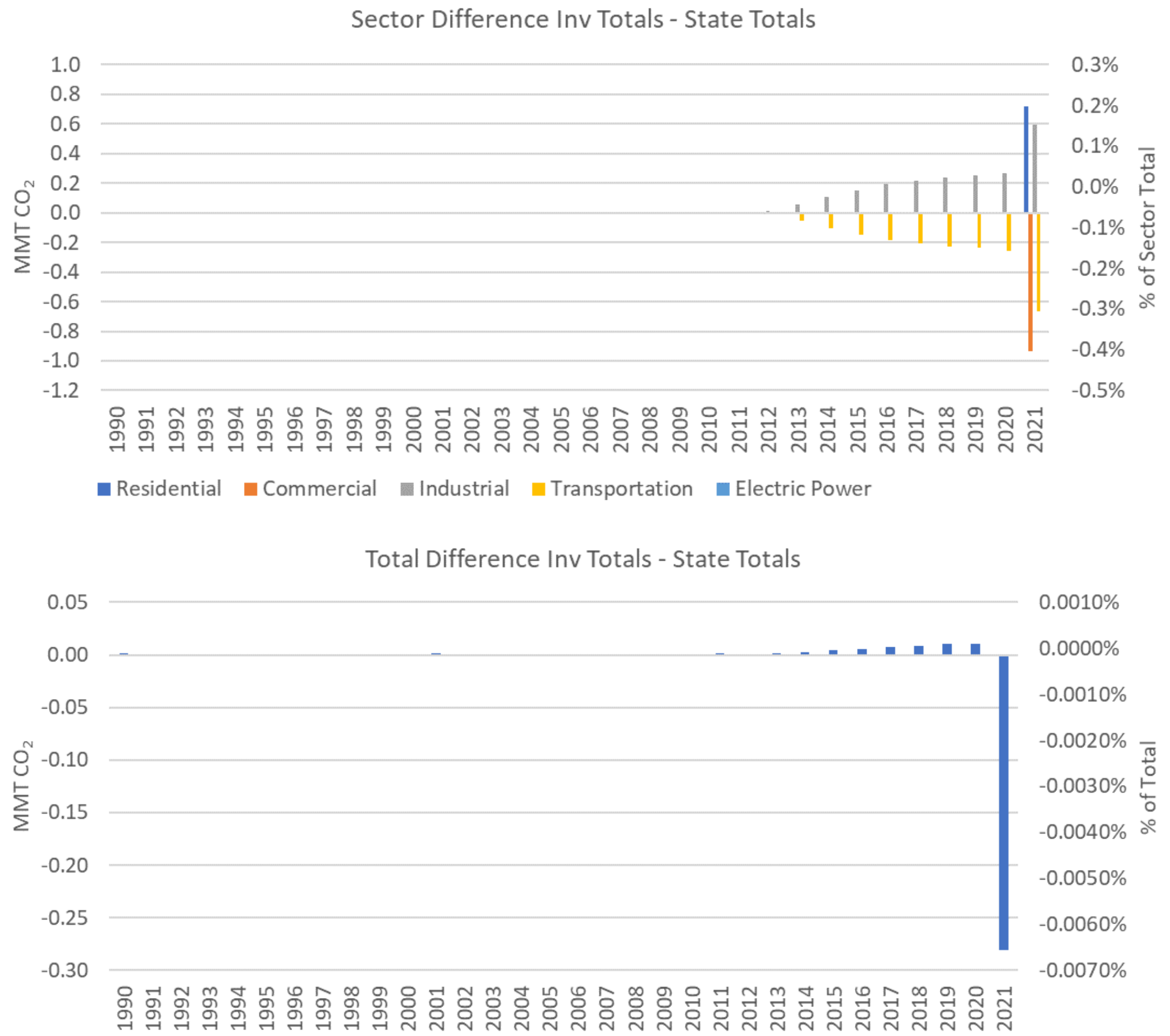
State-level fuel use by fuel type per sector from Steps 1–7 was multiplied by national-level carbon factors from Step 8 (and also multiplied by molecular weight ratios and oxidation fractions) to determine state-level emissions by fuel type and by sector.

2.1.1.2.11. 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 below in Figure 2-12 for FFC CO_2 emissions. 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 February 2023 MER, while the state-level values were based on the June 2023 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 shows more LPG in the industrial sector, which has a higher emissions factor than LPG use in other sectors, so the result is slightly higher total emissions in the state-level estimates. The percentage differences in the 2021 sector totals are small: a 0.2% difference in the residential sector, 0.4% in the commercial sector, 0.1% in the industrial sector, and 0.3% in the transportation sector. The percentage difference in total emissions is also very minor, a 0.007% difference.

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



2.1.1.2.12. 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.

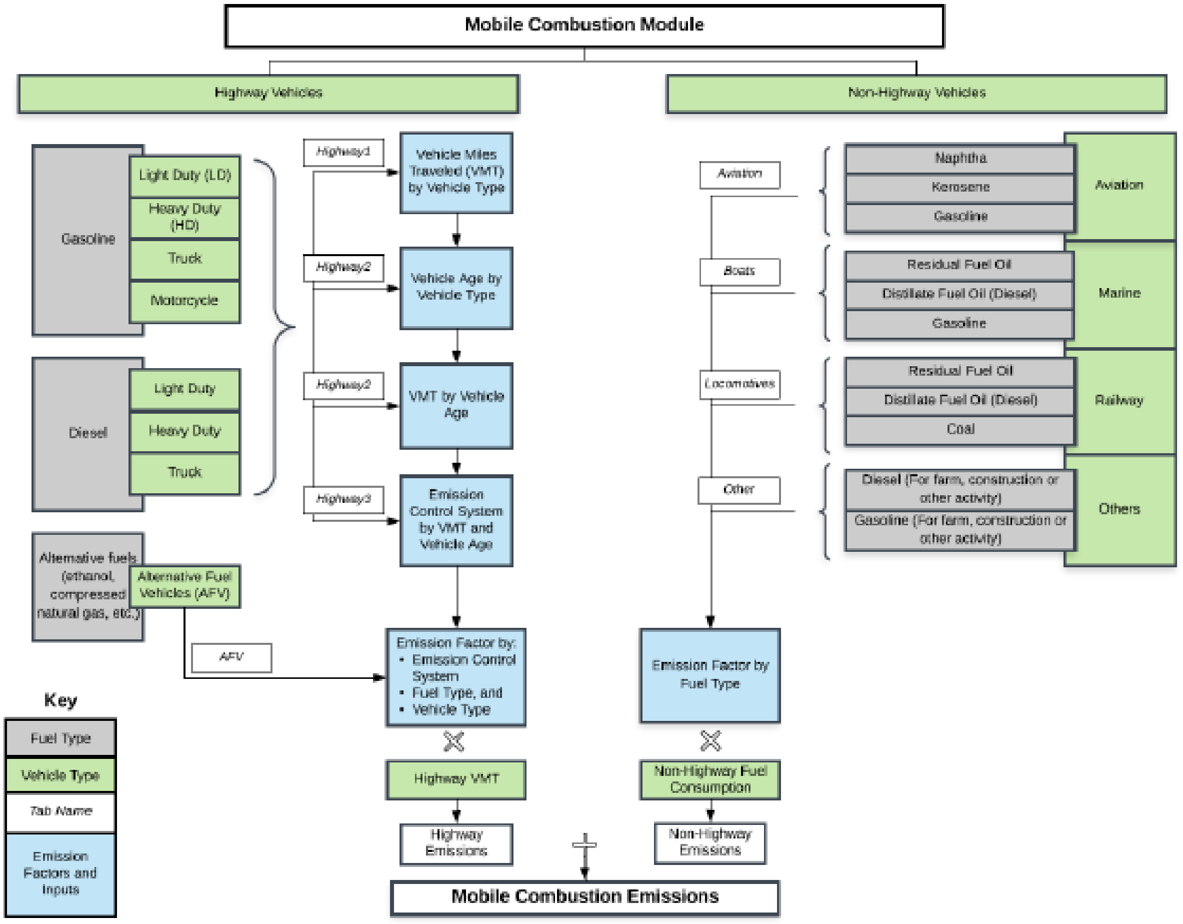
National-level emissions for all sectors were allocated across states based on the same percentage as CO_2 emissions from those sectors and fuel types, as described in the previous section. Appendix A, Tables A-89 through A-104 in the “Stationary non-CO2” Tab, show the percentage breakout of each fuel across sectors that were used in the analysis. For the residential, commercial, and industrial sectors, 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 unable to assess these potential differences. The overall impact of these simplifying assumptions on total state combustion emissions is expected to be small.

2.1.1.2.13. 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 onroad 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 below (EPA 2020).

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



The approach to estimate mobile non-CO_2 emissions 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 23 shows the default data type and source used in developing the state-level estimates. Appendix A, Tables A-105 through A-116 in the "Mobile non-CO_2" 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

Source/Category	Type of Input	Default Source
		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 2023a)
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*
	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 overestimate or underestimate state emissions by assuming a national average of vehicle age distribution 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.

2.1.1.2.14. 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 FFC 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. 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 uses the annual ARMS to collect information on farm production expenditures, including expenditures on diesel fuel, gasoline, LPG, natural gas, and electricity use. A USDA publication (USDA 2020) shows national totals, as well as select states and ARMS production regions. State estimates were survey-derived for 15 states (Alaska, California, Florida, Georgia, Iowa, Illinois, Indiana, Kansas, Minnesota, Missouri, North Carolina, Nebraska, Texas, Washington, and Wisconsin) 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 EIA to obtain agriculture fuel use. CO_2 emissions from FFC as well as 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 2021 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 2023), levels of uncertainty in the national estimates in 2020 for FFC were −2%/+4% for CO_2, −34%/+127% for stationary source CH_4, −26%/+51% for stationary source N_2O, −4%/+29% for mobile source CH_4, and −8%/+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 data sets. As discussed above, the steps involved in determining state-level FFC emissions could result in some overestimation or underestimation of state-level emissions. 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 the underlying data sets and methodologies improves.

2.1.1.4 Recalculations

Consistent with recalculations at the national level, EIA updated energy consumption statistics across the time series relative to the previous *Inventory*. In addition, consistent with the national *Inventory*, the current state-level CO_2 equivalent emissions of CH_4 and N_2O from stationary and mobile sources have been revised to reflect the 100-year GWPs provided in the IPCC AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the IPCC Fourth Assessment Report (AR4), which was used in the previous inventories (IPCC 2007). The AR5 GWPs have been applied across the entire time series for consistency. Prior state inventories used GWPs of 25 and 298 for CH_4 and N_2O, respectively. These values have been updated to 28 and 265, respectively.

2.1.1.5 Planned Improvements

For coking coal, the percentage subtracted by state could be based on other factors like BOF I&S production in each state, as opposed to the percentage of total coking coal use. In some cases, a state could have negative emissions for all fuels if the amount subtracted, as determined from assumed distribution, was greater than consumption data from SEDS for that state. These negative values were corrected to zero, but alternative ways to readjust them 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' NEUs were allocated based on the underlying SEDS data. Allocating across states based on the underlying SEDS data ensures that in no states is NEU larger than in the original SEDS data, which 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, EPA will explore different percentages or a way to use GHGRP petrochemical data without resulting in negative use in any given state.

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 (e.g., FAA data, assumptions based on states with international airports and flights).

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 EPA would have to ensure they are consistent with the national-level factors.

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. EPA will look into reporting these disaggregated data in future state-level reports.

2.1.1.6 References

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

2.1.2.1 Background

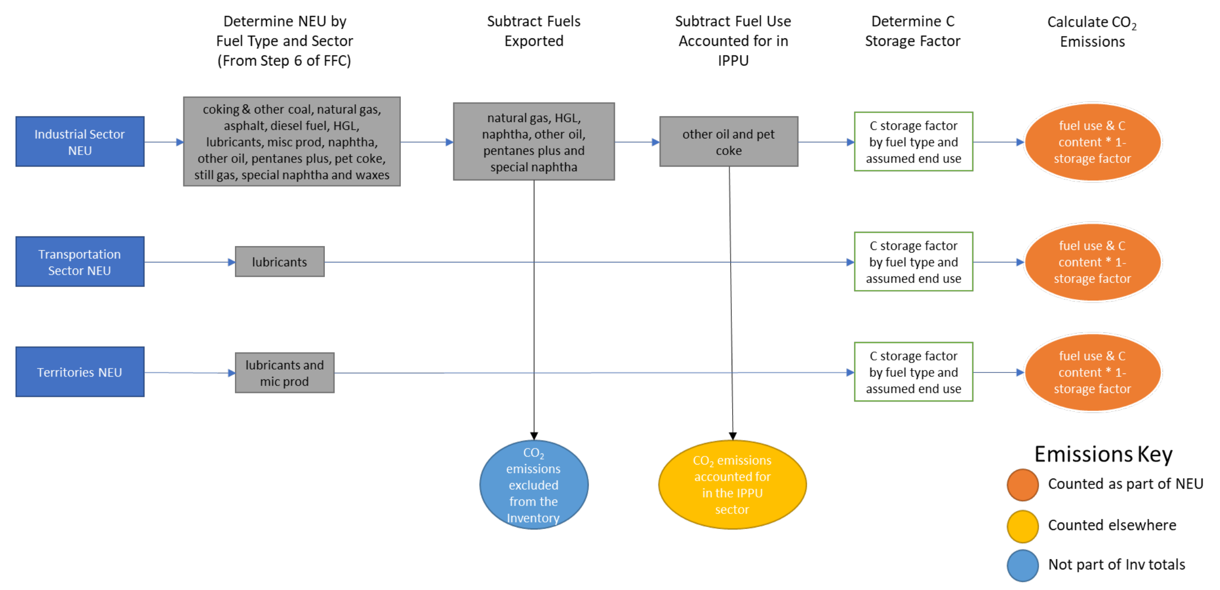
In addition to being combusted for energy, fossil fuels are consumed for NEUs. The fuels used for these purposes and the nonenergy applications of these fuels are diverse, including feedstocks for manufacturing plastics, rubber, synthetic fibers, and other materials; reducing agents for producing various metals and inorganic products; and products such as lubricants, waxes, and asphalt. CO_2 emissions arise via several pathways. Emissions may occur when manufacturing a product, as is the case in producing plastics or rubber from fuel-derived feedstocks. Additionally, emissions may occur during a 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 nonenergy 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 NEU activity data, 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 214. C storage factors are based on the end use of the fuel and assumed fate of the carbon in the products. Appendix A in the "National 2021 NEU CO_2" Tab provides more details on an example of the adjustments made to the national-level NEU data to determine adjusted NEU activity data for 2021.

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.

2.1.2.2.1. 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.

2.1.2.2.2. 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 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 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 assumption could lead to an overestimation or underestimation of NEU emissions in a given state based on the actual amount of product exported. However, it was felt to be reasonable given the lack of export data by state and the small overall adjustment made (2021 export adjustments represent 5.1% of unadjusted nonenergy fuel use). Appendix A, Tables A-82 through A-86 and Table A-88 in the "NEU Adj" Tab, show these adjusted totals.

2.1.2.2.3. 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 nonenergy 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 overestimation 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 reasonable given the lack of data by state on NEU fuels used in IPPU and the small overall adjustment made (2021 IPPU adjustments represent 1.0% of unadjusted NEU fuel use). Appendix A, Tables A-86 and A-87 in the "NEU Adj" Tab, show these adjusted totals.

2.1.2.2.4. Step 4: Determine C Storage Factor by Fuel Type

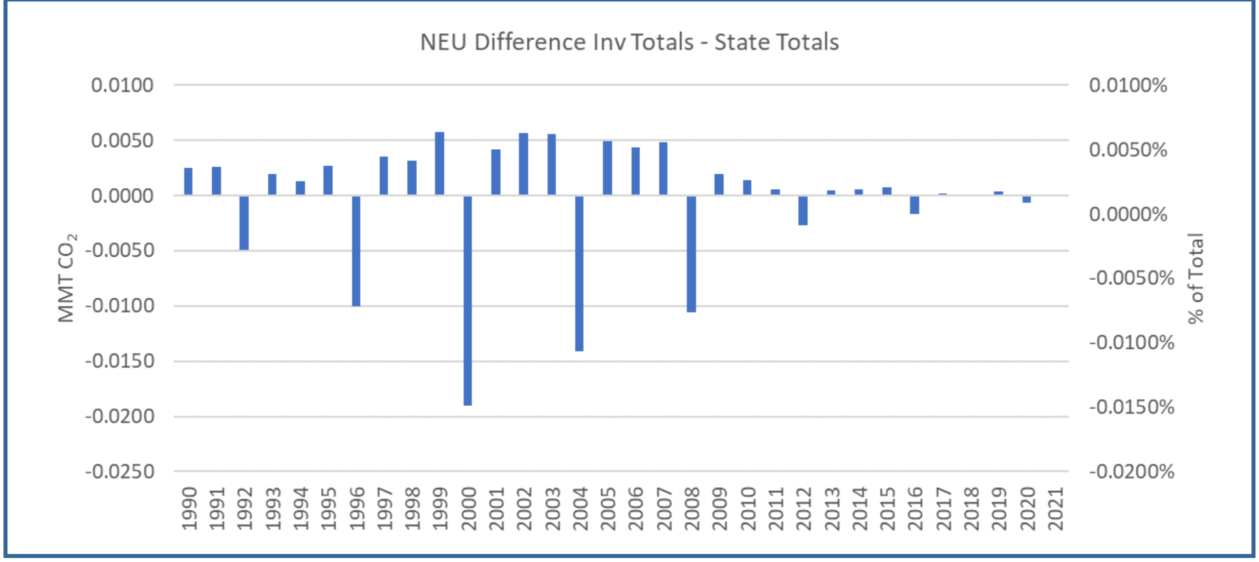
CO_2 emissions can arise from NEUs via several pathways. Emissions may occur when manufacturing a product, as is the case when producing plastics or rubber from fuel-derived feedstocks, or emissions may occur during the product's lifetime, such as during solvent use. Carbon can also be stored from NEUs such as in a final product like plastics or asphalt. Overall, at a national level, about 64% of the total carbon consumed for NEUs 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.

2.1.2.2.5. 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 the fraction of C emitted which is equal to 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 below. As with FFC, these differences represent a very small percentage of total NEU emissions (the maximum percentage difference over time is around 0.015% 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 2020 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 2023), levels of uncertainty in the national estimates in 2020 were −42%/+46% 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 Recalculations

Consistent with national estimates, EIA updated energy consumption statistics across the time series relative to the previous national *Inventory.*

2.1.2.5 Planned Improvements

Planned improvements for state level NEU estimates are consistent with those EPA has planned for improving national estimates for NEUs which are discussed in Section 3.2 of the national *Inventory* report (EPA 2023). 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.

2.1.2.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

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* (EPA 2023) and allocated across states based on the amount of geothermal energy consumed by each state from the SEDS data (EIA 2023). 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 five states in 2021 were California, Nevada, Florida, Michigan, and Indiana, accounting for about 75% of all geothermal energy consumption.

2.1.3.3 Uncertainty

Given its small contribution to the overall FFC portion of the national *Inventory* (0.009% in 2021), an uncertainty analysis was not performed for CO_2 emissions from geothermal production.

2.1.3.4 Recalculations

No recalculations were applied for this current report.

2.1.3.5 Planned Improvements

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.

2.1.3.6 References

EIA (U.S. Energy Information Administration) (2023) *State Energy Data System (SEDS): 1960–2021 (Complete).* Final values, June 23, 2023. U.S. Department of Energy. Available online at: https://www.eia.gov/state/seds/seds-data-complete.php

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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. Incinerating 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 an emission factor based on 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 C stock change methodologies in the agriculture and LULUCF 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 2-4. This is the same approach as currently used in the national *Inventory* (EPA 2023a). The national *Inventory* has more information on the data sources used.

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

Time Series Range	Summary of Data Used
1990–2005	• Waste combusted by state was based on BioCycle report data.
2006–2010	• Waste combusted was based on data from BioCycle, EPA, EIA and the Energy Recovery Council (ERC) on waste combustion.
2011–2021	• Waste combustion data were based on the U.S. EPA GHGRP.

The methodology used for 1990–2005 was to estimate waste combusted by state based on data from multiple years of BioCycle reports.

The methodology used for 2006–2010 was to estimate waste combusted by state based on data from the BioCycle reports, EPA Facts and Figures, EIA (EIA 2006-2010), and Energy Recovery Council data.

The methodology used for 2011–2021 was to estimate waste combustion based on EPA's GHGRP (EPA 2023b). 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, for the percent of MSW combusted assumed by state by year from the different sources, as well as the national *Inventory* report, for more information on the data sources and methodology used.

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 (e.g., because of state waste management policies). The EPA update to the national-level waste incineration emissions estimates 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 overestimating 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 2021 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 2023a), levels of uncertainty in the national estimates in

2021 were −17%/+19% for CO_2 and −54%/+163% 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 Recalculations

Consistent with the national *Inventory*, recalculations in state-level waste incineration include updates to the methods for calculating national level CO_2 emissions. In addition, consistent with the national *Inventory*, the current state-level CO_2-equivalent emissions of CH_4 and N_2O from waste incineration have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4, which was used in the previous inventories (IPCC 2007). The AR5 GWPs have been applied across the entire time series for consistency. Prior state inventories used GWPs of 25 and 298 for CH_4 and N_2O, respectively. These values have been updated to 28 and 265, respectively.

2.1.4.5 Planned Improvements

EPA will look into separating emissions by state based on the category of emissions (e.g., MSW combustion versus tire combustion). EPA will also consider developing state-level MSW carbon factors based on the GHGRP state-level data.

2.1.4.6 References

EIA (U.S. Energy Information Administration) (2006-2010) *Form EIA-923 detailed data with previous form data (EIA-906/920))*. U.S. Department of Energy. Available online at: https://www.eia.gov/electricity/data/eia923/.

EPA (U.S. Environmental Protection Agency) (2023a) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

EPA (2023b) *Data Sets*. Available online at: https://www.epa.gov/ghgreporting/ghg-reporting-program-data-sets

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

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IPCC (2013) *Climate Change 2013: The Physical Science Basis*. *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M.B. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

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 the location of the 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 IBF 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 subtracting IBFs affects jet fuel emissions that are reported in a given state (see Step 7 of the FFC emissions calculations).

2.1.5.2 Methods/Approach

As noted, emissions resulting from the combustion of IBFs 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 and reported as memo items. 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 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.

2.1.5.2.1. 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 multiplied by the national *Inventory* CO_2 emissions factor. National-level CH_4 and N_2O emissions were based on fuel use data multiplied by an emissions factor, and CH_4 emissions from jet fuel use were assumed to be zero. 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 (EIA 2023).

2.1.5.2.2. Residual and Diesel Fuel

National-level residual and diesel fuel emissions were based on fuel use data multiplied by 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 (EIA 2022).[19]

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 Recalculations

No recalculations were applied for this current report.

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[19] Note that the FOKS data were suspended with the 2020 data. For this cycle, the same percentage by state for 2020 was applied to 2021.

2.1.5.5 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 overestimation or underestimation of bunker fuel emissions for some states. Therefore, EPA will look into data specific to jet fuel bunkers by state, such as 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. 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*.

2.1.5.6 References

EIA (U.S. Energy Information Administration) (2022) *Fuel Oil and Kerosene Sales*. U.S. Department of Energy. Available online at: http://www.eia.gov/petroleum/fueloilkerosene.

EIA (2023) *State Energy Data System (SEDS): 1960–2021 (Complete).* Final values, June 23, 2023. U.S. Department of Energy. Available online at: https://www.eia.gov/state/seds/seds-data-complete.php

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 carbon reservoirs in the agriculture, land use change, land use change and forestry 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 biomass- and wood waste–based fuels such as ethanol, biogas, and biodiesel—generates CO_2 in addition to the CH_4 and N_2O 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 carbon reservoirs in the agriculture, land use, land use change, and forestry 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 A-129 in the "Biomass CO_2" Tab, for the breakout of biomass CO_2 emissions by fuel type and sector.

2.1.6.2.1. 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 (FHWA 2021a).

2.1.6.2.2. 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 (EIA 2023).

2.1.6.2.3. 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 (EIA 2023).

2.1.6.2.4. 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 (FHWA 2021b).

2.1.6.2.5. 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 (EIA 2023).

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 Recalculations

No recalculations were applied for this current report.

2.1.6.5 Planned Improvements

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

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.

2.1.6.6 References

EIA (U.S. Energy Information Administration) (2023) *State Energy Data System (SEDS): 1960–2021 (Complete).* Final values, June 23, 2023. U.S. Department of Energy. Available online at: https://www.eia.gov/state/seds/seds-data-complete.php

FHWA (Federal Highway Administration) (2021a) *Highway Use of Gasoline by State, 1949–2020*. Table MF-226. U.S. Department of Transportation. Available online at: https://www.fhwa.dot.gov/policyinformation/statistics/2020/mf226.cfm.

FHWA (2021b) *Private and Commercial Highway Use of Special Fuel, by State, 1949–2020*. Table MF-225. U.S. Department of Transportation. Available online at: https://www.fhwa.dot.gov/policyinformation/statistics/2020/mf225.cfm.

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, CO_2)

- 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*, 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

2.2.1.2.1. Active Underground Mines

To compile national estimates of CH_4 emissions from active underground coal mines for the national *Inventory*, EPA develops emissions estimates for each mine and sums them to a national total. 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, 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 2023).

As described in Section 3.4 of the national *Inventory*, 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 2023) for more detail.

To estimate CH_4 liberated from ventilation systems, EPA uses data collected through its GHGRP[20] (Subpart FF, “Underground Coal Mines”), data provided by the U.S. Mine Safety and Health Administration (MSHA) (MSHA

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[20] 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).

2020), 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 cubic feet of CH_4 per year (about 17,525 metric tons CO_2 equivalent)—have been required to report to EPA's GHGRP (EPA 2022).[21] Mines that report to 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.[22] More information can be found in the national *Inventory* (Chapter 3, Section 3.4 and Annex 3.4) at https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-3-Energy.pdf.

EPA estimates fugitive CO_2 emissions from underground mining using an IPCC Tier 1 method. Emission estimates are based on the IPCC Tier 1 emission factor (5.9 m^3/metric ton) and annual coal production from underground mines from EIA (IPCC 2019; EIA 2022 Table 1). The underground mining default emission factor accounts for all the fugitive CO_2 likely to be emitted from underground coal mining. Estimates of fugitive CO_2 emissions were included for the first time in the national Inventory for 1990–2020 (see Planned Improvements section below).

2.2.1.2.2. 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 EIA's Annual Coal Report (EIA 2022 are multiplied by basin-specific CH_4 contents (EPA 1996, 2005) and a 150% emissions factor (to account for CH_4 from overburden and underburden) to estimate CH_4 emissions (King 1994, Saghafi 2013). For post-mining activities, basin-specific coal production is 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 the American Association of Petroleum Geologists (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 are 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 within which the state is located. For post-mining activities, these emissions are assigned to the state where the coal was produced, even if a portion of such emissions may occur outside the state, such as 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). EPA estimates fugitive CO_2 emissions from surface mining using an IPCC Tier 1 method. Emission estimates are based on the IPCC Tier 1 emission factor (0.44 m^3/metric ton) and annual coal production from surface mines (EIA 2021, Table 1). IPCC methods and data to estimate fugitive CO_2 emissions from post-mining activities (for both underground and surface coal mining) are currently not available. Estimates of fugitive CO_2 emissions were included for the first time in the national *Inventory* for 1990–2020 (see Planned Improvements section below).

2.2.1.3 Uncertainty

The overall uncertainty associated with the 2020 national estimates of CH_4 and CO_2 emissions from coal mining was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006), which is described further in Chapter 3 of the national *Inventory* (EPA 2023). The level of uncertainty in the 2021 national CH_4 estimate is −10%/+22%; for the national fugitive CO_2 estimate, the level of uncertainty is −68%/+76%. Because CH_4

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[21] Underground coal mines report to the EPA under Subpart FF of the GHGRP (40 CFR Part 98). In 2020, 71 underground coal mines reported to the program.

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

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 CH_4 emissions, which are based on coal production and the application of emissions 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 CH_4 emissions estimates. The major sources of uncertainty for estimates of fugitive CO_2 emissions are the Tier 1 IPCC default emission factors used for underground mining (−50%/+100%) and surface mining (−67%/+200%) (IPCC 2019).

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 the 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, 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 Recalculations

No recalculations were applied for this current report.

2.2.1.5 Planned Improvements

Planned improvements for state level coal mining estimates are consistent with those EPA has planned for improving national estimates for coal mining which are discussed in Section 3.4 of the national *Inventory* report (EPA 2023). For more information, see Chapter 3, Section 3.4, of the national *Inventory*.

2.2.1.6 References

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EPA (U.S. Environmental Protection Agency) (1996) *Evaluation and Analysis of Gas Content and Coal Properties of Major Coal Bearing Regions of the United States*. EPA/600/R-96-065.

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IPCC (2011) *Technical Bulletin on the Use of Facility-Specific Data in National Greenhouse Gas Inventories*. Available online at: https://www.ipcc-nggip.iges.or.jp/public/tb/TFI_Technical_Bulletin_1.pdf

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2.2.2 Abandoned Underground Coal Mines (NIR Section 3.5)

2.2.2.1 Background

Underground coal 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 when groundwater or surface water intrudes into the mine 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*, 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 accounts for 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. For the 1990–2019 time series, the model results by coal basin and mine status are then aggregated to the national level.[23] More information on the estimation methodology and model input data can be found in Chapter 3, Section 3.5, of the national *Inventory* (EPA 2023).

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

For the 1990-2020 national *Inventory*, EPA updated the AMM model to include state-level estimates as a regular output. These state-level estimates apply for inventory year 2020 and future inventory years. Previously, the AMM model included only coal basin identifiers; EPA has added state identifiers. Under this approach, both national-level and state-level estimates are generated for an inventory year by the AMM model. The modified model output contains emissions subtotals by state, coal basin, and mine status. These subtotals are then aggregated to generate state-level estimates. The final model result (i.e., national-level estimates) is the average of 10,000 model iterations, but the calculated state estimates are not. Therefore, the sum of the state-level estimates may not exactly equal the final national-level estimate. The state-level estimates are 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 relies 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 provides more accurate state-level estimates.

The disaggregation method used to estimate state-level emission estimates for the 1990–2019 time series is described below. State-level emissions estimates for the 1990–2019 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.

2.2.2.2.1. 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 basins) 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 100% for each year in the time series (see Appendix B, Tables B-1 through B-4, for these 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.

For pre-1972 emissions,[24] 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 2-5 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 2-5. Example State Allocation Factors for the Illinois Coal Basin (Sealed Mines)

State	Basin	Status	Percent (%) of Emissions
IL	Illinois	Sealed	77%
IN	Illinois	Sealed	6%

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[24] 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.

State	Basin	Status	Percent (%) of Emissions
KY	Illinois	Sealed	17%

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

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

Next, EPA normalized 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[25] to equal the national-level emissions estimate (AMM model output #2) that represents the national emissions estimates used in the national *Inventory*.

2.2.2.2.3. 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 2020 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* (EPA 2023), the level of uncertainty in the 2021 national CH_4 emission estimate is −22%/+21%.

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-

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[25] 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).

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 ("pre-1972 mines"). 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 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 Recalculations

No recalculations were applied for this current report.

2.2.2.5 Planned Improvements

For the 1990–2020 national inventory, EPA updated the AMM model to include state-level estimates as a regular output, as described above, implementing planned improvements described in the previous report. These state-level estimates apply for RY 2020 and future years.

2.2.2.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. U.S. online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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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. CH_4 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 that 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.

A recalculation was made in the final national *Inventory* to use basin-level data from GHGRP for certain onshore production sources (equipment leaks, tanks, pneumatic controllers, and chemical injection pumps) to develop basin-level emission estimates, which were then summed to the national level (EPA 2023). The methods used to develop the state-level estimates for petroleum systems follow the Hybrid approach (a combination of Approach 1 and Approach 2), as defined in the Introduction of this report. Most sources follow Approach 2 and rely on relative differences in basic state activity levels (e.g., petroleum production), and do not reflect differences between states due to differences in practices, technologies, or formation types. Consistent with updated information available in the national *Inventory*, Approach 1 was used for the onshore production emission sources using a basin-level approach in the national *Inventory*, and also for petroleum refining. Petroleum refining emissions are allocated to states for years after 2010 using facility-level emissions reported to the GHGRP, Subpart Y. 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

To compile national *Inventory* estimates of GHG emissions (CH_4, CO_2, and N_2O) from petroleum, EPA compiles emissions estimates for emissions sources in each segment of a petroleum system (e.g., exploration, production, transport, refining) into a national total (EPA 2023, Section 3.6). 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-1990-2021-ghg.

The state-level methodology for petroleum systems follows the Hybrid approach. The production sources that rely on Approach 1, consistent with incorporating more disaggregated data in the national-level 2023 GHGI, are discussed further in the following Exploration and Production section. For other industry segments and sources, national emissions from each segment are allocated to all U.S. states, territories, and federal offshore waters (for the production segment only) using activity data sets that have information broken out at a state level, such as the number of oil wells or volume of oil production in each state. Where possible, these data sets are chosen to align with current activity data sets used to develop national *Inventory* estimates. See Appendix B for information on the current state-level underlying proxy data sets (i.e., Tables B-5 to B-7). The specific data sets used to disaggregate national emissions to the state level vary by segment, as described in the following sections.

2.2.3.2.1. Exploration and Production

For the national *Inventory*, EPA uses emissions data collected by the GHGRP to quantify emissions for most exploration and production sources in recent years (i.e., 2010–2021). For sources where recent data are unavailable, and for earlier years of the time series, estimates are developed using emissions factors from the Gas Research Institute (GRI)/EPA (1996) and Radian (1999) studies. Other key data sources for the national estimates include oil well counts and production levels from Enverus, the Bureau of Ocean Energy Management, and total crude oil production from EIA.

Four onshore production emission sources used information available through the updated national *Inventory* (EPA 2023), to implement Approach 1 to develop state emissions: pneumatic controllers, storage tanks, equipment leaks (i.e., from separators, heater/treaters, headers, and wellheads), and chemical injection pumps. These sources relied on basin-specific emission factors and/or activity factors from GHGRP and basin-level activity data (i.e., well counts and oil production) to estimate basin emissions across the time series. The basin emissions were then directly allocated to each state using the same activity data. The state activity data are in Appendix B, Tables B-5 and B-6.

To develop state-level emissions for other petroleum exploration and production emission sources, national *Inventory* emissions were allocated to each state, primarily based on the fraction of oil wells in each state relative to national totals across each year in the time series (Appendix B, Tables B-5 and B-6). Other key state-level proxy data sets used to disaggregate national emissions include the number of oil well completions with and without hydraulic fracturing in each state, as well as the total volume of oil produced in each state. These state data were derived from time series of oil and gas well data from Enverus, consistent with the Enverus data set used as activity data to derive total national emissions. For offshore activities, emissions from state waters in the Gulf of Mexico were allocated based on relative state-level oil 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 data sets used for state allocation were consistent across the entire emissions time series.

2.2.3.2.2. Crude Oil Transport

For the national *Inventory*, 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 EIA, the American Petroleum Institute, and the *Oil and Gas Journal*.

To develop state-level emissions from crude oil transport, national *Inventory* emissions were allocated to each state based on three state proxy data sets. Vented emissions from marine loading were allocated to states based on oil production from offshore wells in state waters from the Enverus data set (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 GHGRP Subpart Y data after 2010 and EIA atmospheric crude oil distillation capacity for 1990–2009 (Appendix B, Table B-7), as described in the next section.

2.2.3.2.3. Refineries

For the national *Inventory*, EPA uses data from the GHGRP Subpart Y 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 are used for the emissions in each year from 2010 forward. Certain activities that are not reported to the GHGRP are estimated using data from Radian (1999). These sources account for a small fraction of refinery emissions. To estimate emissions for 1990–2009, the emissions data from the GHGRP, along with the refinery feed data, are used to derive emissions factors that are applied to the annual refinery feed in years 1990–2009.

To develop state-level estimates for refineries for 2010–2021, national *Inventory* emissions from refineries were apportioned to each state based on that state's share of refinery emissions of each gas, as reported to GHGRP Subpart Y. This method is consistent with national *Inventory* estimates for refineries over these years. For 1990–2009, national *Inventory* emissions from refineries were apportioned to each state based on that state's share of national operating atmospheric crude oil distillation capacity (barrels per calendar day), as shown in Appendix B, Table B-7 (EIA 2022).

2.2.3.3 Uncertainty

The overall uncertainty associated with the 2021 national estimates of CO_2 and CH_4 from petroleum systems was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). Uncertainty estimates for N_2O applied the same uncertainty bounds as calculated for CO_2. As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 were −13%/+19% for CO_2 and N_2O and −10%/+15% 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 data sets. This allocation method introduces additional uncertainty due to sources of uncertainty associated with the location information in each underlying data set (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 data sets 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, other than refinery emissions, are also consistent over time because the same proxy data sets 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 data sets 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 EPA's estimates do not include all CH_4 emissions from abnormal events. For many equipment types and activities, 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 national *Inventory* (e.g., Aliso Canyon leak event). EPA continues to work through its stakeholder process to review new data from EPA's GHGRP and research studies to assess how emissions estimates can be improved.

2.2.3.4 Recalculations

As described in Chapter 3 of the national *Inventory* report, some emission and sink estimates in the national *Inventory* are recalculated and revised with improved methods and/or data. In general, recalculations are made to incorporate new methodologies, or to update activity and emissions factor data sets with the most current versions. These improvements are implemented across the previous national *Inventory's* entire time series to ensure the national emission trend is accurate. See section 3.6 of Chapter 3 in the national *Inventory* report for more details on recalculations in the latest national *Inventory* estimates.

Four onshore production emission sources used a new, basin-level methodology for this year's national *Inventory*. As such, changes in absolute state-level emissions between this version and the previous state report for these sources reflect, to some extent, state-specific practices and data.

As the state-level emissions are otherwise estimated using Approach 2 (national emissions are disaggregated to the state level), changes in absolute state-level emissions between this version and the previous state report will largely reflect recalculations and improvements implemented in the national *Inventory*. Similar to the national *Inventory*, the calculation of state-level estimates has been updated to incorporate updates to the underlying state-level proxy data sets. State-level proxy data sets have been updated across the entire time series, to ensure that the state emission trends are accurate.

Consistent with the national *Inventory*, CO_2 equivalent emissions totals have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of CH_4 has increased from 25 to 28, leading to an increase in the calculated CO_2 equivalent emissions of CH_4, while the GWP of N_2O has decreased from 298 to 265, leading to a decrease in the calculated CO_2 equivalent emissions of N_2O.

2.2.3.5 Planned Improvements

Potential refinements in future state-level inventories include refining state proxies used within each segment and incorporating additional GHGRP data.

2.2.3.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

EIA (U.S. Energy Information Administration) (2022) *Crude Oil Production*. U.S. Department of Energy.

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. U.S. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

GRI (Gas Research Institute)/EPA (1996) *Methane Emissions from the Natural Gas Industry*. https://www.epa.gov/natural-gas-star-program/methane-emissions-natural-gas-industry

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

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IPCC (2013) *Climate Change 2013: The Physical Science Basis*. *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Radian (1999) *Methane Emissions from the U.S. Petroleum Industry.* U.S. Environmental Protection Agency.

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 gathering, 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.

A recalculation was made in the national *Inventory* to use basin-level data from GHGRP for certain onshore production sources (liquids unloading, equipment leaks, tanks, pneumatic controllers, and chemical injection pumps), to develop basin-level emission estimates, which were then summed to the national level (EPA 2023).

The methods used to develop the state-level estimates for natural gas systems follow the Hybrid approach (a combination of Approach 1 and Approach 2), as defined in the Introduction of this report. Most sources follow Approach 2 and rely on relative differences in basic state activity levels (e.g., gas production), and do not reflect differences between states due to differences in practices, technologies, or formation types. Consistent with updated information available from the national *Inventory* (EPA 2023), Approach 1 was used for the onshore production emission sources using a basin-level approach in the national *Inventory*. Future state-level inventory reports may incorporate additional state-specific or region-specific data to improve estimates and better reflect these differences.

2.2.4.2 Methods/Approach

To compile national estimates of CH_4, CO_2, and N_2O emissions from natural gas systems for the national *Inventory*, EPA compiles emissions estimates for emissions sources in each segment of natural gas systems (i.e., exploration, production, processing, transmission and storage, distribution, and post-meter sources) into a national total. Additional information on emissions estimates and data used to develop the national-level emissions estimates for natural gas systems is available online at https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems-ghg-inventory-additional-information-1990-2021-ghg.

The state-level methodology for natural gas systems follows the Hybrid approach. The production sources that rely on Approach 1, consistent with incorporating more disaggregated data in the national-level 2023 GHGI, are discussed further in the following Exploration and Production section. For other industry segments and sources, national emissions from each segment are allocated to all U.S. states, territories, and federal offshore waters (production segment only) using activity data sets that have information broken out at a state level, such as the number of gas wells or volume of gas produced in each state. Where possible, these data sets are chosen to align with current activity data sets used to develop national *Inventory* estimates. See Appendix B for information underlying the estimates (Tables B-8 to B-12). The specific data sets used to disaggregate national emissions to the state level vary by segment, as described in the following sections.

2.2.4.2.1. Exploration and Production

For the national *Inventory*, EPA uses emissions data collected by the GHGRP to quantify emissions for most sources in recent years (i.e., 2011–2021) and data from a GRI/EPA 1996 study for earlier years of the time series or for sources where 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 Bureau of Ocean Energy Management. 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.

Five onshore production emission sources used information available through the updated national *Inventory* to implement Approach 1 and develop state emissions: pneumatic controllers, storage tanks, equipment leaks (i.e., from separators, dehydrators, heaters, compressors, and meters/piping), liquids unloading, and chemical injection pumps (EPA 2023). These sources relied on basin-specific emission factors and/or activity factors from GHGRP and basin-level activity data (i.e., well counts, gas production) to estimate basin emissions across the time series. The basin emissions were then directly allocated to each state using the same activity data. The state activity data are in Appendix B, Tables B-8 and B-9.

To develop state-level emissions for other natural gas exploration and production emission sources, national *Inventory* emissions were generally allocated to states using state-level proxy data sets that align with the activity data used in the national *Inventory* (i.e., well counts, gas production, or condensate production). For example, state counts of gas wells 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). In addition, state-level proxy data sets for natural gas production from Enverus (Appendix B, Table B-9) and state-level lease condensate production from EIA (2022) aligned with national activity data sources. Proxy data for exploration included 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 relative emissions in each state of all other production sources. To account for updates to the national *Inventory* that incorporate CH_4 emission estimates from well blowout events in Ohio, Texas, and Louisiana, CH_4 emissions from these one-time events were allocated each state in the appropriate year (e.g., 60,000 metric tons in Ohio in 2018, 4,800 metric tons in Louisiana in 2019, and 49,000 metric tons in Texas in 2019). In addition, the allocation of national *Inventory* estimates from produced water has been updated to using produced water volumes from Enverus to align the activity data used in the national *Inventory*. The Enverus gas well counts and production levels were used to assign basin-level emissions estimates to the appropriate state. For both exploration and production segments, the sources of proxy data used for state allocation were consistent across the entire emissions time series.

2.2.4.2.2. Processing

For the national *Inventory*, EPA uses emissions data collected by GHGRP to quantify emissions for most sources in recent years (i.e., 2011–2021) and data from GRI/EPA (1996) for earlier years of the time series or for sources where recent data are unavailable. Key activity data include processing plant counts from *Oil and Gas Journal*.

To develop state-level estimates for the processing segment for each year of the time series, EPA apportioned the total national processing segment emissions to each state based on the fraction of national onshore marketed natural gas production occurring in each state (EIA 2022), as shown in Appendix B, Table B-10.

2.2.4.2.3. Transmission and Storage

For the national *Inventory*, EPA uses emissions data collected by the GHGRP and data from a Zimmerle et al. (2015) study to quantify emissions from most sources in recent years (i.e., 2011–2021), 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 (PHMSA 2023).

To develop state-level estimates for the transmission and storage segment for each year of the time series, 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). In the national *Inventory,* CH_4 emissions from anomalous events are added to storage emission totals in several years. In the state-level estimates, these emissions are allocated to the state in which the event occurred, while remaining emissions from storage wells are allocated based on the relative transmission pipeline mileage in each state.

2.2.4.2.4. Distribution

For the national *Inventory*, EPA uses 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., 2011–2021) and GRI/EPA (1996) data for earlier years of the time series or 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 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 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 non-reporters). Complete PHMSA data are available starting in 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), as shown in Appendix B, Table B-12.

2.2.4.2.5. Post-meter Sources

For the national *Inventory,* post-meter sources include leak emissions from residential and commercial appliances, industrial facilities and power plants, and natural gas–fueled vehicles. Leak emissions from residential appliances and industrial facilities and power plants account for the majority of post-meter CH_4 emissions. CO_2 emissions from residential appliances are included in the natural gas residential source within the energy sector and are not accounted for here. There are no N_2O emissions from the post-meter segment. Key activity data include the counts of homes in the United States with natural gas appliances from the American Housing Survey national data set, the number of commercial natural gas customers from EIA, natural gas consumption volumes for industrial and electric generating units from EIA, and counts of compressed natural gas vehicles from the EPA MOVES model. For more information on the post-meter emissions in the national *Inventory*, see Chapter 3 of the national *Inventory* report.

To develop state-level estimates for post-meter emissions for each year of the time series, the EPA national total emissions from residential and commercial appliances were allocated to states using the relative number of residential and commercial natural gas customers in each state from EIA. Industrial and electric generating unit emissions were allocated based on the relative consumption volumes from the EIA SEDS, and compressed natural gas vehicles were allocated to the number of compressed natural gas vehicles in each state, derived from the MOVES model. These proxy data sets are generally consistent with the activity data sets used in the national *Inventory*, except for residential emissions, which are allocated based on data from EIA rather than the American Housing Survey due to the limited state-level information in the survey data set. The same proxy data sets are used across the entire time series for this segment.

2.2.4.3 Uncertainty

The overall uncertainty associated with the 2021 national estimates of CO_2 and CH_4 from natural gas systems was calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). Uncertainty estimates for N_2O applied the same uncertainty bounds as CO_2. As described further in Chapter 3 and Annex 7 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 were −13%/+15% for CO_2 and N_2O and −17%/+17% 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 (or basin-level as applicable) emissions to each state using spatial proxy data sets. This allocation method introduces additional uncertainty due to sources of uncertainty associated with the location information in each underlying data set (e.g., number of non-associated 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 data sets that are consistent with activity factors used in the national *Inventory*. However, this is not always possible when activity factor data sets only include national aggregate statistics. For example, national CO_2 and CH_4 emissions from transmission and storage compressor stations largely rely on station counts developed from GHGRP station counts and scaled up to the national level with an adjustment factor. In the state-level estimates, these emissions are allocated based on share of national transmission pipeline mileage occurring in each state and will therefore include additional uncertainty associated with the accuracy of the state-specific data in the PHMSA data set, as well as the accuracy in which relative state-level pipeline mileage reflects the relative state-level emissions from compressor stations and other sources in transmission and storage. 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 data set. The sources of uncertainty for this category are also consistent over time because the same proxy data sets 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 data sets and methodologies improves.

Given the variability of practices and technologies across oil and gas systems and the occurrence of episodic events, it is possible that EPA's estimates do not include all methane emissions from abnormal events. For many equipment types and activities, EPA's emissions estimates include the full range of conditions, including "super-emitters." For other situations, where data are available, emission estimates for abnormal events were calculated separately and included in the national *Inventory* (e.g., Aliso Canyon leak event and the three well blowout events included for the first time in the 2022 national *Inventory*). EPA continues to work through its stakeholder process to review new data from EPA's GHGRP and research studies to assess how emissions estimates can be improved.

2.2.4.4 Recalculations

As described in Chapter 3 of the national *Inventory* report, some emission and sink estimates in the national *Inventory* are recalculated and revised with improved methods and/or data. In general, recalculations are made to incorporate new methodologies, or to update activity and emissions factor data sets with the most current versions. These improvements are implemented across the previous national *Inventory's* entire time series to ensure that the national emission trend is accurate. See Section 3.7 of Chapter 3 in the national *Inventory* report for more details on recalculations in the latest *Inventory* estimates.

Five onshore production emission sources used a new, basin-level methodology for this year's national *Inventory*. As such, changes in absolute state-level emissions between this version and the previous state report for these sources reflect to some extent state-specific practices and data.

As the state-level emissions are otherwise estimated using Approach 2 (national emissions are disaggregated to the state level), changes in absolute state-level emissions between this version and the previous state report largely reflect recalculations and improvements implemented in the national *Inventory*. See Chapter 3 in the national *Inventory* report for further details on these updates in the national *Inventory*.

To align with these methodological improvements in the national *Inventory*, methodological updates to the state estimates, relative to the previous version, include incorporating the use of the basin-level emissions estimates developed in the national *Inventory* for certain production sources as described above (Exploration and Production section). These new sources have been allocated to the state level following the approaches described in the segment-specific sections above.

For other sources, the calculation of state-level estimates has been updated to incorporate updates to the underlying state-level proxy data sets, following the same procedure as in the national *Inventory*. State-level proxy data sets have been updated across the entire time series to ensure that the state-emission trends are accurate.

Consistent with the national *Inventory*, CO_2 equivalent emissions totals have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of CH_4 has increased from 25 to 28, leading to an increase in the calculated CO_2 equivalent emissions of CH_4, while the GWP of N_2O has decreased from 298 to 265, leading to a decrease in the calculated CO_2 equivalent emissions of N_2O.

2.2.4.5 *Planned Improvements*

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

Potential refinements to processing estimates in future state-level inventories include using emissions levels reported to the GHGRP (along with other data) to apportion emissions to each state. In addition, information on processing plant locations from other data sets 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 using 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 data sets could be incorporated to improve estimates.

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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 such as:

- Wells with no recent production, and that are 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 3.7 million (with around 2.9 million abandoned oil wells and 0.8 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. An estimate of the number of orphaned wells within this population is not developed as part of the methodology for the national- or state-level inventories. Other groups have developed estimates of the total national number of orphaned wells. The Interstate Oil and Gas Compact Commission, for example, estimates 92,198 orphaned wells in the United States (IOGCC 2021). State applications for grants to plug orphaned wells indicate over 130,000 orphaned wells in the United States (U.S. Department of the Interior 2022).

The state-level methodology for abandoned oil and gas wells follows Approach 1, as defined in the Introduction of this report, where emissions from this segment are calculated for each U.S. state in the methodology used to develop the national *Inventory* using activity data sets with information broken out at the state level, including well counts, type (e.g., oil, gas), and plugging status. See Appendix B, Table B-13, for the underlying data sets.

2.2.5.2 Methods/Approach

To compile national estimates of CH_4 and CO_2 emissions from abandoned oil and gas wells for the national *Inventory*, EPA develops emissions estimates for plugged and unplugged abandoned wells for each state and sums to the national level. Key data sources are two research studies—Kang et al. (2016) and Townsend-Small et al. (2016)—for emissions factors, as well as the Enverus database and historical state-level data sets for abandoned well counts.

To develop state-level estimates of GHG emissions from abandoned natural gas and oil wells when developing the national *Inventory*, an estimate of the number of abandoned wells in each state (developed using Enverus and historical data sets), as well as their type (oil versus gas) and plugging status (plugged versus unplugged) were estimated across the time series. Well type and plugging status were derived from Enverus. The applicable emission factor was then applied to the state activity data to estimate emissions for each state. State-level counts of abandoned oil and natural gas wells (which include all nonproducing wells, not only orphaned wells) are available in Appendix B, Table B-13.

2.2.5.3 Uncertainty

The overall uncertainty associated with the 2021 national estimates of both CO_2 and CH_4 from abandoned oil and gas wells were 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 2023), levels of uncertainty in the national estimates in 2021 for both abandoned oil and gas wells were −83%/+204% for CO_2 and −83%/+204% for CH_4.

The uncertainty estimates for the national *Inventory* 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, for example, due to regional emission factors that may not reflect state-specific emissions. The sources of uncertainty for this category are generally consistent over time, and the same data sets were used across the entire time series. The uncertainty method cannot account for state-specific variations in emissions factors, which would 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 data sets and methodologies improves.

2.2.5.4 Recalculations

As described in Chapter 3 of the national *Inventory* report, some emission and sink estimates in the national *Inventory* are recalculated and revised with improved methods and/or data. In general, recalculations are made to incorporate new methodologies, or to update activity and emissions factor data sets with the most current versions. These improvements are implemented across the previous national *Inventory's* entire time series to ensure the national emission trend was accurate. See Chapter 3 in the national *Inventory* report for more details on recalculations in the latest national *Inventory* estimates.

The abandoned oil and natural gas wells calculation methodology was revised for the current national *Inventory*. Abandoned well counts and plugged and unplugged fractions were calculated at the state level and used to estimate emissions, instead of calculating these data at the national level as was done in previous national *Inventories*. Changes in absolute state-level emissions between this version and the previous state report will reflect these recalculations implemented in the national *Inventory*.

Consistent with the national *Inventory*, CO_2 equivalent emissions totals have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of CH_4 has increased from 25 to 28, leading to an increase in the calculated CO_2 equivalent emissions of CH_4, while the GWP of N_2O has decreased from 298 to 265, leading to a decrease in the calculated CO_2 equivalent emissions of N_2O.

2.2.5.5 Planned Improvements

Potential refinements include incorporating improved state-level abandoned well counts for each year of the time series.

2.2.5.6 References

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3 Industrial Processes and Product Use (NIR Chapter 4)

For this methodology report, the IPPU sector is organized into four subsectors: minerals, chemicals, metals, and product use. 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[a]
Cement Production	CO_2	Hybrid approach • 2010–2021: Approach 2 • 1990–2009: Approach 1	Includes emissions from all states, the District of Columbia., tribal lands, and territories (i.e., Puerto Rico) as applicable.
Lime Production	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories (i.e., Puerto Rico) as applicable.
Glass Production	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories (i.e., Puerto Rico) as applicable.
Other Process Uses of Carbonates	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] (i.e., American Samoa, Guam, Northern Mariana Islands, Puerto Rico and U.S. Virgin Islands) as applicable.
Carbon Dioxide Consumption	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] (i.e., American Samoa, Guam, Northern Mariana Islands, Puerto Rico and U.S. Virgin Islands) as applicable.
Ammonia Production	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Urea Consumption for Nonagricultural Purposes	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] (i.e., Puerto Rico, American Samoa, Guam, Northern Mariana Islands, U.S. Virgin Islands) as applicable.
Nitric Acid Production	N_2O	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Adipic Acid Production	N_2O	Approach 1	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Caprolactam, Glyoxal and Glyoxylic Acid Production	N_2O	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Carbide Production and Consumption	CO_2 CH_4	Hybrid approach • Production: Approach 1 • Consumption: Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] (i.e., Puerto Rico) as applicable.

Category	Gas	Approach	Geographic Completeness[a]
Titanium Dioxide Production	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Soda Ash Production	CO_2	Approach 1	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Petrochemical Production	CO_2 CH_4	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
HCFC-22 Production	HFCs	Hybrid approach • 2010–2021: Approach 1 • 1990–2009: Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Phosphoric Acid Production	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories [a] as applicable.
I&S Production and Metallurgical Coke Production	CO_2 CH_4	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories [a] as applicable.
Ferroalloys Production	CO_2 CH_4	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Aluminum Production	CO_2 PFCs	Hybrid approach • 2010–2021: Approach 1 • 1990–2009: Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Magnesium Production and Processing	CO_2 SF_6 HFCs	Hybrid approach • 1999–2021: Approach 1 & 2 • 1990–1998: Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Lead Production	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Zinc Production	CO_2	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Electronics Industry	N_2O NF_3 SF_6 HFCs PFCs	Hybrid approach • 2011–2021: Approach 1 & 2 • 1990–2010: Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.
Substitution of Ozone-Depleting Substances	HFCs PFCs	Hybrid approach	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] (i.e., American Samoa, Guam, Northern Mariana Islands, Puerto Rico and U.S. Virgin Islands) as applicable
Electrical Transmission and Distribution	SF_6	Hybrid approach • 2011–2021: Approach 1 & 2 • 1990–2010: Approach 2	Includes emissions from all states, the District of Columbia, and territories[a] (i.e., Puerto Rico, U.S. Virgin Islands) as applicable.
Nitrous Oxide from Product Uses	N_2O	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] (i.e., American Samoa, Guam, Northern Mariana

Category	Gas	Approach	Geographic Completeness[a]
			Islands, Puerto Rico and U.S. Virgin Islands) as applicable.

[a] Emissions are likely occurring in other U.S. 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)
- CO_2 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, or $CaCO_3$, in the form of limestone or similar rocks, is heated in a cement kiln at a temperature range of about 700 to 1,000 °C (1,300 to 1,800 °F) to form lime (i.e., calcium oxide [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 non-calcinated, 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; in descending order, production is most concentrated in Texas, California, Missouri, and Florida (EPA 2022). In 2021, these four leading cement-producing states accounted for nearly 44% of U.S. production (USGS 2022).

3.1.1.2 Methods/Approach

To develop state-level estimates of emissions from cement production, national emissions from the national *Inventory* were disaggregated using a combination of facility-level emissions data reported to the GHGRP from 2010–2021 (EPA 2022) and USGS clinker production data for 1990–2009 (EPA 2023), as shown in Table 3-2. See Appendix C, Tables 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 (CBI), emissions data by state are not confidential, and therefore are available for this analysis starting in 2010. State-level emissions of CO_2 from cement production 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
2010–2021	• Applied national *Inventory* emissions factors to clinker production data estimated using GHGRP emissions data (IPCC 2006 Tier 2).
1990–2009	• Applied the national *Inventory* emissions factors to actual and estimated clinker production data from USGS (IPCC 2006 Tier 2).

The method used for 2010–2021 (Approach 2) was based on state-level emissions data from the GHGRP to allocate clinker production by state. Facilities that use the Continuous Emissions Monitoring System (CEMS) to measure emissions reported combined combustion and process emissions to GHGRP, 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.

The method used for 1990–2009 (Approach 1) relied on USGS clinker production data, which is the same data source for the national *Inventory*. At the state level, 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 each group to estimate clinker production.

National emissions factors for CO_2 from clinker production and cement kiln dust 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 2021 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 2023), levels of uncertainty in the national estimates in 2021 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 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.

For the 2010–2021 period, 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 determine whether emissions are overestimated or underestimated.

While 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 USGS.

3.1.1.4 Recalculations

No recalculations were applied for this current report consistent with the national *Inventory* (see Section 4.1, page 4-14).

3.1.1.5 Planned Improvements

An important data gap is the production of clinker by each cement-producing state for the full time series of 1990–2021. The USGS Minerals 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. EPA will assess whether industry gross domestic product (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 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, 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.

3.1.1.6 References

EPA (U.S. Environmental Protection Agency) (2022) *Facility Level Information on GreenHouse gases Tool (FLIGHT)* [data set as of August 8, 2022]. Available online at: https://ghgdata.epa.gov/ghgp/.

EPA (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

USGS (U.S. Geological Survey). (2022). *Mineral Commodity Summaries: Cement*. U.S. Geological Survey. Available online at: https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-cement.pdf.

3.1.2 Lime Production (NIR Section 4.2)

3.1.2.1 Background

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 carbonate ($CaCO_3$) and/or magnesium carbonate ($MgCO_3$) —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 into 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 lime production are included in the energy sector. Lime production emissions from the national *Inventory* were disaggregated to 28 states in 2021. Emissions are attributed to only 23 states, as facilities in five of the states (Colorado, Idaho, Minnesota, North Dakota, and Nebraska) produce beet sugar and all CO_2 is considered recovered under the methodology below.

3.1.2.2 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 process emissions reported to the GHGRP and the number of facilities in a state 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, Tables C-3 through C-6 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
2010–2021	• 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 onsite processes were used to estimate the CO_2 emissions captured and subtracted from gross emissions to get net emissions from lime production.
1990–2009	• USGS data on number of lime facilities were 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 onsite processes from 2010–2019 were used to estimate the percentage of emissions captured, multiplied by national emissions and subtracted from gross emissions to get net emissions from lime production.

The methodology used for 2010–2021 was based on process emissions data reported to the GHGRP summed by state (EPA 2010–2021) 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 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 2023a) 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 USGS Mineral Commodity Summaries for lime (1990–2021) only contain U.S. total lime production, with no breakdown by lime type or state. While the USGS Minerals Yearbooks for Lime (1990–2018) have hydrated and quicklime production data by region (Northeast, Midwest, South Atlantic, East South Central, West South Central, and West), additional detail by high-calcium or dolomitic lime or by individual states is not available, and 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): lime production data for high-calcium quicklime; dolomitic quicklime; high-calcium, hydrated; dolomitic, hydrated; 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, other miscellaneous site-specific waste).

3.1.2.2.1. CEMS Adjustment for 2010–2021

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 2010–2021. 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 Subparts 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.

3.1.2.2.2. 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 production. Emissions from lime use 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 2006 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 onsite processes such as purification.

For 2010–2021, 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*. Information on which facilities captured CO_2 for on-site use in 2010–2021 and the states where these facilities are located is 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 2010–2021, 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. Note that some states with beet sugar manufacturing facilities that capture CO_2 also have additional facilities that do not capture CO_2, resulting in net CO_2 emissions greater than zero.

To estimate the quantity of CO_2 captured for beet manufacturing facilities per state, per year for 2010–2021, 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 in 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 onsite 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 from 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.

3.1.2.3 Uncertainty

The overall uncertainty associated with the 2021 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 2023b), levels of uncertainty in the national estimates in 2021 were −2%/+2% 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 GHGRP emissions data for 2010–2021 and the estimated number of facilities for 1990–2009. 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 underestimate 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 quantity 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 for how long plants are idled.

3.1.2.4 Recalculations

No recalculations were applied for this current report, consistent with the national *Inventory* (see Section 4.2, page 4-20).

3.1.2.5 Planned Improvements

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 overestimating 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 2007 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; also reported as 327120 in the 2022 NAICS), 327310 (Cement Manufacturing), 327410 (Lime Manufacturing), and 331111 (Iron and Steel Mills; also reported as 331110 in the 2022 NAICS).

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 lime 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. In 2021, all of the beet sugar manufacturing facilities reporting to the GHGRP captured CO_2 on site, and five 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 onsite 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 precipitated calcium carbonate 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 precipitated calcium carbonate production or during the sugar refining purification processes.

EPA will review time series consistency issues, due to the two methodologies for 1990–2009 and 2010–2021. 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 calculations more closely simulate state trends in emissions.

3.1.2.6 References

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

EPA (U.S. Environmental Protection Agency) (2010–2021) *Envirofacts GHGRP Subpart S and Subpart C Data*. Accessed May 11, 2023. Available online at: https://www.epa.gov/enviro/greenhouse-gas-customized-search.

EPA (2023a) *Aggregation of Reported Facility Level Data Under Subpart S—National Lime Production for Calendar Years 2010 Through 2021.*EPA (2023b) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

U.S. Geological Survey (1991) Table 4. Lime Sold or Used by Producers in the United States, by State. In: *1990 Minerals Yearbook: Lime*.

U.S. Geological Survey (1992) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *1991 Minerals Yearbook: Lime.*

U.S. Geological Survey (1993) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *1992 Minerals Yearbook: Lime.*

U.S. Geological Survey (1994) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *1993 Minerals Yearbook: Lime.*

U.S. Geological Survey (1995) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *1994 Minerals Yearbook: Lime.*

U.S. Geological Survey (1996) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *1995 Minerals Yearbook: Lime.*

U.S. Geological Survey (1997) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *1996 Minerals Yearbook: Lime.*

U.S. Geological Survey (1998) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *1997 Minerals Yearbook: Lime.*

U.S. Geological Survey (1999) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *1998 Minerals Yearbook: Lime.*

U.S. Geological Survey (2000) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *1999 Minerals Yearbook: Lime.*

U.S. Geological Survey (2001) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *2000 Minerals Yearbook: Lime.*

U.S. Geological Survey (2002) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *2001 Minerals Yearbook: Lime.*

U.S. Geological Survey (2003) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *2002 Minerals Yearbook: Lime.*

U.S. Geological Survey (2004) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *2003 Minerals Yearbook: Lime.*

U.S. Geological Survey (2005) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *2004 Minerals Yearbook: Lime.*

U.S. Geological Survey (2006) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *2005 Minerals Yearbook: Lime.*

U.S. Geological Survey (2007) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *2006 Minerals Yearbook: Lime.*

U.S. Geological Survey (2008) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *2007 Minerals Yearbook: Lime.*

U.S. Geological Survey (2009) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *2008 Minerals Yearbook: Lime.*

U.S. Geological Survey (2010) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *2009 Minerals Yearbook: Lime.*

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 2021, glass was produced in 29 states (EPA 2022).

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 2023). 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 process emissions reported to the GHGRP for 2010–2021 and the number of glass facilities in each state for 1990–2009, as shown in Table 3-4 below. The sum of emissions by state is consistent with national process emissions as reported in the national *Inventory*. See Appendix C, Tables C-7 and C-8 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
2010–2021	• GHGRP process emissions data were used to estimate the percentage of emissions by state, multiplied by the national emissions (2006 IPCC Guidelines Tier 3).
1990–2009	• Data on the number of glass facilities were used to estimate the percentage of production by state, multiplied by the national emissions (2006 IPCC Guidelines Tier 3).

The methodology for estimating CO_2 emissions from glass production for years 2010 through 2021 has added new activity data reported to the GHGRP on the quantities of a group of other carbonates (i.e., barium carbonate, potassium carbonate, lithium carbonate, and strontium carbonate) used for glass production (EPA 2022). The state-level method used for 2010–2021 was based on process emissions reported to the GHGRP summed by state (EPA 2022) 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.

The method used for 1990[26]–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 (EPA 2022) 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 2010–2021 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.

3.1.3.2.1. CEMS Adjustment for 2010–2021

Starting in 2010, facilities producing glass and emitting more than 25,000 metric tons of CO_2 equivalent 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.[27] 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 year from 2010–2021 and 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 2021 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 2023), levels of uncertainty in the national estimates in 2021 were −3%/+3% 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 GHGRP emissions data for 2010–2021 and the estimated number of facilities for 1990–2009.

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[26] Due to a transcription error, the national 1990 emission value used for these state-level calculations is not reflected in Tables 4-12 and 4-13 of the current 1990–2021 national *Inventory* report. The 1990 emissions value will be revised in the 1990–2022 national *Inventory* report.

[27] 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.

For estimates from 2010–2021, uncertainty is expected to be lower than for 1990–2009 due to 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.*

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.

3.1.3.4 Recalculations

A methodology refinement was implemented for the current national *Inventory,* using more complete activity data from the GHGRP for 2010–2021 to improve accuracy. The revised values for 1990–2020 resulted in increased emissions estimates for all years. Across the time series, national emissions decreased by an average of 1% compared to the previous national *Inventory.* For 28 states, emissions decreased by 1% over the time series. Emissions for three states (Florida, Mississippi, and West Virginia) were unchanged over the time series.

3.1.3.5 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 data sets 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 equivalent 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. 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 GDP related to glass production by state).

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.

3.1.3.6 References

EPA (U.S. Environmental Protection Agency) (2022) *Facility Level Information on GreenHouse gases Tool (FLIGHT)* [data set as of August 8, 2022]. Available online at: https://ghgdata.epa.gov/ghgp/.

EPA (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

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 byproduct. Emissions from limestone and dolomite used in other process sectors, such as the production of cement, lime, glass, and iron & steel, 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.

3.1.4.2.1. 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. 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. 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 1993–2021, 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 1995–2021, 2022a, 2022b). 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*. The USGS state-level consumption data exclude the District of Columbia and territories; therefore, their CO_2 emissions from limestone and dolomite consumption were not estimated.

During 1990 and 1992, USGS did not publish limestone and dolomite consumption data 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 2021, no data on limestone and dolomite consumption were available from USGS, so state-level consumption values from 2020 were used as a proxy for this year.

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 titled "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, Tables C-9 through Table C-12 in the "Other Process Uses of Carbonates" Tab, for more details on the data used.

3.1.4.2.2. Soda Ash Consumption Not Associated with Glass Manufacturing

The national *Inventory* also estimates national CO_2 emissions from the consumption of soda ash. Excluding soda ash consumption for glass manufacturing, most soda ash is consumed in chemical production, with minor amounts used in soap production, pulp and paper, FGD, and water treatment. 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 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, Puerto Rico, American Samoa, Guam, the Northern Mariana Islands, and the U.S. Virgin Islands using U.S. population statistics as a surrogate for data on soda ash consumption not associated with glass manufacturing (U.S. Census Bureau 2002, 2011, 2021a, 2021b, 2022; Instituto de Estadísticas de Puerto Rico 2021). For each year in the 1990–2021 time series, the fraction of the total U.S. population in each state, the District of Columbia, and territories 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 2021 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 2023), levels of uncertainty in the national estimates in 2021 were −11%/+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 on state data of total limestone and dolomite consumption and state population for soda ash consumption.

3.1.4.4 Recalculations

For the current national *Inventory*, updated USGS data on limestone and dolomite consumption were available for 2019 and 2020, resulting in updated emissions estimates for those years. Compared to the previous national *Inventory*, national emissions for 2019 decreased by 14.7% (1,449 kilotons [kt] CO_2 equivalent) and emissions for 2020 decreased by 18.8% (1,843 kt CO_2 equivalent.). Additional recalculations for emissions from soda ash consumption were performed for 2020 as updated population data were made available from the U.S. Census Bureau for the time series. The updated population data had a negligible impact on the emissions estimated for the 50 states, the District of Columbia, and Puerto Rico due to the low emissions estimated for each state or territory for the sector.

3.1.4.5 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, 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.

3.1.4.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Instituto de Estadísticas de Puerto Rico (2021) *Estimados Anuales Poblacionales de los Municipios Desde 1950.* Accessed February 2021. Available online at: https://censo.estadisticas.pr/EstimadosPoblacionales.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

U.S. Bureau of Mines (1991–1995) *Minerals Yearbook*.

U.S. Census Bureau (2002) *Time Series of Intercensal State Population Estimates: April 1, 1990 to April 1, 2000*. Table CO-EST2001-12-00. Release date: April 11, 2002. Available online at: https://www2.census.gov/programs-surveys/popest/tables/1990-2000/intercensal/st-co/co-est2001-12-00.pdf.

U.S. Census Bureau (2011) *Intercensal Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2010.* Table ST-EST00INT-01. Release date: September 2011. Available online at: https://www2.census.gov/programs-surveys/popest/datasets/2000-2010/intercensal/state/st-est00int-alldata.csv.

U.S. Census Bureau (2021a) *Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2020*. Table NST-EST2020. Release date: July 2021.

U.S. Census Bureau (2021b) *Annual Estimates of the Resident Population for the United States, Regions, States, District of Columbia, and Puerto Rico: April 1, 2020 to July 1, 2021*. Table NST-EST2021-POP. Release date: December 2021.

U.S. Census Bureau (2022) *International Database: World Population Estimates and Projections*. Accessed November 23, 2022. Available online at: https://www.census.gov/programs-surveys/international-programs/about/idb.html.

USGS (U.S. Geological Survey) (1995–2021) *Minerals Yearbook: Crushed Stone Annual Report.*

USGS (2022a) Advanced Data Release of the 2019 Annual Tables, Minerals Yearbook: Crushed Stone Annual Report. Posted June 16, 2022. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/crushed-stone-statistics-and-information

USGS (2022b) Advanced Data Release of the 2020 Annual Tables, Minerals Yearbook: Crushed Stone Annual Report. U.S. Geological Survey, Reston, VA. Posted August 9, 2022. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/crushed-stone-statistics-and-information

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. CO_2 used for enhanced oil recovery is injected underground to enable additional petroleum to be produced. For the purposes of this analysis, CO_2 used in commercial applications other than enhanced oil recovery is assumed to be emitted to the atmosphere. A further discussion of CO_2 used in enhanced oil recovery 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, Puerto Rico, American Samoa, Guam, the Northern Mariana Islands, and the U.S. Virgin Islands using U.S. population statistics as a surrogate for CO_2 consumption data (U.S. Census Bureau 2002, 2011, 2021a, 2021b, 2022; Instituto de Estadísticas de Puerto Rico 2021). For each year in the 1990–2021 time series, the fraction of the total U.S. population in each state, the District of Columbia, and each territory was calculated by dividing the state population by the total U.S. population.

3.1.5.3 Uncertainty

The overall uncertainty associated with the 2021 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 2023), levels of uncertainty in the national estimates in 2021 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 Recalculations

Recalculations were performed for 2020 as updated population data were made available from the U.S. Census Bureau for the time series. The updated population data had a negligible impact on the emissions estimated for the 50 states, the District of Columbia, and Puerto Rico due to the low emissions estimated for each state or territory for the sector.

3.1.5.5 Planned Improvements

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

3.1.5.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Instituto de Estadísticas de Puerto Rico (2021) *Estimados Anuales Poblacionales de los Municipios Desde 1950.* Accessed February 2021. Available online at: https://censo.estadisticas.pr/EstimadosPoblacionales.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

U.S. Census Bureau (2002) *Time Series of Intercensal State Population Estimates: April 1, 1990 to April 1, 2000*. Table CO-EST2001-12-00. Release date: April 11, 2002. Available online at: https://www2.census.gov/programs-surveys/popest/tables/1990-2000/intercensal/st-co/co-est2001-12-00.pdf.

U.S. Census Bureau (2011) *Intercensal Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2010.* Table ST-EST00INT-01. Release date: September 2011. Available online at: https://www2.census.gov/programs-surveys/popest/datasets/2000-2010/intercensal/state/st-est00int-alldata.csv.

U.S. Census Bureau (2021a) *Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2020.* Table NST-EST2020. Release date: July 2021.

U.S. Census Bureau (2021b) *Annual Estimates of the Resident Population for the United States, Regions, States, District of Columbia, and Puerto Rico: April 1, 2020 to July 1, 2021.* Table NST-EST2021-POP. Release Date: December 2021.

U.S. Census Bureau (2022) *International Database: World Population Estimates and Projections*. Accessed November 23, 2022. Available online at: https://www.census.gov/programs-surveys/international-programs/about/idb.html.

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 processes based on natural gas, naphtha, and petroleum coke produce CO_2 and hydrogen, the latter of which is used to produce 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 United States. National energy use information is only available at the broad industry sector level and does not provide data broken out by industrial category. Emissions from fuel used for energy at ammonia plants are accounted for in the energy sector. In 2021, 16 companies operated 35 ammonia-producing facilities in 16 states, with approximately 60% of domestic ammonia production capacity concentrated in Louisiana, Oklahoma, and Texas (USGS 2022).[28]

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 process emissions reported to the GHGRP for 2010–2021 and ammonia production capacity by state and by year for 1990–2009, as shown in Table 3-5. This approach was taken due to limitations in state-level activity data on ammonia production by feedstock or feedstock consumption for ammonia production. The sum of emissions by state is consistent with the process emissions reported in the national *Inventory* (EPA 2023). 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
2010–2021	• GHGRP (Subpart G) process emissions data (gross CO_2) were used to estimate the percentage of emissions by state, multiplied by the national emissions (IPCC 2006 Tier 2).
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).

The methodology used for 2010–2021 was based on process emissions reported to the GHGRP and summed by state (EPA 2022) 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*. The GHGRP has no

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[28] The number of facilities that report to the GHGRP (29 facilities in 17 states) differs from USGS due to (1) the definition of a “facility” used by USGS for two locations (Donaldsonville, LA, and Verdigris, OK); (2) the definition of a facility subject to Subpart G of the GHGRP that requires steam reforming or raw material gasification (see 98.70), which does not appear to be present at the Freeport, TX, facility in the USGS list; (3) the definition of a facility subject to Subpart G of the GHGRP when a facility (like the Beaumont, TX, facility in the USGS list) produces methanol, hydrogen, and ammonia (see 98.240[c]); and (4) an ammonia-producing facility in Midway, TN, that is not in the USGS list.

reporting threshold for ammonia production, so all facilities are included, and these emissions data are, therefore, representative of the industry.

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 1994–2009 (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.

3.2.1.3 Uncertainty

The overall uncertainty associated with the 2021 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 2023), levels of uncertainty in the national estimates in 2021 were −4%/+4% for CO_2 emissions from ammonia production.

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 process emissions reported to the GHGRP for 2010–2021 and ammonia production capacity by state by year for 1990–2009. These assumptions were required because of a general lack of more granular state-level data.

For 2010–2021, uncertainty is expected to be lower due to the use of GHGRP emissions data by state as a surrogate for 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 overestimating or underestimating the percentage of emissions apportioned to each state.

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.

3.2.1.4 Recalculations

Refinements to the national *Inventory* methodology were made for 2010–2021 to directly use data reported to Subpart G of the GHGRP, including the quantity of feedstock used and C content and molecular weight of the feedstock. Based on the updated methodology used in the current national *Inventory*, which affected all years, as well as a few facility resubmissions in 2019 and 2020, recalculations were performed for all years of the time series. The revised values for 1990–2021 resulted in increased emissions estimates for all years. For 1990–2009, national emissions increased by an average of 11% in 24 states, compared to the previous national *Inventory.* For 2010–2020, national emissions increased by an average of 5% in 17 states, compared to the previous national *Inventory.*

3.2.1.5 Planned Improvements

For the GHGRP emissions data used for 2010–2021, 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 4.2.4) because these data by state are considered CBI and are not available. 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. More research on possible aggregation options is needed.

For the state-level ammonia capacity data used for 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*.

EPA will review potential time series consistency issues due to the two methodologies for 1990–2009 and for 2010–2021. Surrogate data on production capacity are used in place of activity data for the 1990–2009 portion of the time series, and more research is needed so calculations during that time period more closely simulate state trends in emissions.

3.2.1.6 References

EPA (U.S. Environmental Protection Agency) (2022) *Facility Level Information on GreenHouse gases Tool (FLIGHT)* [data set as of August 8, 2022]. Available online at: https://ghgdata.epa.gov/ghgp/.

EPA (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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USGS (2022) *Mineral Commodity Summaries: Nitrogen (Fixed)—Ammonia*. Available online at: https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-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

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 U.S. population statistics as a surrogate for data on nonagricultural applications of urea due to limitations in the availability of state-specific activity 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, Puerto Rico, American Samoa, Guam, the Northern Mariana Islands, the U.S. Virgin Islands, and the U.S. Minor Outlying Islands, using U.S. population statistics as a surrogate (U.S. Census Bureau 2002, 2011, 2021a, 2021b, 2022; Instituto de Estadísticas de Puerto Rico 2021). For each year in the time series, the fraction of the total U.S. population in each state, as well as the District of Columbia and the territories, 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 national population for that year.

3.2.2.3 Uncertainty

The overall uncertainty associated with the 2021 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 2023), levels of uncertainty in the national estimates in 2021 were −4%/+4% 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 Recalculations

Based on updated quantities of urea applied for agricultural uses for 2015–2020, updated urea imports from USGS for 2020, and updated urea exports from USGS for 2020, recalculations were performed for 2015–2020 (USGS 2022). Compared to the previous national *Inventory,* state-level emissions decreased for every state by less than 1.0% for 2015 and 2016, and less than 0.5% for 2017. Compared to the previous *Inventory,* state-level emissions increased for every state by 1.0% for 2018 and 2% for 2019. For 2020, emissions for two states (New Jersey and New York) increased by 1% compared to the previous inventory. For 2020, emissions for three states/territories (Rhode Island, Vermont, and Puerto Rico) did not change. For all other states, 2020 emissions decreased between 1% and 7% compared to the previous national *Inventory*.

3.2.2.5 Planned Improvements

Data gaps include data on urea consumption for nonagricultural purposes by state for the full 1990–2021 time series.

3.2.2.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Instituto de Estadísticas de Puerto Rico (2021) *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 (2002) *Time Series of Intercensal State Population Estimates: April 1, 1990 to April 1, 2000*. Table CO-EST2001-12-00. Release date: April 11, 2002. Available online at: https://www2.census.gov/programs-surveys/popest/tables/1990-2000/intercensal/st-co/co-est2001-12-00.pdf.

U.S. Census Bureau (2011) *Intercensal Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2010.* Table ST-EST00INT-01. Release date: September 2011. Available online at: https://www2.census.gov/programs-surveys/popest/datasets/2000-2010/intercensal/state/st-est00int-alldata.csv.

U.S. Census Bureau (2021a) *Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2020.* Table NST-EST2020. Release date: July 2021.

U.S. Census Bureau (2021b) *Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2020 to July 1, 2021.* Table NST-EST2021-POP. Release date: December 2021.

U.S. Census Bureau (2022) *International Database: World Population Estimates and Projections*. Accessed November 23, 2022. Available online at: https://www.census.gov/programs-surveys/international-programs/about/idb.html.

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3.2.3 Nitric Acid Production (NIR Section 4.7)

3.2.3.1 Background

N_2O is emitted during the production of nitric acid, 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 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 byproduct 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 2021, there were 31 active nitric acid production plants in 20 states (EPA 2023).

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 2023). 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 2010–2021. (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 process emissions reported to the GHGRP for 2010–2021 and nitric acid production capacity by state and by year for 1990–2009, as shown in Table 3-6 below. 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
2010–2021	• GHGRP process emissions data were used to estimate the percentage of emissions by state, multiplied by the national emissions (a country-specific approach similar to IPCC 2006 Tier 3).
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).

The methodology used for 2010–2021 was based on process emissions reported to the GHGRP and summed by state (EPA 2022) 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.

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. Using the nitric acid capacity per state to determine the state allocation percentage assumes that facility utilization rates are roughly the same from state to state. Due to limited data availability, nitric acid capacities per state for 1990–2007 were estimated using an EPA review of capacity for 1984 (EPA 1984). Production capacity data for 2008 were only available from Independent Commodity Intelligence Services (ICIS) at the parent company level, as opposed to at the facility level, necessitating a different approach to estimating state capacity data for 2008 (ICIS 2008). First, GHGRP emissions data were averaged by facility for years 2010–2012. These years were used to determine the average because that period was deemed to better represent historical nitric acid production in 2008. These averages were then summed by company to calculate a percentage of total company emissions from each facility. That percentage was then applied to the total company capacity in 2008 to disaggregate nitric acid production capacity by facility. Using facility location, the total company capacity in 2008 was disaggregated by state. The capacity data for 2008 were applied to the years 2008 and 2009. Additional 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; the research also estimated 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 2021 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 2023), levels of uncertainty in the national estimates in 2021 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 and by year for 1990–2009 and process emissions reported to the GHGRP for 2010–2021. These assumptions were required because of a general lack of more granular state-level data.

For 2010–2021, 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.

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.

3.2.3.4 Recalculations

Consistent with the current national *Inventory*, CO_2 equivalent estimates of total N_2O emissions from nitric acid production have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of N_2O has decreased from 298 to 265, leading to an overall decrease in estimates of CO_2 equivalent N_2O emissions. Compared to the previous national *Inventory,* which applied 100-year GWP values from AR4, N_2O emissions decreased by 11% for each year of the time series, ranging from a decrease of 1.0 million metric tons (MMT) CO_2 equivalent in 2020 to 1.6 MMT in 1997.

Methodological refinements were also made for 2008 and 2009 emissions estimates by using GHGRP data from 2010–2012 instead of GHGRP data from 2010–2019 to reflect the nitric acid production capacity in 2008 and 2009 more accurately. Based on the updated methodology, state-level emissions remained unchanged for 10 states and changed by ±900 metric tons CO_2 equivalent for 13 states compared to the previous national *Inventory.*

3.2.3.5 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.

EPA will review time series consistency issues due to the two methodologies for 1990–2009 and 2010–2021. Incomplete surrogate data on 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.

3.2.3.6 References

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EPA (2022) *Facility Level Information on GreenHouse gases Tool (FLIGHT)* [data set as of August 8, 2022]. Available online at: https://ghgdata.epa.gov/ghgp/.

EPA (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

ICIS (Independent Commodity Intelligence Services) (2008) *Chemical Profile: Nitric Acid*. Capacities by Nitric Acid Company as of May 15, 2008. Accessed February 18, 2021. Available online at: https://www.icis.com/explore/resources/news/2008/05/19/9124327/chemical-profile-nitric-acid/.

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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. N_2O is generated as a byproduct 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 facility producing adipic acid uses an N_2O abatement device, but its usage has varied considerably from year to year over the period from 2010–2021, 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 from 1990–2021.

3.2.4.2 Methods/Approach

The national *Inventory* methodology was used to calculate state-level GHG emissions, using an Approach 1 method as defined in the Introduction chapter of this report. The methodology for 2010–2021 used facility-level process emissions reported to the GHGRP (EPA 2022). The methodology for 1990–2009 used emissions calculations 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). Emissions for each year were summed by state (EPA 2022) over the full time series to determine disaggregated CO_2 emissions by state. See Appendix D, Table D-5 in the “Adipic Acid” Tab, for more details on the data used. The 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 2021 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 2023), levels of uncertainty in the national estimates in 2021 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 Recalculations

Updated facility-level emissions data were obtained from the GHGRP for 2010 through 2016 and 2018, and recalculations were performed for those years.

For the current national *Inventory*, CO_2 equivalent estimates of total N_2O emissions from adipic acid production have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5

GWPs have been applied across the entire time series for consistency. The GWP of N_2O has decreased from 298 to 265, leading to an overall decrease in estimates of CO_2 equivalent N_2O emissions. Compared to the previous national *Inventory* which applied 100-year GWP values from AR4, N_2O emissions decreased by 11.1% for each year of the time series, ranging from a decrease of 0.3 MMT CO_2 equivalent in 2008 to 1.9 MMT CO_2 equivalent in 1995.

3.2.4.5 Planned Improvements

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

3.2.4.6 References

EPA (U.S. Environmental Protection Agency) (2022) *Facility Level Information on Greenhouse gases Tool (FLIGHT)* [data set as of August 8, 2022]. Available online at: https://ghgdata.epa.gov/ghgp/.

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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. In the most commonly used caprolactam production process, benzene is hydrogenated to cyclohexane, which is then oxidized to produce cyclohexanone, which in turn is used to produce caprolactam. The production of caprolactam can emit N_2O 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.

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 1990–2021 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 1990–2021 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.

For 1990–2021, 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 2006–2021. An additional caprolactam facility (Evergreen Recycling) was added for 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 2021 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 2023), levels of uncertainty in the national estimates in 2021 were −32%/+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 1990–2021. This assumption was required because of a general lack of more granular state-level data.

For 1990–2021, 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 Recalculations

Recalculations were performed for 2020 to reflect updated caprolactam production data from the American Chemistry Council's *Guide to the Business of Chemistry* (ACC 2022). State-level emissions increased by 9% for Texas and Virginia compared to the previous national *Inventory.*

In addition, for the current national *Inventory*, CO_2 equivalent total emission estimates of N_2O from caprolactam production have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of N_2O decreased from 298 to 265, leading to an overall decrease in estimates of calculated CO_2 equivalent N_2O emissions. Compared to the previous national *Inventory*, which applied 100-year GWP values from AR4, annual N_2O emissions decreased by 11% each year, ranging from a decrease of 0.15 MMT CO_2 equivalent in 2020 to 0.25 MMT CO_2 equivalent in 2010 and 2011.

3.2.5.5 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.

EPA will review time series consistency issues resulting from a lack of activity data (caprolactam production) by state and the use of surrogate data (production capacity) 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.

3.2.5.6 References

ACC (American Chemistry Council) (2022) *Business of Chemistry (Annual Data).*

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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3.2.6 Carbide Production and Consumption (NIR Section 4.10)

3.2.6.1 Background

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 SiC 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 producing calcium carbide are implicitly accounted for in the storage factor calculation for the nonenergy use (NEU) 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. A Hybrid approach, defined in the Introduction chapter of this report, was used to calculate emissions for each state, as described below. To estimate state-level emissions from SiC production, national SiC production data were evenly distributed among the two states identified as being home to SiC production facilities: Illinois and Kentucky. 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 and used to disaggregate national SiC consumption emissions. 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.

3.2.6.2.1. 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, 1995, 1996-2003, 2004–2017; USGS 2020-2022) used in the national *Inventory* (EPA 2023). For the period 1990–2001, reported USGS production data included production from two facilities located in Canada that ceased operations in 1995 and 2001. U.S. SiC production for 1990–2001 was derived by subtracting SiC production emissions data from Canada (ECCC 2022). . As annual U.S. production values are rounded, only 1997 changed with the updated data from Canada. 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 (Illinois and Kentucky). The state-level SiC production was multiplied by the national emissions factors for CO_2 and CH_4 to calculate GHG emissions by state.

3.2.6.2.2. SiC Consumption

Emissions of CO_2 from the consumption of SiC were calculated using Approach 2, as defined in the Introduction chapter of this report. SiC is used primarily for abrasive applications 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, 2021a, 2021b; Instituto de Estadísticas de Puerto Rico 2021). The fraction of the total U.S. population in each state, as well as the District of Columbia and Puerto Rico, was calculated for each year 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 2021 national estimates of CO_2 from carbide 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 2023), levels of uncertainty in the national estimates in 2021 were −10%/+10% 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.

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 Recalculations

Recalculations were performed for 1997 to account for updated data on SiC production from Canada, which are used to revise production data to reflect only U.S. production. Recalculations were performed for Illinois and Kentucky for 1997 to reflect this change in national-level emissions associated with SiC production. As SiC consumption is based on U.S. production and net imports, the update to national production led to recalculations of consumption emissions from each state, the District of Columbia, and Puerto Rico for 1997 as well.

Compared to the previous inventory, Illinois and Kentucky emissions for 1997 increased by an average of 2.7%. Illinois CO_2 emissions increased by 1.33 kt and CH_4 emissions increased by 5.8 metric tons (mt). Kentucky CO_2 emissions increased by 1.32 kt and CH_4 emissions increased by 5.8 mt. Compared to the previous national *Inventory* for all other states, the District of Columbia, and Puerto Rico, CO_2 emissions increased for each by 0.4%, an increase of 0.001 to 0.065 kt CO_2.

Additional recalculations were performed for 2020 as updated population data were available from the U.S. Census Bureau. The updated population data had a negligible impact on the emissions estimated for the 50 states, the District of Columbia, and Puerto Rico due to the low emissions estimated for each state or territory for the sector.

Updated U.S. International Trade Commission data on 2019 SiC exports and 2020 SiC imports resulted in updated SiC consumption estimates for those years. Compared to the previous national *Inventory* (EPA 2022), SiC consumption values for 2019 and 2020 increased by less than 2 metric tons and 20 metric tons, respectively. These minimal increases had a negligible impact on the emissions estimated for the 50 states, the District of Columbia, and Puerto Rico due to the low emissions estimated for each state or territory for the sector.

In addition, for the current inventory, CO_2 equivalent estimates of total CH_4 emissions from carbide production have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of CH_4 increased from 25 to 28, leading to an overall increase in estimates for CO_2 equivalent CH_4 emissions. Compared to the previous national *Inventory*, which applied 100-year GWP values from AR4, annual CO_2 equivalent CH_4 emissions increased by 12% each year.

3.2.6.5 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. 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.

3.2.6.6 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 TiO_2 in 2021 took place in Mississippi, Ohio, Tennessee, and Louisiana.

3.2.7.2 Methods/Approach

To develop state-level estimates of emissions from TiO_2 production, national emissions from the national *Inventory* were disaggregated with an Approach 2 method as defined in the Introduction chapter of this report, using a combination of GHGRP emissions data for 2010–2021 (EPA 2022) as a surrogate for TiO_2 production data and production capacity for 1990–2009 (see Table 3-7). See Appendix D, Tables D-8 and D-9 in the "TiO_2" 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 TiO_2 production were calculated using the Tier 1 method provided by the 2006 IPCC Guidelines and the same annual USGS production data (USGS 1991–2019, 2014–2022) used in the national *Inventory* to calculate national emissions (EPA 2023). National TiO_2 production data were allocated among the eight states with TiO_2 production facilities over the 1990–2021 time series, based on GHGRP emissions data or production capacity, and multiplied by the national emissions factor.

Table 3-7. Summary of Approaches to Disaggregate the National *Inventory* for TiO_2 Production Across Time Series

Time Series Range	Summary of Method
2010–2021	• 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).
1990–2009	• USGS data on TiO_2 production capacity were used to allocate production by state, multiplied by the national emissions factor to get emissions (IPCC 2006 Tier 1).

The methodology used for 2010–2021 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. The GHGRP has no reporting threshold for TiO_2, so these emissions data are representative of the industry. The methodology used for 1990–2009 used USGS production capacity data for each facility to estimate the fraction of total TiO_2 produced in each state.

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 2021 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 2023), levels of uncertainty in the national estimates in 2021 were −13%/+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 GHGRP emissions data for 2010–2021 and facility production capacity for 1990–2009. These assumptions were required because of a general lack of more granular state-level data.

For 2010–2021, 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 2010–2021, national *Inventory* emissions have exceeded GHGRP emissions from 25% to 35%, possibly indicating that emissions are overestimated in some states.

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. 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 earlier in the time series.

3.2.7.4 Recalculations

Based on updated TiO_2 facility-level emissions obtained from the GHGRP for 2019 and 2020 and updated USGS TiO_2 production data for 2020, recalculations were performed for 2019 and 2020. One facility in Tennessee resubmitted its GHGRP report for 2019 and 2020, resulting in updates to the percentage of emissions for each state. Additionally, USGS updated the estimated 2020 TiO_2 production value. Compared to the previous inventory, CO_2 from TiO_2 production increased by 18% (29 kt CO_2) for Louisiana, 34% (195 kt CO_2) for Mississippi, 5% (12 kt CO_2) for Ohio, and 20% (45 kt CO_2) for Tennessee.

3.2.7.5 Planned Improvements

Data gaps include state-level data on TiO_2 production for the full time series 1990–2021. GHGRP emissions data are available for the period 2010–2021 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, EPA will research how to account for varying utilization rates and carbon consumption rate differences for sulfate (non-emissive) and chloride (emissive) processes.

EPA will review potential time series consistency issues in the two methodologies for 1990–2009 and for 2010–2021. Surrogate data on 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 the method to enhance accuracy and consistency of estimated state GHG emissions and trends.

3.2.7.6 References

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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 byproduct 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 national soda ash production emissions can be attributed to Wyoming for the entirety of the 1990–2021 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 2023), 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 1990–2021 time series because no CO_2 is emitted from the processes used in the California facility, which produced soda ash from brines rich in sodium carbonate. Additionally, one facility in Colorado produced soda ash from nahcolite between 2000–2004; however, similar to the California facility, the Colorado facility’s production process did not generate CO_2 emissions. As a result, all national CO_2 emissions can be attributed to Wyoming for the entirety of the 1990–2021 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 2021 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 2023), levels of uncertainty in the national estimates in 2021 were −9%/+8% for CO_2.

State-level estimates for soda ash production have a similar 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 Recalculations

No recalculations were applied for this current report, consistent with Section 4.12 (page 4-61) of the national *Inventory*.

3.2.8.5 Planned Improvements

There are no planned improvements for the soda ash production category. 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.

3.2.8.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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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, as well as CH_4 emissions from the production of methanol and acrylonitrile, are discussed below. The petrochemical industry uses primary fossil fuels (i.e., natural gas, coal, and 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 2021, petrochemicals were produced at 73 facilities in 11 states (EPA 2023). 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, EPA disaggregated national emissions from the national *Inventory* to all applicable U.S. states and territories using production capacities by petrochemical process and 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, Tables D-11 through 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 were estimated as a percentage of total national emissions by state and by year.

The national *Inventory*–derived estimates for carbon black, ethylene, ethylene dichloride, and ethylene oxide are based on facility-level GHGRP emissions for 2010–2021. The GHGRP has no reporting threshold for petrochemical production, so these emissions data are representative of the industry. For 1990–2009, estimates were based on emissions factors derived from GHGRP data and production data from the American Chemistry Council and the International Carbon Black Association (EPA 2023). For all years, the national emissions estimates for acrylonitrile and methanol were based on emissions factors and production data from the American Chemistry Council because the national GHGRP data are considered CBI.

The method used for the national *Inventory* cannot be applied to derive state-level petrochemical emissions due to GHGRP CBI concerns with all the petrochemical types when considering data by state. For example, all ethylene oxide production facilities are in Louisiana and Texas. For reporting year (RY) 2019 through RY 2021, it appears that GHGRP emissions data could pass the CBI aggregation criteria in both states; however, for RY 2010–2018, 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 RY 2019–2021); 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 data (i.e., 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 data.

As an alternative, production capacities were used as a surrogate for actual production and emissions data. 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.

To calculate emissions, 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 annual national *Inventory* emissions per petrochemical (i.e., the aggregated GHGRP emissions for ethylene, ethylene dichloride, ethylene oxide, and carbon black in RY 2010–2021, and the calculated nationwide emissions for other years and for methanol and acrylonitrile in all years). For years where production capacity 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.

3.2.9.2.1. Acrylonitrile

Facility production capacity and location data were available for 1990–1993, 2004, and 2005 from the SRI Directory of Chemical Producers (SRI International 1990–2005) and for 2008, 2009, 2011, 2013, and 2017 from the ICIS (ICIS 2008, 2009a, 2011, 2013, 2017). Facility location data and the percentages of the nationwide capacity held by the two companies with the largest percentage of the total nationwide capacity were available for 1994–2003 from SRI (SRI International 1990–2005).

Several plants expanded between 1996–2001; the estimated capacities in the years prior to the expansion were assumed to be the same as the previous known capacity in 1993, and the estimated capacities in the years after the expansion were assumed to be the same as the known capacity in 2004. Capacities in 2006 and 2007 were estimated using linear interpolation between the known values in 2005 and 2008. The capacities in 2010, 2012, 2014–2016, and 2018–2021 were assumed to be the same as the previously known capacities. Some further adjustments were made when plant closings were known. For example, one facility in Texas closed in 2005, and another closed in 2009.

3.2.9.2.2. Carbon Black

ICIS capacity data were available for 1999, 2002, and 2005. For 1999, only a partial data set 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 all years between 1990–2005, except for 1995 (SRI International 1990–2005). For all years between 1990–2005, this analysis used SRI data.

Capacities for 1995 were estimated using linear interpolation between the known 1994 and 1996 values. Capacities for 2006–2021 were assumed to be the same as in 2005. Five plants closed between 2001–2010. One plant in Texas closed early in 2003 and a second closed in 2010. The plant in Arkansas was idled in 2001 and was assumed to not reopen. One plant in West Virginia closed in 2008, and the second closed in 2009. Typically, when a plant was known to have closed during a year, it was assumed that half of the nameplate capacity was available for that year.

3.2.9.2.3. Ethylene

SRI data on production capacities were available for 1990–1993, 2004, and 2005 (SRI International 1990–2005). The *Oil & Gas Journal* publishes capacities of ethylene production facilities, and data were available for 2007, 2013, and 2015 (O&GJ 2007, 2013, 2015). The capacity for a new unit that started up in 2020 was also available from the *Oil & Gas Journal* (O&GJ 2020).

Because site-specific capacities for 1994–2003 were not known, a linear interpolation of capacities was assumed between 1993–2004, except for known startups and shutdowns. This interpolation resulted in the total capacity being nearly equal to or slightly less than the total annual production from 1996 through 2000, which suggests some of the more significant expansions must have occurred in the mid-1990s. One plant in Texas started up in 1992. Due to the data in the 2004 SRI, it was assumed that this facility was consolidated with a neighboring facility sometime before 2004. One plant in Louisiana started up in 1992. One plant in Texas started up in 1994 and was expanded in 2002. Several plants closed between 1990–2005. One plant in Illinois closed in 1991, and one plant in Kentucky closed in 2000. One plant in Louisiana closed in 2001. Two plants in Texas closed in 2003, and one plant in Texas closed in 2005.

Capacities for 2006 were assumed to be the same as in 2005. Capacities for 2008–2012 and 2014 were estimated using linear interpolation between the known values in 2007, 2013, and 2015. Capacities for 2016–2021 were assumed to be the same as in 2015, except for new startups and expansions. One new plant started up in Texas in 2017, one new plant started up in Louisiana in 2019 and one in 2020, one idled plant in Louisiana was restarted in 2019, one plant in Texas expanded in 2017, two plants expanded in Texas in 2018, one plant in Louisiana expanded in 2019, and one plant in Texas expanded in 2020 (Chevron Phillips Chemical 2018, ExxonMobil 2018, Indorama Ventures 2015, LACC 2016, LyondellBasell 2017, OxyChem 2017, BIC Magazine 2019, O&GJ 2020, Petrotahill 2020). It was assumed that two plants in Texas closed in 2013.

3.2.9.2.4. Ethylene Dichloride

The SRI Directory of Chemical Producers production capacity data for ethylene dichloride were available for 1990, 1991, 1992, 1993, 2004, and 2005 (SRI International 1990–2005). Facility location data and the percentages of the nationwide capacity held by the companies that accounted for the top 50% of the total nationwide capacity were available for 1994–2003 from SRI (SRI International 1990–2005). ICIS data on production capacity are available for the years 2003, 2009, and 2018, although it is not clear whether the data are complete (ICIS 2003,2009b, 2018a). 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.

To maintain consistency, only SRI data were used for 1990–2005. Typically, linear interpolation was used to estimate capacities for 1994–2003, except for four expansions at unknown dates in the late 1990s. It was assumed that one facility expanded in 1996, one in 1998, and two in 1999. Making these assumptions resulted in corporate capacity shares that agreed reasonably well with the SRI percentages.

The ICIS capacities in 2009 matched the capacities in 2005; thus, all capacities were assumed to be unchanged from 2005–2009. The capacities in 2010–2021 also were assumed to be the same as in 2009, except for one facility in Louisiana that closed in 2011 and one new facility in Louisiana that started one new unit in 2010, a second new unit in 2011, and a third new unit in 2021.

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 64%, with a high of 85% in 1997 and a low of 46% in 2011. While these statistics indicate there may be some overestimation 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.

3.2.9.2.5. Ethylene Oxide

SRI data were available for 1990–1993, 2004, and 2005 (SRI International 1990–2005). ICIS data on plant capacities were available for 2004, 2010, 2012, and 2018 (ICIS 2004, 2010, 2012, 2018b). Facility location data and the percentages of the nationwide capacity held by the companies that accounted for the top 50% of the total nationwide capacity were available for 1994–2003 from SRI (SRI International 1990–2005). To maintain consistency, all capacity estimates for 1990–2005 were based on SRI data, except when ICIS information for a few facilities on the dates and size of expansions were applied to the SRI data. Capacities for 2006–2009 were assumed to be the same as the previously known values in 2005. Capacities for 2011 and 2013–2017 were based on linear interpolation between the known capacities in 2010, 2012, and 2018. All capacities in 2019–2021 were assumed to be the same as the known capacities in 2018, except for three facilities that started up in 2019.

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). For example, calculations are based on the information that one plant expanded in 1997, four in 1999, one in 2001, and one in 2002. in the resulting calculations of corporate capacity shares that agreed reasonably well with the SRI percentages. Capacities for new ethylene oxide units started up by Lotte, Sasol, and MEGlobal in 2019 were reported directly or could be estimated from other data reported on company websites (LACC 2016, Sasol 2019, Sasol 2020, EQUATE 2019).

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 104% of capacity. Conversely, the capacity utilization values of 0.44–0.57 in 2019–2021 appear to be unrealistically low. While this could mean capacities were overstated in these years, it also appears possible that the American Chemistry Council production values may not include new onsite captive use production, which would bias the nationwide production values to be low. Average capacity utilization over time was 80%. Although the data indicate there may be some overestimation 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.

3.2.9.2.6. Methanol

SRI data on methanol production capacity were available for 1990– 1993, 2004, and 2005 (SRI International 1990–2005). ICIS data were available for 2002, 2014, 2016, and 2018 (ICIS 2002b, 2014, 2016, 2018c). Facility location data and the percentages of the nationwide capacity held by the companies that accounted for the top 50% of the total nationwide capacity were available for 1994–2003 from SRI (SRI International 1990–2005). To maintain consistency, all capacity estimates for 1990–2005 were based on SRI data.

Capacities in 1994–2003 typically were assumed to be the same as the preceding known value until a known or assumed expansion year, and the capacities in years after the expansion were assumed to be the same as the next known capacity. Capacities in 2006–2009 were assumed to be the same as the known capacities in 2005, and capacities in 2010–2013 were assumed to be the same as the subsequent known capacities in 2014. Capacities in 2015 were assumed to be the same as in 2014 and 2016, except for two new facilities that started up in 2015 and one facility that expanded in 2015. Capacities in 2017 were assumed to be the same as in 2016 and 2018.

Capacities in 2019–2021 were assumed to be the same as in 2018, except for one plant that started up in 2018 (and was not in the ICIS 2018c reference), one plant that started up in 2020, and one plant that started up in 2021. Data on startup dates for expansions and new plants between 2012–2019 were obtained from documentation on company websites (Celanese 2019, OCI 2018, OCI Partners LP 2016, Methanex 2017, Proman 2023). These data were used to prorate capacities based on the approximate percentage of the year that they operated after startup. Capacity for one new unit that started up in 2020 was estimated based on data in the permit to install and operate (Ohio EPA 2017), and it was assumed to be in operation for 33% of the year based on information provided in the Toxics Release Inventory Form R (EPA 2022). The capacity for a new plant started up in 2021 was obtained from the website of an engineering and consulting contractor involved in the construction of the new plant (Worley 2020).

Eight methanol plants closed between 1998–2010. Data on plant closures between 1998–2005 were from OCI (OCI Partners LP 2016; see Appendix D). It was assumed that one plant closed in 2005 and another in 2009 because that was the latest date for which any information about their operation could be located, and neither facility reported to the GHGRP in the first year of reporting in 2010.

3.2.9.3 Uncertainty

The overall uncertainty associated with the 2021 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 2023), levels of uncertainty in the national estimates in 2021 were −5%/+6% for CO_2 and −58%/+48% 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. These assumptions were required because the CBI concerns related to GHGRP data and a general lack of other more granular state-level data.

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 Recalculations

The acrylonitrile and methanol production quantities for 2020 were updated with the revised values in the American Chemistry Council's Business of Chemistry (ACC 2022a, ACC 2022b). These changes resulted in revised CO_2 and CH_4 emissions for 2020, compared to the previous national *Inventory*. As a result, the distribution of estimated emissions at the state level also changed for 2020.

In addition, for the current national *Inventory*, CO_2 equivalent estimates of total CH_4 emissions from acrylonitrile and methanol production have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of CH_4 increased from 25 to 28, leading to an overall increase in estimates for CO_2 equivalent CH_4 emissions. Compared to the previous national *Inventory*, which applied 100-year GWP values from AR4, annual CH_4 emissions increased by 12% each year, ranging from an increase of 5.4 kt CO_2 equivalent in 2011 to 42.1 kt CO_2 equivalent in 1997. The net impact on the entire category from these updates was an average annual 0.1% increase in emissions for the time series. Further discussion on this update and the overall impacts of updating the national *Inventory* GWP values to reflect AR5 can be found in Chapter 9, Recalculations and Improvements.

The use of additional production capacity data from SRI directories of Chemical Producers for 1990–2005 resulted in changes to the total capacity per petrochemical per year, and it also resulted in changes to the percentage of total capacity in each state. These changes to the distribution of production capacities also resulted in corresponding changes to the percentages of total national emissions estimated for each state. Typically, the production capacity (and emissions) per state increased or decreased by less than 10% from the percentages used in the previous state emission estimates. However, the production capacity and emissions for some petrochemicals in some states dropped to zero in the current analysis because the new data provided additional clarity regarding startup, idled, and closure dates for some facilities. Typically, the states with these large changes from the previous analysis had only one petrochemical process unit in the state and/or had a small percentage of the total national capacity in the previous analysis. For example, emissions from methanol production in Oklahoma in 1994, carbon black in Arkansas in 2002–2004, and ethylene oxide in Illinois in 1994 and 1995, and ethylene oxide in Delaware in 2004 all were reduced to zero in the current analysis due to updated information regarding production capacities. The largest increases in emissions per state also occurred for states with small percentages of the total national production capacity. For example, the emissions from methanol production in Delaware in 1993 increased by 80% due to updates in the estimated methanol production capacity in the state in 1993. Similarly, the emissions from carbon black production in Alabama in 1999 increased by 42% due to updated information regarding production capacities.

3.2.9.5 Planned Improvements

Continued research is needed for more information on the 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., additional versions of SRI International Directory of Chemical Producers data, annual or biannual *Oil & Gas Journal* surveys of ethylene steam cracker capacities).

For 2010–2021, 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.

3.2.9.6 References

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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 byproduct during when manufacturing 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 2010–2020 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 4-71 of the national *Inventory,* 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, EPA does not have access to the individual plant estimates for 1990–2009; for those years, EPA has access only to national totals aggregated across the plants.

To develop state-level estimates of HFC-23 emissions from HCFC-22 production, EPA disaggregated national emissions from the national *Inventory* using a combination of facility-level reporting to the GHGRP from 2010–2021, reports verifying emissions by facility for earlier years, and production capacity data, as shown in Table 3-8 below. The sum of emissions by state is consistent with national process emissions as reported in the national *Inventory* over the time series.

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, were used to estimate emissions by state (Approach 2).
2010–2021	• Facility-specific GHGRP data on HFC-23 emissions were compiled by state (Approach 1).

For each state, HFC-23 emissions from 2010–2021 were drawn from facility-level reporting to the GHGRP. The same data were used for the national *Inventory*.

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 is 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. 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 (RTI International 2008), hereinafter referred to as the *2008 Verification Report*, to estimate facility-level emissions and develop state-level estimates for 1990–2009. EPA also used GHGRP data from 2010–2021 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 Consulting 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, and then 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, 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, 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 byproduct 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*.[29] 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

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[29] 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.

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 (minus 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 1991–1993, 1995, and 2002, 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 2000–2003. Its emissions factor was assumed to equal the value calculated for uncontrolled plants in 1999, at 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 (minus 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.

Table 3-9. Facilities Producing HCFC-22 or Destroying HFC-23 Generated During HCFC-22 Production from 1990 to 2021

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	1990–2021
	Washington, WV	2000–2021
Honeywell	El Segundo, CA	1990–1992
	Baton Rouge, LA	1990–2012
LaRoche Industries	Gramercy, LA	1990–1993
MDA Manufacturing/Daikin	Decatur, AL	1993–2021

3.2.10.3 Uncertainty

The overall uncertainty associated with the 2021 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 4-72 of the national *Inventory* (EPA 2023), the uncertainty in the national estimate in 2021 was estimated at −7%/+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 uncertainty in 2006 (−5%/+11% and −9%/+11%, respectively). The 2006 uncertainty in the much smaller emissions from the plant in Alabama was estimated at −48%/+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, 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 Recalculations

Consistent with the national *Inventory*, the CO_2 equivalent estimates of total HFC-23 emissions from HCFC-22 production have been revised to reflect the 100-year GWP for HFC-23 provided in the AR5 (IPCC 2013). With this change, the GWP of HFC-23 has decreased from 14,800 to 12,400, leading to a decrease in CO_2 equivalent HFC-23 emissions in every year compared to the previous inventory. No additional recalculations were applied for this current report.

3.2.10.5 Planned Improvements

During the 2007–2008 review of the HFC-23 emissions estimates provided to EPA by the Alliance for Responsible Atmospheric Policy, RTI International (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, 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 EPA, this would considerably reduce the uncertainty of EPA's 1990–2009 state-level estimates.

3.2.10.6 References

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RTI International (2008) *Verification of Emission Estimates of HFC-23 from the Production of HCFC-22: Emissions from 1990 Through 2006*. U.S. Environmental Protection Agency.

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3.2.11 Phosphoric Acid Production (NIR Section 4.16)

3.2.11.1 Background

Phosphoric acid, or 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 2021, 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, 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 process emissions reported to the GHGRP for 2010–2021 and estimated phosphoric acid production capacity by state for 1990–2009, 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, Tables D-17 through 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
2010–2021	• GHGRP process emissions data were used to estimate the percentage of emissions by state, multiplied by the national emissions (consistent with IPCC 2006 Tier 1).
1990–2009	• Phosphoric acid production capacity data were used to estimate the percentage of production by state, multiplied by the national emissions (consistent with IPCC 2006 Tier 1).

The methodology used for 2010–2021 used a combination of process emissions reported to the GHGRP for each phosphoric acid facility and their assumed use of phosphate rock by origin. The GHGRP has no reporting threshold for phosphoric acid production, so these emissions data are representative of the industry. Consistent with national CO_2 emissions calculations in the national *Inventory*, state-level emissions from phosphoric acid production were estimated using 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) Morocco and Peru (imported).

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 United States 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 was 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 Minerals Yearbook information was used to assign the phosphate rock origin for each year from 1990–2020 (USGS 1994–2020). Where the USGS Minerals Yearbook did not discuss the rock origin for a facility in a given year, 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. 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.

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 facility on an annual basis. The estimated emissions from each facility for each rock type were then 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.

The methodology used for 1990–2009 attributes 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, estimated annual production capacity information, and operational status on phosphoric acid production facilities for 1990–2005, EPA identified facilities operating wet process phosphoric acid production in each state (SRI International 1990–2005). For 2006–2009, EPA proxied using 2005 annual plant capacity information. Based on USGS Minerals Yearbook information on the operations of each facility, the rock origins for each facility were identified on an annual basis. State-level emissions from phosphoric acid production were estimated using the CO_2 content and usage of the same FL/NC, ID/UT, and imported phosphate rock origin categories described above. 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.

3.2.11.3 Uncertainty

The overall uncertainty associated with the 2020 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 2023), levels of uncertainty in the national estimates in 2021 were −18%/+20% 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 GHGRP process emissions data for 2010–2021 and facility production capacity for 1990–2009. These assumptions were required because of a general lack of more granular state-level data.

For 2010–2021, uncertainty is expected to be lower because GHGRP emissions data will be used by state as a surrogate for using phosphoric acid production data by state to calculate emissions.

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.

3.2.11.4 Recalculations

Recalculations were performed for the 1990–2009 portion of the time series to reflect updated data obtained on the annual capacity and operational status of each phosphoric acid production facility in each state, as described above. Additionally, the 2020 value for the total U.S. production of phosphate rock was updated based on updated USGS data. These updates resulted in a decrease of 37 kt CO_2 in 2020 at the national level. The updates to the state-level plant capacity data for 1990–2009 resulted in annual changes ranging from an 8% decrease in 1990 to a 12% increase in 2004 for Florida (−74 to 107 kt CO_2), a 37% decrease in 1999 to a 4% increase in 1990 for Idaho (−46 to 6 kt CO_2), a 80% decrease in 2003 to a 39% decrease in 2001 for Louisiana (−110 to 51 kt CO_2), a 19% decrease in 1992 to a 48% increase in 2005 increase for Mississippi (−9 to 15 kt CO_2), a 37% decrease in 2000 to a 16% increase in 1991 for North Carolina (−57 to 22 kt CO_2), a 10% decrease in 1995 to a 70% increase in 2005 for Texas (−3 to 19 kt CO_2), and a 10% decrease in 1991 to a 109% increase in 1999 for Wyoming (−5 to 46 kt CO_2).

3.2.11.5 Planned Improvements

For the facility-level phosphoric acid production capacity data used for 2006–2009, additional research is needed to more accurately represent the level of production and emissions associated with each state. EPA was able to locate the reference publication for the 1990–2005 time series but was not able to obtain the 2006–2009 publication before publishing this state-level inventory. Other data gaps include the origin of phosphate rock used in some facilities and some years.

3.2.11.6 References

EPA (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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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 and 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 seven distinct production processes: metallurgical coke production, sinter production, direct reduced iron production, pellet production, pig iron[30] production, electric arc furnace (EAF) steel production, and BOF steel production. In addition to the production processes, CO_2 is also generated at I&S mills through the consumption of process byproducts (e.g., blast furnace gas, coke oven gas) used for various purposes, including heating, annealing, and generating electricity. 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 byproducts). Fugitive CH_4 emissions can also be generated from these processes, as well as from sinter, direct iron, and pellet production.

In 2021, I&S production occurred in 31 states, and Indiana, Alabama, Tennessee, Kentucky, Mississippi, and Arkansas were the leading I&S-producing states, accounting for 52% of total U.S. production (AISI 1997–2021).

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[30] "Pig iron" is the common industry term to describe what should technically be called crude iron. Pig iron is a subset of crude iron that has lost popularity over time as industry trends have shifted. Throughout this report and consistent with the national *Inventory*, "pig iron" will be used interchangeably with "crude iron," but it should be noted that other data sets or reports may not use "pig iron" and "crude iron" interchangeably and may provide different values for the two.

3.3.1.2 Methods/Approach

To compile emissions by state from I&S and metallurgical coke production using available data, national emissions were disaggregated from the national *Inventory* with an Approach 2 method as defined in the Introduction chapter of this report, using a combination of coking coal consumption data, process emissions reported to the GHGRP, and data on steel production and employment 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*. See Appendix H, Tables H-1 through 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, which 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).

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:

- Metallurgical coke production
- Steel production—BOF
- Steel production—EAF
- Sinter production
- Iron production
- Pellet production
- Other activities

The methodologies for calculating state emissions from each category are detailed below.

3.3.1.2.1. Metallurgical Coke Production

National emissions from metallurgical 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, while accounting for any coproducts 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 EIA's 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 1960–2021 (EIA 2023). Energy consumption estimates from SEDS use data from surveys of energy suppliers that report consumption, sales, or distribution of energy at the state level, and most 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. 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. This approach assumes that emissions from metallurgical coke production are directly proportional to the amount of coking coal consumed in a state. As discussed in the Energy chapter, state-level coking coal use is based on coke production in a given state, which is not necessarily equal to coke use. Given the lack of specific data, however, coking coal production was determined to be a reasonable surrogate for coke use within a given state because coke production is often integrated with I&S production where the coke is used.

3.3.1.2.2. Steel Production

National 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 2010–2021, process emissions reported to the GHGRP under Subpart Q (I&S facilities) were summed by state (EPA 2023a) 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 2010–2021. Because emissions are reported by unit type in the GHGRP, EPA was able to disaggregate state-level emissions at the process level, including steel production by type, iron, sinter, pellet, metallurgical coke, and other activities. For steel production, GHGRP data were available by process type for 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.

For the years 1990–2009, a combination of employment data from the U.S. Census and production data from the American Iron and Steel Institute (AISI) was used to allocate national emissions from steel production to states (U.S. Census Bureau 1992, 1997, 2002, 2007; AISI 1997–2021). AISI total steel production data were available at the state level for the top five I&S-producing states) for each year, and data for the other states were combined into regions. Percentages of steel production for these lower producing states were approximated using U.S. Census Bureau industry employment data. 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 excluded from 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).[31] 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.

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

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 overestimations 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 overestimation or underestimation of a specific type of steel production in a given state. Given the lack of data, this approach is considered reasonable. However, this is an area for future improvement based on consideration of any available state-level steel production data.

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

For 2010–2021, 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 of 25,000 metric tons of CO_2 equivalent for I&S production is applicable for these process types as well.

For 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 U.S. Census employment data and AISI production data (U.S. Census Bureau 1992, 1997, 2002, 2007; AISI 1997–2021), 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.

3.3.1.3 Uncertainty

The overall uncertainty associated with the 2021 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 2023b), levels of uncertainty in the national estimates in 2021 were −19%/+19% for CO_2 and −20%/+21% 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 a combination of 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 onsite 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 2010–2021, 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.

For 1990–2009, U.S. 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.

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

3.3.1.4 Recalculations

Recalculations were performed for 2020 with updated values of coking coal consumption for each state. This update did not alter the national emissions from metallurgic coke production but only changed the emissions apportioned to each state engaged in this activity. The largest changes in emissions apportioned to each state occurred in Indiana (a 19.2% increase in emissions apportioned) and Michigan (a 14.9% decrease in emissions apportioned).

In addition, for the current Inventory, CO_2 equivalent estimates of CH_4 emissions from sinter production have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous Inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of CO_2 equivalent CH_4 increased from 25 to 28 between the AR4 and AR5 reports, leading to an overall increase in calculated CO_2 equivalent CH_4 emissions. Compared to the previous national *Inventory*, which applied 100-year GWP values from AR4, annual CH_4 emissions from sinter production increased by 12% each year, ranging from 0.78 kt CO_2 equivalent in 2009 to 2.6 kt CO_2 equivalent in 1993. The net impact on the entire category from these updates was an annual 0.002% increase in emissions for each year of the time series, reflecting the relatively low contribution of CH_4 emissions to the overall category.

3.3.1.5 Planned Improvements

AISI production data were only available from 1997–2020 (AISI 1997–2021), so data are incomplete for earlier years of the time series. This is an area for future improvement based on consideration of any available state-level production data.

Census employment data are released every five 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. One area of future improvement is to better understand the completeness of employment data and make adjustments as necessary.

Combustion emissions from GHGRP data are not entirely consistent across reporting facilities 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. One area of future improvement is to examine the GHGRP energy use estimates in comparison to what is assumed in the national *Inventory* calculations and adjust as needed.

EPA plans to compare coking coal consumption data from EIA SEDS to the data from the GHGRP reporting program for the years 2010–2021 as a QA/QC check.

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, EPA plans to compare the industry data to the GHGRP program data across time to see how close they are and if using the industry data is a reasonable approach.

EPA will review time series consistency issues related particularly to steel production. Surrogate data on industry employment were used in place of activity data for all but the top five 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.

3.3.1.6 References

AISI (American Iron and Steel Institute) (1997–2021) *Annual Statistical Report*. Available online at: https://www.steel.org/industry-data/reports/

EIA (U.S. Energy Information Administration) (2023) *State Energy Data System (SEDS): 1960–2021 (Complete).* U.S. Department of Energy. Accessed June 2023. Available online at: https://www.eia.gov/state/seds/seds-data-complete.php

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IPCC (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.). Cambridge University Press.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

U.S. Census Bureau (1992, 1997, 2002, 2007) *Geographic Area Series, Manufacturing*. Available online at: https://www.census.gov/library/publications/1995/econ/mc92-a.html (1992), https://www.census.gov/library/publications/1997/econ/census/manufacturing-reports.html (1997), https://www.census.gov/library/publications/2002/econ/census/manufacturing-reports.html (2002), https://www.census.gov/data/tables/2007/econ/census/manufacturing-reports.html (2007).

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 and other elements such as silicon, manganese, and chromium. 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 by mass), silicon metal (96% to 99% silicon by mass), and miscellaneous alloys (32% to 65% silicon by mass) have been calculated.

Consistent with the national *Inventory*, emissions from the production of ferrochromium and ferromanganese are not included because of the small number of manufacturers of these materials in the United States.

Government information disclosure rules prevent the publication of production data for these production facilities. Additionally, production of ferrochromium in the United States ceased in 2009.

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 2021, ferroalloy production occurred in six states: Ohio, Pennsylvania, Kentucky, Alabama, Michigan, 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 process emissions reported to the GHGRP and the number of facilities in a state (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
2010–2021	• GHGRP facility process emissions data were used. • Remaining emissions reported in the national *Inventory* were allocated across remaining known facilities (IPCC 2006 Tier 1).
1990–2009	• Data on number of facilities that reported to the GHGRP were used to allocate emissions for those facilities. Remaining emissions were allocated evenly across remaining known facilities (IPCC 2006 Tier 1).

To identify all ferroalloy-producing facilities for 1990–2021, the number of facilities in each state was compiled from the USGS Minerals Yearbooks for ferroalloys as available (USGS 2008–2018) 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 from 1990–2007 because the Minerals Yearbooks for years before 2008 did not contain the number of facilities. Additionally, facilities were not included in years that EPA determined the facility was not operational. EPA used internet searches to determine the opening dates of ferroalloys facilities and to determine whether they were operational during all inventory years (AMG Vanadium 2017; Bloomberg 2021a, 2021b; Businesswire 2020, 2017; Centerra Gold 2021; Flessner 2015; D&B 2021; Ferroglobe 2020; Global Titanium Inc. 2010; RTI International Metals 2007; Vanadium Price 2019).

Five of the facilities listed in the USGS Minerals Yearbook also reported to the GHGRP in 2010–2021, 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 2010–2021, process emissions reported to the GHGRP were summed (EPA 2010–2021) 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 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 2021 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 2023), levels of uncertainty in the national estimates in 2021 were −13%/+13% for CO_2 and −13%/+13% 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 process emissions reported to the GHGRP and the number of facilities in a state. These assumptions were required because of a general lack of more granular state-level data.

For 2010–2021, 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.

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 that 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.

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 Recalculations

Recalculations were completed for this report based upon a change made in the 2021 national *Inventory*. The national *Inventory* value for 2014 was revised based upon revised total silicon materials production data from USGS. The impact of this change was a 4.8% increase to CO_2 and 4.9% increase to CH_4 emissions estimates at the national level, which results in a 10% increase in CO_2 equivalent emissions estimates for facilities that do not report to the GHGRP and in the disaggregated state-level inventory.

In addition, for the current Inventory, CO_2 equivalent estimates of total CH_4 emissions from ferroalloy production have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of CH_4 increased from 25 to 28 between the AR4 and AR5 reports, leading to an overall increase in CO_2 equivalent estimates for CH_4 emissions. Compared to the previous Inventory, which applied 100-year GWP values from AR4, annual CH_4 emissions increased by 12% each year, ranging from 1.1 kt CO_2 equivalent in 2003 to 2.0 kt CO_2 equivalent in 1990.

3.3.2.5 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 ferroalloy production at the state level, EPA estimated that all facilities that did not report to the GHGRP produced equal emissions. Data on the size and capacity of each facility would allow EPA to distribute emissions more accurately. As a future improvement, EPA may use Title V or state-level permits to look for capacity data for each facility to better estimate emissions by state.

While production of ferrochromium in the United States ceased in 2009, EPA will assess whether data are available to incorporate emissions from facilities producing ferromanganese and ferrochromium in the national- and state-level inventories over the time series.

3.3.2.6 References

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3.3.3 Aluminum Production (NIR Section 4.19)

3.3.3.1 Background

In addition to consuming large quantities of electricity, the production of primary aluminum results in process-related CO_2 emissions and two 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.

CO_2 is emitted during the aluminum smelting process when alumina (also called aluminum oxide or Al_2O_3) is reduced to aluminum using the Hall-Héroult 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 lining that serves as the cathode. Carbon is also contained in the anode, which can be a carbon mass of paste, coke briquettes, or prebaked carbon blocks from petroleum coke. During reduction, most of this carbon 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 carbon 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 (national and sate level) 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 (i.e., EPA GHGRP data) methods over the time series as discussed in Chapter 4, Section 4.19 (on pages 4-93 through 4-97) of the national *Inventory* (EPA 2023). 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 2010 and later, EPA used the same underlying methods as the as those used for the national *Inventory*, which are facility-specific process emissions reported to EPA's GHGRP under Subpart F: Aluminum Production to estimate state-level emissions (EPA 2022); for 1990–2009, EPA used the emissions estimates reported to EPA's Voluntary Aluminum Industrial Partnership Program (VAIP), and where facility specific emission data were not reported, emissions were disaggregated to each state based on facility-specific reported emission and production data reported in other years. The approach summarized in Table 3-12 below 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
2010–2021	• GHGRP process emissions data were used to calculate emissions by state (i.e., Approach 1).
1990–2009	• Emissions data and associated production data reported to the VAIP were used to allocate emissions at the facility level and to their respective state (Approach 2).

For 2010–2021, 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 United States report their emissions to EPA. CF_4 emissions from LVAEs were estimated by allocating total U.S. LVAE emissions according to each state's yearly percentage of total have CF_4 emissions. The percentages were calculated on a yearly basis (state total/national total per year) to account for non-reporting years.

For 1990–2009, EPA allocated the emissions estimated from the VAIP reported data to their respective facility and state. This allocation did require additional assumptions where VAIP data aggregated some facilities (I.e., Alcoa facilities) at a national level. The VAIP production and emission data for 2007 when the disaggregation between facilities was available were assumed to be representative of years where disaggregated data were not available, and the percentage breakdown from 2007 was applied to the years for which the data were not disaggregated. 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 US Aluminum Association (USAA) primary aluminum production estimates for the U.S., combined with the process emissions and activity data reported under EPA's VAIP.

3.3.3.3 Uncertainty

The overall uncertainties associated with the 2021 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 2021 surrounding the reported CO_2, CF_4, and C_2F_6 emission values were determined to have a normal distribution with uncertainty ranges of approximately −6%/+6%, −16%/+16%, and −20%/+20% their 2021 emission estimates, respectively.

For the 2010 to 2021 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 2010–2021 state-level uncertainties are somewhat higher than 2010–2021 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.[32] The uncertainty of each smelter's CO_2 emissions is estimated at −6%/+6%; the uncertainty of each smelter's HVAE CF_4 emissions is estimated to range from −16%/+16%; and the uncertainty of each smelter's HVAE C_2F_6 emissions is estimated to range from −20%/+20%. The uncertainty associated with LVAE emissions is estimated based on the smelter technology type and is estimated to range from −99/+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 U.S. level. For more details on national-level uncertainty, see the uncertainty discussion in Chapter 4 of the national *Inventory.*

State-level estimates are expected to have significantly higher uncertainties for 1990–2009 than more recent years due to the methods used to apportion emission estimates to each state based VAIP reported data, for which some of the data were aggregated for multiple facilities. 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 from the actual emissions resulting from aluminum production activities in that state.

3.3.3.4 Recalculations

Refer to Section 4.19 (page 4-103) of the national *Inventory* report for a complete list of recalculations for the national *Inventory*.

3.3.3.5 Planned Improvements

EPA will further investigate the sources of historical total primary aluminum production estimates for the earlier years in the time series and potentially update historical estimates to aim for increased consistency throughout the time series. As part of this planned improvement, EPA will review whether historical estimates are broken down into smelter-specific production estimates, which are the basis for calculating smelter, and therefore state, PFC emissions (for non-partners) and CO_2 emissions (for all facilities) for the 1990–2009 time series (i.e., years preceding GHGRP reporting). Additional improvements include evaluating the LVAE emissions calculations method by state for the 2010–2021 time series. Currently, the LVAE CF_4 emissions are based on each state's yearly percentage of total HVAE CF_4 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.*

3.3.3.6 References

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[32] 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 SF_6 and other GHGs (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 4-105 through 4-111) 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 2011–2021, EPA used facility-specific emissions data from 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 magnesium products report to the GHGRP. EPA assumed that non-reporting facilities were located in the same states as reporting facilities.

For 1999–2010, EPA used company-specific reported cover gas emissions data reported to 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 SF_6 Emission Reduction 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
2011–2021	• 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).
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).
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).

3.3.4.2.1. All Processes

The methodology used for all processes for 1990–1998 is based on disaggregating 1999 national emissions by process type and by state and then using that information 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.

3.3.4.2.2. Primary, Secondary, Die Casting, and Sand Casting

The methodology used for 2011–2021 relied on GHGRP-reported emissions. EPA allocated emissions from GHGRP reporting facilities to the states in which the reporting facilities are located. For non-reported estimated emissions or emissions estimated from smaller casting facilities falling under the GHGRP reporting threshold, EPA allocated emissions associated with the non-reporting 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 non-reported emissions for that particular process type.

The methodology used for 1999–2010 relied on emissions reported to EPA as under EPA's SF_6 Emission Reduction Partnership for the Magnesium Industry. 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 non-reported estimated emissions, EPA allocated emissions associated with the non-reporting population proportionally to states with reported emissions for the appropriate process type.

3.3.4.2.3. Permanent, Wrought, and Anode

For 2011–2021, emissions associated with these processes are not reported through the GHGRP. Total U.S. production is reported annually through the USGS Yearbook (USGS 1995-2022). Therefore, EPA used a similar methodology that is used for the non-reported 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.

For 1999–2010, emissions associated with these processes were not reported through the EPA Partnership Program. Total U.S. production is reported through the USGS Yearbook. Therefore, EPA used a methodology similar to the methodology for allocating non-reported emissions for primary, secondary, die, and sand casting to the states. 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.

3.3.4.3 Uncertainty

The overall uncertainty associated with the 2021 national estimates of SF_6, HFC-134a, and CO_2 emissions from magnesium production and processing 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 2020 for all gases in aggregate were −7.0%/+7.1%.

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 2011–2020 time series, the uncertainties associated with the state-level estimates are expected to be low because emissions are mostly estimated and reported at the facility level. Nevertheless, the 2011–2020 state-level uncertainties are somewhat higher than 2011–2020 national-level uncertainties because for some process types, facility-reported data are not available (i.e., permanent, wrought, and anode). For 1999–2010, state-level estimates have a higher uncertainty than national estimates in the same time period, as well as more uncertainty than that of the state-level estimates for 2011–2020. The lower uncertainty for the latter portion of the time series is due to a higher proportion of facility data being available through the GHGRP as compared to EPA Partnership Program for each year. Allocation of estimated but unreported emissions for specific process types (i.e., sand casting, die casting, permanent, wrought, and anode) is also done within this time period based on the state proportions of reported emissions, leading to increased uncertainty due to the assumption that unreported emissions occur in the same proportion across states as reported emissions. For 1990–1998, state-level estimates are expected to have a significantly higher level of uncertainty than that of more recent years 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 more details on national-level uncertainty, see the uncertainty discussion in Chapter 4 of the national *Inventory*.

3.3.4.4 Recalculations

Additional data and new information became available through the GHGRP that affected state estimates:

- GHGRP-reported emissions for CO_2 and SF_6 were updated for a die casting and a permanent mold facility for their 2020 reported emissions data, resulting in decreased 2020 CO_2 and SF_6 emissions.
- Another die casting facility that was a late reporter to the GHGRP has had emissions back-casted to 2001, increasing SF_6 emissions in those years.
- One facility that was previously interpolated for 2014 has CO_2 emissions data available on the FLIGHT tool and has been updated accordingly, resulting in a decrease in 2014 CO_2 emissions.
- One facility's fluorinated ketone and CO_2 emissions from 2016 were updated as an interpolation between reported 2015 and 2017 emissions, in alignment with previous updates to that facility's SF_6 emissions, leading to increased CO_2 emissions and decreased fluorinated ketone emissions.

- HFC-134a emissions from one facility, which were not previously accounted for in the estimate summary, have been accounted for, leading to an increase in 2019 HFC-134a emissions.
- CO_2 emissions from one facility were previously held constant from their 2018 emissions, further research indicated that holding emissions from their 2017 emissions was more reflective of current conditions and was updated, resulting in increased 2019 and 2020 CO_2 emissions from that facility.

In addition, for the current national *Inventory*, estimates of gas emissions from SF_6, HFC-134a, CO_2, and fluorinated ketone have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP value for SF_6 increased from 22,800 to 23,500, leading to an increase in emissions. The GWP value for HFC-13a decreased from 1,430 to 1,300, leading to a decrease in emissions. Compared to the previous Inventory which applied 100-year GWP values from AR4, the average annual change in SF_6 emissions was a 3.1% increase and the average annual change in HFC-134a emissions was 4.5% decrease for the time series. While the GWP value CO_2 remained the same, calculations of CO_2 emissions from permanent mold, wrought, and anode emissions tied to emissions of SF_6 led to 0.02% increase in CO_2 emissions. Overall, emissions from magnesium production and processing increased over the time series.

Refer to Section 4.20 (page 4-110) of the national *Inventory* report for a complete list of recalculations for the national *Inventory*.

3.3.4.5 References

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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 2021, 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 process emissions reported to the GHGRP to calculate process emissions and the number of facilities in a state (see Table 3-14). See Appendix H, Tables H-7 through 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 when applying 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
2010–2021	• GHGRP process emissions data were used to estimate the percentage of emissions by state, multiplied by the national emissions (IPCC 2006 Tier 1).
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).

The methodology used for 2010–2021 was based on process emissions reported to the GHGRP summed by state (EPA 2010–2021) 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 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 2023) to disaggregate 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 Minerals Yearbooks for those years did not contain the number of facilities.

The USGS Mineral Commodity Summaries for lead (1990–2021) only provide primary and secondary lead production as total national values, with no breakdown by state. The USGS Minerals 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.

3.3.5.2.1. Primary Versus Secondary Production 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 RYs 2010–2013 were compiled. Next, the production for the primary facility and secondary facilities from the USGS Minerals Yearbooks 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.

3.3.5.2.2. CEMS Adjustment for 2010–2021

Starting in 2010, lead-producing facilities 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.[33] 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 2016–2021.

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 2021 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 2023), levels of uncertainty in the national estimates in 2021 were −15%/+15% 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 GHGRP emissions data for 2010–2021 and the estimated number and location of facilities for 1990–2009.

For 2010–2021, 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 7% to 36% lower than GHGRP estimates for 2010–2021. 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.

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.

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 Recalculations

Minor recalculations were performed in this report for 2014, 2018, 2019, and 2020 state-level inventory estimates due to updates to the national *Inventory* data set, based upon revised USGS data for secondary lead production. Compared to prior estimates, estimated CO_2 emissions increased by 4% for 2014, 3% for 2018, and less than 1% for 2019. Estimated emissions decreased by 6% for 2020.

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[33] 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.

3.3.5.5 Planned Improvements

More information on 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 2016–2021. Additionally, because the GHGRP data set is available starting with 2010, EPA is assessing the feasibility to review and update lead production data by state for earlier parts of the time series. For example, the estimated number and location of facilities producing lead per state for 1990–2009 still need to be confirmed, especially for 1990–1994.

EPA will review time series consistency issues due to the two methodologies for 1990–2009 and 2010–2021. Surrogate data on the 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 calculations more closely reflect state trends in emissions.

3.3.5.6 References

EPA (U.S. Environmental Protection Agency) (2010–2021) *Envirofacts GHGRP Subpart S and Subpart C Data*. Accessed May 8, 2023. Available online at: https://www.epa.gov/enviro/greenhouse-gas-customized-search

EPA (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

USGS (U.S. Geological Survey) (1995–2009) *Minerals Yearbook: Lead Annual Report*.

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 currently in use in the United States, only the Waelz kiln secondary process results in nonenergy CO_2 emissions. For earlier years in the time series, the emissive electrothermic process was utilized from before 1990–2014, the pig iron zinc oxide furnace process from 2009–2012, and the flame reactor process from 1993–2013. Emissions from fuels consumed for energy purposes during the production of zinc are accounted for in the energy sector. In 2021, 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 process emissions reported to the GHGRP and the number of facilities in a state (see Table 3-15). See Appendix H, Tables H-10 through 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 when applying national methods (e.g., IPCC Tier 2 methods) at the state level. 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
2010–2021	- GHGRP process emissions data were used to estimate the percentage of emissions by state, multiplied by the national emissions (IPCC 2006 Tier 2).
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).

The methodology for 1990–2009 used 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 2023) to calculate disaggregated CO_2 emissions by state for each year. 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, as well as the number of electrothermic furnaces, Waelz kilns, other furnaces, and flame reactor units.

The methodology for 2010–2021 used process emissions reported to the GHGRP summed by state and nationally (EPA 2010–2021) 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 emissions from states with smaller facilities were possibly underestimated.

The USGS Mineral Commodity Summaries for zinc (1990–2021) only had U.S. zinc production as total national values with no breakdown by state. The USGS Minerals 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.

3.3.6.2.1. EAF Dust Consumption Facility Accounting for 2010–2021

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. The one facility utilizing an electrothermic furnace was in operation from before 1990–2014. 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 Operating Co. in Blytheville, Arizona, and American Zinc Recycling Corp. (AZR; formerly Horsehead Corp.) in Beaumont, Texas.

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

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

3.3.6.2.2. 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 two 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 and Waelz kilns) per facility were compiled to calculate the average CO_2 emissions per facility and average CO_2 emissions per unit per facility. Note that 2020 and 2021 GHGRP emissions data were not included in calculating these averages, as 2020 and future year data may not be as representative to apply to 1990–2009 emissions estimates. 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 facility was used to estimate CO_2 emissions for other furnaces, while the 2009 CO_2 emissions value for the AZR facility was used to estimate CO_2 emissions for flame reactor units.

The average CO_2 emissions per unit for electrothermic furnaces and Waelz kilns and the 2009 CO_2 emissions 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 2020 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 2023), levels of uncertainty in the national estimates in 2021 were −18%/+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 2010–2021.

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 2010–2021, uncertainty is expected to be lower than the period from 1990–2009 due to 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 the estimates.

3.3.6.4 Recalculations

Minor recalculations were performed in this report for 2020 state-level inventory estimates due to a revision to the national *Inventory* based on updated EAF dust consumption data. The 2020 national *Inventory* revised estimate for emissions from zinc production decreased by 3% as a result. This update results in a corresponding minor decrease in estimated state-level emissions for 2020.

3.3.6.5 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).

3.3.6.6 References

AZR (American Zinc Recycling) (2021) *Summary of Company History*. Accessed March 3, 2021. Available online at: https://web.archive.org/web/20210620033241/https://azr.com/our-history/.EPA (U.S. Environmental Protection Agency) (2010–2022) *Envirofacts GHGRP Subpart S and Subpart C Data*. Accessed May 8, 2023. Available online at: https://www.epa.gov/enviro/greenhouse-gas-customized-search.

EPA (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Horsehead Corp. (2010) *Form 10-K: Annual Report Pursuant to Section 13 or 15(d) of the Securities Exchange Act of 1934 for the Fiscal Year Ended December 31, 2009*. Available online at: https://last10k.com/sec-filings/zincq/0000950123-10-025167.htm#link_fullReport.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

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

USGS (U.S. Geological Survey) (1990 through 2021) *Mineral Commodity Summary: Zinc*.

3.4 Product Use (Fluorinated Sources, N_2O)

The product use portion of IPPU emissions is a catch-all 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)
- N_2O from product uses (N_2O)

3.4.1 Electronics Industry (NIR Section 4.23)

3.4.1.1 Background

The electronics industry uses multiple GHGs in its manufacturing processes. In semiconductor manufacturing, these include long-lived fluorinated GHGs used for plasma etching and chamber cleaning (common reporting format [CRF] source category 2E1), fluorinated heat transfer fluids (F-HTFs) (CRF source category 2E4) used for temperature control and other applications, and N_2O used to produce thin films through chemical vapor deposition (CRF source category 2H3). Similar to semiconductor manufacturing, the manufacturing of micro-electro-mechanical systems (MEMS) devices (CRF source category 2E5 Other) and photovoltaic cells (CRF source category 2E3) requires using multiple long-lived fluorinated GHGs (F-GHGs) 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 Hampshire, 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 that 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 byproduct. In some cases, emissions of the byproduct 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 byproduct.

N_2O is used in manufacturing semiconductor devices to produce thin films by chemical vapor deposition 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 F-HTFs for controlling temperature, testing devices, 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 semiconductors, MEMS, F-HTFs, and photovoltaics (PV). National emissions were estimated using IPCC Tier 2 methods as discussed further in Chapter 4, Section 4.23 (page 4-124) of the national *Inventory*. In general, EPA used a Hybrid approach to disaggregate national estimates.

3.4.1.2.1. Semiconductor and MEMS Manufacturing

To disaggregate emissions by state for semiconductors and MEMS, EPA used data sources from the GHGRP and the World Fab Forecast (WFF).[34] 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, EPA partnership and program data, and disaggregation of national-level emission estimates, where facility-level data were 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, C_3F_8, CHF_3, SF_6, NF_3, C_4F_8, C_4F_6, C_4F_8O, C_5F_8, CH_2F_2, CH_3F, CH_2FCF_3, $C_2H_2F_4$, and N_2O 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
2014–2021	• 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 non-reporting facilities were allocated by calculating the percentage of TMLA estimated for non-reporting facilities in each state using

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

Time Series Range	Summary of Method
	the WFF data set and multiplying by the total estimate of non-reported emissions in the national *Inventory* (Approach 2). • Emissions from non-reporting MEMS facilities were not estimated, which is consistent with the national *Inventory*.
2013	• Emissions from reported fabs, adjusted for time series consistency in the national *Inventory*, were allocated based on the location of the GHGRP facility. The reported emissions were scaled up by 0.017% to account for time series consistency (Approach 1). • Emissions from non-reporting facilities were allocated by calculating the percentage of TMLA estimated for non-reporting facilities in each state using the WFF data set and multiplying by the total estimate of non-reported emissions in the national *Inventory*. The unreported emissions were scaled up by 0.017% to account for time series consistency (Approach 2). • Emissions from non-reporting MEMS facilities were not estimated, which is consistent with the national *Inventory*.
2011–2012	• 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 non-reporting facilities were allocated by calculating the percentage of TMLA estimated for non-reporting facilities in each state using the WFF data set and multiplying by the total estimate of non-reported emissions in the national *Inventory* (Approach 2). • Emissions from non-reporting MEMS facilities were not estimated, which is consistent with the national *Inventory*.
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).
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). • N_2O emissions data were first reported in 2015, so emissions from MEMS facilities from 1991–2014 were interpolated for N_2O (Approach 2).

From 2014 to 2021, emissions from reported fabs were allocated to the state in which the reporting facility was located as reported through the GHGRP.

From 2011–2013, F-GHGs 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 non-reporters were allocated to each state as described above. Emissions from non-reporting facilities that manufactured semiconductors were estimated by calculating the percentage of TMLA estimated for non-reporting facilities in each state using the WFF data set; the state's percentage of total non-reporter TMLA was then used to allocate the non-reporter portion of national emissions as calculated in the national *Inventory*. Reporter and non-reporter emissions from 2013 were scaled up by 0.017% to account for the differences in the emissions factor used. Emissions from non-reporting MEMS facilities are not estimated, which is consistent with the national *Inventory*.

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. N_2O emissions from MEMS facilities were first reported in 2015 and assumed to be zero in 1990. Emissions from 1991–2014 were interpolated between 1990 emissions and the emissions estimate for 2015. Only one facility in New York, GE Global Research Center, reported N_2O emissions, so all N_2O emissions in the time series were attributed to New York.

Only 27 states were identified as containing semiconductor fabs, six of which also reported emissions from the production of MEMS.

3.4.1.2.2. Fluorinated Heat Transfer Fluids

To estimate state-level emissions of F-HTFs, EPA used a Hybrid approach to disaggregate national emissions. For the national *Inventory*, for years when GHGRP data were available, EPA estimated state-level emissions based on facility location. For earlier years, 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 levels for years prior to GHGRP's availability. Table 3-17 summarizes methods used to compile HTF emissions.

Table 3-17. Summary of Approaches to Disaggregate the National *Inventory* for F-HTFs Across Time Series

Time Series Range	Summary of Method
2011–2021	• National F-HTF emissions were allocated to the states in the same proportion as emissions from reported fabs were allocated to the states in which the reporting facilities were located, as reported through the GHGRP (Approach 1). • Emissions from non-reporters were added to each state's emissions from HTFs by multiplying state emissions of HTFs by the estimated non-reporter GHGRP emissions percentage taken from the national *Inventory* (Approach 2).
2000–2010	• National F-HTF emissions were allocated to states in the same proportion as F-GHG emissions associated with semiconductor manufacturing (Approach 2).
1990–1999	• F-HTF emissions do not occur and are not estimated in the national *Inventory* during 1990–1999 and thus are estimated to not occur at state levels.

From 2011–2021, emissions from reported fabs were allocated to the state in which the reporting facility was located as reported through the GHGRP. Emissions from non-reporters were added to each state's emissions from HTFs by multiplying state emissions of HTFs by the estimated non-reporter 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.

Emissions from 1990–1999 are assumed not to have occurred. F-HTF use in semiconductor manufacturing is assumed to have begun in the early 2000s.

3.4.1.2.3. Photovoltaics

To estimate state-level emissions from PV manufacturing, EPA used a Hybrid approach, applying a GHGRP-derived emissions factor to state-level manufacturing capacity data. Two different emissions factors were developed: one for F-GHGs and one for N_2O. 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 C_2F_6, C_3F_8, CF_4, CHF_3, SF_6, NF_3, C_4F_8, and N_2O.

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

Time Series Range	Summary of Method
2011–2021	• State-level estimates of manufacturing capacity were used to allocate emissions for non-reporters (Approach 2). • Reported facility data were allocated to the state where the facility was located (Approach 1).
2000–2010	• 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 were unavailable (Approach 2).
1998–1999	• State-level emissions were interpolated for 1998 and 1999 (Approach 2).
1990–1997	• Capacity was assumed to be zero during 1990–1997 (Approaches 1 and 2).

For 2011–2021, reported state-level emissions from PV manufacturing were estimated by allocating emissions from GHGRP reporters to the state in which the reporting facility is located. Two PV facilities, Micron Technology in Idaho and Mission Solar in Texas, reported to the GHGRP during this time period (neither for the full period of 2011–2020). Therefore, all the reported emissions were allocated to Idaho and Texas for the years for which reported data are available. Non-reporter emissions were estimated using manufacturing capacity data from DisplaySearch (2010), which provides facility-specific data, including the facility's state. Emissions from non-reporters were calculated by multiplying the manufacturing capacity of each state by emissions factors in million metric tons CO_2 equivalent per megawatt (two emissions factors were developed, one for F-GHGs and one for N_2O) based on reported emissions from Mission Solar.

For 2000–2010, non-reporter emissions were estimated multiplying the proportion of each state's manufacturing capacity in 2009 (the most recent year DisplaySearch data were purchased) by the overall non-reporter estimate used in the national *Inventory*.

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

3.4.1.3 Uncertainty

The overall uncertainty associated with the national emissions estimates for the electronics industry was 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 2021 were –6%/+6% across the electronics industry.

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; 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 Recalculations

State-level estimates from 2015–2021 were updated to reflect updated emissions reported through the GHGRP, relative to the previous national *Inventory*. Gases were added to the state-level estimates for semiconductor manufacturing, MEMS, HTFs, and PV. PV estimates were corrected for 2003–2011 to align with the national *Inventory* and address a summing error related to the total U.S. manufacturing capacity of crystalline silicon. In addition, 2013 emissions for semiconductor manufacturing increased by 0.017%, reflecting adjustments made for time series consistency, in line with the national *Inventory.* State-level N_2O emissions were added for PV and MEMS. Refer to the national *Inventory* report for a complete list of recalculations for the national *Inventory*.

In addition, state-level estimates for HTF emissions are updated to use AR5 GWPs, addressing an error in the national *Inventory* where HTF estimates were still using AR4 GWPs. Thus, HTF emissions might not match estimates published in the national *Inventory*.

3.4.1.5 Planned Improvements

Planned improvements are consistent with those 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*.

3.4.1.6 References

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

3.4.2.1 Background

HFCs, PFCs, and CO_2 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.[35] ODSs such as 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 suppression, and aerosols. HFCs, PFCs, and CO_2 are not harmful to the stratospheric

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[35] 42 U.S.C § 7671, CAA Title VI.

ozone layer, they are GHGs with global warming potentials (GWPs) ranging from 1 for CO_2 to tens of thousands for HFC-23 and some PFCs (EPA 2023).

3.4.2.2 Methods/Approach

As described in the national *Inventory* report (EPA 2023), EPA employs its Vintaging Model to estimate national use, banks, emissions, and transition of ODS-containing equipment and products to substitutes—including HFCs, PFCs, CO_2—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 that contain 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 an additional description of the Vintaging Model and further details such as the end uses modeled (EPA 2023).

An approach similar to the Vintaging Model can be used to develop state-level emissions estimates. California, for example, 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, that is not the case. For instance, EIA (2021) statistics confirm that the use of air conditioning varies by region, which could lead to a significant difference that is not directly related to population. As noted in the national *Inventory*, EPA estimates that residential unitary air conditioning is the second largest emitting (in CO_2 equivalent terms) end use within the refrigeration and air conditioning sector, which accounts for 78% of national emissions (EPA 2023).

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, 2022; Montzka et al. 2023). 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 papers 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 (U.S. Department of Energy 2016) in northern regions and the higher percentage of homes with air conditioning (EIA 2018a, 2018b) 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 were 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, 2022) 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, the Northern Mariana Islands, and the U.S. Virgin Islands) (U.S. Census Bureau 2002, 2011, 2021, 2022; Instituto de Estadísticas de Puerto Rico 2021). Population estimates across the time series were not available for the Federated states of Micronesia, the 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, 2022) were used. Specifically, emissions for HFC-32, HFC-125, HFC-134a, and HFC-143a from 2008–2020 were available. 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, 2022) 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 1990–2021 time series. 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, 2022). Error bars from Hu et al. were not applied or analyzed here. Because these data ended in 2020, the ratio from that year was used for 2021 as well. Likewise, ratios from 2008 were used for 1990–2008. 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 2020 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* (EPA 2023), the uncertainty of national emissions was −4.2%/+14.7% 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) are provided at the state level under the same apportionment as used in the national emission estimates. The Hu et al. (2017, 2022) papers used in these state-level emissions estimates show 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 papers; 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. analyses are 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 2008–2020, so extrapolation before and after that time frame introduces additional uncertainty.

3.4.2.4 Recalculations

No recalculations were applied to the state disaggregation method for this current report. Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 4.24 of the national *Inventory*, given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

3.4.2.5 Planned Improvements

This approach of 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, were incorporated using data from Hu et al. (2022), and similar updates are anticipated. Further extension of these data, when available, can then be used to redistribute the annual emissions after 2020. Also, although emissions derived from atmospheric measurements were not available before 2008, looking at the trends, if any, in the data can show 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, 2022) 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 Hu et al. (2017) paper found that emissions of CFC-11, HCFC-141b, HCFC-142b and HFC-365mfc showed regional distributions expected based on their primary use as a blowing agent for insulating foam. These data sets 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.

3.4.2.6 References

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3.4.3 Electrical Transmission and Distribution (NIR Section 4.25)

3.4.3.1 Background

This 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 three territories: Guam, Puerto Rico, and the Virgin Islands. For Guam, emissions have only been estimated for 2020 and 2021. Future updates to the national *Inventory* will include 1990–2019 emissions estimates for Guam.

3.4.3.2 Methods/Approach (Transmission and Distribution)

As discussed in Chapter 4, Section 4.25 (page 4-151) of the national *Inventory*, 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 SF_6 Emission Reduction Partnership for Electric Power Systems combined with information on total transmission miles in the United States to develop SF_6 emission estimates from electrical transmission and distribution. However, facilities, as defined in the GHGRP or the Emission Reduction 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, EPA used data sources from the GHGRP and Homeland Infrastructure Foundation-Level Data (HIFLD) (U.S. Department of Homeland Security 2019–2021). For years prior to 2011 where GHGRP data were unavailable, state-level SF_6 emissions from electrical transmission and distribution 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 (1) only reported one state or (2) reported for multiple states and there was a reasonable match between the states and total transmission miles reported to the GHGRP and by HIFLD, 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

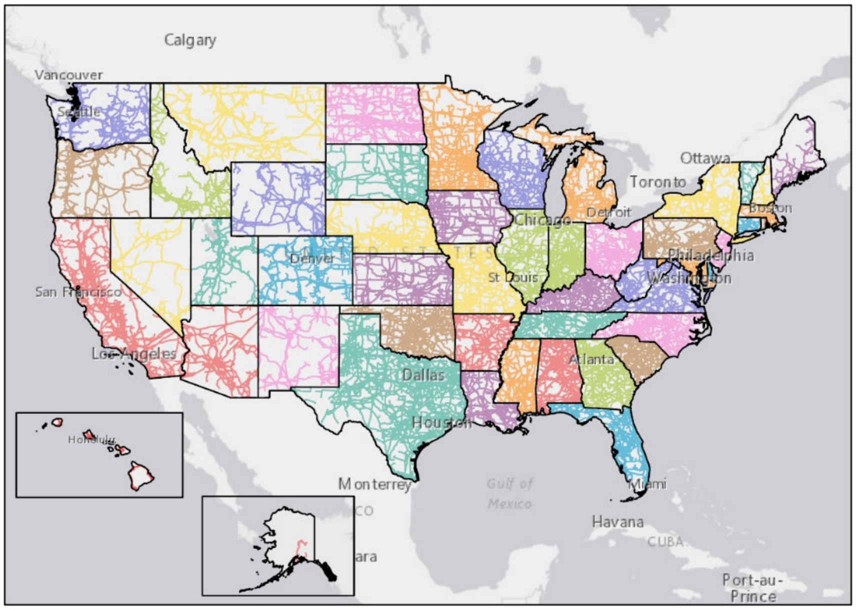
Time Series Range	Summary of Method
2011–2021	• For all GHGRP reporters that had transmission miles in only one state (according to RY 2017–RY 2021 reports, excluding California), their facility-reported emissions and transmission miles were allocated to that state. (Approach 1). • For GHGRP reporters that had transmission miles in multiple states and had a reasonable match, for at least one year, between the states and total transmission miles reported to the GHGRP and by HIFLD, facility-reported emissions and transmission miles were allocated to each state in which their facility lies by the percentage of their transmission miles in each state according to HIFLD for the year with a reasonable match and each following year (Approach 2). • Emissions for California were obtained from the CARB California High GWP Gases Inventory for 2000–2021 (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 divided by adjusted national transmission miles). These state percentages were then applied to the adjusted national emissions estimate (i.e., national emissions excluding GHGRP single-state emissions, and emissions from matched multi-state facilities and California emissions). State transmission miles were obtained from HIFLD data (2021) and scaled using the transmission mile growth rate from UDI data sets (Approach 2).
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 (2021) for all states. State percentages of the total transmission were held constant at the 2021 percentage for all states (Approach 2).

For disaggregating national electrical transmission and distribution 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 national *Inventory* for the entire time series. U.S. transmission miles were obtained from EIA.

Specifically, EIA has published on their U.S. Energy Mapping System web map[36] the electric transmission lines data from HIFLD (U.S. Department of Homeland Security 2021), which were obtained in October 2022. The data set 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.[37]

The fraction of transmission miles greater than 34.5 kV in each state was calculated using geographic information system (GIS) mapping. Figure 3-1 below 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.

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



Source: U.S. 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.

For 2011–2020, 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 2011–2020 (CARB 2020). 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, 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.

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

[37] Transmission miles greater than 34.5 kv in 2021 totaled 753,522 miles based on the HIFLD data set and 737,960 miles based on the UDI data set and GHGRP-reported transmission mileage. Despite the discrepancy, HIFLD data provide the closest match of total miles compared to other data sets previously examined, which provides reasonable confidence for using the percentage breakdown by state that can be obtained using GIS mapping.

For 2011–2021, for all GHGRP reporters that had transmission miles in only one state (according to RYs 2017–2021 reports), their facility-reported emissions and transmission miles were allocated to that state. Approximately 65% of reporting facilities had transmission miles in only one state during RYs 2017–2021. On average, these facilities constituted approximately 14% of the national emissions between 2011–2021. Emissions from GHGRP reporters that had transmission miles in multiple states were allocated to the states reported by percentage of transmission miles in each state according to HIFLD if the GHGRP facility could be cross-walked to the HIFLD data by state and total transmission miles. Approximately 13% of reporting facilities had transmission miles in multiple states during RYs 2017–2021 and were successfully cross-walked and matched to the HIFLD data. On average, these facilities constituted an additional 21% of the national emissions between RYs 2017–2021.

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.[38] The sum of GHGRP-reported transmission miles in only one state and the cross-walked multi-state facilities was also deducted from the total national transmission miles. Because the HIFLD data represent 2021 transmission miles, transmission mileage was scaled down using UDI's transmission mile growth rate for 2011–2021 (UDI 2017, 2013, 2010).

Total facility-reported emissions for cases where a facility's transmission miles are reported in only one state and for multi-state facilities that were cross-walked with the HIFLD data were summed and subtracted from the national emissions estimate.[39] To allocate the remaining national emissions by state, the percentage of 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 were 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 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 EPA can help account for any state-influenced actions (e.g., climate action planning at state and local levels).

Total emissions from 1990–1999 were disaggregated using the percentage breakdown of transmission miles by state from the HIFLD data.

3.4.3.3 Methods/Approach (Manufacture of Electrical Equipment)

Emissions were reported by facility for 2011–2021. 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, EPA used Approach 2 and assumed that all non-reporting facilities are located in the same states as reporting facilities. EPA estimates that GHGRP reporters represent about 50% of all

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[38] 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.

[39] The national emissions estimate was adjusted by deducting California's CARB-reported emissions.

original equipment manufacturer 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 (RYs 2011–2021) was applied to emissions in each year to calculate state emissions from original equipment manufacturers before 2011. The methods used are summarized in Table 3-20.

Additional research is required to understand (1) if EPA's assumption about the portion of original equipment manufacturer emissions covered is accurate and (2) in what states these non-reporting 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
2011–2021	• Emissions reported to the GHGRP were allocated based on reported facility locations (Approach 1). Non-reporters were assumed to be located in the same states with emissions allocated at the same state percentage of the total non-reporting emissions as for the emissions reported to the GHGRP (Approach 2).
1990–2010	• Emissions from the national *Inventory* were allocated to states by applying the average percentage state breakdown across the GHGRP RYs (2011–2020) to national estimates for each year between 1990–2010 in the national *Inventory* (Approach 2).

3.4.3.4 Uncertainty

The overall uncertainty associated with the national *Inventory* of SF_6 emissions from the 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%/+10% and GHGRP reporter emissions uncertainty was estimated to be −10%/+10%. As described further in Chapter 4 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 of the source category were −23%/+24%.

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 data sets and methodologies improves.

3.4.3.5 Recalculations

No recalculations were applied to the state disaggregation method for this current report. Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 4.25 of the national *Inventory* (page 4-148), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

3.4.3.6 Planned Improvements

EPA plans to incorporate facility-specific reported data from the SF_6 Emission Reduction Partnership into the national *Inventory* for 1999–2010 based on historical emissions estimates collected under EPA's SF_6 Emission

Reduction Partnership for Electric Power Systems. 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 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 and/or Emission Reduction Partnership data). Additional research into regional or state-level trends will also be conducted to refine the estimates where possible. EPA also plans to incorporate estimates for additional U.S. territories, including 1990–2022 emissions estimates for Guam.

Additional research into state distribution of original equipment manufacturers will also be conducted to confirm or revise the 50% assumption of non-reported emissions and understand the states in which these emissions take place for non-reporters.

3.4.3.7 References

CARB (California Air Resources Board) (2007). *Sulfur Hexafluoride (SF_6) Emission Reductions from Gas Insulated Switchgear Chapter 10, Sections 95350 to 95359, Title 17*.

CARB (2020) *California Greenhouse Gas Inventory for 2000-2020-by Gas*. Available at https://ww2.arb.ca.gov/sites/default/files/classic/cc/inventory/ghg_inventory_bygas.pdf.

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

UDI (2010) *2010 UDI Directory of Electric Power Producers and Distributors, 118th Edition*. Platts.

UDI (2013) *2013 UDI Directory of Electric Power Producers and Distributors,121st Edition*. Platts.

UDI (2017) *2017 UDI Directory of Electric Power Producers and Distributors,125th Edition*. Platts.

U.S. Department of Homeland Security (2019) *Homeland Infrastructure Foundation-Level Data (HIFLD)*. Accessed March 2021. Available online at: https://hifld-geoplatform.opendata.arcgis.com/datasets/electric-power-transmission-lines.

U.S. Department of Homeland Security (2020) *Homeland Infrastructure Foundation-Level Data (HIFLD).* Accessed October 2021. Available online at: https://hifld-geoplatform.opendata.arcgis.com/datasets/electric-power-transmission-lines/explore?showTable=true.

U.S. Department of Homeland Security (2021) *Homeland Infrastructure Foundation-Level Data (HIFLD): Transmission Lines*. Accessed October 2022. Available online at: https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::transmission-lines/about.

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; 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, the District of Columbia, and U.S. territories in 2021.

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 to this report. See Appendix I, Table I-1 in the "N_2O 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 (e.g., fuel oxidant in auto racing, oxidizing agent in blowtorches) were calculated using the same methodology in the national *Inventory* to calculate national emissions (EPA 2023). 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 U.S. territories (including Puerto Rico, American Samoa, Guam, the Northern Mariana Islands, and the U.S. Virgin Islands) using U.S. population statistics as a surrogate for state-specific N_2O usage (U.S. Census Bureau 2002, 2011, 2021a, 2021b, 2022; Instituto de Estadísticas de Puerto Rico 2021). For each year in the 1990–2021 time series, the fraction of the total U.S. population in each state, as well as the District of Columbia and U.S. territories, 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 the 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. Using 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 2021 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 2023), levels of uncertainty in the national estimates in 2021 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. Using 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. Using 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 Recalculations

For the current Inventory, CO_2 equivalent estimates of total N_2O emissions from N_2O product uses have been revised to reflect the 100-year GWPs provided in the AR5 (IPCC 2013). AR5 GWP values differ slightly from those presented in the AR4 (IPCC 2007), which was used in the previous inventories. The AR5 GWPs have been applied across the entire time series for consistency. The GWP of N_2O decreased from 298 to 265, leading to an overall decrease in estimates for calculated CO_2 equivalent N_2O emissions. Compared to the previous national *Inventory*, which applied 100-year GWP values from AR4, annual calculated CO_2 equivalent N_2O emissions decreased by 11% each year, ranging from a decrease of 430 kt CO_2 equivalent in 1992 to 519 kt CO_2 equivalent for 1997–2001.

Additional recalculations were performed for the 2020 time series as updated population data were made available from the U.S. Census Bureau. The updated population data had a negligible impact on the emissions estimated for the 50 states, the District of Columbia, and Puerto Rico due to the low emissions estimated for each state or territory for the sector.

3.4.4.5 Planned Improvements

EPA recently initiated an evaluation of alternative production statistics for cross-verification and updating time series activity data, emission factors, assumptions, and more, and a reassessment of N_2O product use subcategories that accurately represent trends. This evaluation includes conducting a literature review of publications and research that may provide additional details on the industry. This work remains ongoing, and thus far no additional data sources have been found to update this category.

Pending additional resources and planned improvement prioritization, EPA may also evaluate production and use cycles, and potentially need to incorporate a time lag between production and ultimate product use and resulting release of N_2O. Additionally, planned improvements include considering imports and exports of N_2O for product uses.

Finally, for future inventories, EPA will examine data from the GHGRP to improve the emission estimates for the N_2O product use subcategory. Particular attention will be made to ensure aggregated information can be published without disclosing CBI and time series consistency, as the facility-level reporting data from EPA's GHGRP are not available for all inventory years as required in this state-level inventory. This is a lower priority improvement, and EPA is still assessing the possibility of incorporating aggregated GHGRP CBI data to estimate emissions; therefore, this planned improvement is still in development and not incorporated in the current Inventory report.

3.4.4.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Instituto de Estadísticas de Puerto Rico (2021) *Estimados Anuales Poblacionales de los Municipios Desde 1950.* Accessed February 2021. Available online at: https://censo.estadisticas.pr/EstimadosPoblacionales.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.). Cambridge University Press.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

U.S. Census Bureau (2002) *Time Series of Intercensal State Population Estimates: April 1, 1990 to April 1, 2000*. Table CO-EST2001-12-00. Release date: April 11, 2002. Available online at: https://www2.census.gov/programs-surveys/popest/tables/1990-2000/intercensal/st-co/co-est2001-12-00.pdf.

U.S. Census Bureau (2011) *Intercensal Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2010.* Table ST-EST00INT-01. Release date: September 2011. Available online at: https://www2.census.gov/programs-surveys/popest/datasets/2000-2010/intercensal/state/st-est00int-alldata.csv.

U.S. Census Bureau (2021a) *Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2019; April 1, 2020; and July 1, 2020*. Table NST-EST2020. Release date: July 2021.

U.S. Census Bureau (2021b) *Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2020 to July 1, 2021.* Table NST-EST2021-POP. Release date: December 2021.

U.S. Census Bureau (2022) *International Database: World Population Estimates and Projections.* Accessed November 23, 2022. Available online at: https://www.census.gov/programs-surveys/international-programs/about/idb.html.

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,* available online at: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-5-Agriculture.pdf. 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 [a]
Enteric Fermentation	CH_4	Approach 1	Includes emissions from all states and tribal lands.[a]
Manure Management	CH_4, N_2O	Approach 1	Includes emissions from all states and tribal lands.[a]
Agricultural Soil Management	N_2O	Hybrid (see Section 4.2.2.2, Methods/Approach)	Includes emissions from all states, the District of Columbia, tribal lands and territories.[a] Some components of Alaska and Hawaii were not estimated.
Rice Cultivation	CH_4	Hybrid: • 1990–2015: Approach 1 • 2016–2021: Approach 2	Includes emissions from all 13 states (and tribal lands) cultivating rice.[a]
Liming	CO_2	Hybrid: • 1990–2018: Approach 1 • 2019–2021: Approach 2	Includes emissions from all states (and tribal lands) for which USGS (through Minerals Yearbook and the Mineral Industry Survey) reports limestone and dolomite consumption for agriculture in current and historical yearbooks and surveys.[a]
Urea	CO_2	Approach 1	Includes emissions from all states and territories[a] (i.e., Puerto Rico) were estimated.
Field Burning of Agricultural Residues	CH_4, N_2O	Hybrid: • 1990–2014: Approach 1 • 2015–2021: Approach 2	Includes emissions from all states except Alaska and Hawaii.[a]

[a] Emissions are likely occurring in other U.S. 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 discussions across Chapter 5 of the national *Inventory*. Includes Tribal areas in the conterminous United States. .

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 that reside 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 byproduct, 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

EPA compiles state-level CH_4 emissions from enteric fermentation using the same methods applied in the national *Inventory*. 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
1990–2020	• Cattle: IPCC Tier 2 (Cattle Enteric Fermentation Model model) • Noncattle: IPCC Tier 1 (population × default emissions factor)
2021	• Simplified approach, consistent with Section 5.1 of the national *Inventory*

Please refer to Section 5.1 and Annex 3.10 the national *Inventory* on enteric fermentation for details on the methods applied to estimate state-level emissions for the years 1990–2021 (EPA 2023). Below is a summary:

- For cattle, the Cattle Enteric Fermentation Model (CEFM) was used to estimate CH_4 emissions using the IPCC Tier 2 method. The CEFM utilizes the IPCC Tier 2 method and also other analyses of cattle population, feeding practices, diet data, and production characteristics.
- 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).
- Data Appendix E-1 to this report provides state-level noncattle livestock population numbers for all inventory years. These population data serve as the activity data that are multiplied by default IPCC emission factors to estimate CH_4 emissions from enteric fermentation. The 2021 populations are estimated using a simplified method based on national level data in order to complete the time series.
- Data Appendix E-2 to this report provides state-level cattle population numbers disaggregated by animal type for all inventory years.
- To allow for greater exploration of the underlying data that support cattle enteric fermentation emissions estimates, state-level implied emission factors for all cattle types across the time series are provided in Data Appendix E-3 to this report. These implied emission factors are calculated post-hoc from the CEFM output where emissions estimates are modeled based on data inputs regarding livestock populations, diet attributes, feeding practices, and production characteristics. The resulting enteric fermentation emissions estimates were divided by cattle population numbers to calculate the implied emission factor that describes average CH_4 produced per head of cattle in each state in a given year.

4.1.1.3 Uncertainty

The overall uncertainty associated with the 2021 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* (EPA 2023), levels of uncertainty in the national estimates in 2021 were −11%/+18% for

CH_4. 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 pasture land. 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*.

4.1.1.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 5.1 of the national *Inventory* (page 5-10), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well. In particular, consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous national *Inventory* used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

4.1.1.5 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 that 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.

4.1.1.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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Full citations of references included in Chapter 5.1 (Enteric Fermentation) and Annex 3.10 of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Annex-3-Additional-Source-or-Sink-Categories-Part-B.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 N_2O 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 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

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 N_2O Across Time Series

Time Series Range	Method
1990–2020	• Combination of IPCC Tier 1 and 2 approaches as described in the national *Inventory.*
2021	• Simplified approach, consistent with Section 5.2 of the national *Inventory.*

For 1990–2021, 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 2023). As noted in that section, the basic approach applies a combination of IPCC Tier 1 and Tier 2 methodologies. EPA applies Tier 1 default N_2O emissions factors and CH_4 conversion factors for dry systems from the IPCC (2006), U.S.-specific CH_4 conversion factors 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 Section 4.1.1 Enteric Fermentation).

4.1.2.3 Uncertainty

The overall uncertainty associated with the 2021 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 2023), levels of uncertainty in the national estimates in 2021 were −18%/+20% for CH_4 and −16%/+24% for N_2O. 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 are 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* (EPA 2023).

4.1.2.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 5.2 of the national *Inventory* (page 5-20), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well. In particular, consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) and N_2O (from 298 to 265) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous Inventory used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

4.1.2.5 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 that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.1.2.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Full citations of references included in Chapter 5.2 (Manure Management) and Annex 3.11 of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Annex-3-Additional-Source-or-Sink-Categories-Part-B.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

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 5.3 (pages 5-21 through 5-28), of the national *Inventory*. Additional information on the methodologies and data is also provided in Annex 3.12.

As described in the national *Inventory*, the methodology used to estimate CH_4 emissions from rice cultivation is based on a combination of IPCC Tier 1 and 3 approaches. The IPCC Tier 3 method utilizes the DayCent process-based model to estimate CH_4 emissions from rice cultivation. DayCent is used to simulate hydrological conditions and thermal regimes, organic matter decomposition, root exudation, rice plant growth and its influence on oxidation of CH_4, as well as CH_4 transport through the plant and via ebullition (Cheng et al. 2013). This method captures the influence of organic amendments and rice straw management on methanogenesis in the flooded soils, and ratooning of rice crops with a second harvest during the growing season. In addition to CH_4 emissions, DayCent simulates soil carbon stock changes and N_2O emissions and allows for a seamless set of simulations for crop rotations that include both rice and non-rice crops (EPA 2023).

The IPCC Tier 1 method is applied to estimate CH_4 emissions from rice when grown in rotation with crops that are not simulated by DayCent, such as vegetable crops. The Tier 1 method is also used for areas converted between agriculture (i.e., cropland and grassland) and other land uses such as forest land, wetland, and settlements. In addition, the Tier 1 method is used to estimate CH_4 emissions from organic soils (i.e., Histosols) and from areas with very gravelly, cobbly, or shaley soils (greater than 35% by volume). The Tier 3 method using DayCent has not been fully tested for estimating emissions associated with these conditions (EPA 2023). 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). Within the national *Inventory*, EPA does not currently directly estimate state-level emissions from rice cultivation for the years 2016–2021 because the National Resources Inventory (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 2016–2021 are estimated using a surrogate data method. For this report, the national totals for 2016–2021 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 three years for which state-level emissions have been estimated. Second, the state-level proportions were multiplied by the total national emissions to approximate the emissions occurring in each state from 2016–2021. Data Appendix E-4 to this report lists the total rice cultivated areas of each of the 13 states that host rice cultivation across the 1990–2015 time period. State-level rice cultivated areas are disaggregated to show the land area in each state for which the Tier 3 and Tier 1 methods were used to estimate CH_4 emissions from rice cultivation. State-level total rice harvested areas, which account for land area on which a second rice crop is harvested, are also provided in Data Appendix E-4 to this report.

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* (EPA 2023), sources of uncertainty include incomplete information on management practices, uncertainties in model structure (i.e., algorithms and parameterization), emissions factors, and variance associated with the NRI sample. Levels of uncertainty in the national CH_4 rice cultivation estimates in 2021 were −48%/+48% of total emissions estimated using the Tier 1 method and −90%/+90% of total emissions estimated using the Tier 3 method, with a combined uncertainty of −75%/+75% of national CH_4 emissions from rice cultivation. Uncertainty will be greater for the years 2016–2021, where a surrogate data method is used to extend the time series past the period over which NRI data and direct emissions estimates are available.

4.2.1.4 Recalculations

Consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous national *Inventory* used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

4.2.1.5 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 that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.2.1.6 References

Cheng, K., S.M. Ogle, W.J. Parton, and G. Pan (2013) Predicting Methanogenesis from Rice Paddies Using the DAYCENT Ecosystem Model. *Ecological Modelling*, 261–262(Suppl.): 19–31. https://doi.org/10.1016/j.ecolmodel.2013.04.003.

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Full citations of references included in Chapter 5.3 (Rice Cultivation) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-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

N_2O is naturally produced in soils through the microbial processes of nitrification and denitrification that are driven by the availability of mineral nitrogen. Mineral nitrogen is made available in soils through decomposition of soil organic matter and plant litter, asymbiotic fixation of nitrogen from the atmosphere, and agricultural management practices, which are discussed below.

Several agricultural activities increase mineral nitrogen availability in soils that lead to direct N_2O emissions at the site of a management activity. These activities include synthetic nitrogen 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 (nitrogen-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 nitrogen mineralization from soil organic matter and plant litter in addition to levels of asymbiotic nitrogen fixation.

Indirect emissions of N_2O occur when nitrogen 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 nitrogen and (2) surface runoff and leaching of applied/mineralized nitrogen into groundwater and surface water.

4.2.2.2 Methods/Approach

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 5-28 through 5-48), of the national *Inventory.*

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*. Estimates of N_2O emissions from managed croplands and grasslands are not available for Alaska and Hawaii except for managed manure nitrogen, PRP nitrogen, and biosolid additions for Alaska and managed manure and PRP nitrogen, biosolid additions, and crop residue for Hawaii.

Additional information on methodologies and data is also provided in Annex 3.12 of the national *Inventory.*

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* (EPA 2023). 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 (nitrogen volatilized and leached or runoff) simulated by DayCent, (3) direct emissions estimated with the IPCC Tier 1 method, (4) the components of indirect emissions (nitrogen 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 emissions estimates in 2021 were −35%/+72% of the emissions estimate for direct N_2O and −60%/+131% of the emissions estimate for indirect N_2O across all methodologies at the national scale.

4.2.2.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 5.4 of the national *Inventory* (page 5-47), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well. These improvements included (1) incorporating new USDA-NRCS NRI data through 2017; (2) extending the time series for crop histories through 2020 using USDA-NASS CDL data; (3) incorporating USDA-NRCS CEAP survey data for 2013–2016; (4) incorporating cover crop and tillage management information from the OpTIS remote-sensing data product from 2008–2020; (5) modifying the statistical imputation method for the management activity data associated with tillage practices, mineral fertilization, manure amendments, cover crop management, and planting and harvest dates using gradient boosting instead of an artificial neural network; (6) updating time series of synthetic nitrogen fertilizer sales data, PRP nitrogen, and manure nitrogen available for application to soils; (7) constraining synthetic nitrogen fertilization and manure nitrogen applications in the Tier 3 method at the state scale rather than the national scale; (8) recalibrating the soil carbon module in the DayCent model using Bayesian methods; and (9) applying GWP values from the AR5 (IPCC 2013). Consistent with the national *Inventory*, the updated GWP for calculating CO2 equivalent emissions of N_2O (updated from 298 to 265) reflects the 100-year GWPs provided in the AR5. The previous national *Inventory* used 100-year GWPs provided in the AR4. This update was applied across the entire time series.

4.2.2.5 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 that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.2.2.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Full citations of references included in Chapter 5.4 (Agricultural Soil Management) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-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 (calcium carbonate) and dolomite ($CaMg[CO_3]_2$) are added to soils by land managers to increase soil pH (i.e., to reduce acidification). CO_2 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) are reported under the IPPU chapter.

4.2.3.2 Methods/Approach

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 5-486 through 5-51), of the national *Inventory*.

The current national *Inventory* includes state-level emissions for the years 1990–2018. For this report, a hybrid Approach 1 and Approach 2 was used to extend state-level estimates across the time series. The national estimates for 2019–2021, which were estimated using a linear extrapolation method, are 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 all 50 states as well as the District of Columbia.

Within the national activity data that leverage statistics on the application rates of crushed limestone and dolomite for agricultural purposes, a portion of total limestone and dolomite applied nationally are "withheld" and not allocated to specific states to avoid the disclosure of company proprietary data related to poultry grit and mineral food. In order to allocate this withheld pool of limestone and dolomite to states so that the sum of all limestone and dolomite applied to all states and the District of Columbia, the withheld pools of limestone and dolomite were allocated to states relative to the proportion of total limestone/dolomite consumed by each state.

Data Appendix E-5 to this report provides state-level limestone and dolomite agricultural application rates for all 50 states as well as the District of Columbia across the time series. Separate tables are provided where withheld pools of limestone and dolomite are retained as discrete categories and where the withheld pools of limestone and dolomite are allocated to states using the assumptions and methodology described above.

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* (EPA 2023). A Monte Carlo uncertainty analysis was applied, and the analysis was performed on the amount of limestone and dolomite applied to soils. The emissions factors included the fraction of lime dissolved by nitric acid versus the fraction that reacts with carbonic acid, as well as 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 2020 was −85%/+94% of national emissions estimates.

4.2.3.4 Recalculations

Limestone and dolomite application data for 2018–2020 were updated with the recently acquired data from U.S. Geological Survey, rather than approximated by a ratio method, which was used in the previous national

Inventory. There were also corrections to the national data estimates of total stone sold or used (both limestone and dolomite) based on a QC check. Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 5.5 of the national *Inventory* (page 5-51), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.2.3.5 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 that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.2.3.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Full citations of references included in Chapter 5.5 (Liming) of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

4.2.4 Urea Fertilization (NIR Section 5.6)

4.2.4.1 Background

The use of urea, or $CO(NH_2)_2$, as a fertilizer leads to GHG 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, hydroxyl ion, and bicarbonate. The bicarbonate then evolves into CO_2 and water.

4.2.4.2 Methods/Approach

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. This approach is described in Chapter 5, Section 5.6 (pages 5-51 through 5-53), of the national *Inventory*. Estimates are currently available for all 50 states and Puerto Rico. Data Appendix E-6 to this report provides seasonal and annual urea fertilizer consumption data by state across the time series, which serve as the underlying activity data used to calculate state-level CO_2 emissions from urea application.

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* (EPA 2023). A Monte Carlo uncertainty analysis was applied. The largest source of uncertainty is the default emissions factor, which assumes that 100% of the carbon 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 2020 was −43%/+3%.

4.2.4.4 Recalculations

No recalculations were applied to the state disaggregation method for this current report. Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 5.6 of the national *Inventory* (page 5-53), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.2.4.5 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 that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.2.4.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Full citations of references included in Chapter 5.6 (Urea Fertilization) of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-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 carbon 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, carbon monoxide, and nitrogen oxide, 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

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 5-53 through 5-62), of the national *Inventory.*

The most recent national *Inventory* includes state-level emissions for 1990–2014, but not for 2015–2021. State estimates were developed using Approach 1 for 1990–2014 and Approach 2 for disaggregating 2015–2021 national estimates. National-level emissions for 2015–2021 are estimated using a linear extrapolation of the pattern from the previous years in the national *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 three 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 2015–2021. 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. See Data Appendix E-7 to this report for the underlying state-level activity data detailing the mass of residue burned and the agricultural area burned by crop type from 1990–2014.

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* (EPA 2023). As described in the national *Inventory*, emissions are estimated using a linear regression model with autoregressive moving-average errors for the 2015–2021 period. The linear regression autoregressive moving-average 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. EPA is aware that some agricultural residue burning is not currently captured in the national *Inventory* analysis; please see national *Inventory* planned improvements information. Overall levels of uncertainty in the national CH_4 and N_2O field burning of agricultural residue estimates in 2020 were −16%/+16% for CH_4 and −19%/+19% for N_2O.

4.2.5.4 Recalculations

Consistent with the national *Inventory*, EPA updated GWP values for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) and N_2O (from 298 to 265) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous Inventory used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

4.2.5.5 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 that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

4.2.5.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Full citations of references included in Chapter 5.7 (Field Burning of Agricultural Residues) of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-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).[40] More information on national-level emissions and removals and associated methods is available in Chapter 6 of the national *Inventory,* available online at: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-6-Land-Use-Land-Use-Change-and-Forestry.pdf. Table 5-1 summarizes the different approaches used to estimate state-level LULUCF emissions and sinks completeness. State completeness is consistent with the national *Inventory*. The sections below provide more detail on each category.

See also Chapter 6.1 in the national *Inventory* 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 these data.

Table 5-1. Overview of Approaches for Estimating State-Level LULUCF Sector GHG Emissions and Sinks

Category	Gas	Approach	Geographic Completeness [a]
Forest Land Remaining Forest Land and Lands Converted to Forest Land	Carbon, CH_4, N_2O	Approach 1	Includes estimates from all states (except Hawaii) and tribal lands.[a] 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 • 2016–2021: Approach 2	Includes estimates from all states (except Alaska) and tribal lands.[a]
Grassland and Lands Converted to Grassland			
C Stock Changes	Carbon	Hybrid: • 1990–2015: Approach 1 • 2016–2021: Approach 2	Includes estimates from all states (except Alaska) and tribal lands.[a]
Non-CO_2 Emissions from Grassland Fires	CH_4, N_2O	Hybrid: • 1990–2014: Approach 1 • 2015–2021: Approach 2	Includes estimates from all states (except Alaska) and tribal lands. [a]
Wetlands and Lands Converted to Wetlands			
Coastal Wetlands	Carbon, CH_4	Approach 1	Includes estimates from all states, the District of Columbia, and tribal lands with coastal wetlands (except Alaska and Hawaii).[a]
Peatlands	CO_2, CH_4, N_2O	Approach 2	Includes estimates from all states (except Hawaii) and tribal lands.[a]
Flooded Lands	CO_2, CH_4	Approach 1	Includes estimates from all states, the District of Columbia,

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[40] U.S. Forest Service develops state-level estimates for the forest land as part of their *U.S. Forest Service 2023 Resource Bulletin* (published online at https://doi.org/10.2737/WO-RB-101), including the underlying state-level data.

Category	Gas	Approach	Geographic Completeness [a]
			tribal lands and territories (i.e., Puerto Rico), .[a]
Settlements and Land Converted to Settlements			
Soil Carbon	Carbon	Hybrid: • 1990–2015: Approach 1 • 2016–2021: Approach 2	Includes estimates from all states (except Alaska) and tribal lands.[a]
Settlement Trees	Carbon	Hybrid: • 1990–2015: Approach 1 • 2016–2021: Approach 2	Includes estimates from all states,the District of Columbia, and tribal lands.[a]
Soil N_2O	N_2O	Hybrid: • 1990–2015: Approach 1 • 2016–2021: Approach 2	Estimates from all states (except Alaska) and tribal lands.[a]
Landfilled Yard Trimmings and Food Scrap	Carbon	Approach 2	Estimates from all states, the District of Columbia, tribal lands and territories (i.e., Puerto Rico).[a]

[a] Emissions are likely occurring in other U.S. 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. Tribal Lands are included for estimates within the Conterminous U.S. See planned improvements of the national *Inventory*.

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, disturbances such as fires or pest outbreaks) and anthropogenic activities (e.g., harvesting, thinning, 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, carbon monoxide, and nitrogen oxide when the wood product combusts. Emissions of non-CO_2 gases from forest fires, both wild and prescribed, also occur, along with N_2O emissions from nitrogen additions to the soil and CO_2, CH_4, and N_2O emissions from drained organic soils.

5.1.1.2 Methods/Approach

To compile national estimates for the national *Inventory* of C stock changes from forest ecosystem carbon pools on forest land remaining forest land, as well as non-CO_2 emissions from fires and non-CO_2 emissions from drained organic soils on forest land remaining forest land and land converted to forest land, estimates for each state were produced and summed into a national total. This is described in Chapter 6, Section 6.2 (pages 6-25 through 6-48), of the national *Inventory*. Additional information on the methodologies and data is also provided in Annex 3.13.

Please note Hawaii is not included in the national total or available at the state level at this time. Emissions of non-CO_2 gases from forest fires and non-CO_2 emissions from drained organic soils 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 C stock change in harvested wood are not currently available at the state level. Work is underway to develop an 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 C 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 for 2021 for the C stock changes in forest ecosystem carbon storage pools and non-CO_2 gases from forest fires are provided in the USFS 2023 Resource Bulletin (Domke et al. 2023). Uncertainty analyses for the subcategories are:

- **C stock changes in forest ecosystem carbon storage pools.** The overall uncertainty associated with the 2021 national estimate of C 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 the IPCC Approach 1 (IPCC 2006). As described further in Chapter 6.2 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 were −12.3%/+12.3%. State-level estimates of uncertainty vary significantly among the states but, in general, tend to be higher 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 the state level. The potential for unique circumstances occurring within a state can 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 2021 national estimate of non-CO_2 gases from forest fires was calculated through a Monte Carlo sampling approach, per IPCC Approach 2 (IPCC 2006), employed to propagate uncertainty based on the model and data applied for U.S. forest land. As shown in Chapter 6 of the national *Inventory*, levels of uncertainty in the national estimates in 2021 were −32%/+32% for CH_4 and −71%/+72% for N_2O. State-level estimates of uncertainty vary significantly among the states but, in general, tend to be higher 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 the state level. The potential for unique circumstances occurring within a state can 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 2021 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 2021 were −69%/+82% for CH_4 and −118%/+132% N_2O. State-level estimates of uncertainty vary significantly among the states but, in general, tend to be higher 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.*

5.1.1.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.2 of the national *Inventory* (pages 6-38 through 6-39, 6-42, 6-45, and 6-48), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well. In particular, EPA new National Forest Inventory data in most states were incorporated in the latest Inventory.

EPA updated GWPs for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) and N_2O (from 298 to 265) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous Inventory used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.1.5 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 pages 6-39 through 6-40, 6-42, and 6-48 of Chapter 6.2 in the national *Inventory* for a description of future work to improve these estimates. In addition, as noted by the USFS 2023 Resource Bulletin (Domke et al. 2023), investments are being made to leverage existing state-level forest products information to allow for the disaggregation of harvested wood product estimates at the state level in the future.

5.1.1.6 References

Domke, G.M., B.F. Walters, C.L. Giebink, E.J. Greenfield, J.E. Smith, M.C. Nichols, J.A. Knott, S.M. Ogle, J.W. Coulston, and J. Steller (2023) *Greenhouse Gas Emissions and Removals from Forest Land, Woodlands, Urban Trees, and Harvested Wood Products in the United States, 1990–2021*. Resource Bulletin WO-101. U.S. Department of Agriculture. https://doi.org/10.2737/WO-RB-101.

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Full citations of all references included in Chapter 6.2 (Forest Land Remaining Forest Land) of the national *Inventory* are found in Chapter 10 (References) and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-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 C stock changes to all forest ecosystem carbon pools (i.e., aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon). Section 5.1.2 provides estimates of C stock changes resulting from conversion of cropland, grassland, wetlands, settlements, and other lands to forest land (Domke et al. 2023).

5.1.2.2 Methods/Approach

The methods applied for estimating C 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 6-49 through 6-56), of the national *Inventory*. 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 C stock changes from land conversion in Alaska are currently included in the forest land remaining forest land chapter because there are insufficient data to separate the changes at this time.

5.1.2.3 Uncertainty

The overall uncertainty associated with the 2021 national estimate of the C stock changes in forest ecosystem carbon storage pools for land converted to forest land is described in Chapter 6.3 of the national *Inventory* (EPA 2023). 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 2021 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 be higher 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 the state level, the potential for unique circumstances occurring within a state can 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 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.3 of the national *Inventory* (page 6-55 through 6-56), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

5.1.2.5 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 6-56 of Chapter 6.3 in the national *Inventory*.

5.1.2.6 References

Domke, G.M., B.F. Walters, C.L. Giebink, E.J. Greenfield, J.E. Smith, M.C. Nichols, J.A. Knott, S.M. Ogle, J.W. Coulston, and J. Steller (2023) Greenhouse Gas Emissions and Removals from Forest Land, Woodlands, Urban Trees, and Harvested Wood Products in the United States, 1990–2021. Resource Bulletin WO-101. U.S. Department of Agriculture. https://doi.org/10.2737/WO-RB-101.

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

Full citations of references included in Chapter 6.3 (Land Converted to Forest Land) of the national *Inventory* are found in Chapter 10 (References) and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-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, 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 C 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 results in a net C 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 Database 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), and cropland that has been enrolled in the Conservation Reserve Program (i.e., considered set-aside cropland).

5.1.3.2 Methods/Approach

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 6-56 through 6-68), of the national *Inventory*. 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 carbon 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 2016–2021. Estimates are included for all states except Alaska.

Additional information on methodologies and data is also provided in Annex 3.12 of the national *Inventory*, .

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* (EPA 2023) 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 carbon stocks in cropland remaining cropland in 2021 is −406%/+406%.

5.1.3.4 Recalculations

No recalculations were applied for this current report, consistent with the national *Inventory* (see Section 6.4, page 6-67).

5.1.3.5 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 6-67 and 6-68 of Chapter 6.4 in the national *Inventory*.

5.1.3.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

Full citations of references included in Chapter 6.4 (Cropland Remaining Cropland) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-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 carbon to the atmosphere, particularly conversions from forest land. Moreover, conversion of forests 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 (1) had been in at least one other land use during the previous 20 years and (2) is used to produce food, 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

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 6-68 through 6-75), of the national *Inventory*. For this report, estimates were developed using a hybrid of Approach 1 and Approach 2. The current national *Inventory* includes state-level fluxes for the years 1990–2021 for biomass, standing dead, dead wood, and litter and for the years 1990–2015 for soil organic carbon stock changes. The remaining years in the time series for soil organic carbon 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 2016–2021. Estimates are included for all states except Alaska.

Additional information on methodologies and data is also provided in Annex 3.12 of the national *Inventory*.

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* (EPA 2023) and in further detail 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 the cropland remaining cropland analysis. The combined uncertainty for total carbon stocks in land converted to cropland in 2021 was −94%/+94%.

5.1.4.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.5 of the national *Inventory* (page 6-74), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

5.1.4.5 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 page 6-75 of Chapter 6.5 in the national *Inventory*.

5.1.4.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

Full citations of references included in Chapter 6.5 (Land Converted to Cropland) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-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 on grasslands.

The 2006 IPCC Guidelines recommend reporting changes in biomass, dead organic matter, and soil organic C stocks with land use and management. C 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. These emissions do not currently include emissions from burning perennial biomass (a national *Inventory* planned improvement).

5.1.5.2 Methods/Approach

EPA compiles state-level emissions from grassland remaining grassland using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6.6 (pages 6-76 through 6-88) of the national *Inventory* 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 1990–2021 for biomass, standing dead, dead wood, and litter, as well s for the years 1990–2015 for soil organic carbon 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 2016–2021. Estimates are included for all states except Alaska.

Additional information on national *Inventory* methodologies and data is also provided in Annex 3.12 of the national *Inventory*.

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* (EPA 2023) and in further details in Annex 3.12. The uncertainty analyses for mineral soil organic carbon 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 autoregressive moving-average model to estimate the upper and lower bounds of the emissions estimate. The combined uncertainty for flux associated with C stock changes occurring in grassland remaining grassland in 2021 was −1,417%/+1,417%.

5.1.5.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.6 of the national *Inventory* (page 6-83), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

Consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) and N_2O (from 298 to 265) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous *Inventory* used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.5.5 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 6-83 and 6-84 of Chapter 6.6 in the national *Inventory.*

5.1.5.6 *References*

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Full citations of references included in Chapter 6.6 (Grassland Remaining Grassland) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-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 carbon to the atmosphere, particularly conversions from forest land. Moreover, conversion of forests 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 at least one other land use 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*

EPA compiles state-level emissions from land converted to grassland using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6, Section 6.7 (pages 6-88 through 6-96), of the national *Inventory*. 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 1990–2021 for biomass, standing dead, dead wood, and litter, and for the years 1990–2015 for soil organic carbon stock changes. The remaining years in the time series for soil organic carbon 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 2016–2021. Estimates are included for all states except Alaska.

Additional information on methodologies and data is also provided in Annex 3.12 of the national *Inventory*.

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* (EPA 2023) 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 carbon stocks in land converted to grassland in 2021 was −149%/+149 %.

5.1.6.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.7 of the national *Inventory* (page 6-95), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

5.1.6.5 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 6-95 and 6-96 of Chapter 6.7 in the national *Inventory*.

5.1.6.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

Full citations of references included in Chapter 6.7 (Land Converted to Grassland) and Annex 3.12 of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf and https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-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)
- Flooded land remaining flooded land (CH_4)

5.1.7.1 Coastal Wetlands Remaining Coastal Wetlands

5.1.7.1.1. 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 wetland 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 carbon stocks from seagrasses are not currently included in the national *Inventory* because of insufficient data on distribution, change through time, and carbon stocks or carbon 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:

- C stock changes and CH_4 emissions on vegetated coastal wetlands remaining vegetated coastal wetlands.
- C stock changes on vegetated coastal wetlands converted to unvegetated open water coastal wetlands.
- C stock changes on unvegetated open water coastal wetlands converted to vegetated coastal wetlands.

5.1.7.1.2. Methods/Approach

To compile national estimates of C 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 6-103 through 6-121).

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. Please note that estimates for Hawaii and Alaska are not included in the national total or available at the state level at this time.

5.1.7.1.3. 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:

- **C 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* (EPA 2023), levels of uncertainty in the national estimates in 2021 are −24.1%/+24.1% for biomass C stock change, −8.7%/+18.7% for soil C stock change, and −29.9%/+29.9% for CH_4 emissions. The combined uncertainty across all sub-sources is −37.0%/+37.0%, 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 parts per trillion. State-level estimates of uncertainty will vary significantly among the states but, in general, tend be higher 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*.
- **C 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 dead organic matter 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* (EPA 2023), levels of uncertainty in the national estimates in 2021 are −24.1%/+24.1% for biomass C stock change, −25.8%/+25.8% for dead organic matter C stock change, and −15%/+15% for soil C stock change. The

combined uncertainty across all sub-sources is −32%/+32%, which is primarily driven by the uncertainty in the soil C stock change estimates. State-level estimates of uncertainty will vary significantly among the states but, in general, tend to be higher 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*.

- **C 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 interpreting remote sensing data. Uncertainty specific to coastal wetlands includes differentiation of palustrine and estuarine community classes that determine 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* (EPA 2023), levels of uncertainty in the national estimates in 2021 are −20%/+20% for biomass C stock change, −25.8%/+25.8% dead organic matter C stock change, and −18.1%/+18.1% for soil C stock change. The combined uncertainty across all sub-sources is −33.8%/+33.8%. State-level estimates of uncertainty will vary significantly among the states but, in general, tend to be higher 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*.

5.1.7.1.4. Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.8 of the national *Inventory* (pages 6-110, 6-115, and 6-119), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

Consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous national *Inventory* used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.7.1.5. 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 pages 6-111, 6-115, and 6-119 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 national *Inventory* by state, EPA intends to include these data in future annual publications.

5.1.7.1.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Full citations of the references included in Chapter 6.8 (Wetlands Remaining Wetlands) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.7.2 Peatlands Remaining Peatlands

5.1.7.2.1. 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 peat production. 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 peatland to another use. Onsite and offsite emissions also result from managed peatlands. Onsite emissions from managed peatlands occur as the land is cleared of vegetation and the underlying peat is exposed to sun and weather. Offsite CO_2 emissions from managed peatlands occur from waterborne carbon losses and the horticultural and landscaping use of peat.

5.1.7.2.2. Methods/Approach

State-level estimates were compiled using Approach 2 and 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 Minerals Yearbooks from 1990–2020, 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. Hawaii and Puerto Rico are not estimated because peat production data were not available, and regional data provided in the USGS yearbooks did not include these states as peat producers.

For annual state-level peat production for 1990–2021, 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. States with no individual peat production data and that are not within a peat-producing region are assumed to not be producing peat. State production values were normalized to sum to the national production value.
- For 1994–1997, state-level annual peat production data were obtained from the USGS Minerals Yearbooks for those years (USGS 2020). 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 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 (2020). States with no individual peat production data and that are not within a peat-producing region are assumed to not be producing peat. State production values were normalized to sum to the national production value.
- For 1998–2020, state-level annual peat production data were obtained from the USGS Minerals Yearbooks (USGS 2020, USGS 2022a, USGS 2022b) from 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. States with no individual peat production data and that are not within a peat-producing region are assumed to not be producing peat. State production values were normalized to sum to the national production value.

- State-level peat production in 2021 was estimated as an average fraction of total peat production for the previous 10 years because 2021 USGS data were not available when the national *Inventory* was developed. There is annual variability in the peat production values, which lends itself to using an average, rather than relying solely on the previous year,2020, 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 2021 total U.S. peat production of the conterminous 48 states available from the USGS annual Minerals Commodities Summary (USGS, 2022c).
- Data Appendix E-8 of this report provides state-level peat production data as well as state-level estimated peat area across the time series for all 50 states and the District of Columbia.

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 metric tons 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 the percentage of nutrient-rich versus the percentage of 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 offsite 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 offsite CO_2 emissions. Because of a lack of peat application data, offsite peat was assumed to be applied proportionally to U.S. domestic state population in two separate components: horticulture use (which includes peat application in Hawaii, Alaska, and Puerto Rico) and dissolved organic carbon. Offsite CO_2 emissions were distributed proportionally by the percentage of the total U.S. population (1990–1999: U.S. Census Bureau 2002; 2000–2009: U.S. Census Bureau 2011; 2010–2021: U.S. Census Bureau 2021a, 2021b, 2022, Instituto de Estadísticas de Puerto Rico 2022), as it is assumed that horticulture use is positively correlated to population. EPA intends to continue reviewing this assumption; see the planned improvements below.
- An IPCC (2013a) emissions factor for onsite CO_2 emissions of drained organic soils was applied to peat production to yield onsite CO_2 emissions.
- IPCC (2013a) 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 onsite CH_4 emissions.
- An IPCC (2013a) emissions factor for onsite N_2O emissions was applied to the peat production area of nutrient-rich peat soil only to yield on-site N_2O emissions.

5.1.7.2.3. Uncertainty

The overall uncertainty associated with the 2021 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* (EPA 2023), levels of uncertainty in the national estimates in 2020 were −16%/+16% for CO_2, −58%/+80% for CH_4, and −52%/+53% for N_2O. State-level estimates have a higher uncertainty due to apportioning national data to the state level and due to the assumption that any state without data on peat production is a non-producing state. These assumptions were required due to a general lack of data confirming that states are either producing or non-producing. For more details on national-level uncertainty, see the uncertainty discussion in Section 6.8 of the national *Inventory*.

5.1.7.2.4. Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in the national *Inventory,* given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates (see Section 6.8, page 6-102, of the national Inventory). In particular, the lower 48 states' peat production estimates were updated using the peat section of the *Mineral Commodity Summaries 2022*. The 2022 edition updated 2018 and 2020 national peat estimates (which are used to estimate state peat production). Changes also occurred in estimates for state peat production for onsite and offsite CO_2 emissions due to revised population data for 2010–2020. Additionally, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) and N_2O (from 298 to 265) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013b). The previous Inventory used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.7.2.5. 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 to identify other data and update assumptions (e.g., data on consumption, data and approaches for proxy peat production to better refine where peat is produced). Planned improvements include:

- EPA plans to investigate estimating emissions for Hawaii, Puerto Rico, and applicable territories, pending data availability. Emissions from offsite horticulture use are currently not estimated in non-conterminous states and territories, even though peat spreading is not limited to conterminous states.
- EPA will continue monitoring for data sources to reduce or eliminate the disparity between estimated state peat production and the national peat production estimate, especially for production values in 1990–2000. Some amount of normalization is currently performed for most years throughout the time series.

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 6-103 described in the national *Inventory* at the link provided above.

5.1.7.2.6. References

Bureau of Mines (1990) Peat. In: *Minerals Yearbook.* U.S. Department of the Interior. Available online at: https://digital.library.wisc.edu/1711.dl/EZRI27J2VYVCG8G.

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Cleary, J., N. Roulet, and T.R. Moore (2005) Greenhouse Gas Emissions from Canadian Peat Extraction, 1990–2000: A Life-Cycle Analysis. *Ambio*, 34: 456–461.

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013a) *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. T. Hiraishi, T. Krug, K. Tanabe, N. Srivastava, J. Baasansuren, M. Fukuda, and T.G. Troxler (eds.).

IPCC (2013b) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

U.S. Census Bureau (2002) *Time Series of Intercensal State Population Estimates: April 1, 1990 to April 1, 2000*. Table CO-EST2001-12-00. Release date: April 11, 2002. Available online at: https://www2.census.gov/programs-surveys/popest/tables/1990-2000/intercensal/st-co/co-est2001-12-00.pdf.

U.S. Census Bureau (2011) *Intercensal Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2010.* Table ST-EST00INT-01. Release date: September 2011. Available online at: https://www2.census.gov/programs-surveys/popest/datasets/2000-2010/intercensal/state/st-est00int-alldata.csv.

U.S. Census Bureau (2021a) *Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2020*. Table NST-EST2020. Release date: July 2021.

U.S. Census Bureau (2021b) *Annual Estimates of the Resident Population for the United States, Regions, States, District of Columbia, and Puerto Rico: April 1, 2020 to July 1, 2021*. Table NST-EST2021-POP. Release date: December 2021.

U.S. Census Bureau (2022) *International Database: World Population Estimates and Projections*. Accessed January 2022. Available online at: https://www.census.gov/programs-surveys/international-programs/about/idb.html.

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USGS (2022b) *2020 Minerals Yearbook: Peat* [tables-only release]. Available online at https://www.usgs.gov/centers/nmic/peat-statistics-and-information.

USGS (2022c) *Mineral Commodity Summaries 2020.* Available online at: https://pubs.usgs.gov/periodicals/mcs2020/mcs2020.pdf.

Full citations of other references relevant to Chapter 6.8 (Wetlands Remaining Wetlands) and 6.9 (Land Converted to Wetlands) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.8 Flooded Land Remaining Flooded Land (NIR Section 6.8)

5.1.8.1 Background

Flooded lands are defined as (1) water bodies where human activities have caused changes in the amount of surface area covered by water, typically through water level regulation, such as constructing a dam; (2) water bodies where human activities have changed the hydrology of existing natural water bodies, thereby altering water residence times and/or sedimentation rates, and in turn causing changes to the natural emission of GHGs; and (3) water bodies that have been created by excavation, such as canals, ditches, and ponds (IPCC 2019). Flooded lands include water bodies with seasonally variable degrees of inundation, but these water bodies would be expected to retain some inundated area throughout the year under normal conditions.

Flooded lands are broadly classified as “reservoirs” or “other constructed water bodies” (IPCC 2019). Reservoirs are defined as flooded land greater than 8 hectares and include the seasonally flooded land on the perimeter of permanently flooded land (i.e., inundation areas). IPCC guidance (IPCC 2019) provides default emissions factors for reservoirs and several types of other constructed water bodies, including freshwater ponds and canals/ditches.

Land that has been flooded for more than 20 years is defined as flooded land remaining flooded land and land flooded for 20 years or less is defined as land converted to flooded land. The distinction is based on literature reports that CH_4 and CO_2 emissions are high immediately following flooding (as labile organic matter is rapidly degraded) but decline to a steady background level approximately 20 years after flooding. Emissions of CH_4 are estimated for flooded land remaining flooded land, but CO_2 emissions are not included as they are primarily the result of decomposed organic matter entering the waterbody from the catchment or contained in inundated soils and are included elsewhere in the IPCC guidelines (IPCC 2006).

5.1.8.2 Methods/Approach

EPA compiles state-level emissions from flooded land remaining flooded land using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6.8 (pages 6-121 through 6-129) of the national *Inventory.* For this report, the state-level estimates were developed using Approach 1. Estimates of emissions from reservoirs and associated inundation areas and other constructed waterbodies that include freshwater ponds and canals/ditches include all states and the District of Columbia.

5.1.8.3 Uncertainty

The overall uncertainty associated with national estimates from reservoirs and other constructed water bodies is described in Chapter 6 of the national *Inventory* (EPA 2023). Uncertainty for both reservoirs and other constructed waterbodies is developed using IPCC Approach 2. The total uncertainty for reservoirs is −1 %/+1.7%, and the total uncertainty for other constructed water bodies is −0.7%/+1%. State-level estimates of uncertainty will vary significantly among the states but, in general, tend to be higher 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*.

5.1.8.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.8 of the national *Inventory* (pages 6-128, 6-129, and 6-138), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

Consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous national *Inventory* used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.8.5 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 from flooded land remaining flooded land, see the planned improvements discussion on pages 6-129, 6-138, and 6-139 of Chapter 6.8 in the national *Inventory*.

5.1.8.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

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Full citations of references included in Chapter 6.8 (for flooded land remaining flooded land) of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.9 Land Converted to Wetlands (NIR Section 6.9)

This section describes methods for estimating state-level CO_2 and CH_4 emissions from managing wetlands, as consistent with the national *Inventory,* specifically:

- Land converted to coastal wetlands (CO_2 and CH_4)
- Land converted to flooded land (CO_2 and CH_4)

5.1.9.1 Land Converted to Coastal Wetlands

5.1.9.1.1. 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 active restoration and creation of coastal wetlands through removing hydrological barriers. Land use conversions into coastal wetlands can result in C 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 section provides estimates of CO_2 and CH_4 emissions and removals resulting from converting cropland, grassland, wetlands, settlements, and other lands to vegetated coastal wetlands.

5.1.9.1.2. Methods/Approach

To compile national estimates of C stock changes and CH_4 emissions from land converted to vegetated coastal wetlands for the national *Inventory*, estimates for each state with coastal wetlands and the District of Columbia 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 6-139 through 6-145) of the national *Inventory.* 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.

5.1.9.1.3. Uncertainty

Underlying uncertainties in estimates of soil carbon removal factors, biomass change, dissolved organic matter, and CH_4 emissions include error in uncertainties associated with Tier 2 literature values of soil carbon removal estimates, biomass stocks, dissolved organic matter, and IPCC default CH_4 emissions factors; uncertainties linked to interpretating remote sensing data; and 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* (EPA 2023), levels of uncertainty in the national estimates in 2021 are −20%/+20% for biomass C stock change, −25.8%/+25.8% for dead organic matter C stock change, −18.7%/+18.7% for soil C stock change, and −29.9%/+29.9% CH_4 emissions. The combined uncertainty across all subcategories is −42.6%/+42.6%. 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*.

5.1.9.1.4. Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.9 of the national *Inventory* (page 6-144), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

Consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous *Inventory* used 100-year GWP values provided in the AR4. This update was applied across the entire time series

5.1.9.1.5. 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 land converted to vegetated coastal wetlands, see the planned improvements discussions on pages 6-44 and 6-145 of Chapter 6.9 in the national *Inventory*.

5.1.9.1.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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Full citations of the references included in Chapter 6.9 (Lands Converted to Coastal Wetlands) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.9.2 Land Converted to Flooded Land

5.1.9.2.1. Background

Land that has been flooded for less than 20 years is defined as land converted to flooded land. The distinction is based on literature reports that CO_2 and CH_4 emissions are high immediately following flooding (as labile organic matter is rapidly degraded) but decline to a steady background level approximately 20 years after flooding. Both CO_2 and CH_4 emissions are inventoried for both reservoirs and associated inundation areas and freshwater ponds within the other constructed waterbodies subcategory of land converted to flooded land.

5.1.9.2.2. Methods/Approach

To compile national estimates of C stock changes and CH4 emissions from land converted to flooded land for the national Inventory, estimates for each state and the District of Columbia 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 6-145 through 6-160) of the national Inventory.

5.1.9.2.3. Uncertainty

The overall uncertainty associated with national estimates of CO_2 and CH_4 from reservoirs and other constructed water bodies on flooded land remaining flooded land is described in Chapter 6.9 of the national *Inventory* (EPA 2023). Uncertainty for both reservoirs and other constructed water bodies is developed using IPCC Approach 2. The total uncertainty for CO_2 and CH_4 emissions from reservoirs is −14.9%/+16.8%, and the total uncertainty for CO_2 and CH_4 emissions from other constructed waterbodies is −2.1%/+2.6%. State-level estimates of uncertainty will vary significantly among the states but, in general, tend to be higher 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*.

5.1.9.2.4. Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.9 of the national *Inventory* (pages 6-153 and 6-160), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous national *Inventory* used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.9.2.5. 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 land converted to flooded land, see the planned improvements discussions on pages 6-153, 6-154, and 6-160 of Chapter 6.9 in the national *Inventory*.

5.1.9.2.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.).

Full citations of the references included in Chapter 6.9 (for land converted to flooded land) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.10 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 settlements remaining settlements 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:

- CO_2 emissions from drained organic soils (CO_2)
- Changes in C stocks in settlement trees (CO_2)
- N_2O emissions from settlement soils (N_2O)
- C stock changes in landfilled yard trimmings and food scraps (CO_2)

5.1.10.1 Soil C Stock Changes

5.1.10.1.1. 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 carbon 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%–20% organic carbon 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 result 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, carbon loss from drained organic soils can continue over long periods of time, which vary depending on climate and composition (i.e., decomposability) of the organic matter. See Chapter 6 of the national *Inventory* for more information (EPA 2023).

5.1.10.1.2. Methods/Approach

EPA compiles state-level estimates of soil C stock changes using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6, Section 6.10 (pages 6-161 through 6-164) of the national *Inventory*. EPA used a hybrid of 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 2016–2021. Estimates are included for all states except Alaska.

State-level estimates for soil C stock changes from Settlements Remaining Settlements is available upon request.

5.1.10.1.3. Uncertainty

The overall uncertainty associated with national estimates from soil C stock changes is described in Chapter 6 of the national *Inventory* (EPA 2023). Uncertainty for the Tier 2 approach is derived using a Monte Carlo approach. The uncertainty for total soil C stock changes in 2020 is −54%/+54%.

5.1.10.1.4. Recalculations

No recalculations were applied for this current report, consistent with the national *Inventory* (see Section 6.9, page 6-163).

5.1.10.1.5. 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 C stock changes, see the planned improvements discussions on pages 6-163 and 6-164 of Chapter 6.10 in the national *Inventory*.

5.1.10.1.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

Full citations of the references included in Chapter 6.10 (for soil C stock changes) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.10.2 Changes in C Stocks in Settlement Trees

5.1.10.2.1. 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 versus 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 carbon flux estimates. Annual sequestration increased by 35% between 1990–2021 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 is less than in forests, and this tree cover varies significantly across the United States (e.g., Nowak and Greenfield 2018a).

5.1.10.2.2. Methods/Approach

To compile national estimates of CO_2 emissions and removals from C 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, EPA is applying an Approach 1 method (i.e., using methods consistent with the national

Inventory). A description of the methods and data used to estimate changes in C stocks in settlement trees is found in Chapter 6, Section 6.10 (pages 6-164 through 6-172), of the national *Inventory* (EPA 2023).

5.1.10.2.3. 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 carbon 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 carbon 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 carbon estimates and the forest tree carbon 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* (EPA 2023), levels of uncertainty in the national estimates in 2021 for C stock change are −51%/+51%. 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*.

5.1.10.2.4. Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.10 of the national *Inventory* (pages 6-171 and 6-172), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

5.1.10.2.5. 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 tree C stocks, see the planned improvements discussion on page 6-172 of Section 6.10 in the national *Inventory* for a description of future work to further refine these estimates.

5.1.10.2.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Nowak, D.J. (2012) Contrasting natural regeneration and tree planting in 14 North American cities. Urban Forestry and Urban Greening. 11: 374– 382

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. and E.J. Greenfield (2018a) U.S. urban forest statistics, values and projections. Journal of Forestry. 116(2):164–177

Nowak, D.J., D.E. Crane, J.C. Stevens, and M. Ibarra (2002) Brooklyn's Urban Forest. General Technical Report NE290. U.S. Department of Agriculture Forest Service, Newtown Square, PA

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

Full citations of the references included in Chapter 6.10 (for changes in C stocks in settlement trees) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.10.3 N_2O Emissions from Settlement Soils

5.1.10.3.1. Background

Of the synthetic nitrogen fertilizers applied to soils in the United States, approximately 1–2% are currently applied to lawns, golf courses, and other landscaping within settlement areas, and contribute 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 nitrogen 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.

Nitrogen additions to soils result in direct and indirect N_2O emissions. Direct emissions occur on site due to the nitrogen additions in the form of synthetic fertilizers and biosolids, as well as enhanced mineralization of nitrogen in drained organic soils. Indirect emissions result from fertilizer and biosolids nitrogen that is transformed and transported to another location in a form other than N_2O (i.e., NH_3 and nitrogen oxide volatilization, nitrate 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 2023).

5.1.10.3.2. Methods/Approach

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 described in Chapter 6, Section 6.10 (pages 6-172 through 6-175) of the national *Inventory* . 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 nitrogen and nitrogen 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 2016–2021. Soil N_2O emissions for additions of biosolid nitrogen are only estimated at the national scale for the entire time series. For this source of nitrogen, 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 except Alaska.

The methodology reported here is to provide the reader with an understanding of the approach taken for the 1990-2020 state-level estimates. State-level estimates for 1990-2021 are not available but will be for the next publication covering 1990-2022.

5.1.10.3.3. Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.10 of the national *Inventory* (page 6-175), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

Consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of N_2O (from 298 to 265) to reflect the 100-year GWP values provided in the AR5 (IPCC 2013). The previous Inventory used 100-year GWP values provided in the AR4. This update was applied across the entire time series.

5.1.10.3.4. *Uncertainty*

The overall uncertainty associated with national estimates from N_2O emissions from settlement soils is described in Chapter 6 of the national *Inventory* (EPA 2023). As described:

- The amount of N_2O emitted from settlement soils depends not only on nitrogen 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 carbon availability; rate, application method, and timing of nitrogen 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 nitrogen and biosolids application, which then leads to uncertainty in the results.
- Uncertainties exist in both the fertilizer nitrogen and biosolids application rates in addition to the emissions 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 nitrogen content of biosolids, total sludge applied in 2000, wastewater existing flow in 1996 and 2000, and the biosolids disposal practice distributions to nonagricultural land application and surface disposal. In addition, there is uncertainty in the direct and indirect emissions factors that are provided by IPCC (2006).

Uncertainty is propagated through the calculations of N_2O emissions from fertilizer nitrogen 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 −57%/+85% and −78%/+223%, respectively.

5.1.10.3.5. *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 N_2O emissions from settlement soils, see the planned improvements discussions on page 6-175 of Chapter 6.10 in the national *Inventory*.

5.1.10.3.6. *References*

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

Full citations of the references included in Chapter 6.10 (for N_2O emissions from soils) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.10.4 Changes in Yard Trimmings and Food Scrap C Stocks in Landfills

5.1.10.4.1. 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 contained in landfilled yard trimmings and food scraps can be stored for very long periods. C 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 carbon, 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.

5.1.10.4.2. Methods/Approach

State-level C stocks were compiled using Approach 2 by allocating net national changes in C stocks and associated emissions and removals to states, the District of Columbia, and U.S. territories based on their fraction of total U.S. land area classified as urban area. “Urban area” is defined by the USDA as land area containing densely populated areas with at least 50,000 people (urbanized areas) and densely populated areas with 2,500 to 50,000 people (urban clusters). EPA assumed “urban area” matched the definition of “settlements area” for the purpose of state-level estimates. This approach was applied due to unavailability of state-level activity data on mass of yard trimmings and food scraps discarded to managed landfills, and the assumption that most yard trimmings and food scraps would be generated in densely populated areas. EPA used settlement area estimates from the USDA Economic Research Service’s Major Land Uses data. The total settlements area in the United States includes all U.S. states and the District of Columbia but excludes territories such as Puerto Rico.

State emissions were calculated using the following stepwise process:

1. EPA obtained U.S. settlements area data from the USDA (2017). For years without U.S. settlements area data (2013–2021), settlements area data were forecast using 2002–2012 data to capture the most recent available trends.
2. The fraction of total settlements area was calculated for each state, including the District of Columbia, by dividing the state settlements area by the U.S. total settlements area.
3. The state fraction of settlements area was multiplied by the total national yard trimmings and food scraps C stocks from the 1990–2021 national *Inventory* to estimate state-level yard trimming and food scrap C stocks. This calculation was also performed for grass, leaves, branches, and food scraps to yield state-level C stocks for each subcategory.

Data Appendix E-9 to this report provides activity data related to total land in urban areas and percent of total land area that occurs in urban areas by state (including the District of Columbia and Puerto Rico) across the time series. These data are used in the calculations of carbon storage in landfilled yard trimmings and food scraps in each state.

5.1.10.4.3. Uncertainty

The overall uncertainty associated with the 2021 national estimates of CO_2 from changes in yard trimmings and food scraps C stocks were calculated using the Approach 2 methodology (IPCC 2006). As described further in Chapter 6 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 were −72%/+56% for CO_2. State-level estimates have a higher uncertainty due to apportioning the national estimates to states based on their fraction of the settlements area. These assumptions were required because of a general lack of available state-level data on yard trimmings and food scraps. For more details on national-level uncertainty, see the uncertainty discussion in Section 6.10 of the national *Inventory*.

5.1.10.4.4. Recalculations

Changes that resulted from recalculations to the state-level estimates in 2020 were due to expected forecasted data changes and are reflected in the national *Inventory*; see Section 6.10, page 6-181.

5.1.10.4.5. Planned Improvements

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. EPA will monitor updates to the USDA urban area data. Sources of settlements area data for Puerto Rico and other U.S. territories are also needed to provide a more accurate estimate of net C stock changes in the United States. 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*. For example, updated data are expected in a new release of the *Advancing Sustainable Materials Management: Facts and Figures* report for 2019, 2020, and 2021. The discussion of planned improvements to refine methods for estimating changes in C stocks in landfilled yard trimmings at the national level starts on page 6-181 of Chapter 6.10 in the national *Inventory*.

5.1.10.4.6. References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. U.S. Environmental Protection Agency. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks..

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

USDA (U.S. Department of Agriculture) (August 2017) Urban Area, 1945–2012, by State: Densely-populated areas with at least 50,000 people (urbanized areas) and densely-populated areas with 2,500 to 50,000 people (urban clusters). U.S. Department of Agriculture, Economic Research Service. Available online at: https://www.ers.usda.gov/data-products/major-land-uses/

Full citations of all other references relevant to estimating landfilled yard trimmings and food scraps C stock changes included in Chapter 6.10 (Settlements Remaining Settlements) are listed in Chapter 10 (References) of the national *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.11 Land Converted to Settlements (NIR Section 6.11)

5.1.11.1 Background

Land converted to settlements includes all settlements in an inventory year that had been in at least one other land use 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 United States except 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 to the atmosphere, particularly conversions from forest land. Moreover, conversion of forests 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.

The 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 carbon are reported for forest land converted to settlements, but not for other land use conversions to settlements (EPA 2023).

5.1.11.2 Methods/Approach

EPA compiles state-level estimates of land converted to settlements using the same methods applied in the national *Inventory*. Please see the methodologies described in Chapter 6, Section 6.10 (pages 6-182 through 6-188), of the national *Inventory.* EPA used a hybrid Approach 1 and Approach 2 for state-level estimates. The current national *Inventory* includes state-level emissions for the years 1990–2021 for biomass, standing dead, dead wood, 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 2016–2021. Estimates are included for all states except Alaska.

5.1.11.3 Uncertainty

The overall uncertainty associated with national estimates from land converted to settlements is described in Chapter 6 of the national *Inventory* (EPA 2023). As described:

- The uncertainty analysis for carbon losses for forest land converted to settlements is conducted in the same way as the uncertainty assessment for forest ecosystem carbon 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 carbon 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 of the national *Inventory*.

The overall level of uncertainty for national *Inventory* land converted to settlements estimates is −34%/+34%.

5.1.11.4 Recalculations

Changes that resulted from recalculations to the state-level estimates are the same as those presented in Section 6.11 of the national *Inventory* (page 6-187), given that improvements in the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

5.1.11.5 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 land converted to settlements, see the planned improvements discussions on pages 6-187 and 6-188 of Chapter 6.11 in the national *Inventory*.

5.1.11.6 References

EPA (U.S. Environmental Protection Agency) (2023) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2021*. EPA 430-R-23-002. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

Full citations of the references included in Chapter 6.11 (Land Converted to Settlements) of the national *Inventory* are listed in Chapter 10 (References) of the *Inventory* and available online here: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-10-References.pdf.

5.1.12 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 carbon 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 national *Inventory,* page 6-11*,* Table 6-5), research is ongoing to track carbon across other land remaining other land and land converted to other land. Until reliable and comprehensive estimates of carbon 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. Emissions and removals from other lands and lands converted to other lands will be included in future versions of this publication when they are integrated into the national *Inventory*. See Chapters 6.12 and 6.13 on page 6-189 of the national *Inventory* (EPA 2023).

5.1.12.1 References

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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 that 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 GHG Emissions and Sinks

Category	Gas	Approach	Geographic Completeness [a]
Landfills	CH_4	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands and some territories (i.e., Guam, Puerto Rico), and as applicable.
Wastewater	CH_4, N_2O	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and some territories (i.e., Guam, Northern Mariana Islands Puerto Rico, and U.S. Virgin Islands for domestic wastewater),.[a]
Composting	CH_4, N_2O	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands and territories as applicable.
Anaerobic Digestion at (Standalone) Biogas Facilities	CH_4	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands and territories as applicable.

[a] Emissions are likely occurring in other U.S. 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)
- Anaerobic digestion at biogas facilities (stand alone) (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. CH_4 and CO_2 are the primary constituents of landfill gas generation and emissions. Consistent with the 2006 IPCC Guidelines, net CO_2 flux from C 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*, EPA uses an IPCC Tier 2 approach and several data sources, methods, and assumptions to estimate emissions (see pages 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 2021a) as a proxy for each state's share of CH_4 net emissions over the time series. Table 6-2 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 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.
2010–2021	• 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., non-reporters). The intent of the scale-up factor is to estimate CH_4 emissions from MSW landfills that do not report to the GHGRP. EPA has put significant effort into identifying landfills that do not report to the GHGRP, most recently in 2021. Basic landfill characteristics such as the landfill's 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 2010–2021 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 since these 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)

EPA estimates CH_4 emissions from industrial waste landfills for two industry categories consistent with the national *Inventory*: (1) pulp and paper and (2) food and beverage. Data reported to the GHGRP on industrial waste landfills suggest that most of the organic waste that would result in CH_4 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, 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, 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 10–20%) with 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 these 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, EPA extracted a state-by-state count of mills in the United States from two sources: Data Basin for 2008 and Mills OnLine for 2015–2016 (Conservation Biology Institute 2008; Center for Paper Business and Industry Studies n.d.). The count of facilities is approximately 233 and 332 from Data Basin and Mills OnLine, respectively. The count and percentage of mills by state are shown in Appendix F (Table F-1). According to the Industrial Resources Council, mills are located in 41 states, not including Alaska, Colorado, North

Dakota, Nebraska, Nevada, Rhode Island, South Dakota, Utah, and Wyoming. For comparison, the Subpart TT pulp and paper facilities across RYs 2011–2019 represent a maximum of 92 facilities located across 21 states.

To estimate CH_4 generation and emissions, the Data Basin 2008 percentages by state were applied to the national *Inventory* estimate for the pulp and paper manufacturing sector for 1990–2010, and the Mills OnLine 2015–2016 percentages by state were applied for 2011–2021. 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 this approach were used in an attempt to ensure complete 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.

CH_4 emissions from the pulp and paper sector were disaggregated by applying the percentage of the mills by state as a proxy for 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 dispose 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 2021 update to the EPA Excess Food Opportunities database (EPA 2021b].

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 locations 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 and Figures methodology (EPA 2020) 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 Recalculations

Consistent with the national *Inventory*, the CO_2 equivalent estimates of total CH_4 emissions have been revised to reflect the 100-year GWP for CH_4 provided in the AR5 (IPCC 2013).

EPA conducted a literature review between 2020 and 2022 to investigate other sources of industrial food waste and annual waste disposal quantities. As a result of this effort, EPA decided to revise the food waste disposal factor in the 1990 to 2021 Inventory for select years. A waste disposal factor of 4.86 percent is used for 1990 to 2009 and a revised factor of 6 percent is used for 2010 to the current year. These updates to the national *Inventory,*[41] resulted in changes for years 2010-present for all state-level CH_4 emission estimates.

6.1.1.5 Uncertainty

The overall uncertainty associated with the 2021 national estimates of CH_4 from MSW and industrial waste landfills was calculated using the 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 2021 were −19%/+26% of the estimated CH_4 emissions for MSW landfills and −31%/+25% for industrial waste landfills.

State-level estimates likely have a higher uncertainty due to (1) apportioning the national emissions estimates to each state based on assumptions made to disaggregate the national emissions estimates, which are based on state percentages as reported to the GHGRP, and (2) 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*.

6.1.1.6 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, 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.
- **Industrial waste landfills.** A more complete and comprehensive list of pulp and paper facilities in the United States will be identified, including years of operation since 1990. Further QC on this inventory will be performed by comparing the counts of industrial waste landfills by state in available data sets.

6.1.1.7 References

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[41] See Section 7.1, page 7-17, of the national *Inventory*.

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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 C 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

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 composted material used in this inventory. Years where published data are not available are either interpolated or extrapolated using population growth and published estimates.

Table 6-3. Summary of Availability and Sources for Composting Data

Year Composting Data Available for	Reference Citation
2000	Goldstein and Madtes 2001
2002	Kaufman et al. 2004
2004	Goldstein et al. 2006
2006	Arsova et al. 2008
2008	Arsova et al. 2010
2010	EREF 2016
2011	Shin 2014
2012	ILSR 2014
2013	EREF 2016
2016	WBJ 2016
2020	WBJ 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 and 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 and Figures data published by EPA, are referred to this as the sum of state-reported data in this methodology report. Limitations with the state-reported survey data include its voluntary nature and occasional lack 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, 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 (Goldstein and Madtes 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 since 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's and next year's survey data (the state proportion of material composted). Annual state data were interpolated for 2001, 2003, 2005, 2007, 2009, 2014, 2017, 2018, and 2019. Annual state data for 2021 were extrapolated using population growth (U.S. Census Bureau 2021a, 2021b) and WBJ (2020) estimates of material composted. 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 and Figures reports to cap the total quantity composted across the states and match the state totals to the national *Inventory*. The EPA Facts and Figures national estimates were directly used to estimate the national *Inventory*. The IPCC Tier 1 method used in the national *Inventory* estimates (IPCC 2006) is 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 Recalculations

Consistent with the national Inventory, the CO_2 equivalent estimates of total CH_4 and N_2O emissions have been revised to reflect the 100-year GWP for CH_4 and N_2O provided in the AR5 (IPCC 2013). No additional recalculations were applied for this current report.

6.1.2.4 Uncertainty

The overall uncertainty associated with the 2021 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 2021 were −58%/+58% for CH_4 and for N_2O. 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 uses the windrow method and treats a homogeneous mixture of primarily yard trimmings and some food 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.

6.1.2.5 Planned Improvements

In future annual publications, EPA plans to investigate state volumes of material composted where the report authors (from referenced composting data sources) indicated potentially combined volumes of waste sent to composting, recycling, and anaerobic digestion. EPA will continue to identify annual quantities of material composted in states where data are lacking (e.g., Alaska, Guam). For example, a 2021 desk-based investigation into composting facilities in Alaska revealed operational aerated composting facilities, but the annual capacity and throughput were not identified. EPA will continue to search for relevant data for commercial composting facilities in these states. Planned improvements to the national estimates for composting outlined in Section 7.3 (page 7-57) of the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

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6.1.3 Anaerobic Digestion at Biogas Facilities (stand--alone) (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, CH_4 emissions may result from a fraction of the biogas lost during the process due to leakages and other unexpected events (0–10% 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

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 30 years in the time series (1990–2021). 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*, EPA calculated a weighted average of material digested using masked survey data from the two available survey reports for 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 1990–2021.

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 (kt/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 (kt/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 two 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 Recalculations

Consistent with the national Inventory, the CO_2-equivalent estimates of total CH_4 emissions have been revised to reflect the 100-year GWP for CH_4 provided in the AR5 (IPCC 2013). No additional recalculations were applied for this current report.

6.1.3.4 Uncertainty

The overall uncertainty associated with the 2021 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 −54%/+54% CH_4. 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 2015–2018. 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 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*.

6.1.3.5 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 from stand-alone anaerobic digestion, see the planned improvements discussion starting on pp. 7-62 of Section 7.3 in the national *Inventory*.

6.1.3.6 References

EPA (U.S. Environmental Protection Agency) (2018) *Anaerobic Digestion Facilities Processing Food Waste in the United States in 2015: Survey Results*. EPA/903/S-18/001. Available online at: https://www.epa.gov/sites/default/files/2018-08/documents/ad_data_report_final_508_compliant_no_password.pdf.

EPA (2019) *Anaerobic Digestion Facilities Processing Food Waste in the United States in 2016: Survey Results. EPA/903/S-19/001*. Available online at: https://www.epa.gov/sites/default/files/2019-09/documents/ad_data_report_v10_-_508_comp_v1.pdf.

IPCC (Intergovernmental Panel on Climate Change) (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Institute for Global Environmental Strategies.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.). Cambridge University Press.

6.2 Wastewater Management

This section presents the methodology used to estimate the emissions from domestic and industrial wastewater treatment and discharge (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, 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 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 (1) designed to have periods of anaerobic activity, (2) from anaerobic systems, and (3) from anaerobic sludge digesters when the captured biogas is not completely combusted. N_2O emissions can result from aerobic systems as a byproduct of nitrification, or as an intermediate product of denitrification. Methane emissions will also result from the discharge of treated effluent from centralized treatment plants to water bodies where carbon accumulates in sediments, while N_2O emissions will also result from discharge of centrally treated wastewater to water bodies with nutrient-impacted or eutrophic conditions.

- Industrial wastewater CH_4 emissions originate from in-plant treatment systems, typically comprising biological treatment operations in which some operations are designed to have anaerobic activity or may periodically form anaerobic conditions. N_2O emissions are primarily expected to occur from aerobic treatment systems as a byproduct of nitrification, or as an intermediate product of denitrification. Emissions will also result from discharge of treated effluent to waterbodies.

6.2.1.2 Methods/Approach (Domestic Wastewater)

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) and state-level septic data. In this method, EPA accessed historical U.S. Census data to compile state-level population data for each year of the inventory (1990–1999: U.S. Census Bureau 2002; 2000–2009: U.S. Census Bureau 2011; 2010–2021: U.S. Census Bureau 2021a, 2021b, 2022; Instituto de Estadísticas de Puerto Rico 2021). NEBRA (2022) reported the percent of population associated with septic systems by state for 2018. This percentage was multiplied by the 2018 state-level population and then divided by the total summed national population to estimate the percent of the national population with a septic system in each state and territory in 2018. These state-level percentages were then used for the remainder of the timeseries, as shown in Appendix F, Table F-6.

EPA calculated state- and territory-level emissions by multiplying the proportion of the U.S. population on centralized treatment or septic systems in each state or territory by the national CH_4 and N_2O 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).

EPA did not perform a more detailed approach that would account for the specific types of treatment at centralized systems, such as anaerobic reactors or activated sludge, used in each state (see planned improvements below in Section 6.2.1.6). Similarly, there are insufficient readily available data sources to allow classification of the type of specific water bodies within each state, so EPA did not consider the type of water body 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.

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, 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, EPA was able to estimate the distribution of production for a subset of years in the time series, as discussed below by industry.

For pulp and paper manufacturing, state-level production data are not available, so 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 EPA's ICIS National Pollutant Discharge Elimination System (NPDES) database. EPA acknowledges that this methodology ignores production at mills that either do not discharge wastewater or that discharge to a publicly owned treatment works. In both cases, these mills could be performing onsite treatment and emitting GHGs that cannot be captured.

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, EPA accepted most ICIS-NPDES data as is, but some outliers were determined and handled as described below (see planned improvements below in Section 6.2.1.6).

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.

6.2.1.3.1. Pulp and Paper Manufacturing

- Industrial production data for pulp and paper are highly confidential and are not available by state.
- EPA used the amount of wastewater directly discharged by pulp mills by state—reported to both ICIS-NPDES from Enforcement Compliance History Online (ECHO; 2023) and the Washington Department of Ecology's Permitting and Reporting Information System (PARIS; 2022)—to proportion U.S. national emissions estimates to a state (as shown in Appendix F, Table F-7). Because wastewater flow data housed in ECHO changed in 2016, using older data may cause discontinuities in the time series. EPA determined the distribution of discharge flow by state for 2019–2021 using 2019 ECHO and PARIS data and applied the 2019 distribution to all prior years of the national *Inventory*. There was no wastewater flow reported for the District of Columbia or U.S. territories for this industry.
    - Pulp and paper mills were determined in ECHO using Standard Industrial Classification codes 2611, 2621, and 2631. The prior year state estimate had used a broader definition of the industry based on ECHO's Point Source Category to determine the facility universe, but this was determined to include facilities not relevant to this sector.
- For facilities in states other than Washington, EPA:
    - Downloaded the total pulp and paper permit universe in ECHO, including permits that have discharge monitoring report data (261 facilities in 2021), and permits with information only (e.g., facility address) (414 facilities in 2021).
        - Stormwater permits that were reported for a facility that also reported a non-stormwater permit were removed from the analysis (FLR05A517, MAR053165, LAR05P618, MAR053218).

  - Downloaded 2019–2021 flow data where available (ECHO 2023). Not all facilities report total flow if it is not required by their permit. Total flow was summed by state.
    - EPA determined two state flow outliers, one for Missouri in 2020 and one for West Virginia in 2021. Outliers, determined as values that are at least an order of magnitude larger (10 times) than other years' values for the state, were removed. It is assumed these values are data entry errors in ECHO. An average of the other available values was used as a surrogate for removed values.
  - For permits without flow data, total flow was estimated by using average flow by state, or average national total flow for that year if no state data were available, multiplied by the number of permits without flow data for that state.
- Facilities located in the state of Washington are not currently reported within ECHO due to lagging electronic reporting. To fill this known gap, EPA investigated a separate source for these data and:
  - Downloaded and reviewed permit data for known pulp mills determined from the Washington Department of Ecology's Industrial Facility Permits website.
  - Downloaded 2019 flow data where available (PARIS 2022) for monitoring locations that are associated with process wastewater, per the facility permit.
  - Multiplied the daily flow rate by 365.25 days to estimate a total yearly flow, then multiplied by number of months data were reported (to prevent overestimating annual flow, which was done to better match the methodology in ECHO).
  - Integrated into the other state data for all years.
- EPA calculated the percentage of national flow by state:
  - As with Washington, some states are missing from ECHO (e.g., Montana, Colorado). EPA assumed some of these states have nonzero emissions, but they do not have the data to determine whether there are facilities present or to estimate emissions, so they are reported as not applicable.
- EPA calculated the state-level emissions by multiplying national emissions by the percentage of national flow by state.
- Example: 2021 Georgia emissions
  - Georgia has 22 facilities in the facility universe, of which 14 have reported annual flow data.
  - The total flow based on the sum of reported flows (14 facilities) and calculated flows (8 facilities) from the state average flow of 8,213 million gallons (MMGal) for all facilities was 180,617 MMGal in 2019.
  - Georgia's flow was 8.67% of the total national total flow of (2,085,063 MMGal).
  - Pulp and paper's national CH_4 emissions in 2019 was 31 Gg CH_4, so Georgia's 2019 emissions were estimated to be (31 Gg CH_4 * 9.11% = 2.8 Gg CH_4).

6.2.1.3.2. 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-8). 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:
  - EPA gathered state-level 2021 and 2012 average live weight and total head slaughtered for the following commodities: beef, calves, hogs, and lamb/mutton (USDA 2022a, 2013a). EPA retained

2019 data from the 1990–2019 state-level production data, and 2020 and 2004 data from the 1990–2020 state-level production data.

    - U.S. territories and the District of Columbia 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 the USDA ("D" states), EPA evenly divided the difference between the sum of the state-level data and the reported national-level total to those D states.
    - Similarly, the 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):
    - 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*, EPA determined live weight killed (LWK) by multiplying the average live weight by the total head/1,000 to get to million pounds LWK.
  - 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 at about 95% of the national total, so the percentages were normalized to 100%.
- For poultry processing:
  - EPA gathered state-level 2021 and 2012 poultry live weight data. EPA retained 2019 data from the 1990–2019 state-level production data and 2020 and 2004 data from the 1990–2020 state-level production data. Only young chickens, or broilers, had state-level data available. Turkeys and mature chickens did not.
    - Young turkey data were available by state. 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 2022b, 2013b).
    - Young chickens were used to represent mature chicken processing production by state (USDA 2022b, 2013b).
  - To populate D states for 2021, EPA evenly divided the difference between the sum of the state-level data and the reported national-level total to those D states.
  - To populate D states for 2004, EPA first proxied the reported D states for 2020 because the individual states for 2004 were not available or reported by USDA. This was done to encourage time series consistency and avoid showing states known to have poultry processing as having no emissions for the industry. EPA acknowledges this method could attribute minor emissions to states without poultry in 2004. Then, as with 2020, 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 (young chickens, mature chickens, turkeys) values to determine the proportion of poultry LWK for states.

- To calculate CH_4 emissions, 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 2004 (from the 1990–2020 inventory), 2012, 2019 (from the 1990–2019 inventory), 2020 (from the 1990–2020 inventory), and 2021 state-level proportion of U.S. meat and poultry BOD treated on site by the national effluent CH_4 emissions from meat and poultry.
  - For 2005–2011, used linear interpolation of 2004 and 2012 state-level proportions, and for and 2013–2018, used the 2012 and 2019 proportions. Multiplied those values by the national effluent CH_4 emissions from meat and poultry.
  - For 1990–2003, assumed the state-level proportions to be the same as those determined for 2004.
  - Added plant and effluent emissions for total state-level emissions.
- To calculate N_2O emissions, EPA:
  - Multiplied the 2004 (from the 1990–2020 inventory), 2012, 2019 (from the 1990–2019 inventory), 2020 (from the 1990–2020 inventory), and 2021 state-level proportion of U.S. total nitrogen in both
    - 1) 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 and.
    - 2) 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.
  - For 2005–2011 and 2013–2018, EPA used linear interpolation of 2004 and 2012, and 2012 and 2019 state-level proportions, respectively. Multiplied those values by the national effluent N_2O emissions from meat and poultry.
  - For 1990–2003, assumed the state-level proportions to be the same as those determined for 2004.
  - Added plant and effluent emissions for total state-level emissions.

6.2.1.3.3. Vegetables, Fruits, and Juices Processing

- Annual U.S. production data for vegetables, fruits, and juices processing are available from the USDA. Depending on the commodity, state-level data are available (as shown in Appendix F, Table F-9). 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.”
  - U.S. territories and the District of Columbia are not included in the USDA-reported data.
- EPA determined that the most recent year with complete state-level production values is 2017 because the USDA suspended the reporting of some state-level production values in 2018 and more notably in 2019–2021.
- To better inform the time series, EPA also investigated an earlier year, determined 2012 to be complete, and subsequently determined the state-level production values for 2012. EPA previously investigated and included 2004 during the 1990–2020 Inventory.
- For processing production data:
  - State-level data for potato processing were not available. Instead, 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 20144).

  - For other vegetables, EPA gathered data for asparagus, broccoli, carrots, cauliflower, sweet corn, cucumber (for pickles), lima beans, green peas, snap beans, spinach, and tomatoes (USDA 2015a). Where USDA reported data for "other states," those data were distributed equally among the commodities. 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 2015b, 2015c).
  - Noncitrus fruits are split out into separate commodities (e.g., blueberries, sweet cherries[42]); no state-level data are available for the aggregated "noncitrus fruit" category. Therefore, 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 2015c).
  - Processed noncitrus fruit data are typically calculated in the national *Inventory* as 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, EPA calculated the 2004, 2012, and 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.
- For 2005–2011 and 2013–2016, EPA determined state-level proportions by linear interpolation of 2004 and 2012, and 2012 and 2017 values, respectively. Proportions for 2018–2021 were assumed to be the same as 2017.

6.2.1.3.4. Petroleum Refining

- Annual production data are available from EIA within the Department of Energy (EIA 2023a), as shown in Appendix F (Table F-10).
- Because state-level data may reveal confidential data, production data are aggregated by Petroleum Administration for Defense Districts (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

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[42] The EPA gathered 2004 and 2017 production for apricots; avocados (2012 values reported as "not available"); blueberries, cultivated blueberries (2004 only), and wild blueberries; boysenberries (2004 only); sweet and tart cherries; coffee (2017 only); cranberries; dates; loganberries (2004 only); nectarines; olives; papaya (2012 Hawaii crop reported as "not available"), including guavas and pineapples (Hawaii crops, 2004 only); peaches; pears; plums; prunes (combined with plums in 2004); raspberries; and strawberries.

  - PADD V (West Coast): Alaska, Arizona, California, Hawaii, Nevada, Oregon, and Washington
- Operating capacity by state is available from EIA (2023b) for 1990–2021.
- EPA created state-level annual production data for each year of the time series (1990–2021) 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.
  - 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 California's percentage of national production (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).

6.2.1.3.5. Starch-based Ethanol Production

- State-level ethanol production data are available from EIA's State Energy Data System (SEDS) (EIA 2023c) (as shown in Appendix F, Table F-11).
  - Fuel ethanol production data, including denaturant, in thousand barrels are available for 1960–2021 (EIA 2023c).
  - EPA checked the difference between SEDS national production and the reported production in the national *Inventory* and found small differences—on average, a 0.9% difference for the time series—further confirming SEDS is a good source of state-level production.
  - Typically, the most recent year of data is used as a surrogate for the last year of available production data. For example, during the 1990–2020 *Inventory by State*, 2019 production values were used for 2020. This is due to the timing of when production data are released versus to publication of the *Inventory by State*. However, EPA determined 2020 would not be representative of normal production due to the COVID-19 pandemic affecting national production, and therefore used 2019 values.
- Calculated the percentage of national production by state for every year, using the production data noted above.
- Calculated the state-level emissions by multiplying national emissions by percentage production by state.
- Example: 2021 California emissions
  - 2021 California production value is 2,293 thousand barrels.
  - National production for 2021 is 375,517 thousand barrels.
  - California produced 1.2% of the national production in 2021.
  - Calculate 2021 California emissions as national emissions × percentage of national production (5.9 Gg CH_4 × 0.6% = 0.04 Gg CH_4).

6.2.1.3.6. Breweries

- Annual production data by state are available from the Alcohol and Tobacco Tax and Trade Bureau (TTB 2021) (as shown in Appendix F, Table F-12).
    - Data are available for 2008–2020. Therefore, the calculated percentage of national production for 2008 was used for 1990–2007.
    - Data for 2021 were assumed equal to 2020. See the planned improvements below.
    - These data are for taxable production values only, which account for 94% of total production in 2020. The 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 Recalculations

Recalculations discussed here are specific to state-level production or disaggregated data. To see impacts from updates to national-level data, see the recalculations discussion in Section 7.2 of the Waste chapter (Chapter 7) in the national *Inventory*, available online at https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-7-Waste.pdf. Notably, consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) and N_2O (from 298 to 265) to reflect the 100-year GWPs provided in the AR5 (IPCC 2013).

EPA updated the domestic methodology to include state-level proportions of septic versus centralized treatment based on newly available data (NEBRA 2022). These updates, in conjunction with the changes to the national *Inventory,*[43] resulted in changes for the entire time series for all state-level domestic CH_4 and N_2O emission estimates.

Updates to the following state-level industrial production data, in conjunction with national-level updates, resulted in changes for the entire time series for every state-level total industrial CH_4 and N_2O emission estimates:

- **Pulp and paper.** Including 2019 and 2020 flow estimates for all available state data due to an updated methodology to determine/download flow data from ECHO, affecting all years.
- **Meat and poultry processing.** Including 2012 production data, affecting 2005–2018.
- **Vegetables, fruits, and juices processing.** Including 2012 production data, affecting 2005–2018.

6.2.1.5 Uncertainty

The overall uncertainty associated with the 2021 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

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[43] See Section 7.2, page 7-52, of the national *Inventory*.

described further in Chapter 7 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 were −29%/+32% for CH_4 and −34%/+193% for N_2O. 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. State-level emissions for the time series were estimated based on limited years 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 Section 7.2 of the Waste chapter (Chapter 7) in the national *Inventory*, available online at https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-7-Waste.pdf.

6.2.1.6 Planned Improvements

Generally, EPA plans to review feedback from reviews of the state-level inventory methods and assess potential comparable data sets noted or shared provide comparable data for all states or most states. The steps outlined below may inform the potential improvements for both domestic and industrial state-level emissions estimates. EPA plans to undertake the following assessments as resources allow:

- 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.

For individual industries, EPA notes the following potential improvements.

6.2.1.6.1. Pulp and Paper Manufacturing

- Investigate state-level sources for the production of pulp, paper, and paperboard.
- Investigate additional years of ECHO data to improve the time series. Part of this includes evaluating the facilities present year to year to confirm time series consistency.
- 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.

6.2.1.6.2. Meat and Poultry Processing

- Continue to 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.

6.2.1.6.3. Vegetables, Fruits, and Juices Processing

- Continue to investigate other years of available USDA data for inclusion.
- 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.

6.2.1.6.4. Starch-based Ethanol Production

- Investigate sources to break down wet and dry milling by state over the time series.

6.2.1.6.5. Breweries

- Investigate sources to break down craft and noncraft breweries by state over the time series.
- Investigate changes to reporting state-level data and determine a methodology representative of the available data. Some data are available for 2021; however, due to reporting changes from the Alcohol and Tobacco Tax and Trade Bureau, some states no longer have data available due to confidentiality concerns leaving gaps in the time series and total production.

6.2.1.7 References

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Appendix A – Data Appendices

The data appendices include underlying data used to estimate state-level emissions and sinks (e.g., activity data/factors, etc.).

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: US 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.

Appendix B – State-level GHG Data Caveats

The state-level estimates were developed to be consistent with the national Inventory, meaning they were compiled to avoid double counting or gaps in emissions coverage between States. This was done to ensure that State totals, when summed, would equal totals in the national Inventory.

However, there were some instances where either lack of data or updates in data sources used resulted in state-level totals that did not add up to the national totals for the categories listed. This was true for the following source and/or sink categories:

Table B-1. State Level-GHG Data Differences with National GHG Data

Sector/Emission and/or Sink Category	Years Where Different	% Difference in Sum of State Totals vs. National Total	Reason
Energy- FFC CO_2	2021	-0.007% (% differences within a sector are higher)	The state-level estimates are based on updated energy use data that will be incorporated into the next version of the National *Inventory*.
Energy – NEU CO_2	All	Max 0.0015%	Rounding, adjustments made to match up state-level and national-level NEU values.
Energy – Coal Mines CO_2	All	Averages <0.01% lower across time series	State-level estimates currently do not include CO_2 from methane flaring and recovered coal bed methane. These estimates are currently only estimated at the national level but may be included in the next annual publication of this data, potentially in August 2025.
IPPU – Electronics	All years	Averages 1.2% lower from 2011-2021	State-level estimates for HTF subcategory of the electronics industry emissions are updated to use AR5 GWPs, addressing an error in the national *Inventory* where HTF estimates were still using AR4 GWPs from 2011 to 2021. Thus, HTF emissions might not match estimates published in the national *Inventory*.
LULUCF – • Forest land (harvested wood pools)	All years	Averages ~12% higher in the net LULUCF sector total	State-level estimates do not include emission and removals from carbon stock changes associated with harvested wood

Sector/Emission and/or Sink Category	Years Where Different	% Difference in Sum of State Totals vs. National Total	Reason
• Forest land (N_2O from Forest Soils) • Settlement (change in organic soil carbon stocks) • Settlement (N_2O from settlement soils) • Coastal Wetlands (N_2O from aquaculture)		Note: While a percentage is provided, it is a percentage of net emissions and sinks in the LULUCF sector, so may not accurately reflect relative sectoral contribution in a year, including 2021.	products (HWP), and N_2O emissions from aquaculture as disaggregation of these sources to the state level will require further assessment of potential methods and/or appropriate surrogate data to allocate national estimates to states. In the 1990-2021 publication, Settlement soils (changes in organic soil carbon stocks and settlement soils N_2O) was excluded, but is anticipated to be included in the next version. N_2O from Forest Soils also have similar circumstances and planned improvements.