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 • 2010–2022: 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	Hybrid approach • Non-metallurgical magnesia production: Approach 1 • All other subcategories: Approach 2	Includes emissions from all states. Except for ceramics production, other subcategories also include emissions from 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, and 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.

Category	Gas	Approach	Geographic Completeness[a]
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.
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	HFC-23	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.
Production of Fluorochemicals Other than HCFC-22	HFCs PFCs SF_6 NF_3	Hybrid approach • Large facilities: Approach 1 • Small facilities: 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 • 2010–2022: 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 • 1999–2022: 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 • 2011–2022: Approach 1 & 2 • 1990–2010: Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] as applicable.

Category	Gas	Approach	Geographic Completeness[a]
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 • 2011–2022: 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, and Guam) as applicable.
SF_6 and PFCs from Other Product Use	SF_6, PFCs	Hybrid approach (varies by application) • Military applications: Approach 2 • Scientific applications: Approach 1 & 2 pending data availability	Includes emissions from all states, the District of Columbia, tribal lands, and territories[a] 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 Islands, Puerto Rico, and U.S. Virgin Islands) as applicable.

[a] Emissions may be 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, but in most instances emissions are likely not occurring for categories covered in this chapter.

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, Missouri, California, and Florida (EPA 2023). In 2022, these four leading cement-producing states accounted for nearly 43% of U.S. production (USGS 2023).

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 to 2022 (EPA 2023) and U.S. Geological Survey (USGS)'s *Mineral Commodity Summary* clinker production data for 1990–2009 (EPA 2024), 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
2010–2022	• 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 2010–2022 (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 2022 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 2024), levels of uncertainty in the national estimates in 2022 were −4%/+5% 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 2010–2022 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 1990–2022. 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) (2023) *Facility Level Information on GreenHouse gases Tool (FLIGHT).* Data set as of August 18, 2023. Available online at: https://ghgdata.epa.gov/ghgp/.

EPA (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. 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. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

USGS (U.S. Geological Survey) (2023) *Mineral Commodity Summaries: Cement*. Available online at: https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-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 2022. 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
2010–2022	• GHGRP process emissions data were used to estimate the percentage of gross emissions by state, multiplied by the national emissions (IPCC 2006 Tier 2). • GHGRP data on number and type of facilities that captured CO_2 for use in on-site processes 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).

Time Series Range	Summary of Method
	• GHGRP data on number of facilities that captured CO_2 for use in on-site processes from 2010 to 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 2010–2022 was based on process emissions data reported to the GHGRP summed by state (EPA 2010–2022) 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 2024a) 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's "Lime Sold or Used by Producers in the United States, by State" table (USGS 1991, 1992–2010). 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 (1996–2023) only contain U.S. total lime production, with no breakdown by lime type or state. While the USGS Minerals Yearbooks for Lime (1991–2021) 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 2010–2022

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 to 2022. 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 (PCC) 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 on-site processes such as purification.

For 2010–2022, 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 2010–2022 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 2010–2022, 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 2010–2022, 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 the years 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 over the years 2010–2019 and their locations were used to estimate the number of facilities in each state that captured CO_2 for use in on-site processes in 1990–2009. The number of facilities that captured CO_2 on-site in a state was divided by the total number of facilities in the state for each year 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 the years 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 the years1990–2009 per state, the number of facilities per state that captured CO_2 on-site for the years 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 2022 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 2024b), levels of uncertainty in the national estimates in 2022 were −1%/+1% 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 2010–2022 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 2022, all of the beet sugar manufacturing facilities reporting to the GHGRP captured CO_2 on-site, and three lime manufacturing facilities that reported to GHGRP captured CO_2 on-site. In addition, further research on the use and prevalence of capturing CO_2 for use in on-site processes in 1990–2009 is needed. The current methodology assumes that facilities captured CO_2 on-site over the full time series and that the quantity of emissions captured is evenly distributed among those facilities. More research on the range of CO_2 captured on-site per facility and per year is needed. EPA plans to initiate a review to understand if 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 2010–2022. 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

EPA (U.S. Environmental Protection Agency) (2010–2022) *Envirofacts GHGRP Subpart S and Subpart C Data*. Accessed May 15, 2024. Available online at: https://www.epa.gov/enviro/greenhouse-gas-customized-search.

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EPA (2024b) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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USGS (U.S. Geological Survey) (1996–2023) *Mineral Commodity Summary: Lime*. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/lime-statistics-and-information.

USGS (1991–2021) *Minerals Yearbook: Lime*. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/lime-statistics-and-information.

USGS (1991) Table 4. Lime Sold or Used by Producers in the United States, by State. In: *1990 Minerals Yearbook: Lime*. Available online at: https://search.library.wisc.edu/digital/A5X7AVV22D2URO8R/pages/AEH2VMYOUXX4O38T.

USGS (1992–2010) Table 2. Lime Sold or Used by Producers in the United States, by State. In: *1991–2009 Minerals Yearbook: Lime*. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/bureau-mines-minerals-yearbook-1932-1993 and https://www.usgs.gov/centers/national-minerals-information-center/lime-statistics-and-information.

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 2022, glass was produced in 30 states (EPA 2023).

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 2024). 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 2010–2022 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
2010–2022	• GHGRP process emissions data were used to estimate the percentage of emissions by state, multiplied by the national emissions (2006 IPCC Guidelines Tier 3).

Time Series Range	Summary of Method
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 state-level method used for 2010–2022 was based on process emissions reported to the GHGRP summed by state (EPA 2023) 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 1990–2009 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 2023) 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 2010–2022 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 2010–2022

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.[26] 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 to 2022 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 2022 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 2024), levels of uncertainty in the national estimates in 2022 were −2%/+2% for CO_2.

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

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 2010–2022 and the estimated number of facilities for 1990–2009.

For estimates from 2010–2022, 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

Due to GHGRP resubmissions from one facility for 2017 and a second facility for 2021, and a change in calculations for a facility that was mistakenly identified as a CEMS facility in 2012, recalculations were performed for 2012, 2017, and 2021. Due to the small changes in emissions, the state-level impacts for the three years were less than 1% for all states.

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) (2023) *Facility Level Information on GreenHouse gases Tool (FLIGHT)* Data set as of August 18, 2023. Available online at: https://ghgdata.epa.gov/ghgp/.

EPA (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. 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. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

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 (i.e., iron and steel production, ferroalloy production, and magnesium production), glass production, environmental pollution control, ceramics production, and non-metallurgical magnesia production. This section addresses only limestone, dolomite, soda ash, and magnesite use. Emissions from the use of these carbonates are organized into four subcategories: other uses of carbonates (i.e., limestone and dolomite consumption), ceramics production, other uses of soda ash, and non-metallurgical magnesia production. For industrial applications, carbonates 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, iron and steel, and magnesium, were excluded from this category and are reported under their respective source sections (e.g., Cement 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

For Other Process Uses of Carbonates, a combination of Approach 2 and Approach 1 methodologies was used. The Approach 2 state-level methodology allocates total national process emissions to all applicable U.S. states and territories using state-level consumption of limestone and dolomite for other uses of carbonates, state-level consumption of clay for ceramics production, and state population as a surrogate for other uses of soda ash, due to limitations in availability of state-specific data. The Approach 1 state-level methodology utilizes facility-level consumption of magnesite for non-metallurgical magnesia production.

3.1.4.2.1. Other Uses of Carbonates (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 1993–2022, 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 1995b–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.

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. Ceramics Production

National CO_2 emissions from the consumption of clay for emissive sources were calculated based on USGS data on the national-level consumption of clay for each of the three emissive subcategories (ceramics, glass, and floor and wall tile; refractories; and heavy clay products). USGS does not provide the state-level consumption of clay for each end use; however, USGS does publish annual state-level data on the total consumption of clay. Because no other source of data on state-level clay consumption was identified for any of the emissive sources, the USGS total clay consumption data by state were used.

For 1990–2022, state-level CO_2 emissions for the national *Inventory* were estimated using the USGS annual state values for clay sold or used by producers, compiled in the USGS Minerals Yearbook for Clay and Shale (U.S. Bureau of Mines 1991–1995; USGS 1995a–2022a). The national CO_2 emissions from clay consumption were disaggregated independently by calculating the fraction of clay consumption for each state-level consumption and applying that fraction to the estimated national-level CO_2 emissions for ceramics production 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.

For the full time series, certain state-level clay consumption data were withheld from the USGS publications to avoid disclosing proprietary information. Those values were aggregated and included in a category titled "Other." To ensure that the total reported consumption values for clay were accounted for, the "Other" value was equally distributed to the states for which consumption data were withheld. In 2013–2015, data for additional states were similarly grouped together to avoid disclosing proprietary information. Those values were also equally distributed to the states in each grouping to ensure that the total reported consumption values were accounted for. See Appendix C, Table C-13 in the "Other Process Uses of Carbonates" Tab, for more details on the data used.

3.1.4.2.3. Other Uses of Soda Ash

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, 2021, 2022a, 2022b; Instituto de Estadísticas de Puerto Rico 2021). For each year in the 1990–2022 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.

3.1.4.2.4. Non-Metallurgical Magnesia Production

All national non-metallurgical magnesia production emissions can be attributed to Nevada for the entirety of the time series. National CO_2 emissions from the consumption of magnesite for non-metallurgical magnesia production were calculated based on Nevada Department of Environmental Quality data on the quantities of magnesium ore extracted and processed at the only non-metallurgical magnesia production facility in the United States. See Appendix C, Table C-14 in the "Other Process Uses of Carbonates" Tab, for more details on the data used.

3.1.4.3 Uncertainty

The overall uncertainty associated with the 2022 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 2024), levels of uncertainty in the national estimates in 2022 were −12%/+15% for CO_2.

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

3.1.4.4 Recalculations

For the current national *Inventory*, updated state-level USGS data on limestone and dolomite consumption were available for 2021, removing the use of 2020 as a proxy, resulting in updated emissions estimates. Additional recalculations for emissions from soda ash consumption were performed for 2020 and 2021 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.

Emissions from ceramics production are being included for the first time this year. The new subcategory increased national CO_2 emissions by 756.7 kiloton (kt) CO_2 equivalent in 1990 and 406.5 kt CO_2 equivalent in 2022. The states that saw the largest impact to their overall CO_2 emissions across the full time series include Georgia, Texas, and Wyoming.

Emissions from non-metallurgical magnesia production are being included for the first time this year. The new subcategory only impacted the state of Nevada across the full time series because the only non-metallurgical magnesia production facility in the United States is located in Nevada.

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) (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. 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. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

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U.S. Bureau of Mines (1991b–1995b) *Minerals Yearbook for Crushed Stone*. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/bureau-mines-minerals-yearbook-1932-1993 and https://www.usgs.gov/centers/national-minerals-information-center/crushed-stone-statistics-and-information.

U.S. Census Bureau (2002) Table CO-EST2001-12-00. In: *Time Series of Intercensal State Population Estimates: April 1, 1990 to April 1, 2000*. 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) Table ST-EST00INT-01. In: *Intercensal Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2010.* 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 (2021) Table NST-EST2020. *Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2020*. Release date: July 2021. Available online at: https://www.census.gov/programs-surveys/popest/technical-documentation/research/evaluation-estimates/2020-evaluation-estimates/2010s-state-total.html.

U.S. Census Bureau (2022a) *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.

U.S. Census Bureau (2022b) Table NST-EST2022-POP. In: *Annual Estimates of the Resident Population for the United States, Regions, States, District of Columbia, and Puerto Rico: April 1, 2020 to July 1, 2022*. Release date: December 2022. Available online at: https://www.census.gov/data/tables/time-series/demo/popest/2020s-state-total.html.

USGS (U.S. Geological Survey) (1995a–2022a) *Minerals Yearbook: Clay and Shale Annual Report*. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/clays-statistics-and-information

USGS (1995b–2022b) *Minerals Yearbook: Crushed Stone Annual Report.* 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 4.16)

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, "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, 2021, 2022a, 2022b; Instituto de Estadísticas de Puerto Rico 2021). For each year in the 1990–2022 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 2022 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 2024), levels of uncertainty in the national estimates in 2022 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 and 2021 due to updated population data, resulting in a decrease in emissions of 3% for the District of Columbia for 2020. There was no impact on the emissions estimated for the 50 states and Puerto Rico in 2020 and 2021.

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) (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

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

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

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U.S. Census Bureau (2022b) Table NST-EST2022-POP. In: *Annual Estimates of the Resident Population for the United States, Regions, States, District of Columbia, and Puerto Rico: April 1, 2020 to July 1, 2022*. Release date: December 2022.

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 (HFC-23)
- Production of fluorochemicals other than HCFC-22 (HFCs, PFCs, SF_6, NF_3)
- 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 2022, 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 2023).[27]

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[27] 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.

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 2010–2022 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 2024). 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
2010–2022	• 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 2010–2022 was based on process emissions reported to the GHGRP and summed by state (EPA 2023) 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 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 2022 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 2024), levels of uncertainty in the national estimates in 2022 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 2010–2022 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 2010–2022, 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

For 2021, the urea consumption value was changed from a rounded value to a more precise unrounded value. Also, updated ammonia facility-level emissions were obtained from the GHGRP for 2021. Therefore, recalculations were performed for 2021. A resubmission of GHGRP data for 2021 from one facility in Oregon occurred after the 1990–2021 state-level inventory was completed. Due to the resubmission and changes to the urea consumption value, CO_2 emissions from ammonia production in Oregon for 2021 increased by 3% (2.2 kt CO_2), compared to the previous *Inventory*. Emissions from other states decreased slightly based on increased allocation to Oregon.

3.2.1.5 Planned Improvements

For the GHGRP emissions data used for 2010–2022, 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 2010–2022. 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) (2023) *Facility Level Information on GreenHouse gases Tool (FLIGHT).* Data set as of August 18, 2023. Available online at: https://ghgdata.epa.gov/ghgp/.

EPA (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. 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. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

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

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

USGS (2023) *Mineral Commodity Summaries: Nitrogen (Fixed)—Ammonia*. Available online at: https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-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, 2021, 2022a, 2022b; 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 2022 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 2024), levels of uncertainty in the national estimates in 2022 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 2017–2021, updated urea imports from USGS for 2021, updated urea exports from USGS for 2021, and updated population data for 2020 and 2021, recalculations were performed for 2017–2021 (USGS 2023). Compared to the previous national *Inventory,* state-level emissions increased for every state by less than 1% for 2017, less than 0.05% for 2018, and less than 0.07% for 2019. For 2020, emissions for the District of Columbia decreased by 3% and emissions for Massachusetts decreased by 1%, compared to the previous inventory. Compared to the previous *Inventory,* state-level emissions for 2021 increased by 33% for Alaska, Connecticut, Florida, Hawaii, Maine, North Dakota, Oregon, Pennsylvania, and Vermont, and state-level emissions increased by 32% for all remaining states/territories.

3.2.2.5 Planned Improvements

Data gaps include data on urea consumption for nonagricultural purposes by state for the full 1990–2022 time series.

3.2.2.6 References

EPA (U.S. Environmental Protection Agency) (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. 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. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

U.S. Census Bureau (2002) Table CO-EST2001-12-00. In: *Time Series of Intercensal State Population Estimates: April 1, 1990 to April 1, 2000*. 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) Table ST-EST00INT-01. In: *Intercensal Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2000 to July 1, 2010.* 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 (2021) Table NST-EST2020. In: *Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2020.* Release date: July 2021.

U.S. Census Bureau (2022a) *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.

U.S. Census Bureau (2022b) Table NST-EST2022-POP. In: *Annual Estimates of the Resident Population for the United States, Regions, States, District of Columbia, and Puerto Rico: April 1, 2020 to July 1, 2022*. Release date: December 2022.

USGS (U.S. Geological Survey) (2023) *Mineral Commodity Summaries: Nitrogen (Fixed)—Ammonia*. Available online at: https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-nitrogen.pdf.

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 2022, there were 31 active nitric acid production plants in 20 states (EPA 2024).

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 2024). 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 2010–2022. (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 2010–2022 and nitric acid production capacity by state and by year for 1990–2009, as shown in Table 3-6 below. Facility production capacity and location data were updated for 1990–2005 using the SRI Directory of Chemical Producers (SRI 1990–2005) and were updated for 2006 and 2007 using data obtained from Independent Commodity Intelligence Services (ICIS) (ICIS 2008). 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 in the state-level inventory.

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

Time Series Range	Summary of Method
2010–2022	• 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	• SRI Directory data (1990–2005) and ICIS data (2006–2009) 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 2010–2022 was based on process emissions reported to the GHGRP and summed by state (EPA 2023) 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 1990–2005 were estimated using the SRI Directory of Chemical Producers (SRI 1990–2005). For years 2006–2009, production capacity data were obtained from ICIS at the parent company level, as opposed to the facility level, necessitating a different approach to estimating state capacity data for 2006–2009 (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 2006–2009. 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 2006–2009. 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 2022 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 2024), levels of uncertainty in the national estimates in 2022 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 nitric acid production capacity by state and by year for 1990–2009. This assumption was required because of a general lack of more granular state-level data.

For 2010–2022, 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

The use of production capacity data from the SRI Directory of Chemical Producers for 1990–2005, and the use of ICIS data for 2006–2009, resulted in changes to the total nitric acid capacity per year and per 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. For years 1990–2005, recalculations show that the production capacity (and emissions) per state decreased by less than 21% from the percentages used in the previous state emission estimates. For years 2006 and 2007, recalculations show that the production capacity (and emissions) per state increased by 15% from the percentages used in the 1990–2021 state emissions analysis.

Resubmissions of GHGRP data for 2020 and 2021 from one facility in Texas caused N_2O emissions from nitric acid production to increase by 33% (0.71 kt N_2O) and 42% (0.82 kt N_2O), respectively, compared to the previous *Inventory*. Due to the resulting change in the overall percentages for all states, emissions from other states decreased by 2.0% in 2020 and decreased by 3.0% in 2021.

3.2.3.5 Planned Improvements

Data gaps include nitric acid capacity for 2006–2007 and 2009, 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 2010–2022. 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

EPA (U.S. Environmental Protection Agency) (2023) *Facility Level Information on GreenHouse gases Tool (FLIGHT).* Data set as of August 18, 2023. Available online at: https://ghgdata.epa.gov/ghgp/.

EPA (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. 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*. Accessed February 18, 2021. Previously available online at: https://www.icis.com/explore/resources/news/2008/05/19/9124327/chemical-profile-nitric-acid/.

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. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

SRI (1990–2005). *SRI International Directory of Chemical Producers*.

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 2010–2022, 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 to 2022.

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 2010–2022 used facility-level process emissions reported to the GHGRP (EPA 2023). 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 2023) 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 2022 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 2024), levels of uncertainty in the national estimates in 2022 were −4%/+4% 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

No recalculations were applied for this current report, consistent with the national *Inventory*.

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) (2023) *Facility Level Information on Greenhouse gases Tool (FLIGHT)*. Data set as of August 18, 2023. Available online at: https://ghgdata.epa.gov/ghgp/.

EPA (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. 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. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

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 1990–2022 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 1990–2022 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 1990–2022, 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 the SRI Directory of Chemical Producers for 1990–1993 and 2004–2005 (SRI 1990–1993 and 2004–2005) and from ICIS for 2006. The SRI Directory did not list capacity by facility for 1993–2003. The capacity data were applied to each specific year, where available (1990–1993 and 2004–2006), 1993 SRI capacity data were applied to years 1994–2004, and 2006 ICIS capacity data were applied to years 2006–2022. 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 2022 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 2024), levels of uncertainty in the national estimates in 2022 were −31%/+31% 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 1990–2022. This assumption was required because of a general lack of more granular state-level data.

For 1990–2022, 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 1990–2005 to reflect updated caprolactam capacity data from the SRI Directory of Chemical Producers (SRI 1990–1993 and 2004–2005). State-level emissions for Georgia decreased by 4% in 1990 and increased by an average of 4% per year from 1991 to 2005, compared to the previous national *Inventory*. State-level emissions for Texas decreased by an average of 13% per year from 1990 to 2003 and decreased by 1% per year for 2004–2005, compared to the previous national *Inventory*. State-level emissions for Virginia increased by an average of 7% per year from 1990 to 2003 and decreased by 1% per year for 2004–2005, compared to the previous national *Inventory*.

Recalculations were also performed for 2020 and 2021 to reflect updated caprolactam production data from the American Chemistry Council's *Guide to the Business of Chemistry* (ACC 2023). Compared to the previous *Inventory*, national annual N_2O emissions decreased by 2% in 2020 and 2021, with a corresponding percent decrease in Texas and Virginia in 2020 and 2021.

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

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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, 2020–2023) used in the national *Inventory* (EPA 2024). 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). 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, 2021, 2022;

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 2022 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 2024), levels of uncertainty in the national estimates in 2022 were −10%/+10% for CO_2 and −10%/+11% for CH_4.

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 2020 and 2021 as updated population data were available from the U.S. Census Bureau. The updated population data had a negligible impact (less than 0.5%) on the state-level CO_2 kt emissions estimated for the 50 states and Puerto Rico for 2020 and 2021 due to the low emissions estimated for each state or territory for the sector. Compared to the previous inventory, the District of Columbia 2020 emissions decreased by less than 3% and 2021 emissions decreased by less than 0.5%.

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 2022 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 2010–2022 (EPA 2024; EPA 2023) 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 2024). National TiO_2 production data were allocated among the eight states with TiO_2 production facilities over the 1990–2022 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
2010–2022	• 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 2010–2022 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 2022 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 2024), levels of uncertainty in the national estimates in 2022 were −12%/+13% for CO_2.

State-level estimates are expected to have an overall higher uncertainty because the national emissions estimates were apportioned to each state based on a combination of GHGRP emissions data for 2010–2022 and facility production capacity for 1990–2009. These assumptions were required because of a general lack of more granular state-level data.

For 2010–2022, 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 2010–2022, 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

USGS updated the estimated 2019 and 2020 TiO_2 production values, and recalculations were performed for those years. Compared to the previous inventory, CO_2 from TiO_2 production decreased by 9% in 2019 (21 kt CO_2 for Louisiana, 59 kt CO_2 for Mississippi, 27 kt CO_2 for Ohio, and 27 kt CO_2 for Tennessee) and increased by 12% in 2020 (20 kt CO_2 for Louisiana, 70 kt CO_2 for Mississippi, 28 kt CO_2 for Ohio, and 29 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 1990–2022. GHGRP emissions data are available for the period 2010–2022 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 2010–2022. 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 1990–2022 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 2024), 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 1990–2022 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 and 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 1990–2022 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 2022 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 2024), levels of uncertainty in the national estimates in 2022 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) (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. 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 2022, petrochemicals were produced at 76 facilities in 11 states (EPA 2024). 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 2010–2022, and the *Inventory*-derived estimates for methanol are based on facility-level GHGRP emissions for 2015–2022. The GHGRP has no reporting threshold for petrochemical production, so these emissions data are representative of the industry. For all petrochemicals in 1990–2009, and for methanol in 2010–2014, estimates were based on emissions factors derived from GHGRP data and production data from the American Chemistry Council and the International Carbon Black Association (ACC 2023; EPA 2024). For all years, the national emissions estimates for acrylonitrile were based on emissions factors and production data from the American Chemistry Council because the national GHGRP data are considered CBI. Similarly, the national GHGRP data for methanol in 2010–2014 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 2022, 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 2019–2022); 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. Similarly, GHGRP emissions data for methanol could pass CBI aggregation criteria at the state level in Texas for RY 2015–2022, but it is not possible to aggregate the methanol emissions in 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 2010–2022, the aggregated GHGRP emissions for methanol in RY 2015–2022, and the calculated nationwide emissions for other years and for 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 and 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 2018–2022 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. Additionally, the capacity for a facility in Texas that was reported to be idle in 2002 was estimated as zero for 2002.

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 and 2005, except for 1995 (SRI International 1990–2005). For all years between 1990 and 2005, this analysis used SRI data.

Capacities for 1995 were estimated using linear interpolation between the known 1994 and 1996 values. Capacities for 2006–2022 were assumed to be the same as in 2005. Five plants closed between 2001 and 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).

Because site-specific capacities for 1994–2003 were not known, a linear interpolation of capacities was assumed between 1993 and 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 and 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 most facilities in 2006 were assumed to be the same as in 2005. However, a linear interpolation between the known capacities in 2005 and 2007 was assumed for four facilities that had more than a nominal difference in the known capacities for 2005 and 2007. Capacities for 2008–2012 and 2014 were estimated using linear interpolation between the known values in 2007, 2013, and 2015. Capacities for 2016–2022 were assumed to be the same as in 2015, except for new startups and expansions. One new plant started up in Texas in 2017 and two in 2022, one new plant started up in Louisiana in 2019 and one in 2020, one new plant started up in Pennsylvania in 2022, one idled plant was restarted in Louisiana in 2019, one plant expanded in Texas in 2017, two plants expanded in Texas in 2018, one plant expanded in Louisiana in 2019, and one plant expanded in Texas in 2020 (BIC Magazine 2019; Chevron Phillips Chemical 2018; ExxonMobil 2018; Indorama Ventures 2015; ExxonMobil 2022; LACC 2016; LyondellBasell 2017; OxyChem 2017; O&GJ 2020, 2022; Petrotahill 2020; TotalEnergies 2022). 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 three expansions at unknown dates in the late 1990s. It was assumed that one facility expanded in 1996, one in 1998, and one in 1999. For one facility in this *Inventory*, the linear interpolation values in 1999–2003 were replaced with the 2004 capacity based on new information documenting that the facility expanded in 1998 (Nemeroff n.d.). In addition, two facilities from the previous *Inventory* (one in Texas and one in Louisiana) were removed from the current *Inventory* because it was determined that they produce ethylene dichloride using the direct chlorination process, which emits negligible CO_2 emissions (SRI International 1990–2005). Making these assumptions resulted in corporate capacity shares that agreed reasonably well with the SRI percentages.

For most facilities, the ICIS capacities in 2009 matched the SRI International capacities in 2005; thus, the capacities for these facilities were assumed to be unchanged from 2005 to 2009. For three facilities in 2006–2008, a linear interpolation of capacities was assumed because the known capacities in 2005 and 2009 differed by more than a nominal amount. The capacities in 2010–2022 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 74%, with a high of 91% in 1997 and a low of 51% 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. In the current *Inventory*, the estimated capacity of one facility in 2002 was increased to better reflect the combination of old unit shutdowns and startup of a new unit. Known capacities for 2005 typically were close to the known capacities for 2010. Thus, in previous *Inventories*, capacities for 2006–2009 were assumed to be the same as the previously known capacities in 2005. This approach was applied again for this *Inventory,* except in the case of two facilities. In this *Inventory*, a linear interpolation of capacities was used for 2006–2009 for those two facilities because the known values in 2005 and 2010 differed by more than a nominal amount. Capacities for 2011 and 2013–2017 were based on linear interpolation between the known capacities in 2010, 2012, and 2018. All capacities in 2019–2022 were assumed to be the same as the known capacities in 2018, except for three facilities that started up in 2019 and one facility that started up in 2022.

There were several plant openings and closings 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. The resulting calculations of corporate capacity shares agreed reasonably well with the SRI percentages. Capacities for new ethylene oxide units started up by Lotte, Sasol, and MEGlobal in 2019 and by Gulf Coast Growth Ventures in 2022 were reported directly or could be estimated from other data reported on company websites (EQUATE 2019; ICIS 2022; LACC 2016; Sasol 2019, 2020).

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 from the national *Inventory* across the time series, with the exception of 1995 and 2004 where production was 104% of capacity. Conversely, when using total production from the American Chemistry Council for all years in the times series, the capacity utilization values of 0.39–0.58 in 2019–2022 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 on-site captive use production, which would bias the nationwide production values to be low. Average capacity utilization based on production from the national *Inventory* over time was 86%, and average capacity utilization based on production from the American Chemistry Council for 1990–2022 was 78%. 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, one facility that expanded in 2015, and one facility for which a linear interpolation between the known capacities in 2014 and 2016 was used to estimate the capacity in 2015. Capacities in 2017 were assumed to be the same as in 2016 and 2018. Capacities in 2019–2022 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 and 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 updated for this Inventory based on new information from the owner's website (Koch Methanol St. James 2021).

Eight methanol plants closed between 1998 and 2010. Data on plant closures between 1998 and 2005 were from OCI (OCI Partners LP 2016, 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 2022 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 2024), levels of uncertainty in the national estimates in 2022 were −4%/+4% for CO_2 and −14%/+14% 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 following calculation corrections and changes in assumptions regarding some of the production capacity data used in the previous *Inventory* resulted in minor changes to the total capacity per petrochemical per year for ethylene dichloride, ethylene, and ethylene oxide production, and they 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.

- For ethylene dichloride, one facility in Louisiana and one facility in Texas were removed from the analysis for the current *Inventory* because these facilities produce ethylene dichloride using the direct chlorination process, which emits minimal CO_2 and is not subject to reporting under the GHGRP. For another facility in Louisiana, a linear interpolation was used in the previous *Inventory* to estimate the ethylene dichloride capacity for 1996–2002. New information confirmed that this facility expanded in 1998 (Nemeroff n.d.). Therefore, in this *Inventory*, the capacity for this facility in 1996–1998 was assumed to be the same as the known capacity in 1995, and the capacity in 1999–2002 was assumed to be the same as the known capacity in 2003. For a facility in Kentucky, the capacity in 2006–2008 was assumed in the previous *Inventory* to be the same as the known capacity in 2005. For this *Inventory*, a linear interpolation between the known capacities in 2005 and 2009 was assumed because the known values differed by more than a nominal amount. Collectively, these changes resulted in increases in the percentage of total capacity in Kentucky by 21% to 43% in 2006–2008 and 7% to 9% in most other years. The percentage of total capacity in Louisiana typically decreased by less than 1% per year, except in 2002–2005 where the capacity in Louisiana increased by 3% to 5% and in 1999, 2000, and 2006–2009 where the capacity decreased by 2% to 3%.

- For ethylene oxide, the capacity for one facility in Louisiana was changed in 2002 for this *Inventory* to better reflect expansion and partial shutdown of existing units. This resulted in an increase of 4% of the total capacity in Louisiana and a decrease of 3% in both Delaware and Texas in 2002.
- For ethylene, a typographical error in the calculation spreadsheet resulted in the 1990 and 1991 capacities for one facility in Illinois being excluded from the analysis for the previous *Inventory*. After correcting the error, the percentage of total capacity in Illinois increased by 40% in 1990 and 39% in 1991 for this *Inventory*. For a facility in Louisiana, a calculation error in the sum of the previous capacity and the capacity of an expansion resulted in underestimation of the total expanded capacity for this facility in 2020 and 2021 in the previous *Inventory*. Correcting this error resulted in an increase of 2% in the percentage of total capacity in Louisiana in both years in this *Inventory*. Reductions in the percentage of the total capacity for other states were less than 1% in 1990, 1991, 2020, and 2021.

A methodology refinement for calculating emissions from methanol production was implemented in the national *Inventory* for 1990–2022. For 2015–2021, these changes resulted in a decrease in the reported CO_2 emissions, with the size of the decrease ranging from 43% (873 kt) in 2015 to 61% (2,110 kt) in 2018. For 1990–2014, the refinement resulted in a reduction of 61% each year (287 kt in 2011 to 2,449 kt in 1997). There were no changes in the estimated capacities per facility or in the percentage of total capacity in each state for the current *Inventory*, but as a result of the decrease in nationwide emissions, emissions for each state decreased by the same percentage as the reduction in emissions in the national *Inventory*. Additionally, the methodology refinement reduced CH_4 emissions from methanol production in the national *Inventory* to zero for all years of the time series because the methodology refinement is based on the assumption that all carbon input to the process is converted either to primary or secondary products or to CO_2. Although there were no changes in the estimated capacities per facility or to the percentage of total capacity in each state, the reduction of nationwide CH_4 emissions to zero means that the CH_4 emissions in each state have been reduced by 100% in this *Inventory*.

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 2010–2022, 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 and 2020 under Title VI of the Clean Air Act, which controls production and consumption of HCFCs and other compounds that deplete stratospheric ozone. Production of HCFC-22 for use as a feedstock is allowed to continue indefinitely.

3.2.10.2 Methods/Approach

As discussed on page 4-74 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 2010–2022, 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).
2010–2022	• Facility-specific GHGRP data on HFC-23 emissions were compiled by state (Approach 1).

For each state, HFC-23 emissions from 2010–2022 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 2010–2022 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 to 2010 and a slow increase in HCFC-22 production from 1990 to 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*.[28] To estimate the share of national emissions attributable to each facility, each facility's estimated production was multiplied by its estimated emissions rate, resulting in a provisional emissions estimate for each facility for each year. Each facility's provisional emissions estimate was then divided by the sum of the provisional emissions estimates for both facilities. The resulting fraction was multiplied by the national emissions (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 to 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 and 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 to 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 2022

Company	Plant Location	Years When HCFC-22 Was Produced or HFC-23 Was Destroyed
Arkema	Calvert City, KY	1990–1991
	Wichita, KS	1990–2002
Clean Harbors	El Dorado, AR	2019
DuPont/Chemours	Montague, MI	1990–1995
	Louisville, KY	1990–2022
	Washington, WV	2000–2022
Honeywell	El Segundo, CA	1990–1992
	Baton Rouge, LA	1990–2012
LaRoche Industries	Gramercy, LA	1990–1993
MDA Manufacturing/Daikin	Decatur, AL	1993–2022

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[28] 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.

3.2.10.3 Uncertainty

The overall uncertainty associated with the 2022 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 4-75 of the national *Inventory* (EPA 2024), the uncertainty in the national estimate in 2022 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

The 2019 emissions estimate for Arkansas increased from 0 to 0.05 kg of HFC-23 to reflect newly reported emissions from a facility that destroys HFC-23.

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

EPA (U.S. Environmental Protection Agency) (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. 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. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

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.

SRI Consulting (2004) *CEH Market Research Report: Fluorocarbons*.

3.2.11 Production of Fluorochemicals Other than HCFC-22 (NIR Section 4.15)

3.2.11.1 Background

Fluorochemical production includes processes that produce or transform saturated and unsaturated (HFCs, PFCs, SF_6 NF_3, hydrofluoroethers (HFEs), perfluoroalkylamines, and other fluorinated compounds. Emissions may include reactants, products, and byproducts from the production or transformation process; residual gas vented from containers; and residual emissions from destruction of previously produced fluorinated GHGs. Most saturated HFCs were developed for use as replacements for or alternatives to ozone-depleting substances such as CFCs and HCFCs that have been phased out under the Montreal Protocol, and many saturated HFCs are now themselves being phased out under the Kigali Agreement and U.S. AIM program. PFCs are commonly used in the semiconductor industry. SF_6 is used for electric power systems, magnesium production, and electronics manufacturing, and NF_3 is also used in the semiconductor industry. Other fluorinated GHGs are used for a variety of purposes (e.g., for firefighting, as anesthesia, and as feedstocks for fluoropolymer production). Fluorinated GHG emissions from the national *Inventory* were disaggregated across states in 2023 using facility-level reporting to the GHGRP from 2011 to 2022 and production data, emission factors, and facility-provided emissions data for earlier years.

3.2.11.2 Methods/Approach

As discussed on page 4-81 of the national *Inventory*, methods comparable to the Tier 3 methods in the 2006 IPCC Guidelines (as elaborated by the 2019 Refinement) were used to estimate fluorinated GHG emissions from most U.S. facilities producing fluorinated compounds, while the Tier 1 method was used to estimate fluorinated GHG emissions from U.S. production facilities for which there are fewer data. For the facilities for which Tier 3 methods were used, facility-specific estimates had been developed and summed to arrive at the estimates in the national *Inventory*. For this analysis, therefore, those facility-specific estimates were readily available to disaggregate to the states where the facilities are located. The same was true for one facility for which the Tier 1 method was used, relying on publicly available production capacity data. For the other facilities for which the Tier 1 method was used, confidentiality concerns prohibit the publication of facility-specific emissions estimates because facility-specific production can be back-calculated from the emissions and the Tier 1 emission factors. Thus, for these facilities, the total emissions calculated for the facilities were divided by the number of the facilities operating in each year, and the results were allocated to the states where those facilities are located. The sum of emissions by state is consistent with national process emissions as reported in the national *Inventory* over the time series. Table 3-10 summarizes the approaches used to disaggregate the national *Inventory* for fluorochemical production across the time series.

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

Time Series Range	Summary of Method
1990–2010	• For 17 facilities, facility-specific estimates from the national *Inventory* were compiled by state (Approach 1). For five facilities, the national estimate for all five facilities was divided by five and allocated to each state where the facilities were located (Approach 2).
2011–2022	• For 17 facilities, facility-specific estimates from the national *Inventory* were compiled by state (Approach 1). For five to seven facilities, the national estimate for all five to seven facilities was divided by five to seven, as applicable in that year, and allocated to each state where facilities were located (Approach 2).

3.2.11.3 Uncertainty

The overall uncertainty associated with the 2022 national estimates of fluorinated GHG emissions from fluorochemical production was calculated using the 2006 IPCC Guidelines Approach 1 methodology for uncertainty (IPCC 2006). As described further in Chapter 4 (pages 4-90 to 4-95) and in Annex 7 of the national *Inventory* (EPA 2024), the uncertainty in the national estimates in 2022 was estimated at −19%/+19% for fluorinated GHGs (HFCs, PFCs, SF_6, NF_3).

Emissions uncertainties at the state level are higher than emissions uncertainties at the national level because most states contain only one or two facilities, providing less of an opportunity for facility-level uncertainties to “cancel out” over a large number of facilities. Uncertainties at the state level are likely to be only slightly smaller than uncertainties at the facility level. For fluorochemical production facilities that reported their emissions to the GHGRP in 2022, the relative uncertainties of facility-level emissions are estimated to have ranged from ±17% to ±89%, depending on the shares of emissions coming from process vents whose emission factors have been measured, process vents whose emission factors have been calculated, leaks, and container venting, all of which have different uncertainties. The average relative uncertainty of emissions from facilities that reported their emissions under the GHGRP was estimated to be ±47%. For fluorochemical production facilities that reported only production under the GHGRP, the relative uncertainties of facility-level emissions are estimated at ±98%, but the actual uncertainties for the estimates for these facilities in this analysis are higher because the facility-specific emissions are calculated by dividing the total emissions across these facilities by the number of facilities. This approach is likely to underestimate the emissions of some facilities while overestimating the emissions of others.

These quantitative uncertainty estimates capture only some of the uncertainties in the emissions estimates. The sources of uncertainty in both the 1990–2010 estimates and the 2011–2022 estimates are described in detail in the national *Inventory*. These sources of uncertainty also apply to the state estimates, and like the quantified uncertainty estimates, are likely to have a larger impact on the uncertainties of the state-level estimates than on the uncertainties of the national estimates.

3.2.11.4 Recalculations

This is a new category included for the current (i.e., 1990–2022) *Inventory;* thus, no recalculations were performed.

3.2.11.5 Planned Improvements

EPA is planning to refine its estimates of emissions from facilities that do not report their emissions to the GHGRP after confirming with the facilities that their actual per-facility uncontrolled emissions fall below 25,000 metric tons CO_2 Eq. EPA is also planning to refine its estimates of emissions for other facilities for 1990–2009 (e.g., by comparing these against emissions inferred from atmospheric measurements). Moreover, EPA is continuing to seek data sets that can be used to improve and/or QA/QC emissions estimates, particularly for the years 1990–2009. These data sets may include, for example, real-time facility-specific estimates or additional global “top-down,” atmosphere-based emissions estimates that could be used to establish an upper limit on emissions of certain compounds.

3.2.11.6 References

EPA (U.S. Environmental Protection Agency) (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. 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. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

Full citations of references included in Chapter 4.15 (Production of Fluorochemicals Other than HCFC-22 [CRT Source Category 2B9b]) of the national *Inventory* are available online here: https://www.epa.gov/system/files/documents/2024-04/us-ghg-inventory-2024-chapter-10-references_0.pdf.

3.2.12 Phosphoric Acid Production (NIR Section 4.17)

3.2.12.1 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.. Emissions from fuels consumed for energy purposes during the production of phosphoric acid are accounted for as part of fossil fuel combustion in the industrial end-use sector reported under the Energy chapter. In 2022, phosphoric acid was produced in Florida, Idaho, Louisiana, North Carolina, and Wyoming.

3.2.12.2 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 2010–2022 and estimated phosphoric acid production capacity by state for 1990–2009, as shown in Table 3-11. 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 3-11. Summary of Approaches to Disaggregate the National *Inventory* for Phosphoric Acid Production Across Time Series

Time Series Range	Summary of Method
2010–2022	• 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 2010–2022 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 1990–2022 (USGS 1994–2023). 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.

3.2.12.3 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 2024), levels of uncertainty in the national estimates in 2022 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 2010–2022, 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.

3.2.12.4 Recalculations

The 2021 value for the total U.S. production of phosphate rock was updated based on updated USGS data. These updates resulted in an overall decrease of 35 kt CO_2 in 2021 at the national level. State-level changes include a 5% decrease for Florida (446.0 to 424.7 kt CO_2), a 5% decrease for Idaho (94.9 to 90.4 kt CO_2), a 1% increase for Louisiana (149.1 to 150.7 kt CO_2), and a 5% decrease for North Carolina (161.8 to 154.1 kt CO_2).

3.2.12.5 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.

3.2.12.6 References

EPA (U.S. Environmental Protection Agency) (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. 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. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

SRI International (1990–2005) *Directory of Chemical Producers: United States of America*.

USGS (U.S. Geological Survey) (1994–2023) *Minerals Yearbook. Phosphate Rock Annual Report*. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/phosphate-rock-statistics-and-information.

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 4.18)

3.3.1.1 Background

Iron and steel (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[29] 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 2022, I&S production occurred in 37 states, with seven states accounting for roughly 62% of total raw steel production: Indiana, Alabama, Tennessee, Kentucky, Mississippi, Arkansas, and Ohio (AISI 2023).

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

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[29] “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.

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 2010–2022, process emissions reported to the GHGRP under Subpart Q (I&S facilities) were summed by state (EPA 2024a) 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 were used when estimating state emissions percentages from I&S facilities in 2010–2022. 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).[30] The percentage of employees and steel production across the region aggregated with Maryland in the AISI data (Rhode Island, Connecticut, New Jersey, New York, Delaware, and Maryland) based on the 2007 data were applied across the entire time series.

Furthermore, steel production by state was broken out into BOF and EAF steel production based on the national totals of each type of steel produced from AISI data. Steel production in each state by type was assumed to be proportional to the national totals by type for each year. Once data on steel production by type were determined for each state and year, the total national emissions by steel type was attributed to each state based on steel production in each state. This approach assumes that emissions from steel production are directly proportional to the amount of steel produced in a state. This assumption could lead to 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 2010–2022, 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 2022 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 2024b), levels of uncertainty in the national estimates in 2022 were −16%/+16% for CO_2 and −7%/+7% for CH_4.

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

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 on-site use, this method could overestimate emissions from coking coal for states where facilities transfer coking coal off-site and underestimate emissions for states where facilities transfer coking coal for metallurgical coke production across state boundaries.

For 2010–2022, 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 2009), 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 in the national *Inventory* were performed for the year 2021 using updated USGS values for DRI, pig iron, and scrap steel consumption for both BOF and EAF steel production. Additionally, revisions to GHGRP data for 2020 and 2021 resulted in minor changes to activity data that were adjusted using GHGRP data. Compared to the previous *Inventory*, CO_2 emissions from steel production increased by less than 1% (11 kt CO_2) in 2020 and by less than 1% (216 kt CO_2) in 2021. The largest changes in emissions by state occurred in Alabama, which saw a 13.7% increase in CO_2 emissions from steel production. Finally, the heat content of coal was updated from 23.89 million Btu/ton to 23.91 million Btu/ton in the national *Inventory*, which resulted in a minor increase in CO_2 emissions from pig iron production.

3.3.1.5 Planned Improvements

AISI production data were only available for the years 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 2010–2022 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

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3.3.2 Ferroalloys Production (NIR Section 4.19)

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 2022, ferroalloy production occurred in six states: Ohio, Kentucky, Pennsylvania, Alabama, West Virginia, and Michigan.

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

Time Series Range	Summary of Method
2010–2022	• GHGRP facility process emissions data were used. • Remaining emissions reported in the national Inventory were allocated evenly 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 reported in the national *Inventory* were allocated evenly across remaining known facilities (IPCC 2006 Tier 1).

To identify all ferroalloy-producing facilities for 1990–2022, 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 for the years 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 2010–2022, 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 2010–2022, process emissions reported to the GHGRP were summed (EPA 2010–2022) 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 2022 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 2024), levels of uncertainty in the national estimates in 2022 were −13%/+13% for CO_2 and −12%/+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 2010–2022, 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

No recalculations were performed for the 1990–2021 portion of the time series.

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 4.20)

3.3.3.1 Background

The production of primary aluminum—in addition to consuming large quantities of electricity—results in process-related emissions of CO_2 and two perfluorocarbons: 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 (aluminum oxide, 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 from 2006 forward.

3.3.3.2 Methods/Approach

National emissions of CO_2 and PFCs from aluminum production are estimated using a combination of IPCC Tier 1, Tier 2 and Tier 3 methods (i.e., EPA GHGRP data) over the time series as discussed in Chapter 4, Section 4.20 (on pages 4-121 through 4-127) of the national *Inventory*. IPCC Tier 1 methods were used only to estimate PFC emissions from LVAEs.

Aluminum production emissions calculated nationally were allocated to the state level using a Hybrid approach due to lack of facility-level and/or state-level production data for earlier years of the time series. For 2010 and later, EPA used the same underlying methods that were used for the national *Inventory* (i.e., facility-specific process emissions reported to EPA's GHGRP under subpart F: Aluminum Production were used to estimate state-level emissions); for 1990–2009, EPA used the ratio of each state's smelter capacity to the U.S. total capacity to allocate national emissions to each state. The approach summarized in Table 3-13 was taken to compile aluminum production estimates by state consistent with national totals.

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

Time Series Range	Summary of Method
2010–2022	• GHGRP process emissions data were used to get emissions by state (i.e., Approach 1).
1990–2009	• Data on smelter capacity were used to get percentage of production by state, which was then multiplied by national emissions (Approach 2).

For 2010–2022, 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 HVAE CF_4 emissions. The percentages were calculated on a yearly basis (state total/yearly total) to account for non-reporting years.

For 1990–2009, EPA allocated national totals to each state using the ratio of each state's smelter capacity to the U.S. total capacity, on a yearly basis (i.e., state X emissions = national emissions × [ratio = state X smelter capacity/national smelter capacity]). Capacity data for the years 1990, 1993, 2001, and 2004–2009 were collected from the respective years' USGS Aluminum yearbook, and capacities for other years were interpolated from the aforementioned USGS Aluminum yearbooks' capacity data trends (USGS 1996-2022). Information on idle facilities and shutdowns was incorporated in determining state smelter capacities based on USGS Aluminum yearbook notes and additional sources (including public articles and expert reviewers' feedback). National emissions during this time period were developed using smelter capacity data and the USAA U.S. primary aluminum production estimates (USAA 2020), combined with the process emissions and activity data reported under EPA's Voluntary Aluminum Industrial Partnership Program (VAIP). Facilities under the parent company Alcoa had certain production data aggregated within the 1990–2009 time series; these data were allocated by building percentage assumptions based on all the data and information described above.

3.3.3.3 Uncertainty

The overall uncertainties associated with the 2022 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 2022 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 3% below to 3% above, 8% below to 8% above, and 9% below to 9% above their 2020 emission estimates, respectively.

For the 2010 to 2022 time series, the uncertainties associated with the state-level estimates are expected to be lower than those for the 1990–2009 time series because emissions are estimated and reported at the facility level. Nevertheless, the 2010 to 2022 state-level uncertainties are somewhat higher than 2010 to 2022 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.[31] The uncertainty of each smelter's CO_2 emissions is estimated at -/+6%; the uncertainty of each smelter's HVAE CF_4 emissions is estimated to range from -/+16%; and the uncertainty of each smelter's HVAE C_2F_6 emissions is estimated to range from -/+20%. The uncertainty associated with LVAE emissions is estimated based on the smelter technology type and is estimated to range from -/+99% for each smelter. Because LVAE emissions make up a small share of total PFC emissions, this uncertainty does not have a large impact on the overall uncertainty of PFC emissions at either the smelter or the US level. For more details on national-level uncertainty, see the Uncertainty discussion in Chapter 4 of the national *Inventory*.

State-level estimates are expected to have significantly higher uncertainties for 1990–2009 than more recent years due to the methods used to apportion the national emission estimates to each state based on the capacity data from the USGS Aluminum yearbooks. This approach does not reflect the volatility in actual aluminum production activities in each smelter (and thus in the different states) from year to year, and the estimated emissions in each state may therefore differ from the actual emissions resulting from aluminum production activities in that state.

3.3.3.4 Recalculations

Refer to Section 4.20 (page 4-127) of the national *Inventory* report (EPA 2024) for a complete list of recalculations for the national *Inventory*.

3.3.3.5 Planned Improvements

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

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 (for non-partners) and CO_2 emissions (for all facilities) for the 1990 through 2009 time series (years preceding GHGRP reporting). Additional improvements include evaluating the LVAE emissions calculations method by state for the 2010–2022 time series. Currently, the LVAE CF_4 emissions are based on each state's yearly

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[31] 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.

percentage of total HVAE CF4 emissions. Future iterations of the state disaggregation estimates of LVAE CF_4 emissions will be based on estimates of aluminum production, consistent with the Tier 1 LVAE method and the national *Inventory.*

3.3.3.6 References

EPA (U.S. Environmental Protection Agency) (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

IPCC (Intergovernmental Panel on Climate Change) (2019) *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. E.C. Buendia, K. Tanabe, A. Kranjc, J. Baasansuren, M. Fukuda, S. Ngarize A. Osako, Y. Pyrozhenko, P. Shermanau, and S. Federici (eds.). Available online at: https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/.

USAA (U.S. Aluminum Association). (2020). *U.S. Primary Aluminum Production: Report for August 2020*.

USGS (U.S. Geological Survey). (1996–2022). *Minerals Yearbook: Aluminum.*

3.3.4 Magnesium Production and Processing (NIR Section 4.21)

3.3.4.1 Background

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

3.3.4.2 Methods/Approach

National emissions of SF_6, HFC-134a, Novec 612, and CO_2 from magnesium production and processing are estimated using a combination of IPCC Tier 2 and Tier 3 methods over the time series as discussed in Chapter 4, Section 4.21 (on pages 4-127 through 4-133) of the national *Inventory* (EPA 2024).

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 2011–2022, EPA used facility-specific emissions data from its 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 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 3-14 provides additional specifics on the approaches taken to compile state-level estimates of emissions for magnesium production consistent with national totals.

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

Time Series Range	Summary of Method
2011–2022	• 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 to 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 process for 1990–1998 is based on disaggregating 1999 national emissions by process type and by state and then using that to develop shares of state emissions as a portion of total national emissions. These 1999 state emissions shares by process type were used to allocate estimated total U.S. emissions by process type to states for 1990–1998.

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

The methodology used for 2011–2022 relied on GHGRP-reported emissions (EPA 2024b). 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 2011–2022 emissions associated with these processes are not reported through the GHGRP. Total U.S. production is reported through the USGS Yearbook (USGS 2002, 2003, 2005–2017, 2020–2022). 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 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 2022 national estimates of SF_6, HFC-134a, and CO_2 emissions from magnesium production and processing were calculated using the were calculated using the *2019 Refinement to the 2006 IPCC Guidelines*. As described further in Chapter 4 of the national *Inventory*, levels of uncertainty in the national estimates in 2022 for all gases in aggregate were −9%/+9%.

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 2011–2022 time series, the uncertainties associated with the state-level estimates are expected to be low because emissions are estimated and reported at the facility level for the most part. Nevertheless, the 2011–2022 state-level uncertainties are somewhat higher than 2011–2022 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 that national estimates in the same time period, as well as more uncertainty than that of the state-level estimates for 2011–2022. This is due to a higher proportion of facility data being available through the GHGRP as compared to the EPA Partnership 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:

- Updates to back casting methodology for a die casting facility based on an earlier confirmed opening on the facility. Updates to values previously held constant for 2001-2013 by shifting to interpolation between the new confirmed opening year and the year of first reported data.
- Updates to the estimation methodology of sand casting non-partner GHGRP volumes and updates to the emission factor for sand casting from 1990 to 2011 changed the amount of nonreported sand emissions and the distribution of those emissions to states.

Refer to Section 4.21 (page 4-109) of the national *Inventory* report for a complete list of recalculations for the national *Inventory*.

3.3.4.5 Planned Improvements

One planned improvement would be to investigate information that could be used to update the factors used to allocate emissions from non-reporters. Currently, this is based on the fraction of GHGRP-reported emissions in each state.

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

3.3.4.6 References

EPA (U.S. Environmental Protection Agency) (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990*-*2022.* EPA 430-R-24-004. Available online at: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

EPA (2024b) *Envirofacts. Subpart T: Magnesium Production.* Available online at: http ://www.epa.gov/enviro/facts/ghg/search.html.

U.S. Geological Survey (2002, 2003, 2005–2017, 2020–2022) *Minerals Yearbook: Magnesium*. Available online at: http://minerals.usgs.gov/minerals/pubs/commodity/magnesium/index.html#mis.

3.3.5 Lead Production (NIR Section 4.22)

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 lead 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 2022, emissive lead production occurred in eight states: Alabama, Minnesota, Indiana, Missouri, New York, Florida, California, 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 3-15). 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 is consistent with national process emissions as reported in the national *Inventory*.

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

Time Series Range	Summary of Method
2010–2022	• 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 2010–2022 was based on process emissions reported to the GHGRP summed by state (EPA 2010–2022) 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 2024) 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 (USGS 1995–2022) 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 for the years 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 2010–2022

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.[32] 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 to 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 2016–2022.

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 2022 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 2024), levels of uncertainty in the national estimates in 2022 were −15%/+16% for CO_2.

State-level estimates are expected to have an overall higher uncertainty because the national emissions estimates were apportioned to each state based on a combination of GHGRP emissions data for 2010–2022 and the estimated number and location of facilities for 1990–2009.

For 2010–2022, 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 2010–2022. 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 to 2013. To minimize uncertainty, methods were adjusted to account for differences in emissions from primary and secondary lead production.

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

3.3.5.4 Recalculations

Minor recalculations were performed in this report for 2020 and 2021 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 decreased by approximately 3% for 2020 and 2% for 2021.

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 2016–2022. 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 2010–2022. 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) (2010–2022) *Envirofacts GHGRP Subpart R and Subpart C Data*. Accessed May 13, 2024. Available online at: https://enviro.epa.gov/query-builder/ghghttps://www.epa.gov/enviro/greenhouse-gas-customized-search.

EPA (2024) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022*. EPA 430-R-24-004. 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. Available online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

USGS (U.S. Geological Survey) (1995–2009) *Minerals Yearbook: Lead*. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/lead-statistics-and-information.

USGS (1995–2022) *Mineral Commodity Summary: Lead*. Available online at: https://www.usgs.gov/centers/national-minerals-information-center/lead-statistics-and-information.

3.3.6 Zinc Production (NIR Section 4.23)

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 to 2014, the pig iron zinc oxide furnace process from 2009 to 2012, and the flame reactor process from 1993 to 2013. Emissions from fuels consumed for energy purposes during the production of zinc are accounted for in the energy sector. In 2022, 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 3-16). 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 3-16. Summary of Approaches to Disaggregate the National *Inventory* for Zinc Production Across Time Series

Time Series Range	Summary of Method
2010–2022	• 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 2024) 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 2010–2022 used process emissions reported to the GHGRP summed by state and nationally (EPA 2010–2022) 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 (USGS 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 2010–2022

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 Holding Corp.) in Beaumont, Texas.

The PIZO Blytheville facility was in operation from 2009 to 2012 (ADEQ 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 Holding Corp. 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

Emissions data reported to GHGRP show that per-unit production CO_2 emissions from Waelz kilns are about two times the CO_2 emissions from electrothermic furnaces (EPA 2010–2012). 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 through 2022 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. 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 for the years 1990–2009.

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 2022 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 2024), levels of uncertainty in the national estimates in 2022 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 the number of facilities and production processes for 1990–2009 and GHGRP emissions data for 2010–2022.

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 2010–2022, uncertainty is expected to be lower than for the period 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 2021 state-level inventory estimates due to a revision to the national *Inventory* based on updated EAF dust consumption data. The 2021 national *Inventory* revised estimate for emissions from zinc production increased by 4% as a result. This update results in a corresponding increase in estimated state-level emissions for 2021.

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

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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)
- SF_6 and PFCs from other product use
- N_2O from product uses (N_2O)

3.4.1 Electronics Industry (NIR Section 4.24)

3.4.1.1 Background

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

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

In addition to emissions of unreacted gases, some fluorinated compounds can also be transformed in the plasma processes into different fluorinated compounds which are then exhausted, unless abated, into the atmosphere. For example, when C_2F_6 is used in cleaning or etching, CF_4 is typically generated and emitted as a process 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.

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

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

3.4.1.2 Methods/Approach

Emissions associated with the electronics industry include emissions from manufacturing of semiconductors, MEMS, and PV. National emissions were estimated using IPCC Tier 2 methods as discussed further in Chapter 4, Section 4.24 (on page 4-143) of the national *Inventory* (EPA 2024). In general, EPA used a Hybrid approach to disaggregate national estimates.

3.4.1.2.1. *Semiconductor and Micro-Electro-Mechanical Systems (MEMS) Manufacturing*

To disaggregate emissions by state for semiconductors and MEMS, EPA used data from the GHGRP and the World Fab Forecast (WFF).[33] 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 and disaggregation of national-level emission estimates where facility-level data were not available. For years before 2011, when data gathering under the GHGRP began, each state's estimated share of U.S. total manufactured layer area (TMLA) was multiplied by the national semiconductor emissions estimate to calculate that state's semiconductor emissions. To calculate each state's MEMS emissions, a linear interpolation was used between 1990 (assuming zero emissions from MEMS manufacturing in the state in that year) and 2011, the first year of available GHGRP data. Table 3-17 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 3-17. Summary of Approaches to Disaggregate the National *Inventory* for Semiconductor and MEMS Manufacturing Across Time Series

Time Series Range	Summary of Method
2015–2022	• 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 total TMLA estimated for non-reporting facilities in each state using the WFF data set and multiplying by the total emission factor of each gas in MT of gas per TMLA. These emission factors were derived by performing a linear regression of the MT emissions per gas from reporter facilities via GHGRP (regression y-axis values) with the associated total TMLA of these facilities from the proprietary WFF data (regression x-axis values). • Emissions from non-reporting MEMS facilities were not estimated, which is consistent with the national *Inventory*.
2014	• Emissions from reported fabs were allocated to the state in which the reporting facility was located as reported through the GHGRP. • 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*.
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).

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[33] 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
	- 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 to 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 to 2014 were interpolated for N_2O (Approach 2).

From 2014 to 2022, emissions from reported fabs were allocated to the state in which the reporting facility was located as reported through the GHGRP. From 2015 to 2022, emissions from non-reporters were allocated to each state as described above. For 2014, 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*. Non-reporter emissions from 2014 were scaled up by 0.017% to account for the differences in emissions factor utilized. Emissions from non-reporting MEMs fabs are not estimated, which is consistent with the national *Inventory*.

From 2011 to 2013, fluorinated GHGs (F-GHG) and N_2O emissions from reported fabs, adjusted for time series consistency in the national *Inventory*, were allocated based on the location of the GHGRP facility. Emissions from non-reporters were allocated to each state as described above. Emissions from non-reporting facilities that manufactured semiconductors were estimated using the same approach described above for non-reporter emissions from 2014. Both reporter and non-reporter emissions from 2013 were scaled up by 0.017% to account for the differences in emissions factor utilized. Emissions from non-reporting MEMS facilities are not estimated, which is consistent with the national *Inventory*.

From 2008 to 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 to 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 to 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 to 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 26 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 (F-HTFs)

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 level for years prior to GHGRP's availability. Table 3-18 summarizes methods used to compile HTF emissions.

Table 3-18. Summary of Approaches to Disaggregate the National *Inventory* for Fluorinated Heat Transfer Fluids Across Time Series

Time Series Range	Summary of Method
2011–2022	• 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 to 2022, 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 to 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 to 1999 are assumed not to have occurred. Fluorinated HTF use in semiconductor manufacturing is assumed to have begun in the early 2000s.

Additionally, the state-level HTF emissions estimates utilize GWPs as published in the latest version of 40 CFR part 98 Table A-1, which is comprised of GWPs from the IPCC Fifth Assessment Report (AR5) (and Sixth Assessment Report [AR6] where 100-year GWPs are not available in AR5). This approach is consistent with the rest of the state-level emissions estimates and the national *Inventory*, with the exception of the national HTF emissions estimates from the electronics sector, which apply GWPs as published in the IPCC Fourth Assessment Report (AR4). The HTF GWPs utilized in the national *Inventory* will be updated to reflect those in the latest version of 40 CFR part 98 Table A-1 in the next national *Inventory* cycle (see Section 1.4.1.5).

3.4.1.2.3. Photovoltaics

To estimate state-level emissions from photovoltaics (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 fluorinated 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 3-19 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 3-19. Summary of Approaches to Disaggregate the National *Inventory* for Photovoltaics Across Time Series

Time Series Range	Summary of Method
2011–2022	• 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 2011–2022, reported state-level emissions from photovoltaics (PV) manufacturing were estimated by allocating emissions from GHGRP reporters to the state in which the reporting facility is located. Two PV facilities, Micron Technology and Mission Solar, reported to the GHGRP, during this time period (neither for the full period of 2011 through 2020). Therefore, all the reported emissions were allocated to Idaho and Texas—the states in which Micron Technology and Mission Solar are located, respectively—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_2e per megawatt (MW) (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 using the proportion of each state's manufacturing capacity in 2009 (the most recent year of DisplaySearch data purchased) to the overall non-reporter estimate used in the national *Inventory*.

Manufacturing capacity was interpolated between 1997 and 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 and 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 2022 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, or in other words the uncertainty of a sum of independent variables is lower than the uncertainty of the variables. For years with state- and facility-level GHGRP data, state-level estimates will still be higher than national totals due to the uncertainty of many additional independent variables. State-level estimates will have the most uncertainty for years where state-level activity data were not available, namely years before the start of GHGRP data. Pre-2011 estimates are generated by apportioning the national totals by state-level TMLA estimates, which come from various sources including World Fab Watch and WFF. State-level estimates for 1990–2007 are apportioned using the most recent year of state-level TMLA data (2008), which will add significant uncertainty to those estimates. For more details on national-level uncertainty, see the Uncertainty discussion in Section 4.24 of the national *Inventory*.

3.4.1.4 Recalculations

The list of non-reporting semiconductor manufacturing facilities in 2015 was updated to remove one facility that had been inadvertently included, addressing an error in the national *Inventory*. In addition, state-level estimates for HTF emissions were updated to use AR5 and AR6 GWPs, addressing an error in the national *Inventory* where HTF estimates were still using AR4 GWPs. Thus, overall semiconductor emissions might not sum to estimates published in the national *Inventory*. The error will be addressed in the next national *Inventory* published in April 2025.

Refer to the national *Inventory* report for a complete list of recalculations for the national *Inventory*.

3.4.1.5 Planned Improvements

Planned improvements are consistent with those planned for improving national estimates, given that the underlying methods for state GHG estimates are the same as those in the national *Inventory*. For more information, see Chapter 4, Section 4.24, of the national *Inventory*.

3.4.1.6 References

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3.4.2 Substitution of Ozone-Depleting Substances (NIR Section 4.25)

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.[34] 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 ozone layer; they are GHGs with GWPs ranging from 1 for CO_2 to tens of thousands for HFC-23 and some PFCs (EPA 2024).

3.4.2.2 Methods/Approach

As described in the national *Inventory* report (EPA 2024), 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 80 end uses modeled. See Section 4.25 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 2024).

An approach similar to the Vintaging Model can be used to develop state-level emissions estimates. California, for example, uses this approach (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 (2023) statistics confirm that the

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[34] 42 U.S.C. § 7671, CAA Title VI.

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 largest emitting (in CO_2 equivalent terms) end use within the refrigeration and air conditioning sector, which accounts for 81% of national emissions (EPA 2024).

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, 2024; 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 of 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, which may correspond to the higher use of a second refrigerator or a separate freezer in the midwest (EIA 2023), 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, 2024) to disaggregate national emissions to individual states, territories, and the District of Columbia. For this exercise, data 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 2021). Population estimates across the time series were not available for the Federated states of Micronesias, 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, 2024) were used. Specifically, emissions for HFC-32, HFC-125, HFC-134a, and HFC-143a from 2008–2021 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, 2024) 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 1990–2022 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, 2024). Uncertainty ranges from Hu et al. were not applied or analyzed here.

Because these data ended in 2021, the ratio from that year was used for 2022 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 4.25 of the national *Inventory* (EPA 2024), the uncertainty of national emissions was −4.1%/+15.1% for a 95% confidence interval. State-level estimates are expected to have a higher uncertainty because of the use of population by state or territory during certain steps of the methodology, as described above, and from the use of atmospheric inversions to apportion emissions of four HFCs by state.

This analysis did not calculate the specific activity data and emissions factor (and importantly for this category, the reuse of chemicals not emitted) at each state and how the national activity data and emissions factors could vary based on conditions other than population for the different end uses that comprise the sector. For this reason, the division of emissions by sector (e.g., refrigeration and air conditioning, foams) are provided at the state level under the same apportionment as used in the national emission estimates. The Hu et al. (2017, 2022, 2024) 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 2008–2021, 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 4.25 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, 2024), and similar updates are anticipated. Further extension of these data, when available, can then be used to redistribute the annual emissions after 2021. 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, 2024) 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 Equipment (NIR Section 4.26)

3.4.3.1 Background

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

3.4.3.2 Methods/Approach (Electrical Equipment)

As discussed in Chapter 4, Section 4.26 (on page 4-168) of the national *Inventory* (EPA 2024), EPA used a combination of IPCC Tier 2, Tier 3, and country-specific methods to estimate national SF_6 emissions from Electrical Equipment.

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 US to develop SF_6 emission estimates from electrical equipment used for electricity transmission and distribution. However, facilities, as defined in the GHGRP or the Partnership, in the electrical equipment sector, often cross multiple states. Thus, Approach 2 as described in the Introduction was used to estimate emissions from electrical equipment. To disaggregate emissions by state for electrical equipment, EPA used data sources from the GHGRP and Homeland Infrastructure Foundation Level Data (HIFLD) (U.S. Department of Homeland Security 2019, 2020, 2021, 2022). For years prior to 2011 before GHGRP data were available, state-level SF_6 emissions from electrical equipment were determined by applying the percentage of the total U.S. transmission miles for each state to the total U.S. emissions estimate for the entire time series, modified to include additional state-level or facility-level information in the years it is available. For 2011 and later, the method was modified as described below to first allocate emissions to states as reported to the GHGRP if the facility only reported one state or if the facility reported multiple states and there was a reasonable match between the states and total transmission miles reported to the GHGRP and reported by HIFLD, before applying to the above method to remaining transmission miles. See Table 3-20 for a summary of methods across the time series.

Table 3-20. Summary of Approaches to Disaggregate the National *Inventory* for Electrical Equipment Across Time Series

Time Series Range	Summary of Method
2011–2022	• For all GHGRP reporters that reported having transmission miles in only one state (according to RY 2017–RY 2022 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 between the states and total transmission miles reported to the GHGRP and reported by HIFLD, facility-reported emissions and transmission

Time Series Range	Summary of Method
	miles were allocated to each state in which their facility lies by the percentage of their transmission miles in each state according to HIFLD (Approach 2). • Emissions for California were obtained from the California Air Resources Board California (CARB) GHG Emission Inventory for 2011–2021 (Approach 2). However, for 2022 and in cases where CARB's estimate is smaller than the GHGRP reported emissions plus emissions estimated for non-reporting facilities, EPA used the GHGRP reported emissions plus the non-reporting facilities estimate. • The remaining emissions from the national *Inventory* were allocated to states by calculating the percentage of remaining transmission miles by state (adjusted state transmission miles/adjusted national transmission miles). These state percentages were then applied to the adjusted national emissions estimate (national emissions excluding GHGRP single-state emissions, emissions from matched multi-state facilities and California emissions). State transmission miles were obtained from HIFLD data (2022) 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 (2019) for all states. State percentages of the total transmission were held constant at the 2019 percentage for all states (Approach 2).

For disaggregating national ET&D estimates, state emissions (gas) were determined by multiplying the percentage of the total U.S. transmission miles for each state by the total national estimate from the *Inventory* for the entire time series. U.S. transmission miles were obtained from the U.S. Department of Homeland Security data from Homeland Infrastructure Foundation—Level Data (HIFLD) (U.S. Department of Homeland Security 2023), which was last updated September 2023. 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.[35]

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

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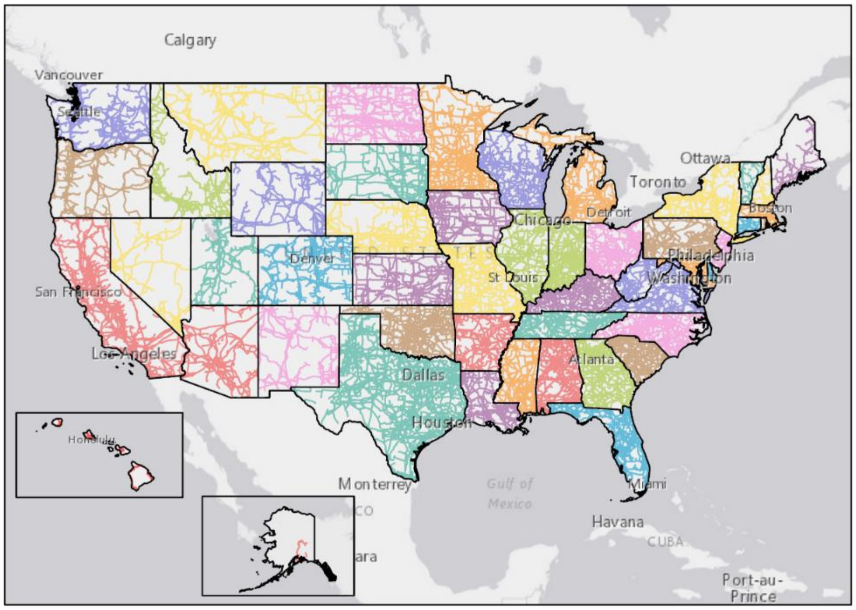
[35] Transmission miles greater than 34.5 kv in 2020 totaled 734,291 miles based on the HIFLD data set and 749,847 miles based on the UDI data set and GHGRP-reported transmission mileage. Despite the discrepancy, HIFLD data provide the closest match of total miles compared to other data sets previously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

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



Source: 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 2011–2021, 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 2011–2021 (CARB 2021, 2023). EPA concluded that these reported values were a more accurate representation of state-level emissions from California. However, CARB estimates are not used in two cases: (1) for 2022, because they are not available yet, and (2) for 2015 and 2016, when CARB's estimates are lower than estimates from GHGRP and for non-reporting facilities, as it is assumed that the GHGRP plus non-reporting facilities estimates better capture emissions from non-reporting facilities in these cases. 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.

For 2011–2022, for all GHGRP reporters that reported having transmission miles in only one state (according to RY 2017–RY 2022 reports), their facility-reported emissions and transmission miles were allocated to that state. Approximately 72% of reporting facilities had transmission miles in only one state during RY 2017–RY 2022. On average, these facilities constituted approximately 15% of the national emissions between 2011 and 2022. Emissions from GHGRP reporters that reported having 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 11% of reporting facilities had transmission miles in multiple states during RY 2017–RY 2022 that were successfully cross-walked and matched to the HIFLD data. On average, these facilities constituted an additional 20% of the national emissions between RY 2017 and RY 2022.

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.[36] 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 2020 transmission miles, transmission mileage was scaled down using UDI's transmission mile growth rate for 2011–2020 (UDI 2010, 2013, 2017).

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.[37] To allocate the remaining national emissions by state, the percentage transmission miles by state was calculated (adjusted state transmission miles/adjusted national transmission miles). These state percentages were then applied to the adjusted national emissions estimate (national emissions excluding GHGRP-only one state emissions and California emissions).

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

The approach taken to disaggregate national emissions enables 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 2011–2022. 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 original equipment manufacturers (OEM) emissions and for state-level estimates, applied the national scale-up factor at the state level.

For years prior to when GHGRP data were reported, using Approach 2, an average percentage state breakdown across the reporting time series (RY 2011–2022) was applied to emissions in each year to calculate state emissions from OEMs before 2011. The methods used are summarized in Table 3-21.

Additional research is required to understand (1) if EPA's assumption about the portion of OEM 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.

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[36] 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.

[37] The national emissions estimate was adjusted by deducting California's emissions (either CARB-reported or estimates for GHGRP reporters and non-reporters, whichever was used in a given year).

Table 3-21. Summary of Approaches to Disaggregate the National *Inventory* for Manufacture of Electrical Equipment Across Time Series

Time Series Range	Summary of Method
2011–2022	• 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 reporting years (2011–2020) to national estimate for each year between 1990 and 2010 in the *Inventory* (Approach 2).

3.4.3.4 Uncertainty

The overall uncertainty associated with the national *Inventory* of SF_6 emissions from electrical equipment source category were calculated using the *2019 Refinement to the 2006 IPCC Guidelines*. Partner reported emissions uncertainty was estimated to be -/+ 10% and GHGRP reporter emissions uncertainty was estimated to be -/+ 20%. As described further in Chapter 4 of the national *Inventory* (EPA 2024), levels of uncertainty in the national estimates in 2022 of the source category were −25%/+25%.

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 improve.

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 4.26 of the national *Inventory* (page 4-177), 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 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 becomes available (e.g., additional facility-level information on state locations of transmission lines obtained through research or additional reporting would facilitate greater use of GHGRP and/or Partnership data). Additional research into regional or state-level trends will also be conducted to refine the estimates where possible. Finally, EPA plans to incorporate estimates for additional U.S. territories and estimate emissions for Guam for all years in the time series.

3.4.3.7 References

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3.4.4 SF_6 and PFCs from Other Product Use (NIR Section 4.27)

3.4.4.1 Background

SF_6 and PFC emissions result from other product use and other processes, including military and scientific applications. Many of these applications utilize SF_6 or PFCs to exploit their unique chemical properties, such as the high dielectric strength of SF_6 and the stability of PFCs. Emission profiles from these processes may vary greatly, ranging from immediate and unavoidable release of all the chemical to largely avoidable, delayed release from leak-tight products after decades of use.

Military applications employ SF_6 and PFCs in many processes. For example, SF_6 is used in the radar systems— commonly known as Airborne Warning and Control Systems (AWACS)—of military reconnaissance planes of the Boeing E-3A type. Other uses of SF_6 in military applications include the oxidation of lithium in navel torpedoes and infrared decoys. SF_6 has also been documented for use in the quieting of torpedo propellers, and it is also a byproduct of the processing of nuclear material for the production of fuel and nuclear warheads.

Military electronics are believed to be a key application for PFC heat transfer fluids, particularly in areas such as ground and airborne radar avionics, missile guidance systems, and sonar. PFCs may also be used to cool electric motors, especially for equipment where noise reduction is a priority (e.g., submarines).

SF_6 and PFCs are also employed in several scientific applications, such as for use in particle accelerators. Particle accelerators can be found in university and research settings, as well as in industrial and medical applications. SF_6 is typically used as an insulating gas and is operated in a vessel exceeding atmospheric pressure. PFCs (particularly PFC-14) may also be used in particle accelerators as particle detectors or counters (Workman et al. 2022).SF_6 may also be employed in other high-voltage scientific equipment, including lasers, x-rays, and electron microscopes.

There is a range of unidentified processes (such as R&D activities) that also use SF_6 and PFCs. PFCs are likely used primarily as HTFs. Emissions are reported for these unknown activities under “Other Scientific Applications.”

3.4.4.2 Methods/Approach

National emissions were based primarily on data reported though the Federal Energy Management Program (FEMP) by the U.S. Department of Energy (DOE) and Department of Defense (DOD), with methodologies from the IPCC used to make additional emission estimates where FEMP data were not readily available(DOE 2022, IPCC 2006). Military application and scientific application emissions were estimated separately using different approaches as discussed in Chapter 4, Section 4.27 (on pages 4-178 through 4-183) of the national *Inventory* (EPA 2024). In general, EPA used a hybrid approach to disaggregate national estimates.

3.4.4.2.1. Military Applications

AWACS emissions from the national *Inventory* were allocated to states based on the distribution of the U.S. AWACS fleet of 33 planes. Alaska and Oklahoma were the only two states assumed to have E-3 planes in the U.S. AWACS fleet, with four planes and 29 planes, respectively, throughout the entire time series.

National emissions from other military applications throughout the time series were disaggregated by equal allocation to all states due to a lack of state-level data.

3.4.4.2.2. Scientific Applications

National *Inventory* particle accelerator emissions were allocated to states in which particle accelerators are operating. State-level emissions from non-DOE research and industrial particle accelerators in the United States were calculated using facility-level emissions estimated by applying an average SF_6 charge and emission factor based on the particle accelerator type.

Reported emissions from DOE particle accelerators were disaggregated equally among the nine states in which they are operating (i.e., California, Illinois, Maryland, Massachusetts, New Mexico, New York, Tennessee, Virginia, and Washington). Emissions from DOE tandem accelerators were disaggregated equally among the states (i.e., New Mexico, California, New York, and Washington) with tandem accelerators located at their facility, and emissions from DOE ion beam accelerators and gas purging (i.e., at Argonne National Lab, Oak Ridge National Lab, and Brookhaven National Lab) were disaggregated equally among the states in which those particle accelerators are located (i.e., Illinois, Tennessee, and New York, respectively).

Emissions from other scientific applications reported by DOE were similarly allocated equally to each of the nine states with DOE particle accelerators listed above.

3.4.4.3 Uncertainty

The overall uncertainty associated with the national emissions estimates of SF_6 and PFCs from other product use was calculated using the *2019 Refinement to the 2006 IPCC Guidelines* (IPPC 2019). As described further in Chapter 4 of the national *Inventory*, levels of uncertainty in the national estimates in 2022 were -36%/+38% across the industry.

State-level estimates are expected to have a higher uncertainty because, in some cases, the national estimates were apportioned to each state equally. This assumption was required because of a general lack of more granular state-level data.

3.4.4.4 Recalculations

This is a new category included for both the current (i.e., 1990–2022) national *Inventory* and state-level estimates, and therefore no recalculations were performed.

3.4.4.5 Planned Improvements

EPA plans to revisit the methodology for determining emissions of SF_6 and PFCs from other product use—in particular, the assumptions that emissions from other military applications (i.e., non-AWACS) are consistent across all states and that emissions from DOE particle accelerators are consistent across all nine states with DOE particle accelerators. Planned improvements also include developing a more complete list of states with DOE facilities for purposes of disaggregating emissions from other scientific applications reported by DOE. Additional collaboration with DOE and DOD will be required to confirm or modify the assumptions regarding the distribution of emissions across states.

3.4.4.6 References

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3.4.5 Nitrous Oxide from Product Uses (NIR Section 4.28)

3.4.5.1 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 2022.

3.4.5.2 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 2024). 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, 2021, 2022a, 2022b; Instituto de Estadísticas de Puerto Rico 2021). For each year in the 1990–2022 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.

3.4.5.3 Uncertainty

The overall uncertainty associated with the 2022 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 2024), levels of uncertainty in the national estimates in 2022 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.

3.4.5.4 Recalculations

Recalculations were performed for 2020–2022 as updated population data for those years 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.

3.4.5.5 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.

3.4.5.6 References

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