6 Waste (NIR Chapter 7)

For this methodology report, the Waste chapter consists of two subsectors: solid waste disposal and wastewater treatment and discharge. More information on national-level emissions and methods is available in Chapter 7 of the national *Inventory*. Note that emissions from waste incineration are discussed in Chapter 2, Section 2.1.4, of this methodology report. Table 6-1 summarizes the different approaches used to estimate state-level waste emissions and completeness across states. Geographic completeness is consistent with the national *Inventory*. The sections below provide more detail on each category.

Table 6-1. Overview of Approaches for Estimating State-Level Waste Sector GHG Emissions and Sinks

Category	Gas	Approach	Geographic Completeness [a]
Landfills	CH_4	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands and some territories (i.e., Guam, Puerto Rico), and as applicable.
Wastewater	CH_4, N_2O	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands, and some territories (i.e., Guam, Northern Mariana Islands Puerto Rico, and U.S. Virgin Islands for domestic wastewater),.[a]
Composting	CH_4, N_2O	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands and territories as applicable.
Anaerobic Digestion at (Standalone) Biogas Facilities	CH_4	Approach 2	Includes emissions from all states, the District of Columbia, tribal lands and territories as applicable.

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

6.1 Solid Waste Disposal

This section presents the methodology used to estimate the emissions from solid waste disposal management activities, which consist of the following sources:

- Landfills (MSW and industrial waste) (CH_4)
- Composting (CH_4, N_2O)
- Anaerobic digestion at biogas facilities (stand alone) (CH_4)

6.1.1 Landfills (NIR Section 7.1)

6.1.1.1 Background

After being placed in a landfill, organic waste such as paper, food scraps, and yard trimmings is initially decomposed by aerobic bacteria. After the oxygen has been depleted, the remaining waste is available for consumption by anaerobic bacteria, which break down organic matter into substances such as cellulose, amino acids, and sugars. These substances are further broken down through fermentation into gases and short-chain organic compounds that form the substrates for the growth of methanogenic bacteria. These CH_4-producing anaerobic bacteria convert the fermentation products into stabilized organic materials and biogas consisting of approximately 50% biogenic CO_2 and 50% CH_4 by volume. CH_4 and CO_2 are the primary constituents of landfill gas generation and emissions. Consistent with the 2006 IPCC Guidelines, net CO_2 flux from C stock changes in landfills are estimated and reported under the LULUCF sector (see Chapter 5 of this report) (IPCC 2006).

More information on emission pathways and national-level emissions from landfills and associated methods can be found in the Waste chapter (Chapter 7), Section 7.1, of the national *Inventory,* available online at https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-7-waste.pdf?VersionId=skK.lO1zbaYrNwnmUKNiyepctaM_yV3z.

6.1.1.2 Methods/Approach (Municipal Solid Waste Landfills)

The MSW landfill state emissions inventories applied Approach 2 for disaggregating national estimates and relied heavily on the Subpart HH data collected through the GHGRP. As explained in the methodology discussion of Section 7.1 of the national *Inventory*, EPA uses an IPCC Tier 2 approach and several data sources, methods, and assumptions to estimate emissions (see pages 7-7 through 7-12 for details on the inputs and equations). The state inventories applied a state percentage of either waste landfilled or net CH_4 emissions by state as reported to Subpart HH (EPA 2021a) as a proxy for each state’s share of CH_4 net emissions over the time series. Table 6-2 summarizes the methodology used to develop the state-level estimates, followed by additional detail. The annual state percentages were applied to the national estimates to retain an IPCC Tier 2 approach consistent with the national *Inventory*.

Table 6-2. Summary of Approaches to Disaggregate the National *Inventory* for MSW Landfills Across Time Series

Time Series Range	Summary of Method
1990–2009	• Applied the percentage of waste landfilled by state (aggregated total as reported by landfills in each state to Subpart HH for historical years) to the national CH_4 net emissions for each year (IPCC 2006 Tier 2) • The state percentage approach accounts for all emissions, including those calculated in the national *Inventory* through back-casting Subpart HH data and scaling up emissions to account for smaller landfills that do not report through Subpart HH.
2010–2021	• Applied the percentage of net CH_4 emissions by state (aggregated total as reported by landfills in each state to Subpart HH) to the national CH_4 net emissions for each year. • The state percentage approach accounts for all emissions, including those calculated by scaling up emissions to account for smaller landfills that do not report through Subpart HH.

Historical waste disposed of since a facility began operating is reported using prescribed methods in the rule to maintain consistency across the facility data. The quantity of waste landfilled by Subpart HH reporters was assumed to be representative of the universe of MSW landfills in the United States because Subpart HH reporters include each state’s highest emitting MSW landfills, which is directly tied to the quantity of waste landfilled. The national *Inventory* methodology back-casts Subpart HH net CH_4 emissions and uses a scale-up factor to account for lower-emitting MSW landfills (e.g., non-reporters). The intent of the scale-up factor is to estimate CH_4 emissions from MSW landfills that do not report to the GHGRP. EPA has put significant effort into identifying landfills that do not report to the GHGRP, most recently in 2021. Basic landfill characteristics such as the landfill's name and location, first year of operation, current operational status, and waste-in-place data have been compiled for these landfills when available. Disaggregating the Subpart HH data by state was determined to be a reasonable assumption considering the lack of historical data for landfills that do not report to the GHGRP.

The methodology used for 1990–2009 applies a state percentage of waste landfilled for this time frame as reported by landfills under Subpart HH of the GHGRP to the national estimates of CH_4 emissions. Approximately 1,200 MSW landfills have reported to the GHGRP since reporting began in 2010. This approach disaggregates national net emissions values by applying the state percentage as a proxy of net emissions.

The methodology for 2010–2021 applies a state percentage of net CH_4 emissions reported by landfills under Subpart HH to the national estimates of CH_4 emissions. Using net CH_4 emissions is consistent with the recent methodological refinements in the national *Inventory* to incorporate reported Subpart HH net CH_4 emissions. Unlike the national *Inventory*, scale-up factors for each state were not developed since these would require significant effort; instead, the national emissions values are disaggregated by a proxy that is assumed to be generally representative of state-by-state emissions.

Emissions from managed landfills located in Puerto Rico and Guam were included because facilities in these territories report to Subpart HH.

6.1.1.3 Methods/Approach (Industrial Landfills)

EPA estimates CH_4 emissions from industrial waste landfills for two industry categories consistent with the national *Inventory*: (1) pulp and paper and (2) food and beverage. Data reported to the GHGRP on industrial waste landfills suggest that most of the organic waste that would result in CH_4 emissions is disposed of at pulp and paper and food processing facilities. Information on both industry categories with respect to the amount of waste generated and disposed of in a dedicated industrial waste landfill is limited; thus, EPA uses a Tier 1 approach to estimate CH_4 emissions. Additionally, no comprehensive list of industrial waste landfills exists. While the information is available in the *Waste Business Journal* (WBJ), the quality of the data is unknown, and the date of data related to each waste management facility included is also unknown. Therefore, EPA does not have information on the number of industrial waste landfills that were operational over the time series and information regarding the number of industrial waste landfills located in each state. The types and amounts of waste disposed of in the operational industrial waste landfills are also limited.

A portion of pulp and paper mills in the United States report to Subpart TT (Industrial Waste Landfills) of the GHGRP. Previous analyses of the 2016 pulp and paper emissions from the GHGRP (RTI 2018) showed that total Subpart TT emissions from facilities associated with a pulp and paper NAICS code generally align (within approximately 10–20%) with the national *Inventory*'s national estimate of emissions from the pulp and paper manufacturing sector. On the other hand, a small number of facilities associated with a food and beverage NAICS code report to Subpart TT, and these emissions are vastly different between Subpart TT and the national *Inventory*.

Because of the data limitations described above, Approach 2 was used to disaggregate the national *Inventory* CH_4 emissions for both industry categories, rather than a more detailed facility-specific, bottom-up approach.

Pulp and Paper Manufacturing

For the pulp and paper source category, EPA extracted a state-by-state count of mills in the United States from two sources: Data Basin for 2008 and Mills OnLine for 2015–2016 (Conservation Biology Institute 2008; Center for Paper Business and Industry Studies n.d.). The count of facilities is approximately 233 and 332 from Data Basin and Mills OnLine, respectively. The count and percentage of mills by state are shown in Appendix F (Table F-1). According to the Industrial Resources Council, mills are located in 41 states, not including Alaska, Colorado, North

Dakota, Nebraska, Nevada, Rhode Island, South Dakota, Utah, and Wyoming. For comparison, the Subpart TT pulp and paper facilities across RYs 2011–2019 represent a maximum of 92 facilities located across 21 states.

To estimate CH_4 generation and emissions, the Data Basin 2008 percentages by state were applied to the national *Inventory* estimate for the pulp and paper manufacturing sector for 1990–2010, and the Mills OnLine 2015–2016 percentages by state were applied for 2011–2021. This approach assumes broadly that each facility is generating an equal amount of waste that is landfilled and, therefore, an equal amount of CH_4 emissions. Consistent with the national *Inventory*, this assumption and this approach were used in an attempt to ensure complete coverage of industrial waste landfills in the United States because the Subpart TT pulp and paper facilities may not equal the total number of pulp and paper facilities disposing of waste in dedicated industrial waste landfills. The exact number of pulp and paper manufacturing facilities that dispose of waste in industrial waste landfills is unknown.

CH_4 emissions from the pulp and paper sector were disaggregated by applying the percentage of the mills by state as a proxy for facilities generating and disposing of waste in industrial waste landfills. No additional calculations were performed, and the IPCC Tier 1 methodology (IPCC 2006) used to generate the national emissions estimates was applied by default.

Food and Beverage Manufacturing

Minimal data are available to characterize the amounts and types of waste generated nationally from food and beverage manufacturers and disposed of in industrial waste landfills. Less is known about the number of facilities in each state that dispose of waste in a dedicated industrial landfill.

A similar approach using a count of assumed industrial food and beverage manufacturing facilities that dispose of waste in an industrial waste landfill by state was applied to the national food and beverage category estimates. The list of food and beverage manufacturing facilities consists of 13 NAICS codes as shown in Appendix F (Table F-2) comprising 9,175 facilities (can be shared upon request). This list was extracted from 2021 update to the EPA Excess Food Opportunities database (EPA 2021b].

The EPA Excess Food Opportunities database includes a low- and high-end estimate of the amount of excess food generated (tons/year). These data were not used in the methodology. Rather, the average percentage of the amount of excess food generated by each state across the selected NAICS codes was used as a proxy for the share of CH_4 generation and emissions estimates. The same approach used for the pulp and paper manufacturing sector was applied whereby the average percentage of excess food by state was applied to the national total amount of CH_4 generation and CH_4 emissions for each year of the time series. This is a broad assumption but allows for the calculation of emissions with limited knowledge on the locations of facilities disposing of food waste into industrial waste landfills.

The percentage of excess food generated by state is presented in Appendix F (see Table F-3). Note that the Excess Food Opportunities database and map do not indicate the management pathway for the excess food. The EPA Facts and Figures methodology (EPA 2020) also does not include an estimation of the amount of excess food being disposed of in industrial waste landfills. Therefore, the percentage of waste disposed of is likely overrepresented for some states and is why the estimates for the District of Columbia, the Virgin Islands, and Puerto Rico have been zeroed out.

6.1.1.4 Recalculations

Consistent with the national *Inventory*, the CO_2 equivalent estimates of total CH_4 emissions have been revised to reflect the 100-year GWP for CH_4 provided in the AR5 (IPCC 2013).

EPA conducted a literature review between 2020 and 2022 to investigate other sources of industrial food waste and annual waste disposal quantities. As a result of this effort, EPA decided to revise the food waste disposal factor in the 1990 to 2021 Inventory for select years. A waste disposal factor of 4.86 percent is used for 1990 to 2009 and a revised factor of 6 percent is used for 2010 to the current year. These updates to the national *Inventory,*[41] resulted in changes for years 2010-present for all state-level CH_4 emission estimates.

6.1.1.5 Uncertainty

The overall uncertainty associated with the 2021 national estimates of CH_4 from MSW and industrial waste landfills was calculated using the Approach 2 methodology (IPCC 2006). As described further in Chapter 7 of the national *Inventory* (EPA 2021), levels of uncertainty in the national estimates in 2021 were −19%/+26% of the estimated CH_4 emissions for MSW landfills and −31%/+25% for industrial waste landfills.

State-level estimates likely have a higher uncertainty due to (1) apportioning the national emissions estimates to each state based on assumptions made to disaggregate the national emissions estimates, which are based on state percentages as reported to the GHGRP, and (2) the application of the scale-up factor to nationally compiled landfill gas recovery databases used in the national *Inventory*. Additionally, state-level estimates before the GHGRP began (i.e., before 2010) may have more uncertainty than state-level estimates after the GHGRP began (i.e., 2010 and afterward). For more details on national level uncertainty, see the uncertainty discussion in Section 7.2 of the national *Inventory*.

6.1.1.6 Planned Improvements

Potential refinements to landfill estimation methods include the following:

- **MSW landfills.** Planned improvements to the state-level estimates are consistent with those presented in Section 7.1 of the national *Inventory*. In particular, EPA plans to improve completeness of emissions from all waste management practices (i.e., open dumpsites) in U.S. territories by identifying data and applying methods to include emissions from open dumpsites in territories.
- **Industrial waste landfills.** A more complete and comprehensive list of pulp and paper facilities in the United States will be identified, including years of operation since 1990. Further QC on this inventory will be performed by comparing the counts of industrial waste landfills by state in available data sets.

6.1.1.7 References

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[41] See Section 7.1, page 7-17, of the national *Inventory*.

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6.1.2 Composting (NIR Section 7.3)

6.1.2.1 Background

This section presents methods used to estimate state-Level GHGs from large-scale commercial composting facilities that typically include sections of the waste that operate in an anaerobic environment where degradable organic carbon in the waste material is broken down, generating CH_4 and N_2O. Even though CO_2 emissions are generated, they are not included in net GHG emissions for composting. Consistent with the national *Inventory*, emissions from residential (backyard) composting are not included in the scope. Additionally, the national *Inventory* assumes windrow is the composting method used, and the waste mixture is homogeneous, consisting primarily of yard waste and some food. Annual throughput data on static and in-vessel commercial composting methods were not identified in secondary (published) data. Consistent with the 2006 IPCC Guidelines, net CO_2 flux from C stock changes in waste material is estimated and reported under the LULUCF sector (see Chapter 5 of this report) (IPCC 2006).

More information on emission pathways and national-level emissions from composting and associated methods can be found in the Waste chapter (Chapter 7), Section 7.3 of the national *Inventory* available online at https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-7-waste.pdf?VersionId=skK.lO1zbaYrNwnmUKNiyepctaM_yV3z.

6.1.2.2 Methods/Approach

EPA compiles national CH_4 and N_2O emissions estimates for commercial composting facilities in the United States using an IPCC Tier 1 method by which an IPCC default emissions factor is applied to the national quantity of material composted. No facility-specific information is used because it is generally unavailable over the time series.

The national *Inventory* was disaggregated to the state level using Approach 2 on the basis of data available for the proportion of material composted by state for select years. Table 6-3 summarizes published state-level estimates of composted material used in this inventory. Years where published data are not available are either interpolated or extrapolated using population growth and published estimates.

Table 6-3. Summary of Availability and Sources for Composting Data

Year Composting Data Available for	Reference Citation
2000	Goldstein and Madtes 2001
2002	Kaufman et al. 2004
2004	Goldstein et al. 2006
2006	Arsova et al. 2008
2008	Arsova et al. 2010
2010	EREF 2016
2011	Shin 2014
2012	ILSR 2014
2013	EREF 2016
2016	WBJ 2016
2020	WBJ 2020

The state-level data were largely compiled from voluntary surveys of state agencies that reported MSW generated and estimates by relevant management pathways (e.g., landfill, recycling, composting). Composting estimates may be directly reported by the state agencies or estimated or adjusted by the report authors using the best available information for available years. Occasionally, data for some states are not available and are indicated as such in the data sources. The WBJ is an annually updated database of which the quality is unknown, but it is used because there is a general lack of data. Both the WBJ 2016 and 2020 were used to estimate state data for 2017–2019. Completeness is one limitation with the available state data used.

The general methodology to estimate the annual quantity of waste composted per year is as follows:

$$Composted_S = \%_S \times N_C$$

where:

$Composted_S$ = the mass of material composted by state (tons/year)

$\%_S$ = the state percentage of material composted, calculated using available state data (%)

N_C = the national estimate of material composted as reported in the EPA Advancing Sustainable Materials Facts and Figures reports (tons/year) (EPA 2020)

The state percentages of material composted were calculated by dividing each state-reported amount of waste composted by the total of all material composted for that year. The sum of all state-reported data is referred to as national estimates by the report authors, but to avoid confusion with the Facts and Figures data published by EPA, are referred to this as the sum of state-reported data in this methodology report. Limitations with the state-reported survey data include its voluntary nature and occasional lack state data for states that did not provide a survey response. The report authors noted they made assumptions to estimate and adjust data to the extent possible. For years where no state data were reported in a specific survey, EPA estimated the data using the prior or next year of available data. These gaps were minimal (i.e., five or fewer states for each survey year).

Because state data are only available for select years, interpolation and extrapolation were required to generate estimates for each year of the time series. State proportions applied to 1990–1999 are the same as those for 2000 (Goldstein and Madtes 2001). No state data exist for this portion of the time series, and there is a large amount of uncertainty surrounding the number of facilities and amount of material composted. This is a conservative approach since it is unknown when a state began compositing operations, so it is assumed if they had operations in 2000 that they did in 1990 as well. Data in between the survey data were interpolated using the prior year's and next year's survey data (the state proportion of material composted). Annual state data were interpolated for 2001, 2003, 2005, 2007, 2009, 2014, 2017, 2018, and 2019. Annual state data for 2021 were extrapolated using population growth (U.S. Census Bureau 2021a, 2021b) and WBJ (2020) estimates of material composted. State percentages for each year are presented in Appendix F (Table F-4).

The formula used for interpolation of the state percentage for the year in question is as follows:

$$y = \left(\frac{y_2 - y_1}{x_2 - x_1}\right) \times (x) - x_1 + y_1$$

where:

y = state percentage of waste composted for the year without data, %

y_1 = state percentage of waste composted for the prior year with data, %

y_2 = state percentage of waste composted for the next year with data, %

x = the year without data

x_1 = the prior year with data

x_2 = the next year with data

The state percentage data were multiplied by the national estimate of material composted from the EPA Facts and Figures reports to cap the total quantity composted across the states and match the state totals to the national *Inventory*. The EPA Facts and Figures national estimates were directly used to estimate the national *Inventory*. The IPCC Tier 1 method used in the national *Inventory* estimates (IPCC 2006) is the product of an emissions factor and the mass of organic waste composted.

The final step in developing the state inventory was estimating the CH_4 and N_2O emissions. For simplicity, the state percentages were multiplied by the annual national emissions estimates.

6.1.2.3 Recalculations

Consistent with the national Inventory, the CO_2 equivalent estimates of total CH_4 and N_2O emissions have been revised to reflect the 100-year GWP for CH_4 and N_2O provided in the AR5 (IPCC 2013). No additional recalculations were applied for this current report.

6.1.2.4 Uncertainty

The overall uncertainty associated with the 2021 national estimates of CH_4 and N_2O from composting (specifically large-scale, commercial composting facilities) was calculated using the 2006 IPCC Guidelines Approach 1 methodology (IPCC 2006). As described further in Chapter 7 of the national *Inventory*, levels of uncertainty in the national estimates in 2021 were −58%/+58% for CH_4 and for N_2O. State-level estimates will have a higher uncertainty than the national estimates because of apportioning the national quantity of material composted (sourced from the EPA Sustainable Materials Management reports and calculated with a mass balance methodology) to each state based on sporadically published waste management data from a voluntary state agency survey for select years. The national methodology also assumes most composting in the United States uses the windrow method and treats a homogeneous mixture of primarily yard trimmings and some food waste. For more details on national-level uncertainty, see the uncertainty discussion in Section 7.3 of the national *Inventory,* available online at https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-chapter-7-waste.pdf?VersionId=skK.lO1zbaYrNwnmUKNiyepctaM_yV3z.

6.1.2.5 Planned Improvements

In future annual publications, EPA plans to investigate state volumes of material composted where the report authors (from referenced composting data sources) indicated potentially combined volumes of waste sent to composting, recycling, and anaerobic digestion. EPA will continue to identify annual quantities of material composted in states where data are lacking (e.g., Alaska, Guam). For example, a 2021 desk-based investigation into composting facilities in Alaska revealed operational aerated composting facilities, but the annual capacity and throughput were not identified. EPA will continue to search for relevant data for commercial composting facilities in these states. Planned improvements to the national estimates for composting outlined in Section 7.3 (page 7-57) of the national *Inventory* will lead directly to improvements in the quality of state-level estimates as well.

6.1.2.6 References

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6.1.3 Anaerobic Digestion at Biogas Facilities (stand--alone) (NIR Section 7.4)

6.1.3.1 Background

Anaerobic digestion is a series of biological processes in the absence of oxygen in which microorganisms break down organic matter, producing biogas and soil. Stand-alone digestion is one of three main categories of anaerobic digestion facilities, which also includes on-farm digesters and digesters at water resource recovery facilities. This section focuses exclusively on stand-alone digesters, which typically manage food waste from different sources, including food and beverage processing industries. Emissions from on-farm digesters and digesters at water resource recovery facilities are reflected under Sections 4.1.2 (Manure Management) and 6.2.1 (Wastewater Treatment and Discharge) of this report. Based on available data, anerobic digestion occurs in the following 31 states: Arizona, California, Colorado, Connecticut, Florida, Georgia, Iowa, Idaho, Indiana, Kansas, Massachusetts, Maryland, Maine, Michigan, Minnesota, Missouri, North Carolina, North Dakota, New Hampshire, New Jersey, New York, Ohio, Oregon, Pennsylvania, Rhode Island, Tennessee, Texas, Virginia, Vermont, Washington, and Wisconsin.

At stand-alone digestors, CH_4 emissions may result from a fraction of the biogas lost during the process due to leakages and other unexpected events (0–10% of the amount of CH_4 generated; IPCC 2006), collected biogas that is not completely combusted, and entrained gas bubbles and residual gas potential in the digested sludge. CO_2 emissions are biogenic in origin and should be reported as an informational item in the energy sector (IPCC 2006).

More information on emission pathways and national-level emissions and methods can be found in Section 7.4 of the national *Inventory*.

6.1.3.2 Methods/Approach

EPA compiles national CH_4 emissions estimates for stand-alone anaerobic digester facilities in the United States using an IPCC Tier 1 method, where an IPCC default emissions factor is applied to the estimated national quantity of material digested. A default CH_4 emissions factor (IPCC 2006) was multiplied by a weighted average annual quantity of material digested by stand-alone digesters from two voluntary EPA data collection surveys (EPA 2018, 2019) and an estimated number of operating facilities per year (see Table 7-47 and Table 7-48, respectively, of the national *Inventory*). No facility-specific quantities of material digested were directly used because of a general lack of facility-specific data over the time series. The methodology applied to generate the national *Inventory* was based on two large assumptions—the number of operational facilities and the weighted average of material digested for two of the 30 years in the time series (1990–2021). The state inventory further takes these assumptions to a state level by assuming that the same percentage of total operational facilities is the same for each year of the time series because of a general lack of data on total operational facilities by state across the time series. Therefore, the state-level inventories are a gross estimate that may be refined in future years if available information by state is obtained.

In the national *Inventory*, EPA calculated a weighted average of material digested using masked survey data from the two available survey reports for 2015 and 2016 (EPA 2018, 2019). The weighted average was applied to an estimated number of operational facilities per year to estimate the annual quantity of material digested. The first step to calculating the state inventory was to disaggregate the annual estimates of the material digested. This was disaggregated by applying a state percentage of operational facilities as reported to the two published EPA survey reports (EPA 2018, 2019). The state proportions of operational facilities in 2015 and 2016 are presented in Appendix F (Table F-5).

The state proportions were multiplied by the national quantity digested for each year in the time series, which forced the total quantities across the states to match the national *Inventory* estimates. The same state percentage was used for each year in the time series because of a lack of compiled data on the number of stand-alone digesters by state between 1990–2021.

The equation used to estimate the annual quantity of material digested per year by state is presented as Equation 1:

$$Digested_S = \%_S \times N_D \qquad \textit{Equation 1}$$

where:

$Digested_S$	= the quantity of material digested by state (kt/year)
$\%_S$	= the state proportion of operational facilities, calculated from the number of operational stand-alone digesters as reported in the EPA surveys (EPA 2018, 2019) for 2015 and 2016; the same state percentage was applied to each year in the time series (%, see Appendix F, Table F-5)
N_D	= the annual national estimate of material digested (kt/year).

The state-specific annual CH_4 generation estimates were calculated using Equation 2:

$$G_{CH4} = Digested_S \times EF_{CH4} \times \frac{1}{1000} \qquad \textit{Equation 2}$$

where:

G_{CH4}	= CH_4 generation from stand-alone anaerobic digesters, kt CH_4
$Digested_S$	= mass (quantity) of material digested by state, kt
EF_{CH4}	= CH_4 emissions factor, 0.8 Megagram/Gigagram (Mg/Gg, wet basis) (IPCC 2006)
1/1,000	= conversion factor, Gg/Mg

The national *Inventory* estimates for CH_4 recovery were estimated using the two years of available EPA survey data (EPA 2018, 2019). The state-specific CH_4 recovery estimates were calculated using Equation 3:

$$R_{CH4} = \%_S \times \ National\ R_{CH4} \qquad \textit{Equation 3}$$

where,

R_{CH4}	= CH_4 recovery from stand-alone anaerobic digesters, kt CH_4
$\%_S$	= state percentage of operational facilities, % (see Appendix F, Table F-5)
National R_{CH4}	= national amount of recovered CH_4, kt

Lastly, the state estimates of net CH_4 emissions were calculated by summing the CH_4 generation and CH_4 recovery estimates:

$$Emiss_{CH4} = G_{CH4} - \ R_{CH4} \qquad \textit{Equation 4}$$

where,

$Emiss_{CH4}$	= CH_4 emissions by state, kt
G_{CH4}	= CH_4 generation from stand-alone anaerobic digesters, kt CH_4
R_{CH4}	= CH_4 recovery from stand-alone anaerobic digesters, kt CH_4

6.1.3.3 Recalculations

Consistent with the national Inventory, the CO_2-equivalent estimates of total CH_4 emissions have been revised to reflect the 100-year GWP for CH_4 provided in the AR5 (IPCC 2013). No additional recalculations were applied for this current report.

6.1.3.4 Uncertainty

The overall uncertainty associated with the 2021 national estimates of CH_4 from stand-alone anaerobic digesters was calculated using the 2006 IPCC Guidelines Approach 1 methodology (IPCC 2006). As described further in Chapter 7 of the national *Inventory*, levels of uncertainty in the national estimates in 2019 were −54%/+54% CH_4. State-level estimates will have a higher uncertainty because of apportioning the national emissions estimates to each state based solely on the number of stand-alone anerobic digester facilities from EPA survey data collected between 2015–2018. Emissions estimates before 2015 will have a higher uncertainty than those in 2015 and later years. These assumptions were required because of limited facility-specific data presented in secondary resources. No attempt was made to collect state-maintained permitting data on annual throughput because EPA is collecting this information under an Information Collection Request. For more details on national level uncertainty, see the uncertainty discussion in Section 7.4 of the national *Inventory*.

6.1.3.5 Planned Improvements

The planned improvements are consistent with those planned for improving national estimates given that the underlying methods for state GHG estimates are the same as those in the national *Inventory*. To find information on planned improvements to refine methods for estimating emissions from stand-alone anaerobic digestion, see the planned improvements discussion starting on pp. 7-62 of Section 7.3 in the national *Inventory*.

6.1.3.6 References

EPA (U.S. Environmental Protection Agency) (2018) *Anaerobic Digestion Facilities Processing Food Waste in the United States in 2015: Survey Results*. EPA/903/S-18/001. Available online at: https://www.epa.gov/sites/default/files/2018-08/documents/ad_data_report_final_508_compliant_no_password.pdf.

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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.

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6.2 Wastewater Management

This section presents the methodology used to estimate the emissions from domestic and industrial wastewater treatment and discharge (CH_4, N_2O).

6.2.1 Wastewater Treatment and Discharge (NIR Section 7.2)

6.2.1.1 Background

Consistent with the national *Inventory* and international guidance, EPA has developed disaggregated state estimates for both domestic and industrial wastewater treatment and discharge, as discussed below:

- Domestic wastewater CH_4 and N_2O emissions originate from both septic systems and centralized treatment plants. Within these centralized plants, CH_4 emissions can arise from aerobic systems that liberate dissolved CH_4 that formed within the collection system or that are (1) designed to have periods of anaerobic activity, (2) from anaerobic systems, and (3) from anaerobic sludge digesters when the captured biogas is not completely combusted. N_2O emissions can result from aerobic systems as a byproduct of nitrification, or as an intermediate product of denitrification. Methane emissions will also result from the discharge of treated effluent from centralized treatment plants to water bodies where carbon accumulates in sediments, while N_2O emissions will also result from discharge of centrally treated wastewater to water bodies with nutrient-impacted or eutrophic conditions.

- Industrial wastewater CH_4 emissions originate from in-plant treatment systems, typically comprising biological treatment operations in which some operations are designed to have anaerobic activity or may periodically form anaerobic conditions. N_2O emissions are primarily expected to occur from aerobic treatment systems as a byproduct of nitrification, or as an intermediate product of denitrification. Emissions will also result from discharge of treated effluent to waterbodies.

6.2.1.2 Methods/Approach (Domestic Wastewater)

EPA estimated state-level domestic wastewater treatment and discharge emissions (CH_4) using a simplified approach to apportion the national emission estimates to each state based on population (i.e., Approach 2 as defined in the Introduction to this report) and state-level septic data. In this method, EPA accessed historical U.S. Census data to compile state-level population data for each year of the inventory (1990–1999: U.S. Census Bureau 2002; 2000–2009: U.S. Census Bureau 2011; 2010–2021: U.S. Census Bureau 2021a, 2021b, 2022; Instituto de Estadísticas de Puerto Rico 2021). NEBRA (2022) reported the percent of population associated with septic systems by state for 2018. This percentage was multiplied by the 2018 state-level population and then divided by the total summed national population to estimate the percent of the national population with a septic system in each state and territory in 2018. These state-level percentages were then used for the remainder of the timeseries, as shown in Appendix F, Table F-6.

EPA calculated state- and territory-level emissions by multiplying the proportion of the U.S. population on centralized treatment or septic systems in each state or territory by the national CH_4 and N_2O emissions for each year of the time series.

This simplified approach assumes the following:

- Every state has the same wastewater treatment system usage as the national *Inventory.*
- Every state has same distribution of discharge to various waterbody types as the national *Inventory.*
- Kitchen disposal usage is the same in every state, and wastewater biochemical oxygen demand (BOD) produced per capita, with and without kitchen scraps, is the same in every state (i.e., assumes total wastewater BOD produced per capita is the same as national production).
- Per capita protein consumption in the United States is the same in every state (i.e., assumes per capita consumption is the same as national consumption).

EPA did not perform a more detailed approach that would account for the specific types of treatment at centralized systems, such as anaerobic reactors or activated sludge, used in each state (see planned improvements below in Section 6.2.1.6). Similarly, there are insufficient readily available data sources to allow classification of the type of specific water bodies within each state, so EPA did not consider the type of water body receiving wastewater discharges within each state.

6.2.1.3 Methods/Approach (Industrial Wastewater)

Consistent with the national *Inventory* and national estimates, both CH_4 and N_2O emissions were estimated for treating industrial wastewater from pulp and paper manufacturing, meat and poultry processing, petroleum refining, and breweries, while CH_4 emissions were also estimated for treating industrial wastewater from vegetables, fruits, and juices processing, and for starch-based ethanol production. These are the industry categories that are likely to produce significant GHG emissions from wastewater treatment. Data on industrial production by state are available or can be estimated from other readily available data for at least some of the time series of the inventory.

EPA estimated state-level emissions by estimating the percentage of the industry production that occurs in each state (i.e., using Approach 2 as described in the Introduction to this report). Where data were readily available, EPA estimated the distribution of production for each year of the time series and multiplied that by the national emissions estimate for each year of the time series. In some cases, due to time and resources, EPA was able to estimate the distribution of production for a subset of years in the time series, as discussed below by industry.

For pulp and paper manufacturing, state-level production data are not available, so EPA estimated state- level emissions by estimating the percentage of wastewater directly discharged in that state compared to the total flow of wastewater directly discharged for that industry, using data reported to EPA's ICIS National Pollutant Discharge Elimination System (NPDES) database. EPA acknowledges that this methodology ignores production at mills that either do not discharge wastewater or that discharge to a publicly owned treatment works. In both cases, these mills could be performing onsite treatment and emitting GHGs that cannot be captured.

EPA then multiplied that percentage by the national emissions estimate to obtain a state-level emissions estimate. Because of the limitation of data resources for this effort, EPA accepted most ICIS-NPDES data as is, but some outliers were determined and handled as described below (see planned improvements below in Section 6.2.1.6).

Both approaches assume the following:

- All facilities in an industry within a state have the same distribution of wastewater treatment operations as the national distribution.
- Every state has the same BOD and total nitrogen in untreated industry wastewater as the national-level estimates.
- Every state has the same nitrogen removal factor as the national-level estimates.
- The percentage of wastewater directly discharged by the state represents the distribution of all pulp and paper production by the state.

Further details on methods and data sources assumptions for each industry treating wastewater are described below.

6.2.1.3.1. Pulp and Paper Manufacturing

- Industrial production data for pulp and paper are highly confidential and are not available by state.
- EPA used the amount of wastewater directly discharged by pulp mills by state—reported to both ICIS-NPDES from Enforcement Compliance History Online (ECHO; 2023) and the Washington Department of Ecology's Permitting and Reporting Information System (PARIS; 2022)—to proportion U.S. national emissions estimates to a state (as shown in Appendix F, Table F-7). Because wastewater flow data housed in ECHO changed in 2016, using older data may cause discontinuities in the time series. EPA determined the distribution of discharge flow by state for 2019–2021 using 2019 ECHO and PARIS data and applied the 2019 distribution to all prior years of the national *Inventory*. There was no wastewater flow reported for the District of Columbia or U.S. territories for this industry.
    - Pulp and paper mills were determined in ECHO using Standard Industrial Classification codes 2611, 2621, and 2631. The prior year state estimate had used a broader definition of the industry based on ECHO's Point Source Category to determine the facility universe, but this was determined to include facilities not relevant to this sector.
- For facilities in states other than Washington, EPA:
    - Downloaded the total pulp and paper permit universe in ECHO, including permits that have discharge monitoring report data (261 facilities in 2021), and permits with information only (e.g., facility address) (414 facilities in 2021).
        - Stormwater permits that were reported for a facility that also reported a non-stormwater permit were removed from the analysis (FLR05A517, MAR053165, LAR05P618, MAR053218).

- Downloaded 2019–2021 flow data where available (ECHO 2023). Not all facilities report total flow if it is not required by their permit. Total flow was summed by state.
  - EPA determined two state flow outliers, one for Missouri in 2020 and one for West Virginia in 2021. Outliers, determined as values that are at least an order of magnitude larger (10 times) than other years' values for the state, were removed. It is assumed these values are data entry errors in ECHO. An average of the other available values was used as a surrogate for removed values.
- For permits without flow data, total flow was estimated by using average flow by state, or average national total flow for that year if no state data were available, multiplied by the number of permits without flow data for that state.

- Facilities located in the state of Washington are not currently reported within ECHO due to lagging electronic reporting. To fill this known gap, EPA investigated a separate source for these data and:
  - Downloaded and reviewed permit data for known pulp mills determined from the Washington Department of Ecology's Industrial Facility Permits website.
  - Downloaded 2019 flow data where available (PARIS 2022) for monitoring locations that are associated with process wastewater, per the facility permit.
  - Multiplied the daily flow rate by 365.25 days to estimate a total yearly flow, then multiplied by number of months data were reported (to prevent overestimating annual flow, which was done to better match the methodology in ECHO).
  - Integrated into the other state data for all years.
- EPA calculated the percentage of national flow by state:
  - As with Washington, some states are missing from ECHO (e.g., Montana, Colorado). EPA assumed some of these states have nonzero emissions, but they do not have the data to determine whether there are facilities present or to estimate emissions, so they are reported as not applicable.
- EPA calculated the state-level emissions by multiplying national emissions by the percentage of national flow by state.
- Example: 2021 Georgia emissions
  - Georgia has 22 facilities in the facility universe, of which 14 have reported annual flow data.
  - The total flow based on the sum of reported flows (14 facilities) and calculated flows (8 facilities) from the state average flow of 8,213 million gallons (MMGal) for all facilities was 180,617 MMGal in 2019.
  - Georgia's flow was 8.67% of the total national total flow of (2,085,063 MMGal).
  - Pulp and paper's national CH_4 emissions in 2019 was 31 Gg CH_4, so Georgia's 2019 emissions were estimated to be (31 Gg CH_4 * 9.11% = 2.8 Gg CH_4).

6.2.1.3.2. Meat and Poultry Processing

- Annual U.S. and state-level production data for red meat processing and poultry processing data are available from USDA-NASS (as shown in Appendix F, Table F-8). Depending on the commodity, limited state-level data are available. Typically, the USDA reports only break out the primary states where the commodity is processed and then present production in "other states."
- For red meat processing:
  - EPA gathered state-level 2021 and 2012 average live weight and total head slaughtered for the following commodities: beef, calves, hogs, and lamb/mutton (USDA 2022a, 2013a). EPA retained

2019 data from the 1990–2019 state-level production data, and 2020 and 2004 data from the 1990–2020 state-level production data.

    - U.S. territories and the District of Columbia are not included in USDA-reported data.

  - For total head slaughtered (thousand head):
    - To populate states for which specific production data are not disclosed by the USDA ("D" states), EPA evenly divided the difference between the sum of the state-level data and the reported national-level total to those D states.
    - Similarly, the USDA provided a total for New England states that was evenly distributed to those states noted (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont).
  - For average live weight (pounds):
    - EPA used the average of available state-level data and the national average to determine the appropriate average live weight for the remaining states (D states). This calculated value was applied to all D states.
    - Similarly, the reported average live weight value for New England states was applied to those states.
  - As with the national *Inventory*, EPA determined live weight killed (LWK) by multiplying the average live weight by the total head/1,000 to get to million pounds LWK.
  - EPA added the disaggregated red meat processing data by state and divided the data by the reported national production to determine the proportion distributed to states. Because of the estimated nature of the calculated values, the total state-level LWK is estimated at about 95% of the national total, so the percentages were normalized to 100%.
- For poultry processing:
  - EPA gathered state-level 2021 and 2012 poultry live weight data. EPA retained 2019 data from the 1990–2019 state-level production data and 2020 and 2004 data from the 1990–2020 state-level production data. Only young chickens, or broilers, had state-level data available. Turkeys and mature chickens did not.
    - Young turkey data were available by state. EPA assumed that states with young turkeys would be representative of turkey processing production; therefore, young turkey data were used as a proxy for total turkeys (USDA 2022b, 2013b).
    - Young chickens were used to represent mature chicken processing production by state (USDA 2022b, 2013b).
  - To populate D states for 2021, EPA evenly divided the difference between the sum of the state-level data and the reported national-level total to those D states.
  - To populate D states for 2004, EPA first proxied the reported D states for 2020 because the individual states for 2004 were not available or reported by USDA. This was done to encourage time series consistency and avoid showing states known to have poultry processing as having no emissions for the industry. EPA acknowledges this method could attribute minor emissions to states without poultry in 2004. Then, as with 2020, EPA evenly divided the difference between the sum of the state-level data and the reported national-level total to those D states.
  - For turkeys and mature chickens, the proportion of young turkeys and young chickens, respectively, was multiplied by the national-level value to determine the pounds of processing production per state.
  - Those values were added together and then divided by the total poultry (young chickens, mature chickens, turkeys) values to determine the proportion of poultry LWK for states.

- To calculate CH_4 emissions, EPA:
    - Multiplied national red meat plant CH_4 emissions by the percentage of U.S. total meat processing and added that to the national poultry plant CH_4 emissions multiplied by the percentage of U.S. total poultry processing by state.
    - Multiplied the 2004 (from the 1990–2020 inventory), 2012, 2019 (from the 1990–2019 inventory), 2020 (from the 1990–2020 inventory), and 2021 state-level proportion of U.S. meat and poultry BOD treated on site by the national effluent CH_4 emissions from meat and poultry.
    - For 2005–2011, used linear interpolation of 2004 and 2012 state-level proportions, and for and 2013–2018, used the 2012 and 2019 proportions. Multiplied those values by the national effluent CH_4 emissions from meat and poultry.
    - For 1990–2003, assumed the state-level proportions to be the same as those determined for 2004.
    - Added plant and effluent emissions for total state-level emissions.
- To calculate N_2O emissions, EPA:
    - Multiplied the 2004 (from the 1990–2020 inventory), 2012, 2019 (from the 1990–2019 inventory), 2020 (from the 1990–2020 inventory), and 2021 state-level proportion of U.S. total nitrogen in both
        - 1) aerobically treated meat and poultry wastewater by the N_2O emissions from meat and poultry processing wastewater treatment for each year in the time series and.
        - 2) discharged meat and poultry wastewater by the N_2O emissions from meat and poultry processing wastewater treatment effluent for each year in the time series.
    - For 2005–2011 and 2013–2018, EPA used linear interpolation of 2004 and 2012, and 2012 and 2019 state-level proportions, respectively. Multiplied those values by the national effluent N_2O emissions from meat and poultry.
    - For 1990–2003, assumed the state-level proportions to be the same as those determined for 2004.
    - Added plant and effluent emissions for total state-level emissions.

6.2.1.3.3. Vegetables, Fruits, and Juices Processing

- Annual U.S. production data for vegetables, fruits, and juices processing are available from the USDA. Depending on the commodity, state-level data are available (as shown in Appendix F, Table F-9). Typically, the USDA reports only identify the primary states where the commodity is processed. For example, production data on broccoli are provided for California and “other states,” while production data on asparagus are provided for Michigan, Washington, and “other states.”
    - U.S. territories and the District of Columbia are not included in the USDA-reported data.
- EPA determined that the most recent year with complete state-level production values is 2017 because the USDA suspended the reporting of some state-level production values in 2018 and more notably in 2019–2021.
- To better inform the time series, EPA also investigated an earlier year, determined 2012 to be complete, and subsequently determined the state-level production values for 2012. EPA previously investigated and included 2004 during the 1990–2020 Inventory.
- For processing production data:
    - State-level data for potato processing were not available. Instead, EPA used state-level potato production (i.e., the production of potatoes grown not processed) as a proxy to determine the states to include (USDA 20144).

  - For other vegetables, EPA gathered data for asparagus, broccoli, carrots, cauliflower, sweet corn, cucumber (for pickles), lima beans, green peas, snap beans, spinach, and tomatoes (USDA 2015a). Where USDA reported data for “other states,” those data were distributed equally among the commodities. EPA added the production for these commodities to determine the percentage of the U.S. total for all “other vegetables,” which is the production value used in the national *Inventory* (not the individual commodities).
  - Processed apples, grapes used for wine, and citrus fruits were also determined at a state level. For apples, where USDA reported data for “other states,” those data were distributed equally (USDA 2015b, 2015c).
  - Noncitrus fruits are split out into separate commodities (e.g., blueberries, sweet cherries[42]); no state-level data are available for the aggregated “noncitrus fruit” category. Therefore, EPA gathered the state-level “utilized production” data for these separate commodities to determine the appropriate states and relative percentage of utilized production for noncitrus fruits (USDA 2015c).
  - Processed noncitrus fruit data are typically calculated in the national *Inventory* as utilized production minus fresh minus apples minus grapes for wine; however, because of the intensive nature of gathering data for the separate commodities, “utilized production” was used as a proxy for processed production data.
- To calculate emissions, EPA calculated the 2004, 2012, and 2017 percentage of U.S. total BOD by state and multiplied that by the national vegetables and fruits emissions for each year in the time series.
- For 2005–2011 and 2013–2016, EPA determined state-level proportions by linear interpolation of 2004 and 2012, and 2012 and 2017 values, respectively. Proportions for 2018–2021 were assumed to be the same as 2017.

6.2.1.3.4. Petroleum Refining

- Annual production data are available from EIA within the Department of Energy (EIA 2023a), as shown in Appendix F (Table F-10).
- Because state-level data may reveal confidential data, production data are aggregated by Petroleum Administration for Defense Districts (PADDs). Production data for the following PADDs and subdistricts are available:
  - PADD I (East Coast)
    - Subdistrict A (New England): Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont
    - Subdistrict B (Central Atlantic): Delaware, District of Columbia, Maryland, New Jersey, New York, and Pennsylvania
    - Subdistrict C (Lower Atlantic): Florida, Georgia, North Carolina, South Carolina, Virginia, and West Virginia
  - PADD II (Midwest): Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Ohio, Oklahoma, Tennessee, and Wisconsin
  - PADD III (Gulf Coast): Alabama, Arkansas, Louisiana, Mississippi, New Mexico, and Texas
  - PADD IV (Rocky Mountain): Colorado, Idaho, Montana, Utah, and Wyoming

[42] The EPA gathered 2004 and 2017 production for apricots; avocados (2012 values reported as “not available”); blueberries, cultivated blueberries (2004 only), and wild blueberries; boysenberries (2004 only); sweet and tart cherries; coffee (2017 only); cranberries; dates; loganberries (2004 only); nectarines; olives; papaya (2012 Hawaii crop reported as “not available”), including guavas and pineapples (Hawaii crops, 2004 only); peaches; pears; plums; prunes (combined with plums in 2004); raspberries; and strawberries.

  - PADD V (West Coast): Alaska, Arizona, California, Hawaii, Nevada, Oregon, and Washington
- Operating capacity by state is available from EIA (2023b) for 1990–2021.
- EPA created state-level annual production data for each year of the time series (1990–2021) by dividing the annual production for each PADD subdistrict by the percentage of operating capacity each state provided in that year.
- Petroleum operating capacity values were not available for 1996 and 1998. These values were linearly interpolated.
- Example: 2019 California emissions
  - California data are included in PADD V.
  - PADD V has a total of 27 refineries with an operating capacity of 2,875,071 barrels.
  - California has a total of 15 refineries with an operating capacity of 1,909,671 barrels (or 66.4% of PADD V capacity).
  - PADD V produced 1,122,935 barrels in 2019.
  - Estimate California production as 1,122,935 barrels × 66.4% = 745,629 barrels.
  - Calculate California's percentage of national production (745,629 barrels/7,460,380 barrels = 10%).
  - Calculate California emissions as national emissions × percentage of national production (4.6 Gg CH_4 × 10% = 0.46 Gg CH_4).

6.2.1.3.5. Starch-based Ethanol Production

- State-level ethanol production data are available from EIA's State Energy Data System (SEDS) (EIA 2023c) (as shown in Appendix F, Table F-11).
  - Fuel ethanol production data, including denaturant, in thousand barrels are available for 1960–2021 (EIA 2023c).
  - EPA checked the difference between SEDS national production and the reported production in the national *Inventory* and found small differences—on average, a 0.9% difference for the time series—further confirming SEDS is a good source of state-level production.
  - Typically, the most recent year of data is used as a surrogate for the last year of available production data. For example, during the 1990–2020 *Inventory by State*, 2019 production values were used for 2020. This is due to the timing of when production data are released versus to publication of the *Inventory by State*. However, EPA determined 2020 would not be representative of normal production due to the COVID-19 pandemic affecting national production, and therefore used 2019 values.
- Calculated the percentage of national production by state for every year, using the production data noted above.
- Calculated the state-level emissions by multiplying national emissions by percentage production by state.
- Example: 2021 California emissions
  - 2021 California production value is 2,293 thousand barrels.
  - National production for 2021 is 375,517 thousand barrels.
  - California produced 1.2% of the national production in 2021.
  - Calculate 2021 California emissions as national emissions × percentage of national production (5.9 Gg CH_4 × 0.6% = 0.04 Gg CH_4).

6.2.1.3.6. Breweries

- Annual production data by state are available from the Alcohol and Tobacco Tax and Trade Bureau (TTB 2021) (as shown in Appendix F, Table F-12).
    - Data are available for 2008–2020. Therefore, the calculated percentage of national production for 2008 was used for 1990–2007.
    - Data for 2021 were assumed equal to 2020. See the planned improvements below.
    - These data are for taxable production values only, which account for 94% of total production in 2020. The approach assumes that this portion of production is still representative of relative production percentages for each state.
    - Data are not available broken out between craft and noncraft production, so the approach assumes each state has the same distribution of craft and noncraft production as the national distribution.
- Calculated the percentage of national production by state.
- Calculated the state-level emissions by multiplying national emissions by percentage production by state.
- Example: 2019 California emissions
    - California production is 17,872,597 barrels.
    - National production is 167,077,233 barrels.
    - California produces 10.7% of national production.
    - Calculate California emissions as national emissions × percentage of national production (5.6 Gg CH_4 × 10.7% = 0.599 Gg CH_4).

6.2.1.4 Recalculations

Recalculations discussed here are specific to state-level production or disaggregated data. To see impacts from updates to national-level data, see the recalculations discussion in Section 7.2 of the Waste chapter (Chapter 7) in the national *Inventory*, available online at https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-7-Waste.pdf. Notably, consistent with the national *Inventory*, EPA updated the GWP for calculating CO_2 equivalent emissions of CH_4 (from 25 to 28) and N_2O (from 298 to 265) to reflect the 100-year GWPs provided in the AR5 (IPCC 2013).

EPA updated the domestic methodology to include state-level proportions of septic versus centralized treatment based on newly available data (NEBRA 2022). These updates, in conjunction with the changes to the national *Inventory,*[43] resulted in changes for the entire time series for all state-level domestic CH_4 and N_2O emission estimates.

Updates to the following state-level industrial production data, in conjunction with national-level updates, resulted in changes for the entire time series for every state-level total industrial CH_4 and N_2O emission estimates:

- **Pulp and paper.** Including 2019 and 2020 flow estimates for all available state data due to an updated methodology to determine/download flow data from ECHO, affecting all years.
- **Meat and poultry processing.** Including 2012 production data, affecting 2005–2018.
- **Vegetables, fruits, and juices processing.** Including 2012 production data, affecting 2005–2018.

6.2.1.5 Uncertainty

The overall uncertainty associated with the 2021 national estimates of CH_4 and N_2O from wastewater treatment and discharge were calculated using the 2006 IPCC Guidelines Approach 2 methodology (IPCC 2006). As

[43] See Section 7.2, page 7-52, of the national *Inventory*.

described further in Chapter 7 of the national *Inventory* (EPA 2023), levels of uncertainty in the national estimates in 2021 were −29%/+32% for CH_4 and −34%/+193% for N_2O. State-level estimates have a higher uncertainty due to apportioning the national emissions estimates to each state based solely on state population (for domestic) or state industry sector production (for industrial). This approach does not address state-level differences in the type of wastewater treatment systems in use or in the conditions of the state's receiving waterbodies. State-level emissions for the time series were estimated based on limited years of state-level data, which also results in higher uncertainty for the state estimates. These assumptions were required due to the general lack of readily available state- or regional-level data. For more details on national-level uncertainty, see the uncertainty discussion in Section 7.2 of the Waste chapter (Chapter 7) in the national *Inventory*, available online at https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Chapter-7-Waste.pdf.

6.2.1.6 Planned Improvements

Generally, EPA plans to review feedback from reviews of the state-level inventory methods and assess potential comparable data sets noted or shared provide comparable data for all states or most states. The steps outlined below may inform the potential improvements for both domestic and industrial state-level emissions estimates. EPA plans to undertake the following assessments as resources allow:

- Determine state-level sources for the type of wastewater treatment systems in use for municipal or domestic or for industrial wastewater (by industrial sector).
- Determine state-level sources for BOD or total nitrogen data in municipal or domestic wastewater or industrial wastewater (by industrial sector).
- As stated in Section 7.2 of the national *Inventory*, investigate additional sources for estimating wastewater volume discharged and discharge location for both domestic and industrial sources.

For individual industries, EPA notes the following potential improvements.

6.2.1.6.1. Pulp and Paper Manufacturing

- Investigate state-level sources for the production of pulp, paper, and paperboard.
- Investigate additional years of ECHO data to improve the time series. Part of this includes evaluating the facilities present year to year to confirm time series consistency.
- Investigate states where data are reported as not applicable and confirm emissions estimates do not apply. Pending findings, determine another source to estimate wastewater flow for these states.

6.2.1.6.2. Meat and Poultry Processing

- Continue to investigate additional years of available USDA data for inclusion to improve the time series.
- Investigate the presence of meat and poultry processing in the U.S. territories or the District of Columbia and, pending findings, additional sources for estimating those emissions. For the District of Columbia, reach out to USDA-NASS to confirm if the District of Columbia is already included in reporting.

6.2.1.6.3. Vegetables, Fruits, and Juices Processing

- Continue to investigate other years of available USDA data for inclusion.
- Investigate the presence of vegetables, fruits, and juices processing in the U.S. territories or the District of Columbia and, pending findings, additional sources for estimating those emissions. For the District of Columbia, reach out to USDA-NASS to confirm if the District of Columbia is already included in reporting.

6.2.1.6.4. Starch-based Ethanol Production

- Investigate sources to break down wet and dry milling by state over the time series.

6.2.1.6.5. Breweries

- Investigate sources to break down craft and noncraft breweries by state over the time series.
- Investigate changes to reporting state-level data and determine a methodology representative of the available data. Some data are available for 2021; however, due to reporting changes from the Alcohol and Tobacco Tax and Trade Bureau, some states no longer have data available due to confidentiality concerns leaving gaps in the time series and total production.

6.2.1.7 References

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