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Waste

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Chapter 7. Waste

Waste management activities—including landfilling, wastewater treatment, and waste combustion—produce greenhouse gas (GHG) emissions such as methane (CH_4) and nitrous oxide (N_2O). Solid waste disposal to landfills is the primary source of waste-management–related emissions, accounting for nearly 72 percent of total waste-management–related emissions. Emissions from wastewater are the next largest source, contributing 25 percent, and the remaining sources contribute just under 3 percent (i.e., from composting and stand-alone anaerobic digestion facilities). Landfills and wastewater are significant sources of methane, with landfills being the third largest source of methane (CH_4). Wastewater treatment also contributes nearly 92 percent of this sector's nitrous oxide (N_2O) emissions and is the second largest source of N_2O overall.

In 2024, emissions from this sector were 166 million metric tons (MMT) CO_2 equivalent (Eq.), accounting for approximately 2.7 percent of gross U.S. GHG emissions as shown in Table 7-1. Emissions decreased nearly 30 percent from 1990 and remained relatively flat from 2023 as shown in Figure 7-1. The decrease since 1990 is largely due to greater use of landfill gas collection and control systems, closure of older landfills, better management practices, and increased diversion of organic waste through state and local policy and regulations targeting reduction of food waste (EPA, 2025).

Emissions from the incineration of waste are accounted for in the energy sector rather than in the waste sector because almost all incineration of municipal solid waste (MSW) in the United States occurs at waste-to-energy facilities where useful energy is recovered. The energy sector also includes an estimate of emissions from burning waste tires and hazardous industrial waste, because virtually all the combustion occurs in industrial and utility boilers that recover energy (EPA, 2025).

Figure 7-1: Trends in Waste Sector Greenhouse Gas Source

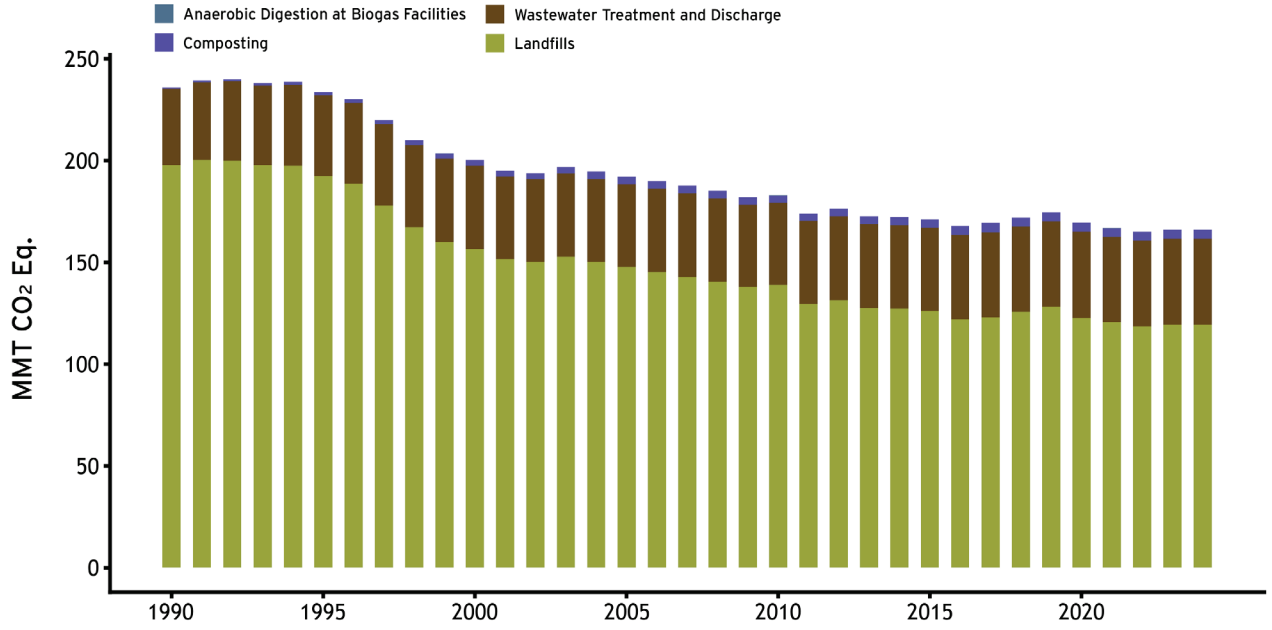


Table 7-1: Emissions from Waste (MMT CO_2 Eq.)

Gas/Source	1990	2005	2020	2021	2022	2023	2024
CH_4	**220.9**	**172.4**	**146.1**	**143.9**	**142.2**	**143.2**	**143.0**
Landfills	197.8	147.7	122.6	120.7	118.6	119.4	119.4
Wastewater Treatment	22.7	22.7	21.0	20.7	20.9	21.2	21.0
Composting	0.4	2.1	2.6	2.6	2.6	2.6	2.6
Anaerobic Digestion at Biogas Facilities	+	+	+	+	+	+	+
N_2O	**15.1**	**19.5**	**23.4**	**22.9**	**23.0**	**22.8**	**23.0**
Wastewater Treatment	14.8	18.1	21.6	21.1	21.2	21.0	21.1
Composting	0.3	1.5	1.8	1.8	1.8	1.8	1.9
Total	**235.9**	**192.0**	**169.5**	**166.8**	**165.2**	**166.0**	**166.0**

+ Does not exceed 0.5 kilotons (kt).

Note: Totals may not sum due to independent rounding.

Unless otherwise noted, all estimates in this chapter are provided in MMT CO_2 Eq. Consistent with GHG inventories from other countries, this report uses 100-year Global Warming Potential values from Table 8.A.1 in Appendix 8.A of the *IPCC Fifth Assessment Report* for calculating CO_2 Eq. emissions. Supplemental data tables published with this *Greenhouse Gas Inventory and Analysis for the United States (GHGIA)* for download include all the tables presented in this chapter as well as tables with unweighted units reported as kilotons (kt).

Methodological Framework

Emissions are estimated based on Volume 5 (Waste) of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (Intergovernmental Panel on Climate Change [IPCC], 2006) and the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2019), using country-specific data where available. Unless otherwise noted, methods are consistent with those used in *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2023* (EPA, 2025). Consistent with IPCC good practices, this *GHGIA* applies higher-tier methods for more significant sources (e.g., Tier 2 and Tier 3 methods, which include using country-specific methods and models, emission factors, and site-specific information) and as data allow for smaller sources, as shown in Table 7-2.

Table 7-2: Method Summary

Category (CRT Code) [a]	Gas(s)	IPCC Methodological Tier	Methodological Refinement Compared to 1990–2023 (EPA, 2025)
Landfills (5A1)			
MSW Landfills	CH_4	Model, country-specific	No change
Industrial Landfills	CH_4	Country-specific	No change
Composting (5B1)	CH_4, N_2O	Tier 1	No change
Anaerobic Digestion at Biogas Facilities (5B2)	CH_4	Tier 1	No change
Waste Incineration (5C1)	CO_2, CH_4, N_2O	See Chapter 3.3	
Wastewater (5D)			
Domestic	CH_4	Tier 1, Tier 2	No change
	N_2O	Tier 1, Tier 2, Tier 3	
Industrial	CH_4	Tier 1, Tier 2, country-specific	No change
	N_2O	Tier 1	

[a] Codes in parentheses represent common reporting table (CRT) codes. The CRT codes are a classification system to organize quantitative reporting of detailed emission and removal data in standardized data tables (i.e., CRTs) to facilitate comparison of national inventory data and trends. The code reflects classification levels (e.g., sector, subsector, category, subcategory). Translating 5A1: 4 = waste sector, A = solid waste disposal subsector, 1 = landfills category (e.g., managed waste disposal sites).

Quality Assurance/Quality Control

To ensure the quality of the waste sector GHG emission estimates, the IPCC general procedures were implemented for quality assurance/quality checking for all categories. Category-specific procedures will be phased in, especially for significant categories in future versions of this report. The procedures that were implemented involved checks specifically focusing on the activity data and methodology used for estimating each source of emissions from the waste sector. Emissions trends were investigated to determine whether any corrective actions were needed. Minor corrective actions were taken as necessary.

Uncertainty

The same uncertainty bounds reported in the *1990–2023 Inventory* (EPA, 2025) were applied for each category and subcategory as applicable, see Table 7-9. A qualitative description of the uncertainties, along with the quantitative uncertainty estimate, is provided within each category.

Future Areas for Improvement

Continuous improvement efforts are important for reflecting the latest science, reducing uncertainties to the extent practicable in estimating emissions from waste management activities, especially for significant categories such as methane emissions from landfills and, wastewater, and nitrous oxide emissions from wastewater. For categories where the methodology has not changed in this report and remains consistent with previous analyses, we plan to review improvements identified in the *1990–2023 Inventory* (EPA, 2025). Any changes that have been incorporated into this report are discussed in the Methods and Recalculations sections of those respective categories.

Below are anticipated actions for potentially more significant methodological changes and/or refinements, to improve inventory transparency and address existing and new challenges with data availability.

- Include an overview of waste management in the United States in the introduction to this chapter.
- Review literature, federal, trade statistics to identify updated data on waste generation, composition, associated management pathways including gas recovery and use for the United States to improve consistency and completeness of estimates over the time series.
- Review any available 2024 Greenhouse Gas Reporting Program (GHGRP) data for additional updates and recalculations.
- Review recent studies estimating methane emissions from landfills using independent methods, including studies based on atmospheric measurements (e.g., Cusworth et al., 2024; Nesser et al., 2024) and engage with researchers on approaches to improve data, emission factors, and/or methods for quantifying emissions.
- Review studies on reported GHGRP data and associated methods (e.g., Stark et al., 2024).
- Review recent studies estimating methane and nitrous oxide emissions from and wastewater treatment using independent methods, including studies based on atmospheric and other measurements (e.g., Sieranen et al., 2024; Song et al., 2023; Song et al., 2024; Song et al. 2026).
- Review available data that could improve estimation parameters, and/or methods for quantifying emissions, such as new survey data published by U.S. Environmental Protection Agency (EPA; e.g., EPA Clean Watersheds Survey; EPA's Anaerobic Digestion Data Collection Project 2022 and 2023 data), along with new reporting to existing compliance and permitting databases.

Future versions of this report will specify more on scope, timing, and plans for phasing in improvements.

7.1 Landfills (Source Category 5A1)

Methane (CH_4) is released from solid waste management, primarily from landfills. In the United States, landfilling is the most common way to manage solid waste, along with recycling, composting, and waste-to-energy incineration. MSW landfills manage household and similar wastes by placing waste in lined areas, covering it daily with soil, and using systems to collect liquids (leachates) and gases. Industrial waste landfills are built in a similar way but are used for non-hazardous industrial and commercial waste. MSW and industrial waste landfills in the United States must meet federal, state, and local regulations to minimize potential environmental, health, and safety impacts.[45] Since 2011, landfills that accepted MSW on or after January 1, 1980 and generate methane in amounts equivalent to 25,000 metric tons of CO_2 Eq. or more per year were subject to reporting annual emissions under EPA's GHGRP.

Once waste is deposited in a landfill, organic materials, such as food, paper, and yard debris, begin to decompose. At first, decomposition occurs in the presence of oxygen, but as oxygen is used up, the process becomes anaerobic (occurring absent of oxygen). Under these conditions, bacteria produce landfill gas, which is made up of roughly equal parts methane (CH_4) and carbon dioxide (CO_2), along with small amounts of other gases (e.g., non-methane volatile organic compounds [NMVOCs] and volatile organic compounds [VOCs]) produced during decomposition and volatilization processes). In GHG inventories, only CH_4 emissions from landfills are estimated, because net CO_2 flux from carbon stock changes of materials of biogenic origin in landfills are reported under the land use, land-use change, and forestry (LULUCF) sector estimates and not reported here to avoid double counting of emissions from biomass-related stock changes (see Chapter 6 of this *GHGIA*). Nitrous oxide (NO_2) emissions (e.g., from sludge application) are assumed to be insignificant (IPCC, 2006).

Methane emissions from landfills depend on several factors, including the amount of waste in place and its composition, landfill design and operating conditions, how much methane is captured and controlled (e.g., the amount of methane captured and either flared or used for energy), and how much CH_4 is reduced (oxidized) as it passes through the landfill cover. Understanding changes in landfilled waste composition over time, particularly for degradable materials in MSW landfills, is important for estimating GHG emissions. Diverting these materials from landfills reduces both CH_4 generation potential and emissions. Although landfill management practices can vary, most follow similar practices, such as applying cover materials to reduce odors and protect public health. The type of cover material (e.g., soil, clay, or alternative materials) can also influence CH_4 oxidation rates (EPA, 2025). Methane production usually begins within the first year after waste is placed in a landfill and can continue for decades as the waste slowly decomposes (IPCC, 2006). Recent measurement studies suggest methane emissions may be higher than previously thought (see references in the "Future Areas for Improvement" included in the introduction to this chapter).

In 2024, landfill CH_4 emissions were approximately 119.4 MMT CO_2 Eq. Emissions from MSW landfills accounted for approximately 84 percent of total landfill emissions (100.6 MMT CO_2 Eq.),

[45] More information on landfill management in the U.S. and applicable regulations can be found at https://www.epa.gov/landfills.

while industrial waste landfills accounted for the remainder (18.8 MMT CO_2 Eq.). Net CH_4 emissions from MSW landfills decreased since 1990 largely because of increased use of landfill gas collection and control systems, closure of older landfills, better management practices, and increased diversion of organics through state and local policy and regulations (see Table 7-3). Landfill gas collection and control is not accounted for at industrial waste landfills in this chapter (see the Methodology discussion for more information).

Table 7-3: Methane Emissions from Landfills MMT CO_2 Eq.

Gas/Source	1990	2005	2020	2021	2022	2023	2024
MSW CH_4 Generation [a]	230.0	303.7	339.4	334.1	329.3	335.7	335.7
Industrial CH_4 Generation	13.6	17.9	21.0	21.0	21.0	20.9	20.9
MSW CH_4 Recovered [a]	(23.8)	(148.4)	(206.4)	(203.4)	(200.0)	(204.9)	(204.9)
MSW CH_4 Oxidized [a]	(20.6)	(23.6)	(29.3)	(28.9)	(29.5)	(30.2)	(30.2)
Industrial CH_4 Oxidized	(1.4)	(1.8)	(2.1)	(2.1)	(2.1)	(2.1)	(2.1)
MSW Net CH_4 Emissions	**185.5**	**131.6**	**103.7**	**101.8**	**99.8**	**100.6**	**100.6**
Industrial CH_4 Emissions [b]	**12.2**	**16.1**	**18.9**	**18.9**	**18.9**	**18.8**	**18.8**
Total Emissions	**197.8**	**147.7**	**122.6**	**120.7**	**118.6**	**119.4**	**119.4**

[a] For years 1990–2004, emissions from MSW landfills are estimated using the first-order decay methodology. A methodological change occurs in 2005. For 2005–2024, directly reported net CH_4 emissions from the EPA's GHGRP data and additional emissions from landfills not reporting to GHGRP are added applying a scale-up factor. More details on the scale-up factor and how it was developed can be found in Annex 5. These data incorporate CH_4 recovered and oxidized for MSW landfills. As such, CH_4 generation, CH_4 oxidation, and CH_4 recovery are not calculated separately.

[b] Methane recovery is not calculated for industrial landfills because this is not a common practice in the United States (EPA, 2025).

Notes: Parentheses indicate negative values. Totals may not sum due to independent rounding.

The total amount of MSW generated is expected to increase as the U.S. population continues to grow. The annual volume of MSW generated and disposed of in MSW landfills varies over time and is influenced by a range of factors, including economic activity, population growth, consumption patterns, and the availability of waste reduction programs such as recycling. The estimated quantity of landfilled waste increased by nearly 19 percent, from about 205 MMT in 1990 to 244 MMT in 2008, before declining by 9 percent to 221 MMT in 2024 (see Table 7-4).

In contrast, the amount of waste disposed of in industrial waste landfills—primarily from the pulp and paper and food processing sectors—has remained relatively stable since 1990. Volumes ranged from 9.0 MMT in 1991 to a peak of 12.2 MMT in 1997 and then declined to 10.1 MMT in 2024 (see Annex 5). Methane (CH_4) emissions from these landfills have likewise remained relatively consistent since the early 2000s, ranging from 19.7 MMT CO_2 Eq. in 2005 to 19.5 MMT CO_2 Eq. in

2024. These estimates focus on sectors that generate organic byproducts capable of producing methane, specifically pulp and paper and food processing. Food and beverage processing facilities have made attempts to reduce organic waste sent to industrial waste landfills—construction and demolition landfills, another category of industrial waste landfill, may receive some degradable materials (e.g., treated wood), but these waste streams are unlikely to produce significant methane emissions and are therefore less relevant for national GHG inventories (EPA, 2025). Future inventories will investigate drivers in trends for industrial waste landfills (e.g., diversion to incineration and recycling/reuse of industrial waste materials, especially organics).

Table 7-4: Solid Waste in MSW and Industrial Waste Landfills Contributing to CH_4 Emissions (MMT unless otherwise noted)

Activity	1990	2005	2020	2021	2022	2023	2024
Total MSW Generated [a]	270	368	333	334	336	338	342
Total MSW Landfilled	205	234	215	216	217	219	221
MSW Last 30 Years [b]	4,876	5,992	6,551	6,561	6,584	6,612	6,635
MSW Since 1940 [c]	6,808	9,925	13,153	13,369	13,585	13,804	14,025
Total Industrial Waste Landfilled [d]	10.2	11.6	10.9	11.0	10.6	10.2	10.1

[a] This estimate represents the waste that has been in place for 30 years or less, which contributes about 90 percent of the CH_4 generation. Values are based on various data sources unchanged from the *1990–2023 Inventory* (EPA, 2025) for years 1940–2024. Updated U.S. Census Data were incorporated for recent years for the United States, District of Columbia, and Puerto Rico and over the time series for territories.

[b] This estimate is the cumulative amount of waste that has been placed in landfills for the 30 years prior to the year indicated and is the sum of the annual disposal rates used in the first order decay model. Values are based on the *1990–2023 Inventory* (EPA, 2025) and extrapolated data are based on annual population updates from the U.S. Census Bureau (2024, 2025).

[c] This estimate represents the cumulative amount of waste that has been placed in landfills since 1940 to the year indicated and is the sum of the annual disposal rates used in the first order decay model. Values are based on the *1990–2023 Inventory* (EPA, 2025) and extrapolated data are based on annual population updates from the U.S. Census Bureau (2024, 2025).

[d] Estimates in this row only include estimated waste landfilled from the food and beverage, and pulp and paper sectors. The waste landfilled is estimated using a single waste disposal factor across the time series for each sector. Data are not available to accurately estimate total industrial waste generated for disposal in industrial waste landfills for any industrial sector.

Note: Totals may not sum due to independent rounding.

Methods

MSW Landfills. The methodological approach for estimating MSW Landfill emissions is generally consistent with the approach described in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2023* (EPA, 2025). Based on available data, both IPCC Tier 2 and 3 approaches are applied to develop a consistent time series of estimated emissions.

Calculations for MSW landfills rely heavily on net methane emissions reported by facilities subject to EPA's GHGRP for 2010–2024. Data for 2024, as well as any updates to previously reported data, were not available at the time this report was prepared. Therefore, the 2024 estimates in

this analysis assume that reported 2023 GHGRP net emissions, recovery, and derived parameters (e.g., weighted average oxidation factors) remain unchanged. For 1990–2009, the methodology uses state survey data (e.g., BioCycle State of Survey reports) on total waste accepted by MSW landfills, to which a national waste disposal factor is applied. Population estimates are used to interpolate annual estimates of waste disposed for years where state survey data are unavailable.

Industrial Waste Landfills. The methodological approach for estimating Industrial Waste Landfill emissions is consistent with the approach described in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2023* (EPA, 2025). Emissions are estimated using an IPCC Tier 2 approach implemented through the IPCC waste model adapted for activity in the United States (IPCC, 2006).

Industrial waste disposed and landfilled over the time series is estimated based on disposal rates from a historical EPA survey and industry data applied to annual industrial production data rather than disposal data due to a lack of data. The *GHGIA* methodology assumes most of the organic waste placed in industrial waste landfills originates from the food processing and pulp and paper sectors; this *GHGIA*'s estimates incorporate updated industrial production data from the United States Department of Agriculture's (USDA's) National Agricultural Service Statistics (2025a, 2025b, 2025c, 2025d, 2026) and the Food and Agricultural Organization of the United Nations (FAO, 2026).

Methane recovery at industrial waste landfills is assumed to be insignificant based on available data collected under EPA's GHGRP for industrial waste landfills (EPA, 2025). Additional detail on the methods, data sources, and assumptions can be found in Annex 5 to this report.

Recalculations

Methods and activity data are generally consistent with the *1990–2023 Inventory* (EPA, 2025), incorporating updated activity data where available, namely for industrial waste landfills.

Industrial Waste Landfills. The estimates reflect updates to annual production of paper and paperboard and wood pulp for 2019–2023 (FAO, 2026) and food production data for recent years (i.e., meat, poultry, fruits, and vegetables) (USDA, 2025a, 2025b, 2025c, 2025d, 2026). The revisions to prior data had insignificant impacts across the time series as compared to the *1990–2023 Inventory* (EPA, 2025) (averaging <0.05 percent decrease). Revisions to annual data had no significant impact on total landfill emission estimates and trends, with an average decrease of less than 0.01 percent across the time series.

Uncertainty

Uncertainty in CH_4 emission estimates from landfills is associated with a number of factors. For MSW landfills uncertainty is associated with

- activity data (e.g., diverse and periodic data sources on historical and current waste generation and landfilled, the number of non-reporting landfills below GHGRP reporting thresholds, landfill gas recovered);
- the representativeness of assumed decay and oxidation rates; and

- degradable organic carbon (DOC) for U.S. landfills, including those used in reported net emissions under GHGRP.

In addition, emissions have been estimated to be higher than those presented here when using other methods to quantify emissions (e.g., calculating emissions based on inverse modeling from atmospheric observations). For industrial waste landfills, uncertainty is associated with lack of data and assumptions to approximate key data (e.g., assumptions on disposal rates, industrial waste landfilled), and, similar to MSW landfills, the representativeness of assumptions on methane generation, oxidation rates, and recovery at industrial waste landfills in the United States.

For this current report, the overall uncertainty associated with national estimates of CH_4 from landfills is assumed to be similar to the *1990–2023 Inventory* (EPA, 2025) given the use of the same basic methodology and data sources for most years, calculated using the *2006 IPCC Guidelines* Approach 2 methodology for uncertainty at the 95-percent confidence level (IPCC, 2006). This confidence level indicates a range of approximately 9 percent below and 14 percent above the emission estimate in 2024. Uncertainty assessments for 2024 are summarized at the end of this chapter in Table 7-10. For MSW landfills, additional uncertainty arises from using 2023 reported emissions and parameters to estimate 2024 emissions, which may over- or underestimate activity trends due to changes in characteristics, including management practices at U.S. landfills.

7.2 Wastewater Treatment and Discharge (Source Category 5D)

Treatment and discharge of wastewater can produce methane (CH_4) and nitrous oxide (N_2O) emissions. Wastewater from homes and industries is treated to remove organic material, solids, nutrients, and other contaminants. In the United States, nearly 80 percent of wastewater is treated in centralized systems, while about 19 percent is treated in on-site systems such as septic tanks. Industrial wastewater may be treated on-site or combined with domestic wastewater in centralized systems (EPA, 2025; IPCC, 2006).

Treatment processes in centralized systems vary but typically include physical removal of solids and biological processes that break down organic material. Wastewater is typically collected using sewer systems and then further treated using primary, secondary, and/or tertiary treatment methods followed by discharge. Each management phase can create anaerobic conditions (e.g., anaerobic phases during tertiary treatment in constructed wetlands and lagoons) contributing to CH_4 ultimately emitted from the treatment system. Sludge produced during secondary treatment may also generate CH_4 if it is further treated in anaerobic digesters. Although some facilities recover or flare this gas reducing CH_4 emissions, some emissions still occur from unintentional leakages (EPA, 2025). Per IPCC guidelines (2019), emissions from anaerobic sludge digestion—including biogas recovery and flaring operations, where the digester's primary use is for treatment of wastewater treatment solids—are estimated and reported under wastewater treatment whereas on-farm and stand-alone digestors (e.g., for processing food waste) are reported in Chapter 5, Agriculture under Section 5.2 and later within this chapter in Section 7.4 , respectively. Emissions from flooded lands or constructed waterbodies (not used for wastewater treatment) are estimated and reported in Chapter 6, under Sections 6.8: Wetlands Remaining Wetlands and 6.9: Lands Converted to Wetlands.

Nitrous oxide is formed during processes that convert nitrogen in wastewater, particularly during nitrification and denitrification. These emissions are often released to the air during treatment, especially in aerated parts of the treatment process (IPCC, 2019).

On-site systems, such as septic tanks, treat wastewater through settling and anaerobic sludge digestion. This digestion produces CH_4 (and biogenic CO_2), which is typically vented, and can also release N_2O and biogenic CO_2 from dispersing effluent through the soil (EPA, 2025).

Wastewater discharges containing dissolved CH_4 and N_2O and additional organic matter can also lead to emissions when treated effluent is released into rivers, lakes, or other water bodies. Methane emissions are generally higher for discharges to slow-moving waterbodies (e.g., lakes and reservoirs), whereas N_2O emissions are higher when discharging to nutrient-impacted or eutrophic waters (IPCC, 2019).

In addition to the configuration and operation of treatment systems (e.g., management under anaerobic conditions), the main factors affecting CH_4 emissions is the amount of organic material in the wastewater, often measured as biochemical oxygen demand (BOD) or chemical oxygen

demand (COD). Higher values generally mean higher emissions. N_2O emissions depend on the amount of nitrogen and how the treatment system is operated (EPA, 2025; IPCC, 2019). Recent studies suggest CH_4 emissions may be lower than previously thought, while N_2O emissions may be higher (see relevant references in the "Future Areas for Improvement" subsection included in the introduction to this chapter).

Total methane (CH_4) emissions from wastewater treatment and discharge were 21 MMT CO_2 Eq. in 2024, including 14 MMT CO_2 Eq. from domestic wastewater treatment and discharge, and 7 MMT CO_2 Eq. from industrial wastewater treatment and discharge (Table 7-5). Methane emissions from domestic wastewater remained fairly steady from 1990 through 2000 but have decreased since that time due to decreasing use of anaerobic systems, including reduced use of on-site septic systems and central anaerobic treatment systems (EPA, 2025). Methane emissions from industrial wastewater emissions have generally increased across the time series, with some fluctuations corresponding to production changes from the pulp and paper manufacturing, meat and poultry processing, fruit and vegetable processing, starch-based ethanol production, petroleum refining, and brewery industries.

Nitrous oxide (N_2O) emissions from wastewater treatment and discharge in 2024 totaled 21.1 MMT CO_2Eq., including 20.6 MMT CO_2 Eq. from domestic wastewater and 0.5 MMT CO_2 Eq. from industrial wastewater (see Table 7-5). N_2O emissions from domestic wastewater have steadily increased over time due to U.S. population growth and increased protein intake. Emissions from industrial wastewater sources have also increased over time with production changes associated with the treatment of wastewater, namely from meat and poultry processing and petroleum refining, but also with contributions from pulp and paper manufacturing and brewery industries.

In total, the wastewater treatment and discharge category emitted 42.1 MMT CO_2 Eq. in 2024.

Table 7-5: Emissions from Wastewater Treatment and Discharge (MMT CO_2 Eq.)

Activity	1990	2005	2020	2021	2022	2023	2024
CH_4	**22.7**	**22.7**	**21.0**	**20.7**	**20.9**	**21.2**	**21.0**
Domestic Treatment	15.1	14.6	11.7	11.4	11.7	12.1	12.0
Domestic Effluent	1.4	1.4	2.1	2.1	2.0	2.0	2.0
Industrial Treatment [a]	5.5	6.1	6.6	6.7	6.7	6.6	6.5
Industrial Effluent [a]	0.7	0.6	0.5	0.5	0.5	0.5	0.5
N_2O	**14.8**	**18.1**	**21.6**	**21.1**	**21.2**	**21.0**	**21.1**
Domestic Treatment	10.5	13.7	16.7	16.3	16.5	16.4	16.6
Domestic Effluent	3.9	3.9	4.5	4.3	4.2	4.1	4.0
Industrial Treatment [b]	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Industrial Effluent [b]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total Emissions	**37.5**	**40.7**	**42.5**	**41.8**	**42.1**	**42.2**	**42.1**

[a] Industrial activity for CH_4 includes the pulp and paper manufacturing, meat and poultry processing, fruit and vegetable processing, starch-based ethanol production, petroleum refining, and breweries industries.

[b] Industrial activity for N_2O includes the pulp and paper manufacturing, meat and poultry processing, starch-based ethanol production, and petroleum refining.

Note: Totals by gas may not sum due to independent rounding.

Methods

The methodological approach for estimating emissions from treatment and discharge of domestic and industrial wastewater is consistent with the *Inventory of Greenhouse Gas Emissions and Sinks: 1990–2023* (EPA, 2025).

The estimates reflect updated data where available. For example, the domestic wastewater estimates are based on updated population data but use the same shares of septic and centralized treatment systems (i.e., publicly owned treatment works) as the *1990–2023 Inventory* (EPA, 2025) given no new housing survey data were available from the U.S. Census. The industrial wastewater estimates reflect updated industrial production data on food products (i.e., meat poultry, fruits, vegetables) from USDA National Agricultural Statistics (USDA, 2025a, 2025b, 2025c, 2025d, 2026a), pulp and paper production from the FAO Statistical Division (FAOSTAT; FAO, 2026a), ethanol grain use from the Renewable Fuel Association (2026), ethanol production from USDA (2026b), petroleum production data from the Energy Information Administration (EIA, 2026), and updated brewery production data from the Alcohol and Tobacco Tax and Trade Bureau's beer statistics (2025). The estimates also reflect updated available per capita protein data from FAO given lack of domestic data sources (FAO, 2026b).

Additional detail on the methods, data sources, and assumptions can be found in Annex 5 to this *GHGIA*.

Recalculations

Methods and activity data are generally consistent with the *1990–2023 Inventory* (EPA, 2025), incorporating updated activity data where available as described below.

- ***Domestic Wastewater.*** The estimates reflect updates to annual population data for the United States, including territories for consistency with the latest published U.S. Census (U.S. Census Bureau, 2024, 2025). The population data were updated for the continental United States, District of Columbia, and Puerto Rico for 2010–2023 and updated across the full time series for other U.S. territories. Revised available protein supply data were updated for 2010–2023 (FAO, 2026b). The revisions had insignificant impacts across the time series as compared to the *1990–2023 Inventory* (averaging <0.2 percent).
- ***Industrial Wastewater.*** The estimates reflect updates to annual production of paper and paperboard and wood pulp for 2019–2023 (FAO, 2023, see USA Tables; FAO 2026a, 2026b), food production data for recent years (i.e., meat, poultry, fruits, and vegetables) (USDA, 2025a, 2025b, 2025c, 2025d, 2026), petroleum production (EIA, 2026); ethanol production (USDA, 2026b); and brewery production (Alcohol and Tobacco Tax and Trade Bureau, 2025). The revisions to recent prior data had insignificant impacts across the time series as compared to the *1990–2023 Inventory (EPA, 2025)* (averaging <0.05 percent).

Revisions to annual data had no significant impact on estimated wastewater emission and trends, with an average slight decrease of less than 0.2 percent across the time series.

Uncertainty

Uncertainty in emission estimates from wastewater is associated with a number of factors. For domestic treatment the uncertainty is primarily due to assumptions to estimate types of treatment in place, and representativeness of surrogate data and assumptions to approximate key estimation parameters in reflecting operational wastewater treatment and discharge systems over time in the United States. Similar factors impact industrial wastewater estimates. As noted, recent independent studies also suggest potential overestimation of CH_4 emissions and underestimation of N_2O emissions (see the "Future Areas for Improvement" in the introduction to this chapter).

For this current report, the uncertainty associated with national estimates of CH_4 and N_2O from wastewater is assumed to be similar to the *1990–2023 Inventory* (EPA, 2025), given the use of the same methodology and data sources for all years, calculated using the *2006 IPCC Guidelines* Approach 2 methodology for uncertainty at the 95 percent confidence level (IPCC, 2006). In 2024, this confidence level indicates a range of approximately 28 percent below and 32 percent above estimated CH_4 emissions and approximately 37 below and 193 percent above estimated N_2O emissions. Uncertainty assessments for 2024 are summarized at the end of this chapter in Table 7-10.

7.3 Composting (Source Category 5B1)

Composting is commonly used in the United States to manage organic wastes such as food scraps, yard trimmings, and wastewater sludge and/or biosolids (BioCycle, 2017, 2023, 2025; USCC, 2025). It reduces methane-generating waste sent to landfills, destroys pathogens, and produces a usable soil amendment that can offset chemical fertilizer use. This source category includes large-scale, commercial composting operations, primarily windrow systems handling yard trimmings, consistent with national survey data (BioCycle, 2017; EPA, 2025; Environmental Research & Education Foundation, 2024). Windrow systems, including windrow systems combined with other systems, account for the largest share of systems in use at food waste composting facilities (nearly 49 percent of systems) (BioCycle, 2017). The estimates exclude waste composted using other methods (e.g., aerated static piles) due to limited data availability. They also do not currently include residential or community composting.

Composting is primarily an aerobic process that converts organic carbon to CO_2; however, localized anaerobic conditions can produce CH_4, and N_2O may form depending on nitrogen content and management practices. Most CH_4 generated is oxidized within the compost pile, resulting in relatively low emissions overall. The estimated CH_4 released into the atmosphere ranges from less than 1 percent to a few percent of the initial carbon content in the material. Composting emissions vary depending on factors such as the waste composition (e.g., residential yard waste, food scraps, wood chips, peat), and process conditions (e.g., temperature, moisture content, aeration). Further, net carbon dioxide flux from carbon stock changes of materials of biogenic origin being composted are reported under the LULUCF sector estimates and not reported here to avoid double counting of emissions from biomass-related stock changes (see Chapter 6 of this *GHGIA*) (IPCC, 2006).

In 2024, composting emissions were estimated at 2.6 MMT CO_2 Eq. for CH_4 and 1.9 MMT CO_2 Eq. for N_2O and have increased fivefold since 1990 (see Table 7-6). Growth in composting has been driven largely by state and local policies restricting landfill disposal of organic waste and expanding collection programs. From 1990 to 2024, the amount of waste composted increased from 3,810 kt to 23,378 kt, with emissions of CH_4 and N_2O rising proportionally (see Table 7-7). These policies, along with increased infrastructure and diversion efforts, have significantly increased the amount of organic waste processed through composting rather than landfilled (EPA, 2025).

Table 7-6: Emissions from Composting (MMT CO_2 Eq.)

Activity	1990	2005	2020	2021	2022	2023	2024
CH_4	0.4	2.1	2.6	2.6	2.6	2.6	2.6
N_2O	0.30	1.5	1.8	1.8	1.8	1.8	1.9
Total	0.7	3.6	4.4	4.4	4.4	4.4	4.5

Note: Totals may not sum due to independent rounding.

Table 7-7: U.S. Waste Composted (kt)

Activity	1990	2005	2020	2021	2022	2023	2024
Waste Composted	3,810	18,655	22,802	22,836	22,964	23,153	23,378

Methods

The methodological approach for estimating emissions from composting is consistent with the *Inventory of Greenhouse Gas Emissions and Sinks: 1990–2023* (EPA, 2025). Consistent with the previous *Inventory*, the estimate of the annual amount of waste composted for 2019–2024 was developed by extrapolation due to lack of annual national compost data by applying the 2018 compost per capita ratio to corresponding updated annual population data from U.S. Census (U.S. Census Bureau, 2024, 2025).

Recalculations

Methods and activity data are generally consistent with the *Inventory* (EPA, 2025), incorporating updated annual population data from the U.S. Census (U.S. Census Bureau, 2024, 2025) for 2018 to 2024. The revisions had insignificant impacts on 2019–2023 estimates as compared to the *Inventory* (EPA, 2025). On average, recalculated emissions decreased by 0.04 percent, due to a slightly lower estimated composting per capita ratio which in turn caused slight decreases in estimated waste composted, and associated emissions for those years.

Uncertainty

Uncertainty in emission estimates from composting is primarily associated assumptions with the waste quantities composted and associated methods for composting, and average characteristics impacting methane generation for each method in practice in the United States.

For this current report, the uncertainty associated with national estimates of CH_4 and N_2O emissions from composting is assumed to be similar to the *1990–2023 Inventory* (EPA, 2025), given the use of the same methodology and data sources for all years and calculated using the *2006 IPCC Guidelines* Approach 1 methodology or error propagation method (IPCC, 2006). The combined uncertainty associated with activity data and default emissions factors indicates a range of approximately 58 percent below and 58 percent above estimated CH_4 emissions in 2024. Uncertainty assessments for 2024 from all waste source categories are summarized at the end of this chapter in Table 7-10.

7.4 Anaerobic Digestion at Biogas Facilities (Source Category 5B2)

Anaerobic digestion is a biological process that occurs inside an enclosed, air-tight vessel (i.e., the anaerobic digester) where microorganisms break down organic matter such as food waste in the absence of oxygen, producing biogas and digestate (i.e., nutrient rich, solid and liquid material left after the digestion process) (EPA, 2025c). The resulting biogas consists primarily of methane (CH_4) and biogenic carbon dioxide (CO_2), with small amounts of other gases, and is flared, used for energy (commonly used for on-site heat, electricity), or upgraded to renewable natural gas and sold. The digestate is often applied as a soil amendment or fertilizer to agricultural fields, land reclamation, or other suitable uses. Under proper operating conditions with regular maintenance, CH_4 emissions are expected to be minimal. Methane emissions can occur from inefficiently operated systems, contaminants in the waste stream (e.g., inert materials such as microplastics), leaks at system connection points, or pressure build-ups which may lead to leaks. Carbon dioxide emissions are biogenic and reported separately (IPCC, 2006).

Anaerobic digesters vary by operating temperature, feedstock type, moisture content, and system design. They may operate under mesophilic or thermophilic conditions and process a wide range of organic materials, including food waste, wastewater solids, manure, and industrial residues. Many systems use co-digestion to enhance methane production by combining multiple feedstocks (EPA, 2025b, 2025c). Digesters are also classified as wet or dry systems based on solids content and may operate in batch or continuous modes. N_2O emissions are assumed to be negligible (IPCC, 2006).

In national GHG inventories, anaerobic digestion systems are generally categorized as stand-alone biogas facilities, on-farm digesters, or systems at water resource recovery facilities. This section focuses on stand-alone facilities, which process waste from single or multiple sources. Emissions from on-farm digesters are included in the manure management category estimates in Chapter 5 (agriculture sector) and emissions from systems at water resource recovery facilities are included in the wastewater treatment and discharge category estimates within this chapter.

From 1990 to 2024, the amount of waste managed by these facilities increased substantially, driven by growing interest in biogas as a renewable energy source and efforts to divert organic waste from landfills. However, estimates for 1990–2015 and some recent years (i.e., 2020–2021 and 2024) rely on extrapolation and interpolation due to limited data availability (EPA, 2025b).

Table 7-8: Emissions from Stand-Alone Anaerobic Digestion at Biogas Facilities (metric tons [MT] CO_2 Eq.)

Activity	1990	2005	2020	2021	2022	2023	2024
CH_4 Generated	22,129	66,388	328,348	347,874	334,093	146,700	240,397
CH_4 Recovered	(21,023)	(63,069)	(311,931)	(330,480)	(317,388)	(139,365)	(228,377)
Net CH_4 Emissions	**1,106**	**3,319**	**16,417**	**17,394**	**16,705**	**7,335**	**12,020**

Notes: Parentheses indicate negative values. Totals may not sum due to independent rounding

Table 7-9: Waste Digested and Estimated Operational Facilities

Activity	1990	2005	2020	2021	2022	2023	2024
Waste Digested (kt)	988	2,964	14,658	15,530	14,915	6,549	10,732
Estimated Operational Facilities (count)	4	12	54	54	96	96	96

Source: EPA, 2025b

Methods

The methodological approach for estimating emissions is consistent with the *Inventory of Greenhouse Gas Emissions and Sinks: 1990–2023* (EPA, 2025a). The estimates incorporate recently published survey data findings from the EPA's Anaerobic Digestion Data Collection Project for 2022 and 2023 (2025a), and 2022 and 2023 data were averaged to approximate 2024 activity data on waste processed and operational facilities. Methane recovered was extrapolated based on activity data (i.e., waste digested) multiplied by a 5 percent default leakage factor (IPCC, 2006). Approximately 80–90 percent of all anaerobic digestion facilities used some or all of the CH_4 generated (EPA, 2025b). The methodology assumes that all CH_4 generated by stand-alone anaerobic digesters is used and approximately 5 percent is leakage and therefore the amount emitted to the atmosphere.

Recalculations

Recalculations were implemented to incorporate 2022 and 2023 survey data from EPA (2025b). Recalculated emissions decrease in 2022 and 2023, by 1 percent and 56 percent respectively, consistent with decreases in revised estimated annual waste digested for those years relative to EPA (2025a).

Uncertainty

Uncertainty in emission estimates from stand-alone anaerobic digestion is associated with a few key factors, namely incomplete, periodic survey data which likely underestimates digestion activity, including biogas recovery, flaring, and energy uses based on low survey response rates.

The survey methods have also been refined over time so EPA urges data users to exercise caution in comparing data across surveys as they may not accurately reflect activity trends.

For this current report, the uncertainty associated with national estimates of CH_4 from stand-alone anaerobic digestion is assumed to be similar to EPA (2025a), given the use of the same basic methodology and data sources for all years and calculated using the *2006 IPCC Guidelines* Approach 1 methodology or error propagation method (IPCC, 2006). The combined uncertainty associated with activity data and default emissions factors indicates a range of approximately 54 percent below and 54 percent above estimated CH_4 emissions in 2024. Uncertainty assessments for 2024 from all waste source categories are summarized at the end of this chapter in Table 7-10.

7.5 Waste Incineration (Source Category 5C1)

Emissions of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) from waste incineration are reported in the energy sector because most waste combustion in the United States occurs at waste-to-energy facilities and industrial boilers that recover energy. In 2024, waste combustion resulted in 12.2 MMT CO_2 Eq. of emissions. See Section 3.3 of Chapter 3 on energy for more information.

Non-hazardous industrial and medical waste incineration are additional sources of emissions from waste combustion; however, data for these sources are limited and emissions are not estimated. An analysis of medical waste incineration (EPA, 2025) indicates emissions are less than 500 kt CO_2 Eq. per year and are therefore considered insignificant for national inventory reporting. A similar analysis of sewage sludge incineration, based on total sludge generation and assumed incineration rates, also found emissions below 500 kt CO_2 Eq. per year and insignificant. See information in Annex 5 to this *GHGIA*.

7.6 Waste Uncertainty Summary

Table 7-10 shows the uncertainty summary for each waste sector source. A discussion of the uncertainty ranges is included in each source category's respective chapter section.

Table 7-10: Quantitative Uncertainty Summary by Waste Sector Source

Source	Gas	2024 Estimate ($MMT CO_2$ Eq.)	Uncertainty Range Relative to Emission Estimate ($MMT CO_2$ Eq.)		Uncertainty Range Relative to Emission Estimate (%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Landfills (Total)	**CH_4**	**119.4**	**108.7**	**136.1**	**–9%**	**14%**
MSW Landfills	CH_4	100.6	98.6	120.7	–2%	20%
Industrial Landfills	CH_4	18.8	16.0	26.1	–15%	39%
Wastewater Treatment	**CH_4**	**21.0**	**15.1**	**27.7**	**–28%**	**32%**
Domestic	CH_4	14.0	9.4	19.7	–33%	41%
Industrial	CH_4	7.0	4.1	11.1	–42%	58%
Wastewater Treatment	**N_2O**	**21.1**	**13.4**	**62.1**	**–37%**	**193%**
Domestic	N_2O	20.7	12.4	61.1	–40%	195%
Industrial	N_2O	0.5	0.5	1.5	–2%	199%
Composting	**CH_4**	**2.6**	**1.1**	**4.1**	**–58%**	**58%**
Composting	**N_2O**	**1.9**	**0.8**	**3.0**	**–58%**	**58%**
Anaerobic digestion at biogas facilities	**CH_4**	**0.01**	**0.00**	**0.02**	**–54%**	**54%**

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Please see the *Inventory of greenhouse gas emissions and sinks: 1990–2023* (EPA, 2025) for additional references.

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