Trashing the Climate:

Methane from Municipal Landfills

ENVIRONMENTAL INTEGRITY PROJECT

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THE ENVIRONMENTAL INTEGRITY PROJECT:

The Environmental Integrity Project (EIP) is a nonpartisan, nonprofit organization established in March of 2002 by former EPA enforcement attorneys to advocate for effective enforcement of environmental laws. EIP has three goals: 1) to provide objective analyses of how the failure to enforce or implement environmental laws increases pollution and affects public health; 2) to hold federal and state agencies, as well as individual corporations, accountable for failing to enforce or comply with environmental laws; and 3) to help local communities obtain the protection of environmental laws. For more information on EIP, visit: www.environmentalintegrity.org

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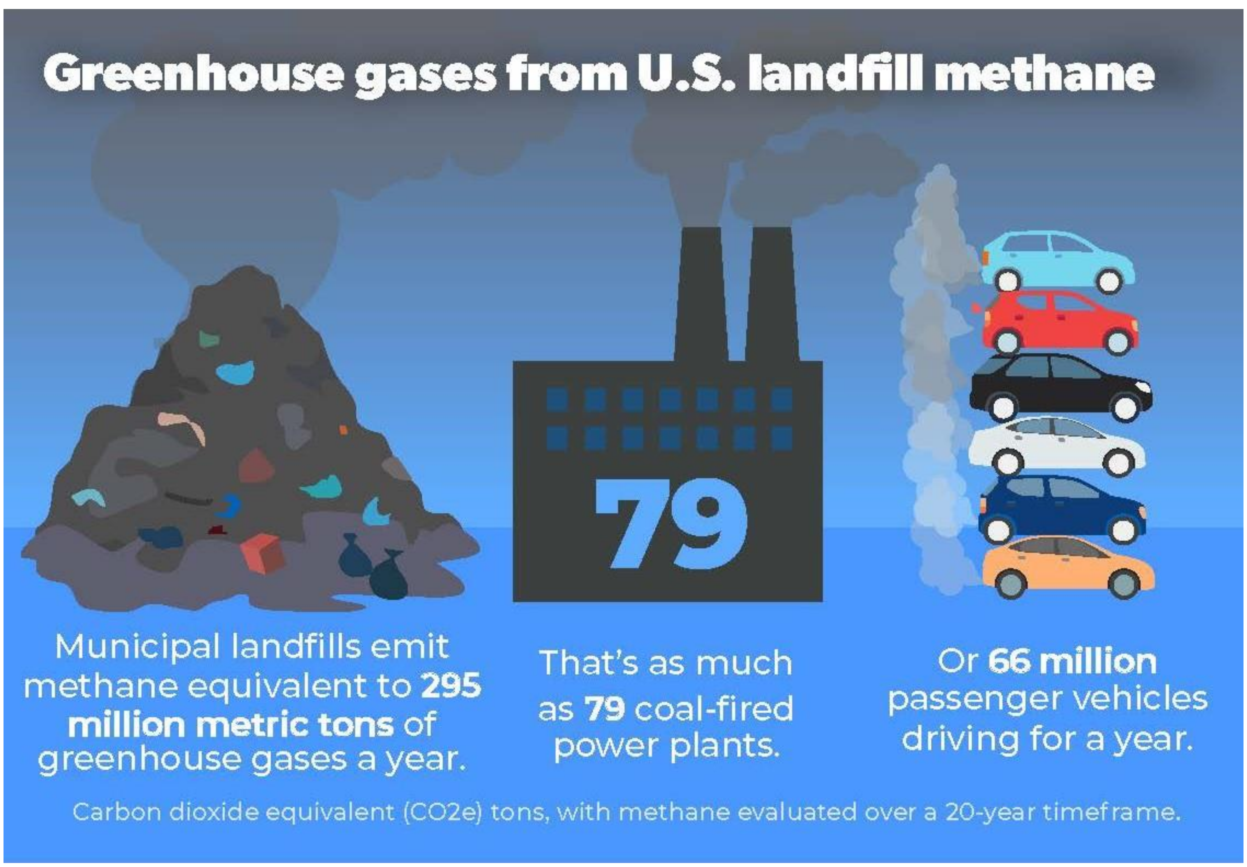
Trashing the Climate:
Methane from Municipal Landfills

Executive Summary

Municipal landfills are one of the largest sources of methane in the United States, responsible for an estimated 14.3 percent of total methane emissions. When organic components of municipal solid waste such as food scraps, yard trimmings, and paper break down in landfills, they generate methane.

EPA estimates that U.S. municipal waste landfills emitted a total of 3.7 million metric tons of methane in 2021, equivalent to about 295 million metric tons of greenhouse gases (carbon dioxide equivalent, or CO_2e tons), if the effects of methane are evaluated on a 20-year timeline.[1] This is as much greenhouse gas pollution as from 66 million gasoline-powered passenger vehicles on the road for a year (about a quarter of all American cars, SUVs, vans, and pickup trucks), or from 79 coal-fired power plants.[2]

Methane is one of the most potent greenhouse gases, trapping about 80 times as much heat as carbon dioxide over 20 years.[3] Reducing methane from landfills therefore presents an

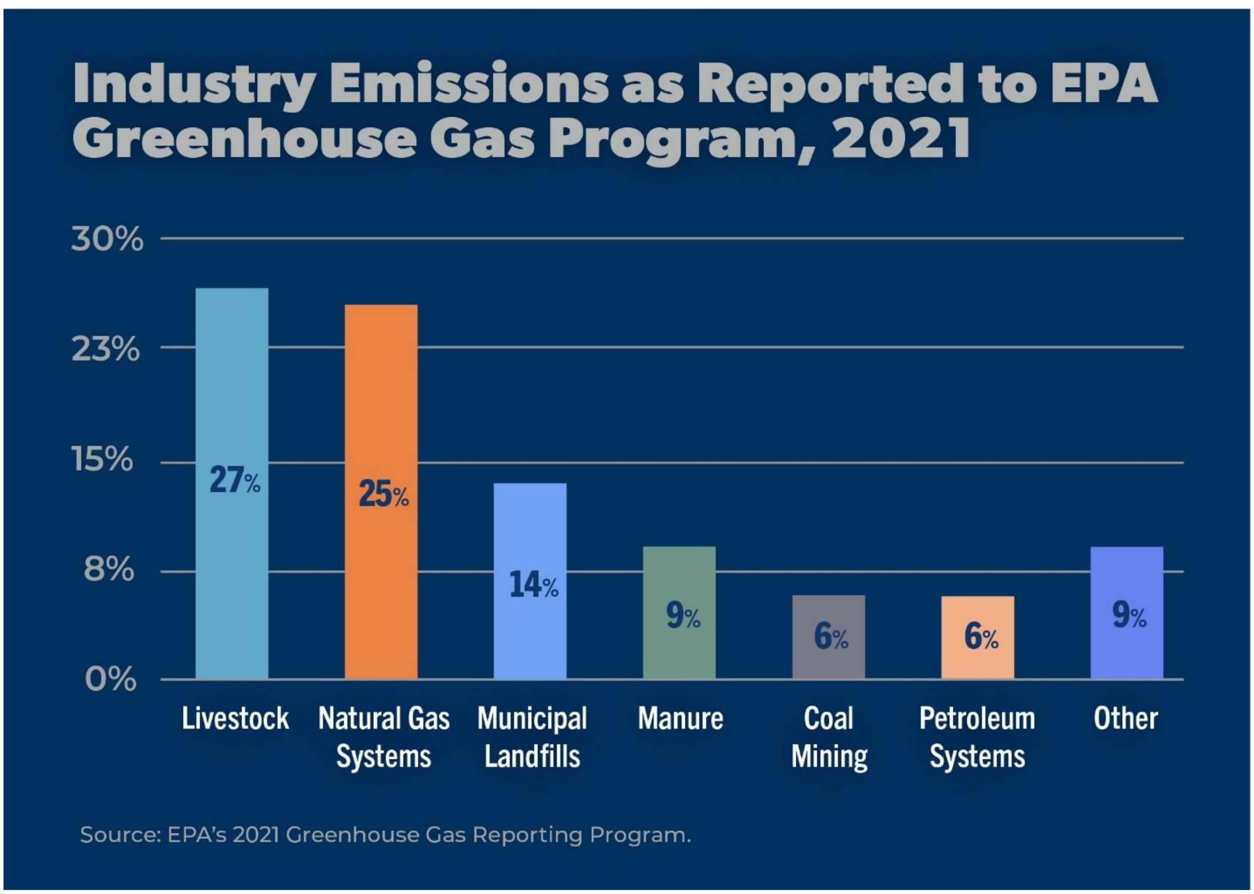


opportunity to significantly reduce greenhouse gas emissions in the face of climate change, through actions like installing landfill methane collection systems and reducing and composting food waste.

Food waste, in particular, is a growing problem that can be addressed. Americans throw out about 40 percent of their food,[4] and the volume of food waste generated in the U.S. increased by 70 percent between 1990 and 2017.[5] On a global scale, if wasted food were a country, it would be the third-largest emitter of global greenhouse gases, behind China (21 percent) and the United States (13 percent). This is according to an EPA report that includes all emissions from the growing, processing, and transporting of wasted food, and not just methane from landfills.[6]

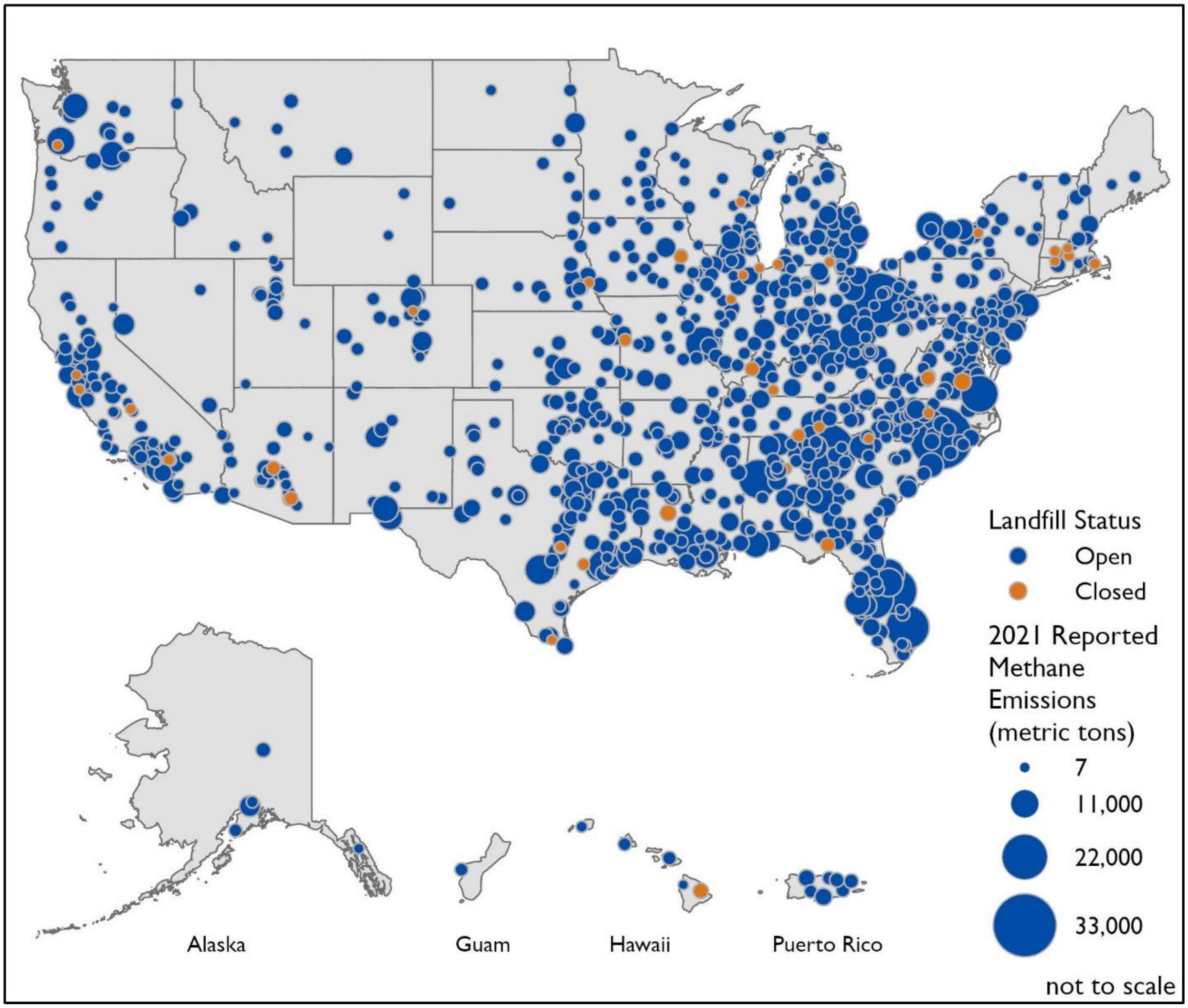
The necessary solutions to the landfill methane problem include discouraging food waste by consumers and businesses and encouraging more composting and recycling of waste. Also needed are federal regulations that require the installation of gas collection systems and monitors at landfills, as well as covering materials on landfills that help contain emissions.

Figure I: Methane Emissions by Sector



The Environmental Integrity Project (EIP) examined data from the EPA's Greenhouse Gas Reporting Program to characterize methane emissions reported by more than 1,100 municipal landfills. EPA requires landfills operating since 1980 to estimate their methane emissions using a model and to report their annual emissions to a national database. The program only applies to larger landfills that generate at least 1,000 metric tons of methane before any gas collection.

Figure II: Municipal Landfills and Reported Greenhouse Gas Emissions

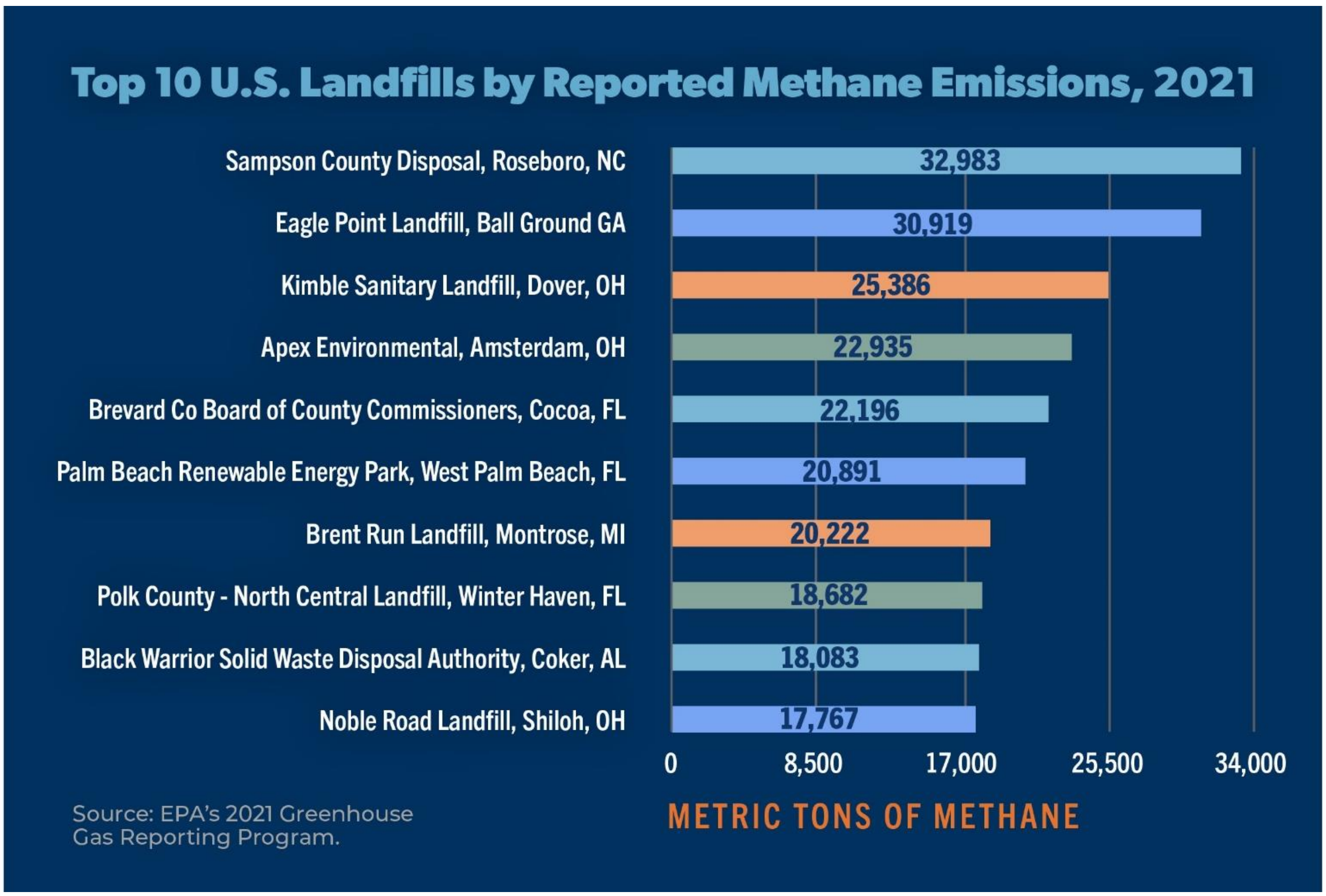


The 1,127 landfills that reported to the EPA's Greenhouse Gas Reporting Program in 2021 are geographically distributed across the entire U.S. but are generally more concentrated in the eastern half of the country.

By state, Texas and California had the highest methane emissions from landfills, but they also have about twice as many landfills as other states. However, states vary in how much trash is contained in landfills and how many landfills have installed systems that collect and burn or re-direct landfill gas. For example, California has the most landfilled waste of any state, but also regulates landfills more strictly than other states, so has proportionately lower emissions. In comparison, Texas, where landfills are subject to only federal regulations, reported about 130,000 more metric tons of methane emissions than California in 2021, despite having added 20 percent less trash to its landfills over the last 10 years.

The 10 landfills that reported releasing the most methane emitted about 230,000 metric tons of the greenhouse gas in 2021, about as much carbon as from five coal-fired power plants operating 24 hours a day for a year. (All carbon dioxide equivalents in this report are based on a 20-year global warming potential unless otherwise noted.) These top emitters are all active landfills with gas collection systems that somewhat reduce their methane emissions. The biggest polluter, the Sampson County Disposal in North Carolina, for example, emits more than 10 times as much as the average landfill that reported to EPA.

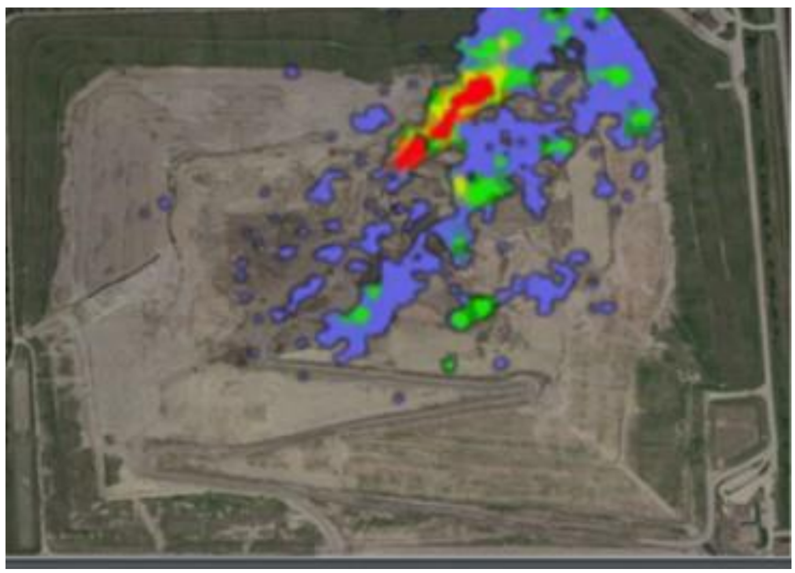
Figure III: Top Landfill Emissions



More than one million people live within a mile of a landfill in the U.S.[7] Fifty-four percent of landfills are in communities with a higher percentage of people-of-color or low-income population than the national average, according to an EPA demographic dataset called *EJScreen*. These nearby residents are often negatively impacted by the landfills, as demonstrated by the case studies in this report from Alabama (see page 27) and Maryland (page 30). In Uniontown, Alabama, a community that is 98 percent Black and 64 percent below the poverty line, neighbors complain about odors, nausea, headaches, and other illnesses from a landfill that receives 93 percent of its garbage from out of state. In the Curtis Bay and Brooklyn neighborhoods of Baltimore, a community that is 60 percent Black or non-white Hispanic, a nearby landfill owned by the city is one of the top methane emitters in Maryland.

The evidence suggests that EPA is significantly underestimating methane emissions from landfills and that stronger regulations are needed. For example, models currently used by EPA to estimate emissions rely on a combination of default values and site-specific variables, such as how much trash has been dumped over time and the type of covering over the waste. However, the models assume that landfill covers and gas collection systems work as designed and effectively control emissions, but little information is collected about how well these systems perform.

Figure IV: Emissions from a California Landfill



New technologies, like this picture taken using an airborne imaging spectrometer, offer better ways to monitor and estimate methane emissions.

The Environmental Integrity Project and allies sued EPA on July 29, 2022, arguing that the agency's outdated methods of estimating emissions of air pollutants from landfills meant significant under reporting.[8] In response, on April 10, 2023, EPA and EIP reached an agreement[9] that requires EPA to review the current methodology used to estimate landfill methane and, if necessary, to revise the methods no later than August 2024.[10]

New technologies offer better ways to monitor and estimate methane emissions. Airborne measurements of methane emissions at landfills do not correspond with reported emissions. The surveys have shown very large methane plumes over some landfills, often the result of problems with gas control systems and landfill covers.[11] An aerial image of a methane plume captured at a landfill in California is shown in Figure IV.[12] Models like EPA's Greenhouse Gas Reporting Program often do not account for the kinds of leaks and other events that are captured by these aerial surveys. However, on May 5, EPA proposed to revise its methodology to try to capture some of these events. The proposed regulations would also provide more information in the future about how many landfills in the U.S. operate gas collection systems that must meet federal standards.[13]

Methane emissions from landfills can be reduced by recycling or composting waste. Landfill operators can also control this pollution by using gas collection systems that capture a higher percentage of methane emissions, and by ensuring the methane's destruction in high-efficiency flares. Unfortunately, federal regulations that exist today for these gas collection systems are weak and incomplete and need to be strengthened and expanded to apply to more landfills.

Many landfills in the U.S. have gas control systems that are not required but were installed to collect gas to generate electricity sold to offset landfill operating costs. While those financial incentives encourage practices that reduce methane, they are not enough to assure that these gas recovery systems are well operated or that methane emissions are accurately reported.

Stronger federal rules for municipal landfills are necessary to curtail methane emissions.

There are currently no comprehensive data on how many landfills in the U.S. have gas controls systems that are operated to meet regulatory requirements. EPA's Landfill Methane Outreach Program estimates that 609 landfills of 1,381 for which data was available (an additional 1,256 landfills did not have sufficient data available) may be subject to federal regulations, based on voluntarily reported numbers that may be inaccurate or out-of-date. Some landfills that meet the requirements may opt to use on-site testing to demonstrate that emissions were low enough to avoid the obligation to install a gas collection system that complies with federal standards, which is allowed under the current regulations. While most landfills have some kind of gas collection system, the voluntarily-installed systems are not subject to any operational standards or monitoring requirements.

Despite significant methane emissions from municipal landfills, federal regulators are, so far, not doing enough to curb methane emissions. EPA rules function as a regulatory floor and states are authorized to set more stringent standards. California and Oregon have already issued stronger rules for landfills, and California is considering further improving its standards.[14] Maryland has issued draft rules and Washington legislators passed a law requiring the state environmental agency to issue regulations. These states are requiring that pollution controls be operated at a greater number of landfills and that gas control systems meet stronger performance standards.

More must be done to curb landfill methane. The failure to adequately address air pollution from landfills contributes to climate change and disproportionately affects communities of color and low-income neighborhoods near dumps, creating an environmental injustice. Improved control and monitoring are necessary.

Recommendations:

1. **Stronger federal regulations for landfill gas collection systems:** Stronger EPA rules for municipal landfills are necessary to curtail methane emissions. Lower thresholds for requiring the installation of gas collection systems and stronger operational requirements, as implemented by states like California and Oregon, could significantly reduce methane emissions from landfills by requiring control systems at more landfills. In addition, states are issuing stronger operational standards for landfill gas collection and control systems. Among other things, these standards require higher combustion efficiencies at flares, and the monitoring and repair of on-site equipment for gas leaks. Other proven methods of reducing methane from landfills should be required, including covering waste with materials like soil or clay that boost collection system efficiency and/or remove methane before it enters the air. More organic waste should also be diverted from landfills. The U.S. EPA should encourage these best practices in its regulations.

2. **EPA should establish a uniform method for estimating emissions from landfills.** In the U.S., members of the public, government officials, landfill operators, scientists, and others rely on landfill emissions data that is calculated using a methodology established by EPA. However, this methodology differs depending on the context. For example, the method for calculating emissions for state inventories and some permitting decisions is different from the method used to determine whether a gas control system must be installed. And both of these are different from the two methods that can be used to estimate emissions for EPA's Greenhouse Gas Reporting Program. These variations can produce substantially different results, which makes it difficult to accurately estimate landfill methane emissions or to design cost-effective strategies to reduce them.

3. **Direct measurement of methane:** The EPA should also promote the direct measurement of methane at landfills. Techniques exist for measuring landfill emissions directly in ways that can be used to control and quantify pollution. EPA should require such direct measurement in its new regulations for landfills. Aircraft and drone-based techniques can take short-term "snapshots" of landfill methane that can be used to identify and fix leaks. Ground-based instruments can be used to

generate an annual estimate of sitewide emissions without relying on models. The EPA recently took an important step by approving a type of drone technology for use in regulatory monitoring at landfills. The federal agency also included provisions supporting the development of new monitoring techniques in rules recently proposed for the oil and gas industry. The EPA should include a similar requirement in new regulations for landfills.

4. **Improve reporting requirements**: The EPA should finalize its proposed rule requiring landfill operators to identify applicable regulatory performance standards when reporting to the Greenhouse Gas Reporting Program. As landfill emissions data from direct measurement studies becomes more widely available, it will be important to assess regulatory drivers affecting the best and worst performers. At present, it is not possible to run this analysis on any meaningful scale. In fact, the only way for members of the public to determine whether landfill gas control systems are voluntary or subject to regulation is to review permit documents for individual landfills. With over 1,000 landfills in the country, this effectively makes it impossible to conduct such an analysis on a national scale.

5. **More composting and recycling, less food waste:** More emphasis should be placed on preventing organic waste from being thrown into the trash and dumped into landfills in the first place. Instead of landfilling organic waste, consumers and municipal governments can use composting to prevent most of the methane from being produced, in addition to other environmental and economic benefits. Officials and decision-makers at all levels should include organics diversion in plans for addressing climate change. Consumers and businesses should also be encouraged to reduce their food waste and recycle organic materials like paper and cardboard more.

6. **Avoid burning trash:** Waste incineration and processing waste into petrochemicals should not be considered as potential solutions. Both are known to produce toxic air pollutants, such as mercury, lead, and nitrogen oxides. Incinerators are also disproportionately located in low-income and minority communities, which further adds to the pollution burden borne by these populations.

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Introduction

Municipal solid waste landfills are a large and often overlooked source of pollution, especially methane. When organic waste in a landfill decomposes, it forms landfill gas, which contains primarily a mixture of methane and carbon dioxide, along with a small amount of other compounds. While some methane is produced immediately after waste is deposited in the landfill, not all the waste breaks down immediately. As the waste decomposes, methane is still produced for years after the waste is initially deposited. For example, landfills that stopped accepting waste in the 1980s are still producing methane today.

Landfills are one of the largest sources in the U.S. of methane, a powerful climate-altering pollutant that traps 120 times more heat in the atmosphere as carbon dioxide immediately after being emitted into the atmosphere.[15] Over 20 years, methane has about 80 times greater effect on global warming than carbon dioxide over a 20-year lifespan[16] This report focuses on methane because landfills' high contribution to overall emissions creates an opportunity to achieve significant and near-term benefits by reducing landfill methane. Despite its potency, methane has a short lifespan in the atmosphere, so reducing methane emissions now will have a considerable impact on temperature in the short term. Leading climate experts have stated that substantial greenhouse gas emissions reductions need to be achieved within the next decade in order to avoid the catastrophic effects associated with 1.5°C in warming.[17]

Landfills are one of the largest sources in the U.S. of methane, a powerful climate-altering pollutant that is about 80 times more effective at causing the climate to warm than carbon dioxide.

In addition to their greenhouse gas effects, landfills are also sources of toxic air and water pollutants that can harm human health and ecological systems. Landfills emit multiple air pollutants, including smog-forming compounds and the known carcinogens benzene and vinyl chloride.[18] Landfills have also long been associated with a wide variety of water pollutants.[19] The EPA recently announced plans to develop new water pollution standards for landfills[20] after finding per and polyfluoroalkyl substances (PFAS or "forever chemicals") in 95 percent of 200 landfills tested after assessing discharge data.[21] PFAS are a group of manufactured substances present in industrial and consumer products that break down slowly and can build up in the environment and in human bodies over time. This can potentially cause adverse health outcomes, such as developmental delays in children, increased risk of prostate, kidney, and testicular cancers, and suppression of immune system function. [22]

The EPA has issued regulations under the federal Clean Air Act that require pollution control systems at some landfills. These rules establish standards for the operation and monitoring of these systems at landfills over a certain size that emit certain amounts of pollutants (non-methane organic compounds). They do not apply to landfills below the size and emission rate thresholds, even if the operator of one of these smaller landfills chooses to install a gas collection system for financial reasons, such as selling energy generated from the gas. Thus, landfills below these thresholds are effectively unregulated for Clean Air Act purposes, even if there is a gas control system installed. Some states—including California and Oregon—have been issuing regulations that are stronger than EPA's. Among other things, these state rules set thresholds at lower levels, requiring the installation of regulated gas-control systems at more landfills. These states also require that regulated gas control systems meet stronger performance standards, such as improved combustion efficiency at flares and more frequent performance testing. For a spreadsheet that compares state and federal requirements for landfills, click here.

Landfills That Report Emitting Methane

This report uses data reported to EPA's Greenhouse Gas Reporting Program to characterize methane emissions from municipal landfills.[23] Municipal landfills are required to report to EPA's program if they accepted waste on or after January 1, 1980, and generate at least 1,000 metric tons of methane before any gas collection. In 2021, 1,127 landfills reported to the program. EIP adjusted reported emissions to reflect the latest science, which finds that methane is about 80 times more potent than carbon dioxide over a 20-year time horizon.[24] See Appendix A for a detailed discussion on methodology.

Over 1,100 municipal solid waste landfills reported emitting 3.3 million metric tons of methane to the Greenhouse Gas Reporting Program in 2021.

These 1,127 landfills are located across the entire U.S. but are generally more concentrated in the eastern half of the country. It should be noted, however, that only landfills large enough to report emissions are included in this analysis. The exact number of municipal waste landfills in the U.S. is unknown, although EPA estimates up to 2,000 operational landfills.[25] (See map on page 5 showing locations of known landfills).

Eighty-three percent of reporting landfills are currently open and accepting waste, while the other 17 percent are closed but still produce enough methane from older waste to be required to report. Active municipal landfills are, on average, 40 years old, but some landfills have been accepting waste since the 1930s. The 193 closed landfills have been retired for an average of 19 years. Seventy-four percent of landfills that reported to EPA have gas collection and control systems to reduce emissions.

Landfills that reported to EPA contain 10.6 billion metric tons of municipal waste, three billion tons of which were added in the last 10 years. In 2021 alone, 331 million metric tons of waste were added to landfills. On average, each landfill contained 3.4 million metric tons of trash, covering just over 470,000 square meters. The average landfill has a total permitted capacity of 21 million metric tons of waste. Despite increases in recycling and composting practices, the amount of trash dumped in landfills has been gradually increasing over the last decade.

Greenhouse Gases from Landfills

According to the 2023 U.S. Greenhouse Gas Inventory, municipal solid waste is the third largest source of methane emissions, emitting approximately 3.7 million metric tons of methane in 2021, or more than 14 percent of all the man-made methane emitted in the country.[26] By comparison, methane emissions associated with livestock were responsible for about 27 percent of all methane emissions, and natural gas systems emitted about 25 percent. As stated earlier, the total methane emissions from municipal landfills were equivalent to emissions from 79 coal-fired power plants running for one year.[27]

Municipal landfills in the U.S. released 3.7 million metric tons of methane in 2021, or more than 14 percent of all the methane in country.

Over 1,100 municipal solid waste landfills reported emitting 3.3 million metric tons of methane to the EPA Greenhouse Gas Reporting Program in 2021, or about 266 million metric tons of greenhouse gases (carbon dioxide equivalents, or CO_2e) using a twenty-year time frame.[28] (Note that this number is slightly smaller than the estimate from EPA's Greenhouse Gas Inventory mentioned above since the inventory estimate includes smaller landfills exempt from greenhouse gas reporting rules.)

The top 25 percent of landfills reporting to the Greenhouse Gas Reporting Program emitted more than half of all methane emissions associated with municipal waste. Several landfills reported close to or over 30,000 metric tons of methane each (about 10 times more than the average landfill that reported to EPA). These high emitters are generally active landfills that have installed gas collection systems that capture only a portion of their greenhouse gases. They are not necessarily the landfills that contain the most waste, as factors such as composition of the waste, how long it has sat in the landfill, rt, and efficiency of the gas collection system also affect emissions. The 10 landfills with the highest reported emissions are listed in Table I.

Table I: Top Ten U.S. Landfills by Reported Emissions

Landfill Name	City, State	Age (yrs)	Total Quantity of Waste in Landfill (metric tons)	Waste Added in the Last 10 Years (metric tons)	Reported Emissions (metric tons of methane)	Reported Emissions (metric tons of CO_2e)
Sampson County Disposal	Roseboro, NC	25	23,567,989	13,627,837	32,983	2,628,722
Eagle Point Landfill	Ball Ground, GA	19	17,671,587	11,675,928	30,919	2,464,268
Kimble Sanitary Landfill	Dover, OH	61	16,873,320	8,918,594	25,386	2,023,296
Apex Environmental	Amsterdam, OH	16	20,723,050	13,062,714	22,935	1,827,892
Brevard Co Board of County Commissioners	Cocoa, FL	49	21,128,991	6,127,293	22,196	1,769,038
Palm Beach Renewable Energy Park	West Palm Beach, FL	32	17,708,708	6,265,406	20,891	1,665,025
Brent Run Landfill	Montrose, MI	28	15,958,979	7,021,970	20,222	1,611,679
Polk County - North Central Landfill	Winter Haven, FL	44	17,806,156	5,180,445	18,682	1,488,940
Black Warrior Solid Waste Disposal Authority	Coker, AL	24	7,236,456	2,581,095	18,083	1,441,200
Noble Road Landfill	Shiloh, OH	24	16,051,091	9,110,786	17,768	1,416,094

Source: EPA's 2021 Greenhouse Gas Reporting Program. CO_2e calculated using the most recent estimate (International Panel on Climate Change Sixth Assessment Report, 20-year global warming potentials).

Emissions by State

Table II lists the ten states with the highest reported emissions from municipal waste landfills. Landfills in Texas reported emitting the most methane. Texas also has the most landfills of any state in the country. It exceeded the second-highest state, California, by more than 100,000 metric tons of methane, despite having less waste in its landfills.

California also has a much higher proportion of landfills with gas collection systems. On average, Florida landfills are the highest emitters. Each landfill in Florida emitted on average 5,200 metric tons of methane, which was much higher than the national average of 3,000 metric tons.

Table II: Top 10 States by Reported Emissions from Municipal Waste Landfills

State	Total Reported Emissions (Metric Tons of Methane)	Total Reported Emissions (Metric Tons of CO2e)	Number of Landfills	% of Landfills with Gas Collection Systems	Total Quantity of Waste in Landfills (Metric Tons)
TX	389,437	31,038,131	98	72%	1,018,067,371
CA	260,214	20,739,081	94	96%	1,575,534,337
FL	239,792	19,111,446	46	70%	501,026,912
GA	188,349	15,011,377	48	65%	324,600,177
OH	188,032	14,986,119	42	79%	522,385,830
MI	155,552	12,397,486	49	86%	609,299,295
NC	148,647	11,847,191	38	74%	218,322,768
AL	125,495	10,001,980	27	63%	157,085,456
IL	111,627	8,896,680	54	83%	545,086,364
VA	110,249	8,786,809	37	70%	309,660,679

Source: EPA's 2021 Greenhouse Gas Reporting Program. CO_2e calculated using the most recent estimate (International Panel on Climate Change Sixth Assessment Report, 20-year global warming potentials).

How Landfills Currently Estimate Methane Emissions

Landfills are not required by EPA to directly measure methane emissions. EPA's Greenhouse Gas Reporting Program, the source of much of the data discussed in this report, allows landfill operators with gas collection and control systems to choose one of two methods when estimating and reporting their annual methane emissions. The first allows operators to calculate emissions based on the amount of decomposable material in the waste coupled with a decay rate that is influenced by multiple factors. This approach is generally referred to as a "first-order decay" method, and is also used by smaller, older landfills that do not have gas collection and control systems. The second, which is available only for landfills that have a gas collection and control system installed, starts with the amount of gas recovered from the system and back-calculates from there to arrive at an emissions estimate.

There are multiple assumptions built into both these formulas, including about the effectiveness of gas controls systems and landfill cover at controlling emissions. Both methods can produce vastly different results, with no clear pattern between the two, and each landfill chooses which number to report as their official estimate. For example, El Sobrante Landfill, southeast of Los Angeles, estimated emitting over 23,000 metric tons of methane using one method and less than 5,000 metric tons using the other method. El Sobrante chose to use the smaller value for its official estimate.

These differences introduce considerable uncertainty into the methods used to estimate emissions from landfills. The first order decay method often, but does not always, produce a higher emissions estimate, but there is no consistent relationship between the two estimates. For landfills that have two possible estimates for their emissions (those with gas controls), if the higher number is used regardless of the method used, landfill emissions would be as high as 5.7 million metric tons of methane, or 455 million metric tons of CO_2e. This is a 71 percent increase from the total reported emissions. Even when using the lower estimate for all landfills, landfills still would have emitted 2.3 million metric tons of methane, a reduction of 31 percent from the reported estimate. Even using the most conservative emissions estimate and excluding landfills that do not meet EPA's reporting threshold, landfills would still be a significant source of methane emissions, comprising roughly 9 percent of total methane emitted in the country.

Both emission methods rely on assumptions about how waste breaks down and how well engineered control systems like landfill cover types and gas collection systems work. However, they omit other critical variables, like local climate, control system design, and on-site management practices that impact both how much methane is created and how much is ultimately emitted to the atmosphere.

EPA Estimates Compared to Direct Measurement

Over the past several years, airborne sampling methods have measured methane plumes from a variety of landfills across the country. In general, these studies have shown poor correlation between sampled data and EPA's modeled estimates. The aerial flights have also revealed large and persistent plumes at some landfills that are not accounted for using EPA's current methods for estimating emissions.

Figure V: Representation of Emissions from a Landfill[29]

Point source emissions are represented by the large yellow arrow; area sources are represented by small blue arrows.

A survey of California methane emissions found that landfills were among the largest emitters in the state. Landfills emit from leaks and hot spots ("point sources" as shown by the large arrow in Figure V) and diffusely through the landfill cover ("area sources" as shown by the small arrows in Figure V). The state conducted surveys to detect point sources as well as additional surveys that measured both point and area sources. More than 400 landfills were included in the point source survey which found that landfills were the largest emitters of this type, representing approximately 40 percent of point source emissions in the state.[30] Subsequent surveys in other parts of the U.S. have also detected large methane plumes.[31] Sources of these large-scale emissions have included cracks or weak points in the landfill cover, ineffective gas capture and control systems, and gaps in control systems created when a landfill is under construction or expanding.[32]

Repeated measurements of point sources at the same sites, over multiple years and during different seasons, showed that these emissions tended to persist over time.[33] The survey also found that the landfill point sources tended to have much higher emission rates than plumes detected at other methane sources such as oil and gas facilities and wastewater treatment plants.[34] Estimates of the annual emissions that would result from these leaks do not correspond with reported emissions, which assume that the landfill's gas control systems and cover are operating as designed.

EPA has recently recognized this flaw and proposed revisions to its Greenhouse Gas Reporting Program that may account for increased landfill emissions due to periods of poor gas collection and control system performance or cover function.[35] These changes are not final, however, and the Agency is still soliciting input on some aspects of the proposed revisions.

How Landfill Methane Can Be Controlled

Landfill methane emissions are usually reduced at municipal landfills using pollution reduction technology and cover practices. The federal Clean Air Act requires certain landfills to install and operate gas collection and control systems, which are discussed in greater detail below. Another federal environmental law (the Resource Conservation Recovery Act) also requires that landfill operators install specific liners and follow cover material practices that help to reduce landfill gas emissions. Additionally, the organic waste that causes methane to be emitted from a landfill can be disposed of in other ways that, if done properly, will emit far less methane.

Although EPA revised some of its Clean Air Act rules in recent years, the changes have been minor. EPA regulations function as a regulatory floor and states are fully authorized to set more stringent standards in order to more effectively limit pollution. States have been issuing rules setting stronger emissions standards for landfills. California and Oregon have already issued rules, and California will hold a public workshop in May 2023 to discuss further strengthening its standards.[36] Maryland has issued draft rules and Washington state passed a law imposing some requirements and is developing rules to flesh out its control standards. These states are establishing lower thresholds for installing a collection system, which means more municipal landfills have collection systems. These states also require more on-site control measures to reduce emissions from municipal landfills.

Gas Collection Systems

The most common kind of pollution control technology for landfills is a gas collection and control system. These systems control the amount of gas generated by the landfill by sucking gas out of the waste heap through a network of pipes, sometimes with the help of a vacuum. The gas is then routed to a control device of some kind, which combusts the methane in the gas. Control devices include flares, boilers, internal combustion engines and gas turbines, which burn the gas to produce electricity and heat. Although these collection systems and combustion devices burn methane, carbon dioxide is not removed and is generated as a byproduct of combusting the methane. As is typical with systems for the control of air pollution, EPA not only requires the installation of the system but also establishes standards for how the systems must be operated. For example, many control devices must burn or control at least 98 percent of emissions of non-methane organic compounds.

While 74 percent of the landfills reporting to EPA's greenhouse gas program have gas collection systems, not all are required to have them. The thresholds requiring controls can differ but older landfills at which waste is still accepted may be required to install controls if they are over a certain size and emit over 34 metric tons per year of non-methane organic compounds.

The exact number of landfills required to operate gas collection and control systems is currently unclear. Of the 10 landfills with the highest reported emissions, for example, only eight are required to install and operate gas collection systems, while two don't meet current federal thresholds. EPA's Landfill Methane Outreach Program, a voluntary program that collects data on landfills, estimates 609 landfills are subject to federal regulations, out of 1,381 sites with sufficient data to make a determination. [37] However, this analysis relies on voluntarily reported data that may be out-of-date or inaccurate, and is not comprehensive (the database contains more than 2,600 landfills). EPA is proposing to help address this information gap by requiring landfill operators to identify regulations, if there are any, governing their gas collection and control system when reporting to the Greenhouse Gas Reporting System.[38]

An owner of a landfill that does not meet the size and pollution thresholds requiring a control system might voluntarily elect to install a system for financial reasons, such as using the gas to generate energy for sale. However, EPA's standards for how gas collection and control systems must be operated – for example, that they combust 98 percent of non-methane organic compounds – apply only at landfills that exceed the size and pollution thresholds requiring installation of the system. Similarly, EPA's requirements for monitoring and reporting of emissions data from the landfill apply only if the landfill operator was required to install the system. In other words, systems installed voluntarily for financial reasons do not have to meet EPA rules for system efficiency and performance or comply with associated monitoring and reporting requirements. For example, they are not required to monitor the systems to ensure they are preventing landfill gas from escaping from the surface of the landfill.

When Collection Systems Are Required

Whether EPA requires a gas collection system at a particular landfill depends on several factors, including active or closed status and closure date, if applicable. The primary factors, though, are the design capacity (how much waste the landfill is designed to hold) and the emissions rate of the landfill, using emissions of non-methane organic compounds or "NMOC."[39]Active landfills with a design capacity over 2.5 million metric tons, by mass, and 2.5 million cubic meters, by volume, and an NMOC emission rate of at least 34 metric tons per year are generally required to install controls.[40]

However, some states, including California and Oregon, set lower thresholds for the installation of gas collection and control systems, meaning that more landfills will be required to install and operate controls. These thresholds are usually based on the amount of waste in the landfill and the heat input (a measure of electrical energy) or methane generated by the landfill. In addition, EPA, Oregon, and California allow operators of some landfills to avoid installing pollution controls based on measurements of methane at the landfill's surface. The states require lower sampled methane levels for operators that use this option: below 200 parts per million ("ppm") while EPA uses 500 ppm.

Finally, the timing of when a collection system is installed can be critical in reducing methane emissions. Currently, federal rules require the installation of collection systems two and half years after the already high threshold is met. In fact, "early" collection of landfill gas, within a few months of waste placement, plays a critical role in reducing emissions and odors. Further, methane emissions could be reduced at newly constructed landfills by requiring that collection systems be designed and planned from the beginning, e.g., alongside considering the initial liner requirements.

Leak Detection and Repair

EPA's current regulations include no equipment leak detection or control requirements at all for municipal landfills. Leak detection and repair is the process by which sources of air pollution can detect and correct leaking components. Leaking equipment, such as valves, pumps, and connectors, are a large source of methane as well as emissions of volatile organic compounds and hazardous air pollutants, also known as air toxics. Leaks can occur from the collection system components of the landfill and through the landfill itself on the surface. Leak detection and repair has been increasingly recognized by EPA as an effective practice for controlling fugitive gas leaks from equipment used in the petrochemical sector. California and Oregon regulations establish leak detection requirements for reducing emissions from leaks in control equipment at landfills. EPA's regulations do not require leak detection from these systems.

Landfill Cover

The soil or other material that is placed on top of waste at a landfill is referred to as landfill "cover." Cover material and application practices can have a significant effect on methane emissions from a landfill.

Certain types of material can remove methane from waste piles before it reaches the air through a process called "oxidation," a reaction in soils in which naturally occurring bacteria consume methane, transforming it into carbon dioxide, which does not cause the planet to warm as quickly as methane. Oxidation of methane at landfills is affected by multiple factors including the type of cover,[41] moisture,[42] temperature,[43] texture,[44] and daily/interim cover maintenance. Engineered cover systems, referred to as "biocovers" typically involve placing a highly oxidizing type of cover material over a layer of coarse material, like gravel or broken glass, that promotes even gas distribution, and then placing the coarse material on top of the waste layer.[45] A large-scale study in Denmark found that a whole biocover layer had a methane oxidation efficiency between 81 and 100 percent.[46] Compost, which is a product of a different method of reducing landfill methane – organics diversion – can also be used as an oxidizing layer at landfills. However, studies have shown that the oxidizing efficiency of compost decreases significantly after 100 days.[47] Therefore, compost would have to be replaced on a regular basis if used as oxidizing landfill cover.

Landfill cover can also be applied in ways that help to reduce methane emissions. Generally, the application of thicker and denser cover as soon after waste is disposed as possible will help to reduce emissions and can even significantly boost the efficiency of gas collection systems.[48] Federal solid waste rules require cover at only two stages: daily cover, which is a relatively thin layer placed over waste at the end of each day,[49] and final cover, which is thicker and generally required at landfills that have reached capacity or no longer receive waste.[50] Some states require "interim cover," which must be thicker than daily cover and placed at some interim stage, often 180 days after waste is last deposited.[51] However, interim cover is not required under any federal regulations – not solid waste rules or air pollution standards. Requiring application of a thicker cover layer during an interim stage – after daily cover but long before the landfill's final closure – would likely have significant emission reduction benefits.

For daily cover, which is applied to waste on a daily basis, a thicker soil cover will help to decrease methane emissions as well as minimizing the exposed surface during daily operations.[52] Peeling back the daily or intermediate cover before adding new waste can also promote movement of landfill gas to the collection system as continuously applying daily cover layers can trap landfill gas within surficial waste layers.[53] Final cover, which is typically thicker and less permeable than daily cover, is generally not installed until the entire landfill has reached capacity or the facility has stopped receiving waste. However, if final cover is installed incrementally onto parts of the landfill that have reached their final contours, this can help to minimize methane emissions.[54]

Cover requirements for landfills are primarily addressed under solid waste laws, specifically the Resource Conservation and Recovery Act (RCRA). Rules issued under the federal Clean Air Act impose only minimal cover requirements and these apply only at landfills that exceed the size and emissions rate thresholds requiring operation of a gas control system. At these landfills, operators must perform cover maintenance, monitor cover integrity, and implement cover repairs "as necessary on a monthly basis," to comply with operational requirements regarding concentrations of methane allowed at the surface of the landfill. However, EPA does not currently require the use of oxidizing cover material or cover-based methane reduction practices in regulations issued under RCRA or the Clean Air Act.

Organics Diversion

Because landfill gas is formed by the decomposition of organic material in the waste at landfills, part of a comprehensive approach to reducing greenhouse gases from landfills is keeping organic material, like yard waste and food scraps, out of landfills in the first place. This is often referred to as "organics diversion." It is important to note that burning waste, which is highly polluting, it not considered an acceptable organics diversion method by most environmental advocacy organizations. The benefits of organics diversion are discussed below as is the state of organics diversion in the U.S.

Benefits of Organics Diversion

Organic waste is the driver behind landfill methane emissions. The Zero Waste International Alliance, a network of advocates that promote positive alternatives to landfilling and burning waste, has methods of addressing waste by preference in what is called the Zero Waste Hierarchy, shown below in Figure VI. The hierarchy identifies the three best ways of reducing waste as rethink/redesign, reduce, and reuse in that order. Recycling or composting organic waste are fourth in the hierarchy in terms of overall waste reduction but are the best ways to manage waste once it is no longer possible to rethink/redesign, reduce, or reuse it.

The two methods of "recycling" organic waste that are most widely recognized are composting and anaerobic digestion.[55] Composting is a process that allows organic waste to decompose in the presence of oxygen, which minimizes methane production.[56] The greenhouse gas reductions that can be obtained by composting rather than landfilling organic waste largely depend on how effectively the method of composting avoids anaerobic (oxygen-free) conditions, which produce methane.[57] However, composting in general is a particularly effective way of largely avoiding methane emissions.[58] Anaerobic digestion is a process in which microorganisms break down waste in the absence of oxygen to produce methane that can be burned to produce electricity.[59] It also produces a wet leftover mixture called "digestate" that can be nutrient-rich and used as a soil amendment,[60] though the "Zero Waste" alliance recommends composting of the digestate before mixing it with soil in order to prevent release of harmful compounds produced during the anaerobic digestion process.[61] The EPA has estimated that composting and anaerobic digestion can each achieve a 95 percent methane reduction efficiency when compared to landfilling organic waste.[62]

Composting—particularly at the smaller, more local scale—is considered preferable to anaerobic digestion by most zero waste advocates.[63] Composting has many benefits for the climate, ecosystems, and communities. The composting process creates nutrient-rich soil that reduces erosion and stormwater pollution and sequesters carbon.[64]

Figure VI: Zero Waste Illustration

Composting, particularly at the local scale, is considered preferable to anaerobic digestion by the Zero Waste Hierarchy and most zero waste advocates.

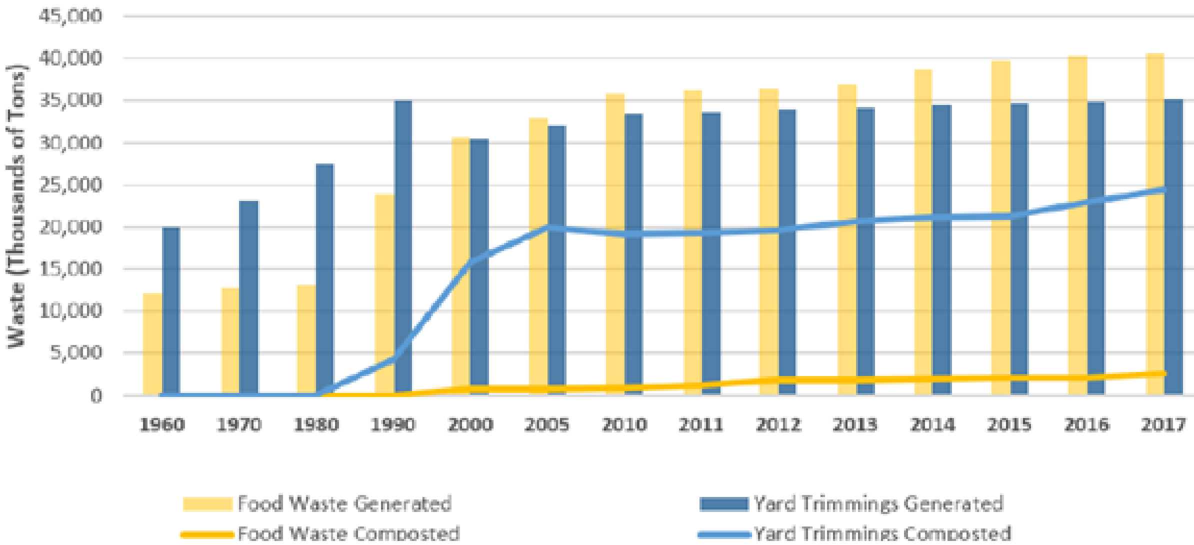
By removing waste from landfills, composting avoids taking up landfill space and extends the life of those landfills by creating space for disposal of other materials.[65] In addition, composting facilities can employ significantly more people per ton of waste than landfilling waste (or burning it in an incinerator). A report recently released by the Global Alliance for Incinerator Alternatives found that composting creates 6.6 jobs per 10,000 tons per year of waste handled, which is almost four times as many as from landfilling and incineration (1.8 and 1.7 per 10,000 tons of waste respectively).[66]

Organics Diversion in the United States

The EPA estimates that organic waste consisting of food, yard, paper, and wood wastes made up 63 percent of the waste stream from residences and commercial and institutional facilities in the U.S. in 2018. Food and yard waste made up over 50 percent of the organic portion of the waste stream.[67]

Food waste, which alone constitutes about 24 percent[68] of the waste stream, is of particular interest to climate advocates because it decomposes more quickly than other types of organics and can release more methane before the installation of gas control systems.[69] Food waste has also increased in recent decades. EPA estimates that the amount of food waste generated per year increased by 70 percent between 1990 and 2017.[70] In 2017, Americans threw out in their household trash about 40 million tons of food waste, making food waste about 15 percent of total municipal waste.[71]

Figure VII: Trends in Generation and Composting of Food and Yard Waste, 1960-2017



Source: EPA Downstream Management of Organic Waste in the U.S.

There are no federal laws that require diversion of organic waste from landfills. However, there are examples of such laws at the state and local level. As of 2021, eight states had laws on the books for keeping food scraps out of landfills and 18 states had laws targeting yard waste, according to the U.S. Composting Council.[72] The state of California require municipalities to develop organics diversion ordinances, with state enforcement beginning in 2022 and local enforcement beginning in 2024.[73]

While not mandating organics diversion in any way, the U.S. government has created incentives for this important landfill methane reduction tool. In 2022, the U.S. Congress passed the Bipartisan Infrastructure Law. EPA acknowledges that this provided unprecedented funding to support state and local waste management infrastructure and recycling programs in which EPA will improve health and safety and help establish and increase recycling programs nationwide. The law channels $275 million to EPA's Solid Waste Infrastructure for Recycling Program, which is intended to improve management and disposal post-consumer waste materials and includes infrastructure for recycling, which includes composting and other "recycling" of organics.[74] The law also provides $75 million total from Fiscal Year 2022 to 2026 for grants to fund a new Recycling Education and Outreach Grant Program, funding projects that make composting more accessible to communities while providing education on how to compost and its benefits.

Impact on Local Neighborhoods and Communities of Color

The evidence shows that landfills are a large source of methane emissions and that much can be done to better estimate, reduce, and prevent their climate impacts. However, the problems associated with landfills are not limited to methane emissions. Communities living near landfills bear the brunt of their environmental impacts, including air and water pollution, truck traffic, and groundwater contamination.

According to EPA's Environmental Justice Screening and Mapping Tool (EJScreen), 54 percent of landfills reporting to the Greenhouse Gas Reporting Program have communities within one mile of the landfill that exceed the national average for either percent people of color (40 percent) or percent low-income (30 percent).[75] These trends are similar when comparing demographic data for a three-mile radius around the same landfills, as well as demographic data for landfills included in EPA's Landfill Methane Outreach Program database, which includes over 1,300 additional landfills, all generally smaller than those reporting to the Greenhouse Gas Reporting Program.

Of the 1,127 landfills that reported to the Greenhouse Gas Reporting Program in 2021, 1,026 of them have demographic data available through EJScreen for a one-mile radius. The total population living within one mile of these landfills is 1.26 million people. Around 597,000 (or 47 percent) are considered people of color and 393,000 (or 31 percent) are considered low income. When landfills are in more densely populated areas, they are more likely to be in communities of color. Fourteen landfills have a surrounding population of at least 10,000 people within one mile of the property, and ten of these are in communities where the percentage of people of color is higher than the national average.

Environmental Justice Case Studies

Arrowhead Landfill, Uniontown, AL

Ben Eaton, a Perry County Commissioner, stands at the entry of Arrowhead Landfill in Uniontown, Alabama.

Uniontown, Alabama[76] in Perry County is within what is colloquially known as "the Black Belt." The name comes from the exceptionally fertile black soil in the region. Rivers and streams from several large basins—the Sipsey-Warrior, Coosa-Tallapoosa, Alabama-Cahaba, Tombigbee, and Chattahoochee—course through the Black Belt. Early pioneers in the 1820s and 1830s settled in the Black Belt and constructed a network of cotton plantations that enslaved half of Alabama's enslaved population. In the Post Civil War era, the Black Belt counties played a critical role in organizing and movement building towards, during, and after the Civil Rights Movement. According to 2020 U.S. Census data, Uniontown, AL, has a total population of 1,918 with a median household income of $19,428. Sixty-four percent of the population lives below the federal poverty line and 98 percent of the residents are Black.

History of the Arrowhead Landfill: The wide availability of high-quality water resources in the Black Belt, particularly the aquifers, can be the source of high volume and quality water that requires little or no treatment before use. Uniontown is now home to many sources of high-volume producers of wastewater, like a catfish processing facility, a recently closed cheese processing plant, and the Arrowhead Landfill ("Arrowhead"). The Perry County Commission first approved the landfill on June 28, 2005.

Perry County Associates, Arrowhead's original owner, initially applied in 2007 for a Clean Air Act Title V operating permit for a municipal landfill with a design capacity less than 2.5 million metric tons and 2.5 million cubic meters ("m^3"). However, in 2010, due to the owner's decision to begin accepting coal ash from the disastrous Tennessee Valley Authority (TVA) Plant Kingston coal ash spill, the owners updated the design capacity to 2.8 m^3 and 3.8 million metric tons claiming that due to the higher specific weight of coal ash compared to solid waste the TVA coal ash effectively used more of the landfill's permitted volume than originally permitted. The original owners initially estimated emissions to be over the threshold that required landfill gas controls to be installed. However, despite now taking more municipal waste, which generates more landfill gas than coal ash, the new owners in 2021 determined emissions to be only 8 percent of the original estimate, which allowed the landfill to avoid installing required gas controls.

Out-of-State Owners Bring in Most Waste from Outside Alabama: The most recent solid waste permit for Arrowhead includes an approved waste volume of 15,000 tons per day. Additionally, the permit allows Arrowhead to accept waste from 32 states outside of Alabama. This amounts to almost six million tons of waste per year disposed at Arrowhead. In fact, Henry "Lynn" Phillips, an environmental engineer who has advocated alongside residents in Uniontown for years, has concluded that as of mid-2021, 93 percent of the waste coming to Arrowhead is not from Alabama. Phillips notes that "waste originating outside of Alabama has increased every quarter since the end of 2019, reaching 663,516 tons in 2021."[77]

Ben Eaton, who lives near Arrowhead, has been active in opposing the expansion of the landfill for years. Eaton was elected to the Perry County Commission in 2018. Although he now has a representative vote in decisions made at the County Commission level that affect

Uniontown, he still feels that though the County as a whole may benefit economically from the landfill, Uniontown continues to be harmed.

On January 26, 2010, the original owners of Arrowhead filed a bankruptcy petition seeking protection under Chapter 11 of the federal bankruptcy code. Given that the landfill was in the process of accepting TVA coal ash, that agency assisted the bankruptcy receivers in maintaining operations during the project. Eventually, the ownership of the landfill shifted from owners in Georgia to Arrowhead Environmental Partners, LLC ("Arrowhead Partners") which lists its principal mailing address on file with the Alabama Secretary of State's Office as being in Jericho, New York. Arrowhead Partners' own website boasts of "direct rail access" and "proven and unparalleled rail transfer capabilities including the ability to unload up to 12,000 tons per day."[78] The current CEO of Arrowhead Partners is a frequent speaker and presenter at North American conferences and seminars promoting the advantages of shipping solid waste on railways.

Residents Near Arrowhead Voice Concerns About Problems at Landfill: Robust community opposition to the Arrowhead Landfill has been well documented in national media over the years. Residents working with attorneys filed what's called a Title VI Complaint[79] alleging that the Alabama Department of Environmental Management discriminated on the basis of race in permitting the disposal of coal ash at the landfill. One of the complainants and community leaders, Esther Calhoun, rightly pointed out in testimony before the U.S. Commission on Civil Rights in 2016 that "[w]e saw pictures of people in hazmat suits loading the coal ash in Kingston, while in Uniontown, workers were provided with little protection and community members with nothing."[80] Later that year, the commission wrote a scathing report concluding that EPA did not substantively incorporate civil rights impacts in the movement of coal ash to the Arrowhead Landfill in Uniontown.[81]

Problems Only Getting Worse: The negative impacts of the landfill are well documented in publicly available records. Hundreds of complaints about odor and adverse health effects like nausea, upper respiratory tract irritation and headaches have been made since 2010, with over one hundred complaints filed in 2021 alone. Alabama's environmental agency recently issued a notice of violation and a proposed consent order against Arrowhead for its failures to maintain, re-apply and compact landfill cover for weeks.[82] However, the state agency has otherwise not responded meaningfully to the complaints from local citizens and cannot conduct the critical air monitoring necessary to determine whether the landfill may be causing the adverse health effects.

How Stronger Federal Regulations Would Help: Because waste comes from 33 states to Arrowhead, a national approach is needed to address methane emissions and environmental justice impacts from municipal landfills on communities like Uniontown. If some individual states more stringently regulate their own landfills thereby providing an economic advantage for companies who ship municipal solid waste to other states with weaker standards, like Alabama, the already long-enduring environmental injustice in Uniontown will not improve and could even worsen. Stronger federal regulations under the Clean Air Act for landfills—like requiring more landfills to install gas controls, improving landfill cover practices and requirements, and enhancing monitoring requirements—will help to protect people living near Arrowhead. Ben Eaton, for one, enthusiastically supports improving the Clean Air Act standards for landfills: "Alabama should have the same policy of protection against (municipal) landfills as the other states. Other states should not be allowed to dump their waste on our poor, black community: this is injustice. To be equal is to be treated equally, otherwise, why bother to learn the pledge of allegiance? Liberty and justice for all should apply to small communities like mine the same way it does to other states with better laws for (municipal) landfills."

Baltimore, Maryland

Landfills and Incinerators: Not Good Neighbors

Environmental justice advocates in Baltimore City, Maryland are waging a war on waste. South Baltimore—particularly the neighborhoods of Curtis Bay and Brooklyn—has long been an epicenter of industrial pollution within Maryland. Because residents face pollution and safety risks from many industrial sites, community groups in Curtis Bay and Brooklyn are active on multiple environmental justice issues. However, addressing the disposal of municipal solid waste has been a particular focus of community activists for years because of the neighborhoods' proximity to incinerators and landfills, two types of highly polluting waste disposal facilities.

Children play at the Curtis Bay Recreation Center in South Baltimore close to the CSX coal export terminal.

In 2020, the Curtis Bay and Brooklyn neighborhoods had a median household income of $32,599 and 32 percent of family households in the area lived below the poverty line that year.[83] This is a significantly higher poverty rate and lower median income than of the United States, which had a median household income of $67,521 and 8.7 percent of families living below the poverty line,[84] and the State of Maryland, with a median household income of $87,063 and 9 percent of families living below the poverty line in 2020.[85] Curtis Bay and Brooklyn are also majority Black and Hispanic, with a racial breakdown of 36 percent African American, 24 percent Hispanic, 32 percent White, and 1.6 percent Asian, with the approximately 7 percent remaining categorized as "all other races (Non-Hispanic)" and "two or more races (Non-Hispanic)".[86]

Baltimore's municipal solid waste landfill, the Quarantine Road Landfill, is located about two miles from the heart of Curtis Bay. In 2020, this landfill was the second largest emitter of methane in the entire state.[87] That year, the Baltimore City Department of Public Works (DPW), which operates the landfill, reported emitting 5,518 tons of methane, which is equivalent to about 474,548 tons of carbon dioxide over a 20-year time horizon. In 2020, Baltimore DPW also reported emitting 3.5 tons of toxic air pollutants.[88] This included 200 pounds of benzene,[89] a known human carcinogen;[90] two tons of toluene,[91] which can irritate the eyes and lungs, and, at higher levels of exposure, impairs nervous system function;[92] and 400 pounds of dichlorobenzenes,[93] a group of pollutants that can cause cancer, anemia, and respiratory problems.[94]

Despite being one of the top three methane emitters in Maryland every year from 2017 through 2020,[95] the Quarantine Road Landfill is not required under federal regulations to operate a gas control system. Instead, Baltimore DPW voluntarily installed a gas control system in 2009 and uses it to route gas to the nearby Coast Guard Yard for energy generation. Baltimore DPW consistently reports to state regulators that this gas collection system captures 30 percent or less of landfill gas at the site. From 2018 to 2020, the facility reported an average system efficiency of approximately 27.3 percent.[96] By comparison, the average reported efficiency of all landfill gas control systems in Maryland was 59 percent in 2020.[97] State regulators in Maryland are poised to issue new state-wide regulations for the control of landfill methane that will likely require Baltimore DPW to upgrade this system and operate according to performance standards for the first time.[98] Baltimore DPW is also planning a major expansion of the Quarantine Road Landfill, which is expected to fill up by the end of 2027.[99]

In addition to accepting municipal solid waste for disposal, Quarantine Road Landfill accepts ash from Baltimore's trash-to-energy incinerator, known locally as BRESCO (short for Baltimore Refuse Energy Systems Company). Incinerator ash is a toxic byproduct of burning trash and groundwater contamination has been measured repeatedly at the landfill.[100] Much of the incinerator ash from BRESCO – 130,000 tons in 2021– is disposed of at the Quarantine Road Landfill.[101] BRESCO is located 4 miles north of Curtis Bay and ranks within the top five polluters in the state for highest toxic air pollution emitted as well as nitrogen oxides and sulfur oxides,[102] both of which can trigger asthma attacks.

Community Stops Plan to Build a Second Incinerator in South Baltimore: The movement for more sustainable waste policies, sometimes called Zero Waste, in South Baltimore was ignited by a plan to build a second trash incinerator in this part of the City four miles from the existing incinerator. The proposed second plant would have been the largest incinerator in the U.S., permitted to emit particularly high amounts of the neurotoxins lead and mercury. This incinerator, proposed by a company called Energy Answers and permitted in 2010, would have been built in Curtis Bay about a mile from the high school and elementary school. The facility was under consideration at a time when the incinerator industry was touting waste combustion as a way of avoiding landfill methane emissions.[103] After a multi-year campaign led by local students against the Energy Answers incinerator, state regulators determined in 2016 that the permit to build the facility had expired.

Plans to Reduce Pollution from Solid Waste: Advocates in Baltimore are now seeking to drastically change Baltimore's approach to dealing with municipal solid waste. To divert waste from both the BRESCO incinerator and the Quarantine Road Landfill, the South Baltimore Community Land Trust—one of the main groups active on environmental justice issues in South Baltimore—has called on Baltimore City to finance the construction of a composting facility. A recently passed Maryland law requires many large commercial facilities to divert food waste from landfills and incinerators. However, the requirement does not apply if there is no alternative disposal facility within 30 miles,[104] and Baltimore currently lacks the infrastructure to compost or otherwise divert large amounts of organic waste. South Baltimore Community Land Trust is calling not only for composting infrastructure but also demanding community involvement in planning of the facility and the imposition of rigorous operational and labor standards to avoid odor and other adverse effects on the local community.[105]

Recommendations:

EPA Should Strengthen Its Landfill Emission Regulations

The EPA should strengthen its regulations for the control of landfill methane. Currently, EPA regulates old and new landfills under a set of requirements issued under two sections of the federal Clean Air Act.[106] However, these regulations are not strong enough to address the serious problem of landfill methane. Multiple states have issued stronger regulations and there are additional cost-effective measures for the control of landfill methane that EPA's rules do not incorporate.

At minimum, EPA should revise its regulations to ensure that they meet the stringency of the most protective state rules. All rules for the control of landfill emissions – either at the state or federal level take the general approach of requiring installation of a gas collection and control system for landfills that meet certain size or emissions thresholds. However, states have set lower thresholds, requiring gas controls at smaller landfills. The states of Oregon, California, and Washington[107] all use lower thresholds than EPA's that are more closely tied to whether a landfill produces enough gas to operate controls. Maryland has proposed to issue similar regulations. The most stringent of these state thresholds, adopted in Oregon, requires a gas control system at landfills that hold 200,000 tons of waste in place and 732 tons of methane emissions unless the operator can demonstrate surface methane emissions below a certain level. The Oregon Department of Environmental Quality estimated when it passed the rule in late 2021 that it would require 15 additional landfills in the state to install gas control systems.[108]

In addition, the state regulatory approach includes stronger operational requirements to ensure that gas collection and control systems function effectively. California and Oregon require the phase-out of open flares for the combustion of landfill gas. Open flares operate less efficiently than enclosed flares and are more difficult to monitor. The states also require flares at landfills to meet a performance requirement of 99 percent methane destruction efficiency in lieu of EPA's rule requiring 98 percent destruction efficiency tied to a group of pollutants called nonmethane organic compounds. Importantly, the state approach also establishes more meaningful monitoring requirements that are better tailored to capture problems at a landfill. States require landfill operators to monitor for and repair component leaks in the gas system, which is an approach that is increasingly used in the oil and gas industry, and EPA's rules do not. Both EPA and states require quarterly monitoring of surface methane at landfills, but the states require an operator to account for more of the area of the landfill when monitoring.

EPA should also go above and beyond what states have done in a few key areas. Advancements in emissions monitoring focused on methane have been incorporated into EPA's recently proposed new rules for the oil and gas industry, as discussed in more detail below. In these rules EPA establishes programs for identifying and correcting leaks from oil and gas equipment as well as leaks so big that they qualify facilities as "super emitters." EPA requires leak monitoring on a periodic or continuous basis, which will provide more representative data than the quarterly sampling that is currently required for landfills. These programs should be replicated in new regulations for landfills.

In addition, the type of cover that is placed on top of waste in a landfill can remove a substantial amount of methane before it enters the air through a process called "oxidation." Cover can also boost the efficiency of gas collection systems. Landfill cover is primarily regulated under solid waste disposal laws however, and not under laws for the control of air pollution. The EPA should require landfill operators to maintain and implement an EPA-approved landfill cover design plan that addresses air pollution.

EPA Should Establish a Uniform Method of Estimating Emissions at Landfills

In the U.S., members of the public, government officials, landfill operators, scientists and others rely on landfill emissions data that is calculated using a methodology established by EPA. However, this methodology differs depending on the context. For example, the method for calculating emissions for state inventories and some permitting decisions is different from the method used to determine whether a gas control system must be installed. And both of these are different from the two methods that can be used to estimate emissions for EPA's Greenhouse Gas Reporting Program. The different methods can produce substantially different results. This inconsistency makes it difficult to present and discuss facts about air pollution from landfills and to analyze trends and factors influencing landfill emissions. EPA should establish one unform set of methods for estimating emissions from municipal waste landfills.

EPA Should Promote Direct Measurement Techniques of Landfill Emissions

It is extremely important that EPA take steps to promote direct measurement of landfill methane. The reported emission estimates discussed in this report are based on formulas developed by EPA, which differ according to context, as discussed above. EPA should do more to promote direct measurement of methane and other emission from landfills. Multiple methods, such as aircraft and drone-based techniques, exist for measuring short-term "snapshots" of emissions from landfills.[109] In addition, ground-based instruments have been used to inform research on landfill emissions and can be used to generate an annual estimate of sitewide emissions without relying on first order decay models. EPA has recently taken an important step by approving a type of drone technology for use in regulatory monitoring at landfills.[110] This technology gathers snapshots of emissions at individual points on a landfill's surface rather than generating a sitewide annual value that could be used in permitting and regulatory decisions. Nevertheless, short-term measurements help landfill operators know when gas control systems need to be adjusted. The drone-based method should help those operators that wish to avoid having a person conduct monitoring by walking the surface of a landfill, which can be time-consuming and pose safety risks.

EPA Should Finalize Its Proposal to Require Landfill Operators to Report Whether Gas Control Systems are Subject to Regulations

The EPA currently has no comprehensive data about how many landfills in the U.S. operate gas control systems that are subject to regulations[111] and how many maintain systems voluntarily. This is a significant information gap that, at present, prevents EPA and the public from assessing how regulatory requirements affect landfill performance at a sector scale. It also makes little sense for EPA to omit this requirement since landfill operators already report systems information to EPA and operators are already required to determine whether they are subject to regulation. On May 5, 2023, EPA Administrator Michael Regan signed a proposed rule change that, if finalized, will require landfill operators to identify applicable Clean Air Act standards when reporting to the Greenhouse Gas Reporting Program.[112]This is a positive step forward that will help regulators and the public better understand the effect of regulatory policy on landfill emissions. EPA should finalize this proposed change.

Composting Should be Incentivized in Climate Policies

Diverting organic waste from landfills can have outsized effects in terms of fighting climate change. Composting, in particular, has many environmental benefits in addition to reducing greenhouse gases and can also create jobs. Yet composting and other organics diversion methods often take a backseat in climate policies, even when those policies incentivize other toxic forms of waste disposal like waste incineration.

As an example, twelve states in the Northeast implement the Regional Greenhouse Gas Initiative aimed at reducing greenhouse gases. Under this initiative, fossil fuel-fired power plants in participating states must obtain allowances that permit their carbon dioxide emissions. These facilities can purchase allowances from the sponsors of offsetting projects that reduce greenhouse gas emissions. While landfill gas capture systems are eligible to create offsets, composting facilities are not eligible despite their capacity to quantifiably reduce methane.[113] Similarly, there are multiple federal and state incentives for facilities that incinerate municipal solid waste to create energy; in fact this practice is subsidized as "renewable energy."[114] State renewable portfolio standards sometimes also subsidize energy generated from landfill gas capture systems as renewable energy.[115] Yet similar credits are not widely available for composting facilities.

Officials that develop or implement plans for reducing greenhouse gases at every level of government should evaluate how organics diversion can be built into those plans. This is particularly important for agencies that implement plans that encourage other waste disposal methods that are viewed as sustainable because of their methane reduction capacity and other co-benefits.

Incineration Should Not be Viewed as a Solution to the Problem of Landfill Emissions

Burning municipal solid waste rather than landfilling it is sometimes presented as a favorable approach for reducing landfill methane.[116] However, waste incineration is a highly polluting process and should not be encouraged as a method of reducing landfill methane. Multiple analyses have shown that burning trash emits high rates of toxic air pollutants, particularly the neurotoxins lead and mercury, and these rates can be higher per unit of energy generated than those produced when burning coal.[117] Trash incinerators are also large sources of carbon dioxide themselves. In addition, incinerators generate a byproduct, toxic incinerator ash, which is often disposed of at landfills.

Waste incinerators also disproportionately harm environmental justice communities. A 2019 report by the Tishman Environment and Design Center at The New School found that 79 percent of U.S. municipal solid waste incinerators are located in environmental justice communities, and that between 67 percent and 83 percent of the twelve incinerators that emit the most nitrogen oxides, sulfur dioxide, lead, mercury, particulate matter, and carbon monoxide are located in environmental justice communities, depending on the pollutant.[118]

The U.S. must reduce landfill methane, but it must do so without increasing toxic pollution in the air that people breathe and without further threatening the health of low-income communities and communities of color. Composting and improved pollution controls are solutions to the problem of landfill methane. Incineration is not a solution; it is exchanging one problem for another.

Appendix A: Methodology and Data Caveats

The exact number of municipal waste landfills in the United States is not known. The 2023 US Greenhouse Gas Inventory estimates that there are between 1,300 and 1,700 operational municipal waste landfills in the country.[119] EPA's Landfill Methane Outreach Program, which collects data on municipal landfills to encourage landfill gas recovery, counts 2,637 municipal landfills, including over 1,300 closed sites.[120] However, reporting to LMOP is entirely voluntary and this is not an exhaustive list of landfills in the United States. EPA's Greenhouse Gas Reporting Program (GHGRP) database contains information for 1,127 municipal landfills that reported emissions in 2021.[121]

The analysis in this report primarily relies on the GHGRP, as this has the most comprehensive and up-to-date information on municipal landfill emissions. According to EPA regulations, all landfills that accepted waste on or after January 1, 1980 and generate more than 1,000 metric tons of methane before accounting for gas collection (soil oxidation from landfill cover is accounted for in this threshold) must report.[122] Each landfill that meets the threshold is required to report basic facility information, such as location and year of waste acceptance, as well as annual waste-in-place, emissions factors, and gas collection systems, which is used to estimate greenhouse gas emissions from these landfills. The GHGRP estimates that this covers about 92 percent of emissions from this industry.[123]

The GHGRP presents emissions data in metric tons of carbon dioxide equivalents, using a global warming potential of 25 for methane.[124] This reflects the International Panel on Climate Change (IPCC) Fourth Assessment Report using a 100-year timeline. The 2023 U.S. Greenhouse Gas Inventory uses a global warming potential of 28 for methane, also using a 100-year timeline but warming potentials from the IPCC's Fifth Assessment Report.[125] This analysis uses the updated global warming potential of 79.7 from the IPCC's Sixth Assessment Report with a 20-year timeline, which more closely reflects the lifespan of methane in the atmosphere. For example, according to the GHGRP, 58th Street Landfill in Miami, FL, reported emitting 60,334 metric tons of greenhouse gases (CO_2e), or 2,413 metric tons of methane. Using the updated global warming potential and a 20-year period, this becomes 192,346 metric tons of CO_2e.

These data were accessed using the GHGRP's 2021 summary data for all reporting facilities (accessed October 2022). Additional data were obtained using EPA's Envirofacts database in October 2022.[126] This analysis was limited only to methane emissions generated from landfilled waste, adjusted for any gas collection and control methods, such as landfill cover or flares. About half (564) of the landfills included in this report also reported emissions from other processes, primarily stationary combustion which is derived from the combustion of landfill gas or waste, often as a fuel source. These emissions were not included in this report.

EJScreen Data

EIP relied on data downloaded from EPA's EJScreen Version 2.1 on January 10, 2023 to evaluate demographic characteristics of people living within one to three miles of a municipal landfill.[127]

There are limitations to characterizing nearby communities using demographic information from EJScreen. Ultimately, the population estimates included in this report likely undercount the affected population. EIP used landfill location information available through the Greenhouse Gas Reporting Program, which only requires landfills to report a single coordinate location for the entire property. Most of these coordinates are located in the middle of the reporting landfill, while others are located on a property boundary or near an entrance gate. Estimates based on the boundary of a landfill, not a single point, would be far more accurate, but landfill boundary information was not available for this project.

EJScreen 2.1 is a screening tool developed by the U.S. Environmental Protection Agency that utilizes demographic estimates from the Census American Community Survey (ACS) 2016-2020 5 Year Estimates (ACS 2020). The ACS is not a full census of all households, but instead relies on surveys to estimate the demographic breakdown of an area at the block-group level. Due to uncertainty associated with demographic and environmental estimates, particularly when looking at small geographic areas or rural areas, EJScreen is meant to be used as a screening tool and not as the basis for decision-making. For a complete list of limitations and a detailed description of methodology, refer to the EJScreen Technical Documentation.[128]

Appendix B: Comparison of Estimated Emissions

For landfills that use landfill gas collection systems, there are two options to calculate emissions: the first order decay method and the back-calculation method. The first order decay method calculates total methane generation using amount of waste and adjusts for the methane collected by the collection system. The back-calculation method uses the total amount of methane collected and gas collection efficiency to calculate the total methane generation, which is used to determine the amount of methane emitted. These two methods can produce substantially different results. For example, El Sobrante Landfill in California estimated over 23,000 metric tons of methane emitted using the first order decay method, compared to less than 5,000 metric tons using the back-calculation method. Reporting landfills calculate their emissions both ways and choose which method to report. El Sobrante chose to use the back-calculation method for their reported emissions.

The first order decay method often, but does not always, results in a higher estimate than the back-calculation method. Both methods have a similar range, from a few metric tons to over 60,000 metric tons of methane. This upper end is much higher than the highest reported value of 33,000 metric tons. However, the average of emissions using the first order decay method is about double the average using the back-calculation method, at 5,153 metric tons of methane compared to 2,470 metric tons. There is no consistent pattern between the two values. The below table compares emissions using both methods for the 10 landfills with the most waste accumulated over the last ten years. The estimated emissions vary significantly based on the calculation method. Landfills often choose to report the smaller value.

Comparison of Emissions Estimation Methods for the 10 Landfills Containing the Most Waste Over the Last 10 Years. Orange Highlight Indicates Reported value.

Landfill Name	City, State	Metric Tons of Waste Placed in the Last 10 Years	Methane Emissions (Metric Tons)	
			First Order Decay	Back-calculation
El Sobrante Landfill	Corona, CA	25,871,056	23,183	**4,754**
Grows LDFL Waste MGMT	Morrisville, PA	25,852,917	28,544	**7,080**
Waste Management Disposal Services of Oregon	Arlington, OR	22,711,657	4,692	**9,055**
Newton County Landfill	Brook, IN	21,905,395	49,201	**4,965**
Waste Management of Michigan Incorporated	Wayne, MI	21,865,085	198	**6,693**
Apex Regional Landfill	Las Vegas, NV	21,566,292	61,400	**3,934**
Sunshine Canyon Landfill	Sylmar, CA	21,323,686	404	**15,263**
Olinda Alpha Landfill	Brea, CA	20,865,800	**17,620**	7,655
Roosevelt Regional Landfill	Roosevelt, WA	20,435,965	10,091	**9,773**
Denver Arapahoe Disposal Site	Aurora, CO	20,410,788	29,337	**1,139**

End Notes

[1] EPA (2023) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection 8 Agency, EPA430-R-23-002. https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Main-Text.pdf

[2] EPA, Greenhouse Gas Equivalencies Calculator, accessed April 19, 2023. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[3] IPCC, Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (2021), available at https://report.ipcc.ch/ar6/wg1/IPCC_AR6_WGI_FullReport.pdf p. 1017. The 20-year global warming potential for non-fossil methane is about 5% lower than for fossil methane.

[4] Roni A Neff, Rebecca Kanter, and Stefanie Vandevijvere, "Reducing Food Loss And Waste While Improving The Public's Health," Health Affairs, November, 2015. Link: https://www.healthaffairs.org/doi/10.1377/hlthaff.2015.0647

[5] EPA, Downstream Management of Organic Waste, p. 6.

[6] EPA, Downstream Management of Organic Waste in the United States: Strategies for Methane Mitigation, p. 9, January 2022, https://www.epa.gov/system/files/documents/2022-01/organic_waste_management_january2022.pdf.

[7] U.S. Environmental Protection Agency, "EJScreen: Environmental Justice Screening and Mapping Tool," Accessed January 2023. Link: https://www.epa.gov/ejscreen

[8] Environmental Integrity Project et. al. vs. Environmental Protection Agency, Case 1:22-cv-02243-RC, filed July 29, 2022. Link: https://environmentalintegrity.org/wp-content/uploads/2023/04/Landfill-complaint.pdf

[9] Environmental Integrity Project vs. Environmental Protection Agency, Case 1:22-cv-02243-RC, Consent Decree, filed April 20, 2023. Link: https://environmentalintegrity.org/wp-content/uploads/2023/04/16-Consent-Decree.pdf

[10] The methods that were the subject of the EIP lawsuit are used to estimate emissions for purposes of state inventories and in some permitting decisions, and not the Greenhouse Gas Reporting Program.

[11] Duren at al (2020), The California methane survey final project report, California Energy Commission

[12] Image source: Adapted from California Air Resources Board, Landfill Methane Research Workshop: Methane Remote Sensing for Leak Identification and Mitigation, December 5, 2022

[13] EPA, Revisions and Confidentiality Determinations for Data Elements Under the Greenhouse Gas Reporting Rule, Supplemental Proposed Rule, May 5, 2023, at 108-111, Prepublication Version, https://www.epa.gov/system/files/documents/2023-05/Supplemental%20Proposal%20and%20Preamble%20to%20GHGRP%20June%202022%20Proposal.pdf (last visited May 11, 2023).

[14] California Air Resources Board, Public Workshop on Potential Improvements to the Landfill Methane Regulation, https://ww2.arb.ca.gov/events/workshop-lmr-potential-improvements.

[15] Balcombe et al., "Methane emissions: choosing the right climate metric and time horizon," *Environmental Science: Processes and Impacts*, 20, 1323-1339, September 10, 2018. Link: https://doi.org/10.1039/C8EM00414E

[16] Table 7.15, International Panel on Climate Change, Climate Change, Climate Change 2021, the Physical Science Basics, Sixth Assessment Report, p. 1017, https://report.ipcc.ch/ar6/wg1/IPCC_AR6_WGI_FullReport.pdf.

[17] IPCC, 2018: Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, p. 12 ("In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO2 emissions decline by about 45% from 2010 levels by 2030 (40–60% interquartile range), reaching net zero around 2050 (2045–2055 interquartile range).") Available at https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf.

[18] ATSDR, Landfill Gas Basics, https://www.atsdr.cdc.gov/hac/landfill/html/ch2.html; California Air Resource Board, Vinyl Chloride and Health, https://ww2.arb.ca.gov/resources/vinyl-chloride-and-health.

[19] See, e.g, Table 5-3: Comparison of Subtitle D Non-Municipal and Municipal Raw Wastewater Pollutant Concentrations (ug/L), EPA, Development Document for Final Effluent Limitations Guidelines and Standards for the Landfills Point Source Category, January 2000, https://www.epa.gov/sites/default/files/2015-11/documents/landfills-eg_dd_2000.pdf.
[20] EPA, Landfills Effluent Guidelines, https://www.epa.gov/eg/landfills-effluent-guidelines.
[21] EPA, Effluent Guidelines Program Plan 15, January 2023, p. 6-13, https://www.epa.gov/system/files/documents/2023-01/11143_ELG%20Plan%2015_508.pdf#page=48.
[22] EPA, Our Current Understanding of the Human Health and Environmental Risks of PFAS, https://www.epa.gov/pfas/our-current-understanding-human-health-and-environmental-risks-pfas.
[23] GHGRP data uses AR-4 100-year GWPs.
[24] EPA's database converts methane to "carbon dioxide equivalents" on a 100-year time horizon, using older estimates that assume methane is 25 times more potent than carbon dioxide over this longer time period.
[25] U.S. Environmental Protection Agency, "Inventory of Greenhouse Gas Emissions and Sinks: 1990-2020" (2022), Link: https://www.epa.gov/system/files/documents/2022-04/us-ghg-inventory-2022-main-text.pdf p. 7-18
[26] The Greenhouse Gas Inventory uses data from the GHGRP, and then uses an 11 percent scale-up factor to account for municipal landfills not required to report. EPA, Inventory of Greenhouse Gas Emissions and Sinks: 1990-2021 (2023), Link: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Main-Text.pdf p. 7-9
[2727] U.S. Environmental Protection Agency, "Greenhouse Gas Equivalencies Calculator." Accessed April 19, 2023. Link: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
[28] IPCC, Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (2021), available at https://report.ipcc.ch/ar6/wg1/IPCC_AR6_WGI_FullReport.pdf p. 1017
[29] California Air Resources Board, Landfill Methane Research Workshop: Methane Remote Sensing for Leak Identification and Mitigation (Dec 5, 2022), p 8 https://ww2.arb.ca.gov/sites/default/files/2022-12/Methane%20Remote%20Sensing.pdf
[30] Duren et al (2019), California's methane super-emitters, Nature https://doi.org/10.1038/s41586-019-1720-3
[31] Ayundele et al, Key Strategies for Mitigating Methane Emissions from Municipal Solid Waste, RMI, 2022 https://rmi.org/insight/mitigating-methane-emissions-from-municipal-solid-waste/; Pennsylvania Department of the Environment (2023), Methane Overflight Study Overview https://files.dep.state.pa.us/Air/AirQuality/AQPortalFiles/Advisory%20Committees/Air%20Quality%20Technical%20Advisory%20Committee/2023/3-9-23/AIRBORNE%20METHANE%20AQTAC%20MEETING%20230309.pdf;
[32] Duren et al (2020), The California methane survey final project report, California Energy Commission, 19.
[33] Duren et al (2019), California's methane super-emitters, Nature https://doi.org/10.1038/s41586-019-1720-3; Ayundele et al, Key Strategies for Mitigating Methane Emissions from Municipal Solid Waste, RMI, 2022 https://rmi.org/insight/mitigating-methane-emissions-from-municipal-solid-waste/; Jeong, S., et al. (2017), Estimating methane emissions from biological and fossil-fuel sources in the San Francisco Bay Area, Geophys. Res. Lett., 44, 486–495, doi:10.1002/2016GL071794; Ren, X., Salmon, O. E., Hansford, J. R., Ahn, D., Hall, D., Benish, S. E., et al. (2018), Methane emissions from the Baltimore-Washington area based on airborne observations: Comparison to emissions inventories. Journal of Geophysical Research: Atmospheres, 123, 8869–8882. https://doi.org/10.1029/2018JD028851
[34] Duren et al (2020), The California methane survey final project report, California Energy Commission, Figure 13, p. 22. California Air Resources Board, Landfill Methane Research Workshop: Methane Remote Sensing for Leak Identification and Mitigation, p 16-17. https://ww2.arb.ca.gov/sites/default/files/2022-12/Methane%20Remote%20Sensing.pdf
[35] EPA, Revisions and Confidentiality Determinations for Data Elements Under the Greenhouse Gas Reporting Rule, Supplemental Proposed Rule, May 5, 2023, at 108-111, Prepublication Version, https://www.epa.gov/system/files/documents/2023-

05/Supplemental%20Proposal%20and%20Preamble%20to%20GHGRP%20June%202022%20Proposal.pdf (last visited May 11, 2023).

[36] California Air Resources Board, Public Workshop on Potential Improvements to the Landfill Methane Regulation, https://ww2.arb.ca.gov/events/workshop-lmr-potential-improvements.

[37] Landfill Methane Outreach Program. https://www.epa.gov/lmop/lmop-landfill-and-project-database. Accessed April 19, 2023.

[38] EPA, Revisions and Confidentiality Determinations for Data Elements Under the Greenhouse Gas Reporting Rule, Supplemental Proposed Rule, May 5, 2023, at 115-116, 337 Prepublication Version, https://www.epa.gov/system/files/documents/2023-05/Supplemental%20Proposal%20and%20Preamble%20to%20GHGRP%20June%202022%20Proposal.pdf (last visited May 10, 2023).

[39] Under the 2016 revisions to the New Source Performance Standards and Emission Guidelines, landfills must install a collection system if there is a design capacity greater than or equal to 2.5 million Mg and 2.5 m^3 and a nonmethane organic compound emission rate of 34 Mg/year or more. This threshold applies under Subparts XXX and Cf. *See* 40 C.F.R. §60.33f(a)(3); 40 C.F.R. §60.762(b)(1). The applicable requirements depend on the year in which the landfill was constructed, reconstructed or modified.

[40] 40 CFR § 60.33f(a); 40 C.F.R. § 60.762(b). Landfill operators that report between 34 and 50 metric tons per year of NMOC need not install controls if they measure surface methane levels below 500 ppm. If the NMOC rate is over 50 metric tons of NMOC per year, this option is not available. 40 C.F.R. 60.35f(a)(6); 40 C.F.R. § 60.764(a)(6).

[41] Huber-Humer, M. (2004). International research into landfill gas emissions and mitigation strategies – IWWG working group "CLEAR." Waste Management, 24(4), 425–427. https://doi.org/10.1016/j.wasman.2004.02.005.

[42] Currie, J. A. (1965). Diffusion Within Soil Microstructure a Structural Parameter for Soils. Journal of Soil Science, 16(2), 279–289. https://doi.org/10.1111/j.1365-2389.1965.tb01439.x.

[43] Börjesson, G., Sundh, I., & Svensson, B. (2004). Microbial oxidation of CH4 at different temperatures in landfill cover soils. FEMS Microbiology Ecology, 48(3), 305–312. https://doi.org/10.1016/j.femsec.2004.02.006; Spokas, K. A., & Bogner, J. E. (2011). Limits and dynamics of methane oxidation in landfill cover soils. Waste Management, 31(5), 823–832. https://doi.org/10.1016/j.wasman.2009.12.018.

[44] Gebert, J., & Groengroeft, A. (2009). Role of soil gas diffusivity for the microbial oxidation of methane in landfill covers. *Proceedings Sardinia.* [hereinafter "Gebert 2009"].

[45] EPA, Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from Municipal Solid Waste Landfills, p. 17, 2011, https://www.epa.gov/sites/default/files/2015-12/documents/landfills.pdf.

[46] Cassini, F., Scheutz, C., Skov, B. H., Mou, Z., & Kjeldsen, P. (2017). Mitigation of methane emissions in a pilot-scale biocover system at the AV Miljø Landfill, Denmark: 1. System design and gas distribution. *Waste Management*, *63*, 213–225. https://doi.org/10.1016/j.wasman.2017.01.013.

[47] Wilshusen, J. H., Hettiaratchi, J. P. A., & Stein, V. B. (2004). Long-term behavior of passively aerated compost methanotrophic biofilter columns. Waste Management, 24(7), 643–653. https://doi.org/10.1016/j.wasman.2003.12.006.

[48] See, e.g., Hanson et al, "Executive Summary-Estimation and Comparison of Methane, Nitrous Oxide, and Trace Volatile Organic Compound Emissions and Gas Collection System Efficiencies in California Landfills," (March 25, 2020) [hereinafter "CARB 2022 Emission and GCCS Efficiencies Report-Executive Summary"] at 3. https://ww2.arb.ca.gov/sites/default/files/2020-12/CalPoly_LFG_Study_03-30-20_ExecSummary.pdf.

[49] 40 C.F.R. §258.21(a).

[50] 40 C.F.R. § 258.60

[51] *See e.g.* 39 Tex. Admin. Code § 330.165, 2006; Fla. Admin. Code 62-701.500, 2015; 27 CCR § 20700(a). EPA's Greenhouse Gas Reporting Program defines intermediate cover as "the placement of material over waste in a landfill for a period of time prior to the disposal of additional waste and/or final closure as defined by state regulation, permit, guidance or written plan, or state accepted best management practice." 40 C.F.R.

§ 98.348. However, the GHRP does not set any requirements for emissions control and addresses only the reporting of information.
[52] Ayundele et al, Key Strategies for Mitigating Methane Emissions from Municipal Solid Waste, RMI, p. 49 https://rmi.org/insight/mitigating-methane-emissions-from-municipal-solid-waste/.
[53] Ayundele et al, Key Strategies for Mitigating Methane Emissions from Municipal Solid Waste, RMI, p. 49, 2022 https://rmi.org/insight/mitigating-methane-emissions-from-municipal-solid-waste/.
[54] Ayundele et al, Key Strategies for Mitigating Methane Emissions from Municipal Solid Waste, RMI, p. 49, 2022 https://rmi.org/insight/mitigating-methane-emissions-from-municipal-solid-waste/.
[55] *See e.g.* Zero Waste Alliance, Zero Waste Hierarchy at https://zwia.org/zwh/; MDE, Yard Waste, Food Residuals, and Other Organic Materials Diversion and Infrastructure Study Group – Final Report – July 2019, pp. 8-10, available at https://mde.maryland.gov/programs/LAND/RMP/Documents/HB%20171%20final%20report.pdf.
[56] EPA, Global Mitigation of Non-CO2 GHGs Report: 2010-2030 (2013), Landfills, p. III-10, at https://www.epa.gov/sites/production/files/2016-06/documents/mac_report_2013-iii_waste.pdf (entire report available at https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases/global-mitigation-non-co2-ghgsreport-2010-2030).
[57] *See id* at III-11; California EPA, Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities, p. 3 (May 2017) at https://ww2.arb.ca.gov/sites/default/files/classic/cc/waste/cerffinal.pdf.
[58] *See id* at III-11.
[59] *Id.* at III-11.
[60] https://www.epa.gov/anaerobic-digestion/basic-information-about-anaerobic-digestion-ad
[61] Zero Waste International Alliance, Composting and Anaerobic Digestion Policy, at https://zwia.org/composting-and-anaerobic-digestion-policy/ (last accessed June 1, 2021).
[62] EPA, Global Mitigation of Non-CO2 GHGs Report: 2010-2030 (2013), Landfills, p. III-6, at https://www.epa.gov/sites/production/files/2016-06/documents/mac_report_2013-iii_waste.pdf (entire report available at https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases/global-mitigation-non-co2-ghgsreport-2010-2030).
[63] Zero Waste International Alliance, Composting and Anaerobic Digestion Policy, at https://zwia.org/composting-and-anaerobic-digestion-policy/ (last accessed June 1, 2021).
[64] https://mayor.baltimorecity.gov/sites/default/files/BaltimoreFoodWaste&RecoveryStrategy_Sept2018.pdf page 7
[65] *Id.* at 10.
[66] Ribeiro-Broomhead, J. & Tangri, N. (2021). Zero Waste and Economic Recovery: The Job Creation Potential of Zero Waste Solutions. Global Alliance for Incinerator Alternatives, pp. 13-14 https://zerowasteworld.org/zerowastejobs/.
[67] EPA, Downstream Management of Organic Waste in the United States: Strategies for Methane Mitigation, January 2022, p. 5 ("Dowmstream Management of Organic Waste") https://www.epa.gov/system/files/documents/2022-01/organic_waste_management_january2022.pdf.
[68] *Id.* p 6.
[69] *Id.* p. 9.
[70] EPA, Downstream Management of Organic Waste, p. 6.
[71] EPA, Advancing Sustainable Materials Management: 2018 Tables and Figures, Table 1 (Dec. 2020), https://www.epa.gov/sites/default/files/2021-01/documents/2018_tables_and_figures_dec_2020_fnl_508.pdf.
[72] U.S. Composting Council, "Organics Bans & Mandates," https://www.compostingcouncil.org/page/organicsbans (last updated June 2021).
[73] Western City, What Cities Need to Know About SB 1383 and Funding Organic Waste Management, Feb. 1, 2020, https://www.westerncity.com/article/what-cities-need-know-about-sb-1383-and-funding-organic-waste-management.
[74] EPA, Solid Waste Infrastructure for Recycling Grant Program, https://www.epa.gov/infrastructure/solid-waste-infrastructure-recycling-grant-program

[75] The demographic data are from EJScreen and represent estimated total population, people of color, and low-income residents within one mile of the coordinates given for each landfill in the GHGRP. EJScreen defines low-income as people living within the selected area that have a household income less than or equal to two times the poverty level. EJScreen data is based on both the 2016-2020 American Community Survey (ACS) and the 2010 Census, depending on how the one-mile buffer around the facility intersects the surrounding census block groups. More information about EJScreen can be found in their technical documentation: https://www.epa.gov/sites/default/files/2021-04/documents/ejscreen_technical_document.pdf

[76] *See generally* Terence L Winemiller, *Black Belt Region in Alabama,* Encyclopedia of Alabama (December 19, 2019), http://encyclopediaofalabama.org/article/h-2458.

[77] Comments of H. Lynn Phillips, P.E. to the Ala. Dep't of Env't Mgmt. on Permit No. 53-03 (April 14, 2022)[hereinafter "Lynn Phillips Comments"]; *see also* Dennis Pillion, *Millions of Pounds of Garbage from Other States Again Flooding Rural Alabama*, AL.com (January 13, 2022), https://www.al.com/news/2022/01/millions-of-pounds-of-garbage-from-other-states-again-flooding-rural-alabama.html.

[78] Arrowhead Environmental Partners, LLC, https://arrowheadenvironmentalpartners.com/about/why-arrowhead/ (last visited January 5, 2023).

[79] Title VI of the Civil Rights Act of 1964, 42 U.S.C. § 2000d allows any person who believes that he or she, individually, or as a member of any specific class (color, race, or national origin) has been subject to discrimination may file a complaint against an agency receiving federal funds.

[80] This is in reference to the coal ash being considered hazardous waste under the Comprehensive Environmental Response and Liability Act ("CERCLA") at the site of the spill in Tennessee, but being considered only solid waste under the Resource Conservation Recovery Act ("RCRA") for disposal at the Arrowhead Landfill in Alabama.

[81] *See* U.S. Commission on Civil Rights, Environmental Justice: Examining the Environmental Protection Agency's Compliance and Enforcement of Title VI and Executive Order 12,898 65-69 (September 2016), https://www.usccr.gov/files/pubs/2016/Statutory_Enforcement_Report2016.pdf.

[82] *In re Perry County Associates, LLC Arrowhead Landfill,* Ala. Dep't of Env't Mgmt Consent Order No. 22-XXX-CSW (October 28, 2022), https://adem.alabama.gov/newsEvents/notices/nov22/pdfs/11perry.pdf.

[83] Demographic data for Curtis Bay and Brookly and Baltimre City is from the Baltimore Neighborhood Indicators' 2020 Vital Signs report - https://bniajfi.org/vital_signs/.

[84] U.S. Census Bureau, Income and Poverty in the U.S., Table B.2, p. 54, https://www.census.gov/content/dam/Census/library/publications/2021/demo/p60-273.pdf

[85] U.S. Census Bureau, Maryland Profile, 2020 ACS 5-year estimate tables https://data.census.gov/table?g=0400000US24&tid=ACSST5Y2020.S1901 (median household income) https://data.census.gov/table?g=0400000US24&tid=ACSST5Y2020.S1701 (percent belowe poverty line).

[86] Baltimore Neighborhood Indicators Alliance, Vital Signs 2020, Brooklyn/Curtis Bay/Hawkins Point, Census Demographics, https://bniajfi.org/community/Brooklyn_Curtis%20Bay_Hawkins%20Point/.

[87] 2020 Maryland Emissions Inventory.

[88] 2020 Maryland Emissions Inventory.

[89] 2020 Quarantine Road Landfill Emissions Certification Report ("ECR").

[90] CDC, Facts About Benzene, https://emergency.cdc.gov/agent/benzene/basics/facts.asp.

[91] 2020 Quarantine Road Landfill Emissions Certification Report.

[92] ATSDR, Toxic Substances Portal, Toluene (Jan. 21, 2015), https://www.atsdr.cdc.gov/phs/phs.asp?id=159&tid=29; International Programme on Chemical Safety, Environmental Health Criteria 52: Toluene (1985), http://www.inchem. org/documents/ehc/ehc/ehc52.htm#SubSectionNumber:1.1.5.

[93] 2020 Quarantine Road Landfill ECR.

[94] ATSDR, Toxic Substances Portal, Dichlorobenzene (Jan. 21, 2015), https://www.atsdr.cdc.gov/PHS/PHS.asp? id=702&tid=126.

[95] Maryland 2017-2020 Emissions Inventories.

[96] 2018-2020 Quarantine Road Landfill ECRs.

[97] 2020 Maryland Greenhouse Gas Inventory, at https://mde.maryland.gov/programs/air/climatechange/pages/greenhousegasinventory.aspx.
[98] *See* MDE, Air & Radiation Regulations Public Hearings, Meeting and Request for Comments, https://mde.maryland.gov/programs/Regulations/air/Pages/reqcomments.aspx.
[99] Baltimore DPW, FY 2023 Capital Improvement Program Presentation, Bureau of Solid Waste, January 2022, https://planning.baltimorecity.gov/sites/default/files/FY23%20CIP%20Slides%20-%20Solid%20Waste.pdf
[100] See, e.g., Baltimore DPW, Semi-Annual Environmental Monitoring Reports, Quarantine Road Municipal Landfill Refuse Disposal Permit #2014-WMF-0325 Millennium Industrial Landfill :1st Semi-Annual Rseport 2021, p. 3, 2nd Semi-Annual Report p. 2.
[101] Baltimore City DPW, Draft 10-year Solid Waste Master Plan, March 2023, at 79, https://publicworks.baltimorecity.gov/sites/default/files/Baltimore%20SWMP%20Update_FINAL%20DRAFT%20TO%20POST_3-30-23_CLEAN.pdf.
[102] 2020 Maryland Emissions Inventory.
[103] *See, e.g., Power,* Energy From Waste: Greenhouse Gas Winner or Pollution Loser? July 1, 2016, https://www.powermag.com/energy-waste-greenhouse-gas-winner-pollution-loser/ .
[104] MD Code, Environment, § 9-1724.1.
[105] South Baltimore Community Land Trust, Baltimore Needs a Compost Facility, https://www.sbclt.org/baltimore-needs-a-compost-facility/.
[106] EPA's regulations issued under sections 111 and 112 of the Clean Air Act have largely been harmonized with one another to function as one set of requirements.
[107] The State of Maryland has issued draft regulations but those regulations were not final as of the issuance of this report.
[108] Oregon Department of Environmental Quality, Rulemaking, Action Item I Landfill methane rules, Statement of Fiscal and Economic Act, p. 10, 2021, https://www.oregon.gov/deq/EQCdocs/100121_I_LandfillMethane.pdf.
[109] Scientific Aviation (2021), Airborne Methane Emissions Measurement Survey: Final Summary Report; Ren et al (2018), Methane Emissions From the Baltimore-Washington Area Based on Airborne Observations: Comparison to Emissions Inventories, Journal of Geophysical Research: Atmospheres, https://doi.org/10.1029/
2018JD028851; Olaguer et al (2022), Landfill Emissions of Methane Inferred from Unmanned Aerial Vehicle and Mobile Ground Measurements, Atmosphere, https://doi.org/10.3390/atmos13060983.
[110] EPA, Other Test Method 51 (OTM-51) - UAS Application of Method 21 for Surface Emission Monitoring of Landfills, https://www.epa.gov/system/files/documents/2022-12/OTM%2051-%20UAS%20Application%20of%20Method%2021%20for%20Surface%20Emission%20Monitoring%20of%20Landfills.pdf.
[111] 87 Fed. Reg. 74707 (December 6, 2022).
[112] EPA, Revisions and Confidentiality Determinations for Data Elements Under the Greenhouse Gas Reporting Rule, Supplemental Proposed Rule, May 5, 2023, at 115-116, Prepublication Version, https://www.epa.gov/system/files/documents/2023-05/Supplemental%20Proposal%20and%20Preamble%20to%20GHGRP%20June%202022%20Proposal.pdf (last visited May 11, 2023).
[113] RGGI, Offsets, available at https://www.rggi.org/allowance-tracking/offsets (last accessed Jan. 29, 2023).
[114] *See, e.g.*, Congressional Research Service, The Energy Credit or Energy Investment Tax Credit, Updated April 23, 2021 (tax credits for "waste energy recovery"), https://crsreports.congress.gov/product/pdf/IF/IF10479#:~:text=Waste%20energy%20recovery%20property%20that,if%20construction%20begins%20in%202023.
PJM, Comparison of Renewable Portfolio Standards (RPS) Programs in PJM States, https://www.pjm-eis.com/~/media/pjm-eis/documents/rps-comparison.ashx.
[115] PJM, Comparison of Renewable Portfolio Standards (RPS) Programs in PJM States, https://www.pjm-eis.com/~/media/pjm-eis/documents/rps-comparison.ashx.
[116] *See* Wheelabrator, Baltimore, at https://www.wtienergy.com/plant-locations/energy-from-waste/wheelabrator-baltimore.

[117] See EIP, https://environmentalintegrity.org/wp-content/uploads/2016/11/FINALWTEINCINERATOR REPORT-101111.pdf.
[118] Ana Isabel Baptista & Adrienne Perovich, *U.S. Municipal Solid Waste Incinerators: An Industry in Decline* at 15 & App. E, Tishman Env't and Design Ctr. (May 2019), https://static1.squarespace.com/static/5d14dab43967cc000179f3d2/t/5d5c4bea0d59ad00012d220e/1566329840732/CR_GaiaReportFinal_05.21.pdf.
[119] US Environmental Protection Agency, "Inventory of Greenhouse Gas Emissions and Sinks: 1990-2021," (2023), Link: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Main-Text.pdf p. 7-6
[120] Landfill Methane Outreach Program. https://www.epa.gov/lmop/lmop-landfill-and-project-database. Accessed April 19, 2023.
[121] An additional 16 landfills were expected to report to GHGRP, but did not.
[122] Under 40 CFR, Part 98, Subpart HH – Municipal Solid Waste Landfills https://www.epa.gov/sites/default/files/2018-02/documents/hh_infosheet_2018.pdf
[123] https://www.epa.gov/system/files/documents/2022-01/waste_profile_01-10-2022.pdf p. 4
[124] https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-98/subpart-A/appendix-Table%20A-1%20to%20Subpart%20A%20of%20Part%2098
[125] US Environmental Protection Agency, "Inventory of Greenhouse Gas Emissions and Sinks: 1990-2021," (2023), Link: https://www.epa.gov/system/files/documents/2023-04/US-GHG-Inventory-2023-Main-Text.pdf p. ES-3
[126] Additional data was limited to the 2021 reporting year, except for some waste-in-place data. Landfills must report waste added for each year the landfill accepted waste, but twenty-three landfills were missing some years of data. In these cases, data from a previous reporting year was used to fill in the gap. In addition, 31 landfills had missing waste data that could not be supplemented using a previous reporting year, but this missing data concerned very old waste, in most cases prior to 1960. In addition, nine landfills were listed as open, but did not report waste added in 2021. Of these, four had not been accepting waste in recent years, and for the remaining five, it was unclear if they accepted waste in 2021 or not.
[127] U.S. Environmental Protection Agency, "EJScreen: Environmental Justice Screening and Mapping Tool," Accessed January 2023. Link: https://www.epa.gov/ejscreen
[128] U.S. Environmental Protection Agency, "EJScreen Environmental Justice Mapping and Screening Tool Technical Documentation," October 2023. Link: https://www.epa.gov/system/files/documents/2023-01/EJScreen%20Technical%20Documentation%20October%202022.pdf