



LEADING WITH LANDFILLS

The Immense, Cost-Effective Potential of Advanced Technology To Reduce Methane Emissions at Landfills Nationwide

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Foreword

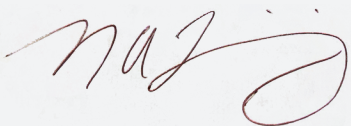
Cutting methane pollution is the most immediate, cost-effective way to slow warming over the near term. Since methane traps significantly more heat than carbon dioxide — but dissipates from the atmosphere sooner — fast action to curb methane is essential to keep our climate targets within reach. That is why RMI is working with a partner network of satellite and sensor operators through its WasteMAP platform to make methane emissions visible and define mitigation measures, policies, and market incentives that slash this super-potent greenhouse gas.

Landfills are a major but addressable source of climate pollution, generating methane as buried organic waste decomposes. Recent aerial and satellite remote sensing surveys have observed super-emitting methane plumes at landfills across the United States, with emission rates 40%–50% higher on average than inventory estimates. Landfill emissions also tend to be larger and more persistent than other sources of methane, which underscores the strong potential climate benefits of addressing these fugitive emissions.

The good news is that we have viable solutions to cut landfill methane pollution today. To avoid future methane generation, we must keep organic waste out of landfills — through waste prevention, food rescue, and organics recycling. At the same time, we must strengthen pollution controls for the landfilled waste that will continue generating methane for decades to come. There are proven best practices and readily available technologies that can increase landfill gas collection and slash methane pollution. As this Energy Vision study shows, expanding gas collection systems to more landfills, installing these systems earlier, and using real-time monitoring and controls can cut 59.2 million metric tons of CO₂e annually at just \$9.58/ton CO₂e.

Advanced landfill gas controls can unlock meaningful progress toward global 2030 methane reduction targets. And, the environmental, health, and economic benefits far exceed implementation costs. Stronger landfill pollution controls reduce local exposure to odors, ozone, and health-harming compounds in landfill gas — protecting workers and nearby residents. It also makes business sense: advanced landfill gas capture can save landfills money over time on operations while generating additional revenue for energy projects.

As this Energy Vision study makes clear, improving landfill gas collection is one of the most cost-effective opportunities to slow near-term warming, while boosting domestic energy production, improving air quality, and protecting public health. Policymakers and landfill operators can help close the gap on the Global Methane Pledge by integrating these best practices into landfill operations and regulatory and incentive programs today.



Tom Frankiewicz, *Principal, RMI Climate-Aligned Industries Program*

Executive Summary

- Methane is an extremely potent but short-lived greenhouse gas. Cutting methane emissions now is the strongest lever available to slow global warming in the coming decades.
- Landfills are the third-largest source of U.S. methane, accounting for 17% of total anthropogenic emissions, according to EPA greenhouse gas inventories. Food waste has an outsized impact, as it accounts for 20% of municipal solid waste (MSW) landfill tonnage but is responsible for 58% of fugitive methane emissions.
- Upon meeting fairly lax thresholds under federal law, or stricter thresholds in a few states, MSW landfills must build gas collection and control systems (GCCS) to capture the methane-rich gas generated by decomposing organic matter. But these gas collection systems are often quite inefficient and usually do not collect landfill gas from active cells where waste is still being deposited.
- It is an important yet long-term endeavor to prevent food from being landfilled in the first place, by redistributing the edible portion and diverting the rest to generate renewable energy and recycle nutrients. However, we also need solutions *now* based on the status quo where a huge amount of methane is being emitted from both food waste and non-food organic waste in landfills.
- The good news is that there are extremely cost-effective options to improve the efficiency of existing landfill gas collection systems through real-time monitoring and automated tuning systems, install them much earlier at working faces (in time to capture the methane-rich biogas from decomposing food waste), and to build them at high-emitting landfills that have no gas collection systems whatsoever. In this report, we refer to these options collectively as “advanced landfill tech.”
- **Implementing these three options – 1) real-time tech; 2) early action; and 3) new gas capture systems at all economically feasible high-emitting landfills – would cut U.S. MSW landfill emissions by 49.1% from the 2023 level. This would decrease total U.S. methane emissions by approximately 7.2% (49.4 million metric tons of CO₂ equivalent) relative to the 2023 level.** (All CO₂ equivalency calculations in this report are based on the EPA standard 100-year Global Warming Potential of methane being 28 times as powerful as CO₂.)
- Total estimated capex for these three feasible options, affecting nearly 900 landfills, would be \$1.3 billion and anticipated annual operations and maintenance would cost \$250 million. **The fully loaded annual cost of implementing advanced landfill tech – factoring in capex and opex** (based on the equipment having an 8-year lifespan) – **is just \$8.35 per metric ton of CO₂ equivalent abated. That is considerably**

less expensive than other notable greenhouse gas reduction options including oil and gas methane reduction measures, switching from fossil natural gas to renewable power generation, cleaning up the transportation sector, and implementing direct air capture of CO₂.

- Alternatively, including new gas capture at high-flow but less economically feasible landfills would deepen the cumulative cut from these options to 58.9% from MSW landfills or 8.63% from total U.S. methane (59.2 million metric tons of CO₂ equivalent). This combination would cost approximately \$1.8 billion in capex and \$340 million in annual opex. The fully loaded annual cost would be \$9.58 per metric ton of CO₂ equivalent abated – still incredibly cost-effective relative to the other greenhouse gas reduction options.
- Energy Vision also calculated that if all food waste were ultimately diverted from landfills, implementing the real-time tech option and new gas capture systems options would still cut 4.1% from total U.S. methane in 2023. This underscores that **these advanced landfill tech options are worth implementing even as efforts to redistribute and divert food waste gradually gain momentum. There is no conflict between these priorities; both should be pursued.**
- There are also many second- and third-order methane mitigation measures worth pursuing at landfills, including incorporating remote/aerial monitoring of leaks, adopting best practices in daily and intermediate cover, and decreasing the spacing between wellheads.
- There is also almost entirely untapped potential at some industrial landfills, which face no existing or planned regulatory requirements to install GCCS, yet collectively emit almost one fifth of the emissions that MSW landfills do.
- Options to accelerate implementation of advanced landfill tech include tighter regulations; direct subsidies; and expanding incentives for beneficial use of gas (to produce renewable natural gas or generate electricity) at landfills implementing best practices for gas capture. Additional methane capture at landfills above and beyond regulations could also be made eligible for use in state-level “compliance offset protocols,” for example, to help meet mandatory reductions in power emissions.
- The current landfill market incentives heavily favor the production of renewable natural gas (RNG), which can have significantly lower greenhouse gas emissions than fossil natural gas when produced at landfills with high collection efficiency. Over 100 landfill RNG projects are operational and over 100 more are planned or under construction. We therefore expect that virtually all the captured gas from the three feasible options today would be upgraded to RNG, which, at 93 million MMB-TU/year, would nearly double the total U.S. RNG supply (as of 2023).

- **The business case for adopting advanced landfill tech is very compelling.** Conservatively valuing the additional 93 million MMBTU/year of RNG produced at \$20/MMBTU (environmental attributes plus the commodity gas) in the years ahead, that equates to \$1.86 billion annually in new gross revenue generated. Meanwhile, the estimated cost of the three options feasible today is \$1.3 billion in onetime capex and \$250 million in annual opex. Aggregated across all the candidate landfills, this means an average overall payback period of less than a year once the new equipment is operational, after which this would be a significant net revenue earner for many years. *(The calculations in this report are based on the direct costs of all the advanced landfill tech feasible today and the additional revenue from the incremental gas capture; they exclude capex or opex associated with RNG plant installation.)*
- The bottom line: adopting advanced landfill tech to address a large source of current U.S. methane emissions would be a major, quick win at a very low cost relative to many other climate solutions.



A landfill wellhead with real-time tech. Photo Source: LoCI Controls.

I. Introduction

The world needs practical, cost-effective solutions to cut greenhouse gases and start bending the curve on climate change. The top near-term priority is to slash emissions of methane, an extremely potent but short-lived greenhouse gas. Cutting methane emissions soon is the strongest lever available to slow global warming in the coming decades. 159 countries, including the U.S. under the Biden administration, have signed the Global Methane Pledge, each committing to cutting their methane emissions 30% by 2030 (known as “30x30”) from 2020 levels.

The challenge is how the U.S. can feasibly and cost-effectively reach 30x30 in the next five years. Energy Vision’s May 2024 report [Meeting the Methane Challenge](#) set out the first concrete roadmap for exactly how the U.S. could achieve 30x30. It evaluated multiple options for how much methane could feasibly be reduced, at what costs, on what timeframes, and at what comparative “bang for the buck” (or cost-effectiveness) in methane abatement. Recognizing various city, state, federal, and international goals to divert materials – especially organic waste – from landfills, that report intentionally fo-

cused on non-landfill solutions to address the U.S. methane challenge.

This report serves as a follow-up to *Meeting the Methane Challenge* on the matter of methane emissions from landfills. According to EPA greenhouse gas inventories, landfills account for 17% of U.S. methane emissions, making them the third-largest source, behind only enteric fermentation (i.e., cow belches) at 27% of U.S. methane emissions and natural gas systems at 25%.¹ Moreover, recent remote sensing surveys suggest that actual landfill methane emissions may be 40-50% higher than bottom-up estimates like EPA GHG inventories, but for the sake of consistency we use the EPA data.²

While fully diverting food waste out of landfills remains an important long-term goal, we recognize that the U.S. needs cost-effective options *now* to tackle methane emissions by 2030. (See the box in Section III titled, “How Advanced Landfill Tech Fits into Multiple Paths to 30x30.”) This report therefore focuses on feasible, cost-effective options for implementing advanced technology at municipal solid waste landfills *today*, based on the status quo, where an enormous amount of methane leaks into the atmosphere from both food waste and non-food

1 https://www.epa.gov/system/files/documents/2024-04/us-ghg-inventory-2024-main-text_04-18-2024.pdf

2 <https://www.science.org/doi/10.1126/science.adi7735>; <https://acp.copernicus.org/articles/24/5069/2024/>

organic waste.

Almost 60 million metric tons of food waste are disposed in U.S. landfills every year, accounting for 20% of landfill tonnage. However, food waste has an outsized impact, as it is responsible for 58% of fugitive methane emissions.³ This is partly because food waste is so prevalent and conventional landfill gas collection systems are generally inefficient, and partly because food waste breaks down quickly – before most landfill gas collection systems are installed. As this report details, there are extremely cost-effective options to improve the efficiency of existing landfill gas collection systems, install them much earlier at working faces (in time to capture the methane-rich biogas from decomposing food

waste), and to build them at high-emitting landfills that have no gas collection systems whatsoever.

This report also quantifies how much methane would be captured if advanced landfill technology were implemented *and* all food waste were ultimately diverted from landfills. The results are still significant, showing that installing advanced landfill technology and diverting food waste from landfills are not rival approaches and both should be pursued. Advanced landfill technology can be implemented faster, making more of a difference to reaching 30x30, so it should be a high priority. The report concludes with policy options that would accelerate the installation of advanced landfill technology and start cutting methane emissions right away.

3 https://www.epa.gov/system/files/documents/2023-10/food-waste-landfill-methane-10-8-23-final_508-compliant.pdf

Snapshot of EPA Landfill Regulations

Greenhouse Gas Reporting Program (GHGRP)

The EPA Greenhouse Gas Reporting Program (GHGRP) was created in 2009, covering landfills and other stationary sources of air pollutants and greenhouse gases. Any landfill – whether open or closed – that emits at least 25,000 metric tons of carbon dioxide equivalent (CO₂e) per year must report its emissions to the GHGRP, except if it stopped accepting waste prior to 1980.

A landfill can discontinue reporting to the GHGRP if its emissions fall below 25,000 metric tons of CO₂e per year for 5 years in a row, or below 15,000 metric tons of CO₂e for 3 consecutive years. However, it would have to resume reporting if its recorded emissions ever rose above 25,000 metric tons of CO₂e.

Of note, however, the Greenhouse Gas Reporting Program's future is uncertain. In April 2025, a senior Trump Administration EPA official ordered staff to draft a rule that would exclude 40 of the 41 sectors that are now required to submit data to the GHGRP, including landfills.⁴ Regardless, the following gas capture regulations for landfills still apply.

Gas Capture Regulations for Municipal Solid Waste Landfills

The existing gas capture regulations for municipal solid waste landfills date back to 1996 (and were mostly kept intact in the EPA's latest New Source Performance Standards or NSPS from 2016). These require a landfill to install a gas collection and control system (GCCS) if it has both:

- A permitted landfill design capacity of at least 2.5 million megagrams as well as at least 2.5 million cubic meters of municipal solid waste; and
- An estimated emission rate of at least 34 megagrams per year of non-methane organic compounds (NMOCs) for open landfills or 50 megagrams per year of NMOCs for closed landfills.

Upon reaching both of these thresholds, a landfill must do all of the following:

- Develop and submit a gas collection and control system (GCCS) design plan within 12 months

4 <https://www.propublica.org/article/trump-epa-greenhouse-gas-reporting-climate-crisis>

of initially exceeding the NMOC emission rate threshold.

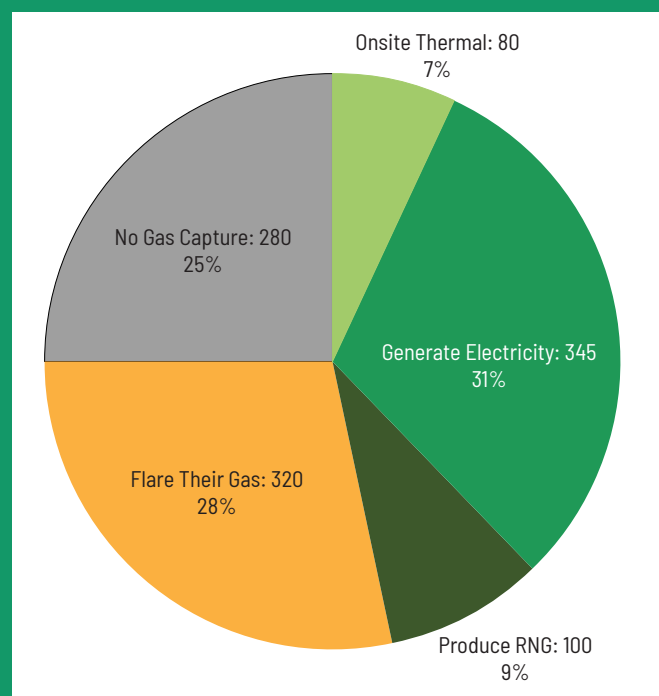
- Install and operate a GCCS within 30 months of first exceeding the NMOC emission rate threshold. The system must meet specific NMOC reduction criteria.
- Take measurements at each gas collection point once per month to ensure negative pressure as well as the temperature of the landfill gas being within specified limits.⁵
- Monitor surface emissions once per quarter to ensure the GCCS is working properly.
- Expand any existing GCCS into each area where waste is placed within 5 years if actively accepting waste, or within 2 years if the area is closed or at final grade.

About a quarter (280) of the 1,125 municipal solid waste landfills reporting to the GHGRP in 2023 did not have gas collection systems, because even though they were emitting at least 25,000 metric tons of CO₂e annually, they did not reach the two separate thresholds on permitted size and NMOC levels that would have required them to install gas collection systems. In a few instances, landfills may have been in the process of building gas collection systems but they were not yet operational at the time of reporting. For context, 100 landfills (almost 10%) reporting to the GHGRP in 2023 produced renewable natural gas (RNG), about 80 others used their gas for onsite thermal uses (i.e., as boiler fuel), around 345 other GHGRP landfills generated electricity, and roughly 320 others reporting to the GHGRP flared their landfill gas (see Figure 1 to the right).

There are many ways in which landfill regulations could be changed to cut the sector's large fugitive methane emissions, such as adopting a methane emissions threshold and reducing the size requirements and lag time for installing gas capture systems. EPA published a very useful series of white papers in October 2024 on these potential measures.⁶ Several states – California, Oregon, Washington, Michigan, and Maryland – have indeed adopted

much stronger landfill regulations compared to the federal baseline, and Colorado is in the process of doing so (see case study in Section IV, Policy Options to Accelerate Implementation). We discuss the technical measures later in this section and the policy measures in Section II. There may be equally effective incentives to encourage installation of gas capture prior to it being required, especially if there is sufficient demand from voluntary carbon markets that recognize the GHG reduction and climate benefits of doing so (see Section IV for more).

Figure 1: How the 1,125 Landfills Reporting to the GHGRP in 2023 Used Their Gas



Source: Energy Vision chart based on EPA *GHGRP Reporting Year 2023* data, EPA Landfill Methane Outreach Program (LMOP) data from September 2024, Energy Vision-Argonne National Laboratory *RNG Database 2023 Calendar Year*

⁵ Oxygen and nitrogen concentrations must also be monitored once per month at each gas collection point and recorded but the 2016 NSPS removed the need for operators to take corrective action for exceedances in either case. <https://www.federalregister.gov/documents/2016/08/29/2016-17687/standards-of-performance-for-municipal-solid-waste-landfills>

⁶ <https://www.epa.gov/stationary-sources-air-pollution/non-regulatory-public-docket-municipal-solid-waste-landfills>

II. High-Impact Landfill Options That Can Be Implemented Today, Based on the Status Quo

Energy Vision's calculations in this report are based on the methane reductions of different scenarios run in the Environmental Protection Agency (EPA)'s Landfill Gas Emissions Model (LandGEM), as well as empirical cost estimates from industry practitioners. All CO₂ equivalency calculations in this report are based on the EPA standard 100-year Global Warming Potential of methane being 28 times as powerful as CO₂.

Top Three Impactful Measures to Cut Methane from Landfills

Energy Vision found that the three highest-impact options feasible now to cut methane leaking from municipal solid waste landfills are:

1. Improve the efficiency of existing landfill gas collection systems through the use of real-time technology. We refer to this option as **"real-time tech."**
2. Install gas collection systems much earlier at working faces (in time to capture the methane-rich biogas from decomposing food waste). We refer to this option as **"early action."**
3. Build gas collection systems at high-emitting landfills that currently lack them, but which are not otherwise required to do so yet. We refer to this option as **"new gas capture systems."**

These high-impact options are detailed below and summarized in Figure 2 (see next page). It was beyond the scope of this study to model additional, second- and third-order landfill options that can also be implemented today based on the status quo, but we provide a brief overview of them in the box at the end of this section, along with a snapshot of the significant potential at industrial landfills.

Figure 2 (see next page) features the following individual options as well as the Total Feasible Today combination and the Total with Stretch Targets combination:

Option 1 is installing real-time well monitoring and automated tuning systems at all existing landfills with gas collection systems.

Option 2 is early expansion (by at most one year after waste is deposited) of gas collection systems to landfill working faces which emit at least 5,000 metric tons of carbon dioxide equivalent (MT of CO₂e) annually, incorporating real-time monitoring and automated tuning systems.

Option 3.a. is installing gas collection systems with real-time monitoring and automated tuning systems at landfills that don't have any gas collection systems but which emit at least 50,000 metric tons of CO₂e annually, with gas flow rates of at least 700 standard cubic feet per minute (scfm).

Option 3.b. is installing gas collection systems with real-time monitoring and automated tuning systems at all landfills that don't have any gas collection systems but which emit at least 50,000 metric tons of CO₂e annually (including less economically viable "stretch targets" with gas flow rates between 250 and 700 scfm). See the accompanying text for more details on each option.

Figure 2: Emission Reductions, Costs, and Bang for the Buck of Advanced Technology Options at Municipal Solid Waste Landfills

Advanced Landfill Technology Option	Annual Emission Reductions*	Percent Reduction from MSW Landfill Methane in 2023	Percent Reduction from Total U.S. Methane in 2023	Capital Costs**	Annual Operations & Maintenance Costs**	Bang for the Buck: Methane Reduction (MT CO ₂ e) Annually Per Million Dollars of Capex Invested**	Fully Loaded*** Annual Cost Per MT of CO ₂ e Abated (at 8-Year Equipment Lifespan)
1. Real-Time Tech	22.3 million MT CO ₂ e	22.1%	3.24%	\$658 million capex	\$141 million opex	33,852	\$10.02
2. Early Action	21 million MT CO ₂ e	20.8%	3.05%	\$430 million capex	\$72 million opex	48,697	\$6.01
3.a. New Gas Capture Systems at High-Emitting, High-Flow Landfills	6.2 million MT CO ₂ e	6.1%	0.90%	\$213 million capex	\$37 million opex	28,915	\$10.32
3.b. New Gas Capture Systems at High-Emitting Landfills of All Flow Rates	16 million MT CO ₂ e	15.9%	2.33%	\$732 million capex	\$127 million opex	21,870	\$13.64
Total Feasible Today (Options 1+2+3a)	49.4 million MT CO ₂ e	49.1%	7.19%	\$1.3 billion capex	\$250 million opex	37,955	\$8.35
Total with Stretch Targets for Landfills Lacking Gas Capture Systems (Options 1+2+3b)	59.2 million MT CO ₂ e	58.9%	8.63%	\$1.82 billion capex	\$340 million opex	32,541	\$9.58

Source: Energy Vision calculations using data from EPA Landfill Gas Emissions Model (LandGEM) scenarios and empirical cost estimates from industry practitioners. 2023 U.S. methane emissions data is from EPA's 2025 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2023.⁷

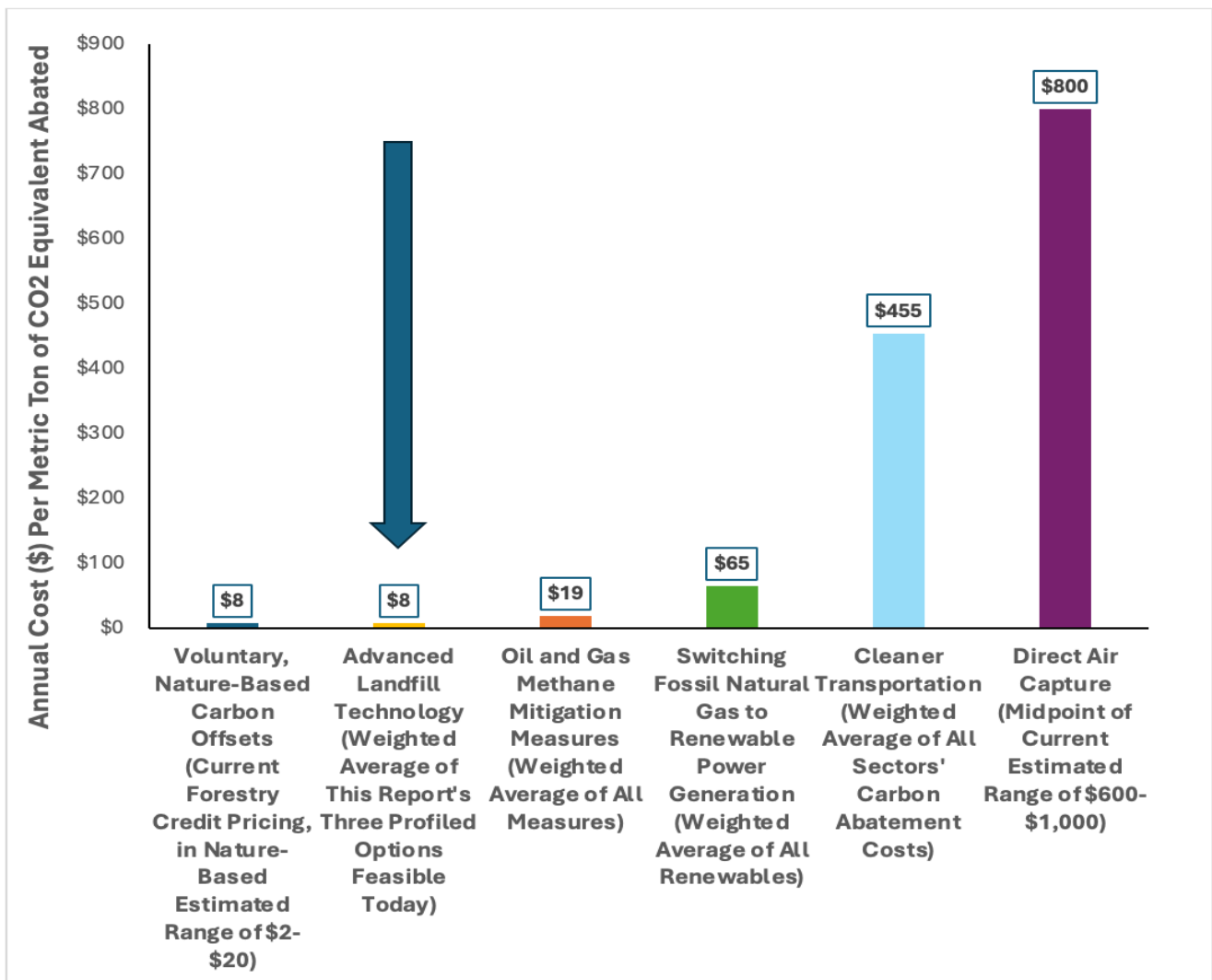
*Annual emission reductions reflect the amount of methane collected by gas capture systems minus a conservative 5% lost in the upgrading process to renewable natural gas (which is what we expect virtually all the captured gas to be used for given the current market incentives; see Section IV for more) or to flaring where applicable. We then subtract another 5% from that to conservatively account for methane leakage in pipelines on the way to the end users. These losses are typically lower empirically, and pipeline leakage may not be relevant for the small systems who wouldn't realistically produce RNG, but we err on the side of being conservative to play it safe and have ample margin to cover other real-world inefficiencies that may occur, such as during maintenance. CO₂e calculations are based on the EPA standard 100-year Global Warming Potential of methane being 28 times as powerful as CO₂.

**These are the direct costs of the advanced landfill tech, excluding capex or opex associated with RNG plant installation.

***Fully loaded annual cost means capital costs divided over the 8-year advanced landfill technology equipment lifespan plus annual opex.

⁷ The Trump administration declined to publish the final EPA greenhouse gas inventory report, but it was obtained by Environmental Defense Fund via a Freedom of Information Act request on May 7, 2025 and posted in full on their website. https://www.edf.org/freedom-information-act-documents-epas-greenhouse-gas-inventory?tab=complete_report

Figure 3: Advanced Landfill Tech Has Lower Annual Cost Per Metric Ton of CO2 Equivalent Abated Than Other Notable Climate Strategies



Source: Energy Vision chart. The voluntary nature-based carbon offsets column uses current forestry credit pricing from [Allied Offsets](#) of \$7.84 per metric ton of CO2 equivalent abated as of July 8, 2025, rounded up to match the other columns at the nearest whole dollar value, with recent empirical examples of nature-based voluntary carbon offsets ranging from approximately \$2 to \$20 per metric ton of CO2 equivalent abated. The landfill column is drawn from Energy Vision calculations for this report's three profiled options that are feasible today, using data from EPA Landfill Gas Emissions Model (LandGEM) scenarios and empirical cost estimates from industry practitioners (see Figure 2 above); it is rounded down from \$8.35 per metric ton of CO2 equivalent abated to match the other columns at the nearest whole dollar value. The oil and gas methane mitigation column is from [Energy Innovation](#), which found in a 2021 analysis using the U.S. Energy Policy Simulator 3.3.0 that the weighted average cost of all oil and gas industry methane abatement measures (like properly casing and sealing wells, monitoring for methane leaks, and improving pipeline and equipment maintenance) in the Build Back Better and Infrastructure Investment and Jobs Acts is \$19 per metric ton CO2e. The switching fossil gas to renewables and cleaner transportation columns are from [Goldman Sachs](#), whose 2025 Carbonomics analysis found slight decreases in the costs of renewables and cleaner transportation from the previous year, with larger decreases in solar photovoltaic costs and battery-electric passenger car costs diluted by stubbornly high costs for offshore wind and heavy-duty vehicles, respectively. The direct air capture column is from the [Boston Consulting Group](#), whose 2023 analysis concluded that in order for direct air capture to be widely adopted, its full cost would need to fall from \$600-\$1,000 per metric ton of CO2 today to below \$200 and ideally closer to \$100 by 2050, if not earlier.



A landfill wellhead with real-time monitoring and automated tuning technology. Photo Source: LoCI Controls.

1. Real-Time Tech

THE BOTTOM LINE

Real-time well monitoring and automated tuning systems at all existing landfills with gas collection and control systems (GCCS) would reduce MSW landfill emissions by 22.1% and total U.S. methane emissions by 3.24% (22.3 million metric tons of carbon dioxide equivalent) from the 2023 level.

Estimated capital costs would be \$658 million; annual operations and maintenance costs would be \$141 million (with the equipment lasting at least 5 years, and likely 8-10 years total). In terms of methane reduction for capex invested, or “bang for the buck,” this is the second-most cost-effective of the three landfill options analyzed in this report (see Figure 2 above). **The fully loaded annual cost factoring in capex and opex (based on the equipment having an 8-year lifespan) is only \$10.02 per metric ton of CO₂ equivalent abated.** (These calculations are based on the direct costs of the real-time tech; they exclude capex or opex associated with RNG plant installation.)

The incremental costs per wellhead equipped with

this technology are relatively low: \$7,000 in capex and \$1,500 in annual operations and maintenance, with a baseline 75% coverage of wellheads at a typical landfill sufficient to significantly improve overall results.

The real-time tech option assumes installation at all 845 open and closed landfills reporting in the EPA Greenhouse Gas Reporting Program (GHGRP, see box above) that already have GCCS in place. We conservatively assume an average 15% increase in gas capture thanks to these systems, although empirically some increases may be significantly higher (see box below, Empirical Results of Real-Time Tech).

DESCRIPTION

About 91% of municipal solid waste landfilled in the U.S. is disposed in landfills with gas capture and collection systems according to EPA⁸, but these systems are typically inefficient and rarely extend to working faces (see “Early Action” option below). Furthermore, without continued investment, conventional GCCS often decline in efficiency as they age.

Meanwhile, landfill gas emissions are dynamic – they change significantly on a daily and seasonal basis.

8 <https://www.regulations.gov/document/EPA-HQ-OAR-2024-0453-0008>

Emission rates of these gases, particularly methane, are influenced by fluctuations in atmospheric conditions such as barometric pressure, temperature, and wind speed. However, existing federal regulations only require landfill operators to check wellhead pressure, temperature, nitrogen content, and oxygen content on a monthly basis. As a result, a traditional GCCS with wellheads whose vacuum is adjusted manually on a monthly basis (if at all) results in inconsistent flow rates and quality of gas being captured amid the constantly changing environmental conditions.

Too much vacuum means low-quality gas (especially elevated nitrogen levels, which often has to be flared instead of used productively) and elevated temperatures. Too little vacuum means gas is escaping elsewhere, which is harmful to the climate, causes the landfill to lose revenue it could have earned by using that gas to generate electricity or renewable natural gas (RNG), and raises odor concerns for the local community. (RNG is derived from decomposing organic waste and is upgraded to be virtually identical to fossil natural gas, but crucially it involves no leaky fossil fuel extraction or fracking, and it can have significantly lower lifecycle greenhouse gas emissions than fossil gas when sourced from landfills with high gas collection efficiency. According to Q3 2024 data from California's Low Carbon Fuel Standard program, landfill RNG used in the transportation sector averaged a 52.4% lower carbon intensity than gasoline/diesel.⁹ See Section IV for more on landfill RNG carbon intensity.)

A GCCS can achieve optimal performance throughout changing environmental conditions via the installation of real-time monitoring and automated tuning systems at wellheads. These systems monitor all relevant parameters (including gas composition, flow rates, temperature, and pressure) and remotely adjust valves to change vacuum rates and gas composition as often as needed to maximize GCCS uptime and efficiency. High gas quality is maintained by optimizing the balance between ox-

ygen and methane composition, reducing the risks of air intrusion from any cracks in piping. This also helps prevent sub-surface fires, improving community safety. Additionally, automated tuning systems compensate for underperforming wells by increasing vacuum pressure in adjacent active wells to capture more gas.

Furthermore, these systems provide rapid notification of problems that must be fixed manually like well malfunction. Operators quickly receive a notification rather than the traditional default of the issue remaining undetected until the next monthly manual inspection. This means malfunctioning wellheads or leaking pipes could be fixed much sooner, preventing extended releases of methane into the atmosphere and improving the GCCS bottom line.

Empirical Results of Real-Time Tech

Real-time well monitoring and automated tuning systems were pioneered by private company LoCI Controls. LoCI systems support gas collection operations on over 65 U.S. landfills.¹⁰

Several of LoCI's results, which are calculated according to the prestigious American Carbon Registry (ACR)'s "Methodology for the Quantification, Monitoring, Reporting, and Verification of Greenhouse Gas Emissions Reductions and Removals from Landfill Gas Destruction and Beneficial Use Projects,"¹¹ are publicly available.

At the Hamm Landfill in Lawrence, Kansas, the use of LoCI's real-time tech led to an average 32% increase in gas capture over four years. The project generated a 614,633 MMB-TU incremental increase in methane captured over four years, or an estimated \$3.8 million increase in gross annual revenue to

⁹ See chart on p. 14 of Energy Vision's report, *A Path to a Healthier America: Ditching Old Diesel Trucks* <https://energy-vision.org/wp-content/uploads/2025/03/ditching-diesel.pdf>

¹⁰ <https://www.prnewswire.com/news-releases/loci-controls-increases-methane-capture-at-landfill-group-project-by-32-302274332.html>

¹¹ The ACR's landfill gas credits were one of the first methodologies to meet the Core Carbon Principles of the Integrity Council for the Voluntary Carbon Market in April 2024. <https://acrcarbon.org/our-markets/integrity-council-for-the-voluntary-carbon-market-icvcm/>

the producer at an assumed \$25/MMBTU (environmental attributes plus commodity gas). The project operator was also able to reduce downtime at the plant by over 90%, from 73 hours per month to just 6.¹²

At the Roosevelt Regional Landfill, Klickitat Public Utility District in Washington State, the amount of gas captured had been declining for years prior to the installation of LoCI's real-time tech. The LoCI system reversed that trend, increasing gas capture by 12% compared to the starting point, totaling more than 150,000 MMBTUs over 2.5 years. It also significantly improved the quality of the collected gas by lowering the proportions of nitrogen and oxygen, meaning more landfill gas could be upgraded to RNG.¹³

Another private firm in the advanced landfill tech industry, Apis Innovation, has deployed its technology at over 80 landfills and has published the results of one project so far:

At Vancouver Landfill in British Columbia, Canada, the use of Apis real-time tech led to a 12% increase in methane capture over one year relative to the baseline of the two previous years.¹⁴

For many landfills considering an RNG project, they would need to capture 2–4% more landfill gas to reach the breakeven point for the required investment. Higher gas capture rates like the 15% being averaged from deployment of LoCI technology mean a payback period of a couple months compared to a typical payback period of a few years.

2. Early Action

THE BOTTOM LINE

Early expansion of gas collection systems to landfill working faces, with real-time monitoring and automated tuning systems, would cut MSW landfill emissions by 20.8% and total U.S. methane emissions by 3.05% (21 million metric tons of carbon dioxide equivalent) from the 2023 level.

Estimated capital costs would be \$430 million; annual operations and maintenance costs would be \$72 million (with the equipment lasting at least 5 years, and likely 8–10 years total). The horizontal wells in working faces do not function nearly as long as the standard vertical wells in closed parts of landfills, but they are much cheaper and simply left in place as more waste is added and more horizontal wells are installed higher up. The real-time monitoring and tuning devices last much longer; they would be removed from the abandoned horizontal wells and installed at subsequently placed ones, which is factored into the annual opex estimates. **In terms of capex “bang for the buck” in methane reduction, this is the most cost-effective of the three landfill options analyzed in this report (see table above). The fully loaded annual cost factoring in capex and opex (based on the equipment having an 8-year lifespan) is just \$6.01 per metric ton of CO₂ equivalent abated.** (These calculations are based on the direct costs of the early action equipment; they exclude capex or opex associated with RNG plant installation.)

The early action option assumes the system extension is operational by at most one year after waste has been deposited, at all 432 open landfills reporting in the GHGRP whose working faces emit at least 5,000 metric tons of CO₂ equivalent annually (based on modeled generation from LandGEM figures) – a reasonable threshold to justify the expense of extending the GCCS.

We assume an approximately 75% efficiency at the newly installed systems in working faces, which in-

12 https://locicontrols.com/hubfs/PDFs/Case%20Studies/LoCI-CaseStudy-LFG-RPP_11124.pdf?hsLang=en

13 https://locicontrols.com/hubfs/PDFs/Case%20Studies/LoCI-CustomerCaseStudy-KlickitatPUD_080124.pdf?hsLang=en

14 <https://www.apisinnovation.com/post/vancouver-case-study>



Horizontal gas collectors with real-time tech at a landfill. Photo Source: LoCI Controls.

cludes a 15% increase relative to the baseline of a new traditional GCCS thanks to the real-time technology.¹⁵

DESCRIPTION

EPA estimates that 61% of methane generated by landfilled food waste is not captured by GCCS and escapes into the atmosphere.¹⁶ Because food waste decays in just a few years (50% of the carbon in food waste is degraded to landfill gas within 3.6 years), its emissions frequently occur before landfill gas collection systems are installed or expanded into working faces. Current federal regulations only require existing GCCS to be expanded to new areas within five years of waste being deposited at an active face, or within two years if the area is closed or at final grade.

Expansion of GCCS to active faces within a year of

waste being deposited could therefore capture a huge amount of methane that is otherwise escaping into the atmosphere. This is especially the case from food waste, whose methane emissions in landfills increased steadily by 295% from 1990 to 2020 due to increasing amounts of food waste being disposed even as overall landfill emissions declined due to general improvements in GCCS (see Figure 4 below).¹⁷

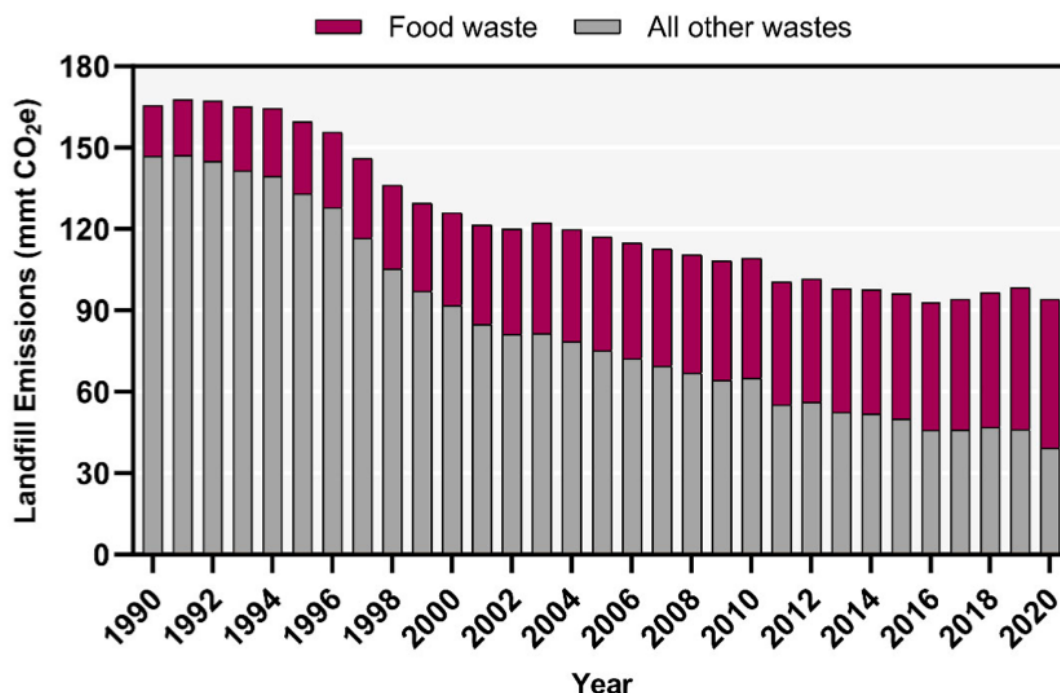
This early action option has unique logistical challenges, but they can all be addressed cost-effectively with existing technology. The working faces of landfills are inherently less stable than closed faces, since waste is still being deposited and is not fully compacted. There is a greater potential for the gas collecting equipment to be damaged by the movement of heavy machinery and by waste being placed. This accordingly means greater safety risks for workers operating in these areas. Plus there may

¹⁵ Specifically, we assume a 65% baseline efficiency for a new traditional GCCS + 15% more than that from real-time tech, or $.65 \times 1.15 = .7475$.

¹⁶ https://www.epa.gov/system/files/documents/2023-10/food-waste-landfill-methane-10-8-23-final_508-compliant.pdf

¹⁷ Ibid.

Figure 4: Contributions of Food Waste to Methane Emissions at U.S. Municipal Solid Waste Landfills



Source: EPA, [Quantifying Methane Emissions from Landfilled Food Waste](#), October 2023.

be higher risks of fires breaking out in active faces since less top cover means more oxygen gets in and can feed any flames. Gas quality is also unstable there since the waste is at different stages of decomposition, with new volumes being added regularly. Lesser but very addressable challenges include applying and removing daily cover and potentially more issues of pests and rodents getting into recently deposited waste.

The solution to capture methane from working faces, based on existing technology, is to install horizontal gas collecting wells there. As noted above, they don't function nearly as long as the standard vertical wells in closed parts of landfills. However, they're much less expensive and are meant to be disposable in place. When they inevitably get damaged or filled in by leachate, they're simply left there as more waste is added above and additional horizontal wells are installed higher up.

The incorporation of real-time tech would improve the efficiency of the horizontal gas collectors and streamline their replacement process, as landfill operators would receive rapid notifications of problematic performance. And when it's time to abandon the horizontal wells, the much longer lasting real-time devices are removed and installed at sub-

sequent wells. As noted above, early action could capture a huge amount of methane, making this the most cost-effective option analyzed in this report.

Once an active face with horizontal wells is done accepting waste, then conventional vertical collection wells would be drilled.

3. New Gas Capture Systems

THE BOTTOM LINE

We assessed two options for new gas capture systems: a smaller feasible subset and a larger stretch goal. The feasible option (see 3.a. below) of installing gas collection systems with real-time monitoring and automated tuning systems (including at working faces) at high-emitting, high-flow landfills that don't have any gas collection systems would lower MSW landfill emissions by 6.1% and total U.S. methane emissions by 0.9% (6.2 million metric tons of carbon dioxide equivalent) from the 2023 level. Alternatively, the stretch goal (see 3.b. below) of installing these systems at high-emitting landfills with lower gas flows would cut MSW landfill emissions by 15.9% and total U.S. methane emissions by 2.33% (16 million MT of CO₂e) from the 2023 level.

- **3.a. New Gas Capture Systems at High-Emitting, High-Flow Landfills**

The 0.9% reduction in total U.S. methane emissions assumes installation at all 43 open landfills in the GHGRP that currently lack a gas collection system and whose annual emissions are at least 50,000 metric tons of CO₂ equivalent, with gas flows of at least 700 standard cubic feet per minute (scfm). This subset with gas flows of 700+ scfm are the most economically viable for gas capture and beneficial use.¹⁸ We assume an approximately 75% efficiency at the newly installed systems in working faces, which includes a 15% increase relative to the baseline of a new traditional GCCS thanks to the real-time technology.¹⁹

Estimated capital costs for this subset of landfills would be \$213 million; annual operations and maintenance costs would be \$37 million (with the equipment lasting at least 5 years, and likely 8-10 years total). Compared to real-time tech and early action at landfills with existing GCCS, this option has lower bang for the buck in terms of methane reduction for capex invested, but it is still extremely cost-effective (see Figure 2 above). The fully loaded annual cost factoring in capex and opex (based on the equipment having an 8-year lifespan) is only \$10.32 per metric ton of CO₂ equivalent abated. (These calculations are based on the direct costs of installing new GCCS with real-time tech; they exclude capex or opex associated with RNG plant installation.)

- **3.b. New Gas Capture Systems at High-Emitting Landfills of All Flow Rates**

The alternative 2.33% reduction in total U.S. methane emissions assumes installation at all

187 open landfills in the GHGRP that currently lack a gas collection system and whose annual emissions are at least 50,000 metric tons of CO₂ equivalent, including ones with lower gas flows (at least 250 scfm). Landfills in this larger set with lower gas flows (between 250 and 700 scfm) are generally not seen by developers as attractive candidates for biogas-to-electricity or biogas-to-RNG systems. However, certain types of flares can operate well at low landfill gas flows, combusting the methane and releasing the less potent greenhouse gas CO₂ instead of the much more potent methane escaping into the atmosphere. Emissions from these high-emitting landfills with low flows are still deemed addressable methane, even if they don't result in an energy recovery project.

Estimated capital costs for all these new GCCS would be \$732 million; annual operations and maintenance costs would be \$137 million (with the equipment lasting at least 5 years, and likely 8-10 years total). Relative to the other options analyzed in this report, installing new gas capture systems at high-emitting landfills of all flow rates has the lowest bang for the buck in terms of methane reduction for capex invested, but it is still very cost-effective (see Figure 2 on page 9) relative to other GHG reduction measures. The fully loaded annual cost factoring in capex and opex (based on the equipment having an 8-year lifespan) is \$13.64 per metric ton of CO₂ equivalent abated. (These calculations are based on the direct costs of installing new GCCS with real-time tech; they exclude capex or opex associated with flaring or any beneficial use projects.)

¹⁸ This is especially true for landfills that can avoid the major expense of a Nitrogen Rejection Unit in the RNG production process by using real-time tech in GCCS to control inlet nitrogen concentrations to reach the desired specifications. A Nitrogen Rejection Unit typically accounts for 35-50% of a landfill RNG project's capex and a large portion of its opex, as it's one of largest electricity-consuming parts of the processing system. For landfill GCCS with manual tuning, forgoing a Nitrogen Rejection Unit often means that 25% less landfill gas makes it to RNG, but the use of real-time tech with automated tuning covers that difference while meeting the nitrogen specifications for RNG production. Many larger landfills have Nitrogen Rejection Units to maximize the amount of landfill gas they can upgrade to RNG, but smaller landfills often can't afford them, so it's useful to know there is a viable workaround via real-time tech.

¹⁹ Specifically, we assume a 65% baseline efficiency for a new traditional GCCS + 15% more than that from real-time tech, or $.65 \times 1.15 = .7475$.



A vertical wellhead with real-time tech at a landfill.
Photo Source: LoCI Controls.

DESCRIPTION

About 9% of municipal solid waste landfilled in the U.S. is disposed in landfills without gas capture and collection systems, according to EPA. But as detailed above, within that subset, many landfills emit high amounts of greenhouse gases and accordingly have to report to the GHGRP. They just may not meet the formal federal criteria for having to install a GCCS, whether because their permitted landfill design capacity is below the threshold or their non-methane emissions are below the threshold.

This leaves a clear gap, wherein a landfill could be emitting large amounts of methane and yet legally not have to do anything about it. Installing GCCS at high-emitting landfills that don't have them is the most obvious step to capture methane emissions. Doing so is more capital-intensive because full GCCS are considerably more expensive than just adding real-time tech or expanding an existing system to a working face. Incorporating all three aspects into a new GCCS is even more expensive but allows for the greatest methane capture.

We have therefore separated out the most economically attractive subset – those with gas flows above 700 scfm – as a feasible option today.²⁰ Its capex cost-effectiveness is close to the real-time tech option at landfills with existing GCCS (see Figure 2 above).

Meanwhile, we consider the larger set including gas flows of 250+ scfm to be a stretch goal that is achievable but not based on private sector funding alone (at least in the current market). Due to the relatively high costs of installing a GCCS from scratch combined with lower flows of methane captured, this broader option's capex bang for the buck is the lowest of all those analyzed in this report. There would need to be government funding, much higher voluntary carbon abatement credit prices, or other incentives in order for the economics to be viable.

Total Potential Impact from the Options

Implementing these three feasible options – real-time tech, early action, and new gas capture systems at high-emitting, high-flow landfills – would cut MSW landfill emissions by 49.1% and total U.S. methane by 7.19% (49.4 million metric tons of CO₂ equivalent) based on 2023 emissions (or 7.37% from total U.S. methane in 2020). Total capex would be \$1.3 billion and annual operations and maintenance would cost \$250 million. The fully loaded annual cost, factoring in anticipated capex and opex (based on the equipment having an 8-year lifespan), is only \$8.35 per metric ton of CO₂ equivalent abated. (These calculations are based on the direct costs of the advanced landfill tech, excluding capex or opex associated with RNG plant installation.)

²⁰ As noted in Footnote 18, these plants would be especially viable for RNG production if they were to adopt real-time tech and not have to install a Nitrogen Rejection Unit.

If new collection systems are installed at all open landfills emitting at least 50,000 MT of CO₂e annually, including ones with lower gas flows (250+ scfm), then the three options would collectively cut MSW landfill emissions by 58.9% and total U.S. methane by 8.63% (59.2 million metric tons of CO₂ equivalent) based on 2023 emissions (or 8.84% from total U.S. methane in 2020). In that case, **total estimated capex would be \$1.82 billion and annual operations and maintenance would cost \$340 million. The fully loaded annual cost, factoring in capex and opex (based on the equipment having an 8-year lifespan), is just \$9.58 per metric ton of CO₂ equivalent abated.** (As noted above, these calculations are based on the direct costs of the advanced landfill tech, excluding capex or opex associated with RNG plant installation.)

These are much lower costs per metric ton of CO₂ equivalent abated than other notable climate strategies like oil and gas methane reduction measures, switching from fossil natural gas to renewable power generation, cleaning up the transportation sector, and implementing direct air capture of CO₂. Advanced landfill tech's costs per metric ton of CO₂ equivalent abated are just slightly above current pricing for forestry voluntary carbon credits (\$7.84 as of July 8, 2025) and well within the recent empirical range for nature-based voluntary carbon credits of \$2-20 per metric ton of CO₂ equivalent abated (see Figure 3 on page 10).

Additional Landfill Options That Can Be Implemented Today, Based on the Status Quo

We recognize that there are additional second- and third-order options that could be implemented today at many landfills to increase methane capture. It was beyond the scope of this paper to model them, so we just note there is further potential to reduce landfill methane emissions by adopting any of the following example options:

- **Incorporate advanced monitoring of methane leaks.** A growing number of studies using aerial/satellite methane detection have shown that many landfills are emitting far more methane than they have self-reported, typically from data gathered on very limited, error-prone walking surveys once per quarter that avoid working faces.²¹ Incorporating methane emissions data taken by drones, rovers, airplanes, satellites, or continuous fenceline monitors would allow operators to pinpoint where large methane plumes are occurring and take early corrective action.
- **Decrease space between landfill gas collection wells.** Installing wells at for example a 100-foot radius instead of a 200-foot radius would capture landfill gas that may otherwise be escaping where the vacuum is weakest in between vertical wells.
- **Better leachate removal.** Since the accumulation of liquid ("leachate") in landfills harms the efficiency of gas collection systems, it is important to integrate pumps (including dual-phase wells that extract both gas and liquids simultaneously in separate pipes).
- **Minimize the size of working faces and improve daily cover.** Since working faces often leak the most methane at landfills, reducing their size to the smallest extent possible for safe, effective operations and adopting best practices for materials and application of daily cover could prevent significant methane leaks.

21 See for example <https://www.science.org/doi/10.1126/science.adi7735> and <https://cdn.sanity.io/files/xdjws328/production/4820df5770ec505062a6f29d5f6c6f9bb7f31071.pdf>

- **Improve intermediate and final cover.** Some additional methane could be naturally “oxidized” into CO₂ (a much less potent greenhouse gas) and water by passing through well-designed intermediate and final soil covers – especially when biochar or biocover is added, as it increases the aeration of the soil and promotes the growth of methane-oxidizing bacteria.
- **Switch to using enclosed flares.** A majority of landfills use open flares to burn off gas they don’t want or that’s of too low quality for productive use, but enclosed flares are more efficient in methane destruction, and over time the emissions reduction would be substantial. The EPA white paper on this topic estimates that installing only enclosed flares at new landfills would result in 320,000 fewer metric tons of methane (nearly 9 million metric tons of CO₂ equivalent) emitted cumulatively by 2060, while doing that plus replacing all existing open flares with enclosed flares would cut 2.7 million metric tons of methane (75.6 million metric tons of CO₂ equivalent) cumulatively by 2060.²²

The aforementioned EPA series of white papers goes into depth on many of these topics and is a very useful resource.²³ In some cases EPA models how much additional methane could be captured relative to the baseline, noting that many of these options would involve additional costs for landfill owners/operators but generally not going into further detail on costs or cost-effectiveness in methane abatement.

Almost Entirely Untapped Potential at Industrial Landfills

While this paper focuses on municipal solid waste (MSW) landfills, industrial landfills have emitted almost one fifth the methane produced by MSW landfills for the last few years (in 2023, they emitted 18.9 million metric tons of CO₂ equivalent compared to 100.6 million metric tons of CO₂ equivalent from MSW landfills). Unlike MSW landfills, industrial landfills face no requirements to install GCCS once certain thresholds are met, but they may have major potential to cut their methane emissions as well.

Industrial landfills are only required to measure their emissions if they have a design capacity of at least 300,000 metric tons and accepted waste since 1980. If these emissions are at least 25,000 metric tons of CO₂ equivalent per year, then the owners/operators must report them to the EPA Greenhouse Gas Reporting Program (GHGRP), but they don’t have to do anything to mitigate them. This is another major gap in the current landfill regulations. Nor is there any real appetite in the industrial landfill sector thus far for capturing and putting the landfill gas to beneficial use, largely due to the substantial capex costs and the absence of any approved pathways to earn federal/state credits.

Two sectors are responsible for virtually all industrial landfill methane emissions: the pulp and paper sector and the food and beverage sector. Of the 11.1 million tons of industrial waste landfilled in 2021, slightly more than half came from pulp and paper and slightly less than half came from food and beverage processing.²⁴ In many ways, these industrial waste streams are very well suited for anaerobic digestion or other non-landfill processing/disposal, and as with MSW landfills, it is likely that industrial landfills will continue to operate and accept material for years to come. Paper and pulp waste doesn’t generate methane as quickly as food waste does, but it does so for much longer, making it a highly suitable feedstock for GCCS (without necessarily needing early action).

However, only one out of the 167 industrial landfills reporting to the Greenhouse Gas Reporting Program (GH-

22 EPA, MSW Landfill Gas Collection and Control System (GCCS) Installation Lag Time and Nonmethane Organic Compound (NMO) Destruction Efficiency, October 2024. <https://www.epa.gov/stationary-sources-air-pollution/non-regulatory-public-docket-municipal-solid-waste-landfills>

23 <https://www.epa.gov/stationary-sources-air-pollution/non-regulatory-public-docket-municipal-solid-waste-landfills>

24 https://www.epa.gov/system/files/documents/2024-04/us-ghg-inventory-2024-main-text_04-18-2024.pdf

GRP) had an active gas collection system in 2021.²⁵ This was the highest-emitting industrial landfill in the country, Vonco II in Minnesota, which flared all the gas it captured, emitting 227,196 metric tons of CO₂ equivalent in 2023.²⁶ (For reference, if the gas currently being flared were upgraded to RNG, it would amount to over 75,000 MMBTU/year, with a potentially significant upside if additional wells were installed and real-time tech were adopted. Vonco II reported having 27 wells on its approximately 70 acres of landfill area, a density almost three times lower than EPA's default one well per acre recommendation for MSW landfills.)²⁷ Data is scarcer for industrial landfills and some may have different constraints than their MSW counterparts that might make installing gas collection systems unviable on chemical/safety grounds, but this is not the case for all industrial landfills.

Some could install gas collection systems utilizing real-time tech, including on working faces if food and beverage processing waste is being deposited, along with any or all of the second- and third-order options listed above. Installing gas capture systems from scratch would be expensive, but the most bang for the buck would come from focusing on the much smaller subset of industrial landfills emitting the most methane. Notably, of the 162 entities in the Industrial Waste category reporting to the GHGRP in 2023, the 45 emitting over 50,000 metric tons of CO₂ equivalent annually (the same total emissions threshold we used in Option 3 above) accounted for 68.1% of the total reported in that category.²⁸ Of those, 16 facilities emitted over 100,000 metric tons of CO₂ equivalent annually, accounting for 35.3% of the total, and 4 emitted over 200,000 metric tons of CO₂ equivalent annually, accounting for 13.1% of the total.

It was beyond the scope of this report to assess the feasibility of installing GCCS at specific industrial landfills. However, based on GHGRP facility level data for the 16 highest-emitting industrial landfills, the vast majority – 13 – contained paper and pulp waste. (Of the remaining three, one had wood waste and two had “other industrial solid waste” so they would probably not be as feasible candidates.) Two of those 13, including Vonco II, also had food processing waste. So while we cannot assess GCCS feasibility without further details of each site, this subset is indicative of the large theoretical potential among industrial landfills overall.

Collectively, installing GCCS at suitable industrial landfills could make a significant impact. For example, a modest 20% overall reduction in industrial landfills' methane emissions would cut total U.S. methane by 0.55% (from the 2023 level), and a more ambitious 40% overall reduction in their methane emissions would cut total U.S. methane by 1.1% – that's more than the 0.9% from the option of installing new gas capture systems at high-emitting, high-flow MSW landfills (see Option 3.a. above). Every percentage point matters on the way to 30x30.

The bottom line: industrial landfills should not get a de facto free pass to keep emitting large amounts of methane and other greenhouse gases largely unchecked. Any combination of tighter regulations, state support, and market incentives (see Section IV, Policy Options to Accelerate Implementation, below) could make a significant difference in curbing emissions from this important yet overlooked sector.

25 Ibid. ; <https://www.epa.gov/ghgreporting>

26 <https://ghgdata.epa.gov/ghgp/service/facilityDetail/2023?id=1004449&ds=E&et=&popup=true>

27 <https://ghgdata.epa.gov/ghgp/service/html/2023?id=1004449&et=undefined> This calculation is based on the reported 300 scfm flow rate to the flare, as well as the methane concentration and operating hours. It also factors in a 5% loss in the RNG upgrading process and another conservative 5% loss from pipeline leakage in distribution to end consumers.

28 <https://ghgdata.epa.gov/ghgp/main.do>

III. Remaining Impact of Advanced Landfill Technology in Idealized Future Scenario Where All Food Waste is Diverted From Landfills

As noted previously, Energy Vision's 2024 report *Meeting the Methane Challenge* calculated the total feasible potential for anaerobic digesters (ADs) to process the country's food waste. Those calculations assumed that the edible half of the food that's currently discarded would first be redistributed and the other, inedible half would be diverted from landfills to ADs instead. Reducing food waste going to landfills is a key priority for cutting methane emissions, recovering nutrients, reducing the overall waste burden, and living more sustainably. So what remaining impact would the advanced landfill technology options detailed in this report have if all food waste were to be redistributed and diverted?

To model that, we assume that the real-time tech option and the new gas capture systems option are fully implemented and then all food waste would eventually be diverted from landfills. The food waste already in landfills would decompose within a few years, leaving only non-food waste in landfills. (The early action option would be vastly less impactful once food waste is no longer present in working facilities, so we have conservatively excluded that option from this scenario.) **Energy Vision calculated that once food waste is out of the picture, implementing the real-time tech option and new gas capture systems options would still cut 4.11% from total U.S. methane in 2023** (or 3.81% from the higher total of U.S. methane in 2020; see box below for how this would fit in a viable path to 30x30).

That's almost half of the 8.63% total methane reduction from the three options deployed at the status quo (including the aforementioned stretch goals for landfills without gas capture systems). The estimated annual cost per metric ton of CO₂ abated would be \$13.76 (based on the direct costs of the advanced landfill tech, excluding capex or opex associated with RNG plant installation), which is still very cost effective relative to other notable climate solutions

(see Figure 3 on page 10).

This underscores that these advanced landfill technology options are worth implementing even as efforts to redistribute and divert food waste gradually gain momentum. There is no conflict between these priorities; both should be pursued simultaneously. From a practical standpoint, the advanced landfill technology options could be implemented in just a few years (including just a few months for installing real-time tech at existing gas capture systems) – much faster than massively scaling up food redistribution and diversion from landfills to anaerobic digesters. Given the urgency of cutting methane emissions soon to stave off the worst of climate change, implementing these extremely cost-effective advanced landfill technology options should be a tangible, immediate priority.



Food waste. Photo Source: [FoodandYou \(Flickr\)](https://www.flickr.com/photos/foodandyou/)

Meanwhile, working to scale up food redistribution and food waste diversion is a much larger and more difficult endeavor, as it requires behavioral change by hundreds of millions of people, as well as major new logistics and infrastructure investments across the country (to separate and transport food for redistribution or diversion from landfills to ADs). Other developed countries have shown that food waste can be reduced significantly: for example, Japan cut its overall food waste per capita by 31% between 2008 and 2020, and the U.K. cut its overall food waste per capita by 18% from 2007 to 2021.²⁹

29 <https://wedocs.unep.org/handle/20.500.11822/45230>; <https://www.wrap.ngo/resources/report/courtauld-commit->

Although very little progress has been made in the U.S. in the past decade in terms of reducing food waste going to landfills, the programs and infrastructure are finally being put in place to tackle it in much of the U.S. For example, New York City has now implemented mandatory organics separation from regular garbage collection, meaning more of its food waste will be diverted from landfills to ADs. And when completed in Q1 2026, the Linden Renewable Energy food waste to RNG project being developed by private firms South Jersey Industries, RNG Energy Solutions and Captona in Linden, NJ will be able to process 1,475 tons of food waste daily from New

York City and northern new Jersey. That amount is equal to nearly 40% of the food waste generated in New York City, to be processed at a single plant using anaerobic digesters.³⁰

More broadly, the private company Divert processed over 315,000 tons of inedible food waste in 2024 in the U.S. using ADs, a 52% annual increase; it is expanding its food redistribution and food waste AD infrastructure to 30 facilities across the U.S. by 2031 that will be within 100 miles of 80% of the population.³¹ That expansion would allow Divert to process 5% of all wasted food in the U.S. by 2031.³²

[ment-milestone-report-2023](#)

30 <https://www.wastedive.com/spons/sjis-flagship-rng-facility-earns-2024-energy-vision-leadership-award/729302/>; <https://www.nyc.gov/assets/dsny/downloads/resources/reports/zero-waste-plan/zero-waste-plan.pdf>
31 <https://divertinc.com/divert-processed-over-630m-pounds-of-unsold-food-products-in-2024/>
32 <https://www.wastedive.com/news/divert-north-carolina-anaerobic-digestion-food-waste/712641/>

How Advanced Landfill Tech Fits into Multiple Paths to 30x30

There are multiple paths to cutting methane 30% by 2030 (30x30). *Meeting the Methane Challenge* laid out the potential methane reductions from building anaerobic digesters (ADs) and from various options in the oil and gas sector.³³ The figures used there are based on 2020 emissions, so for consistency here we likewise use the absolute landfill methane reductions relative to 2020 emissions to calculate progress to 30x30. We lay out two sample paths below, one based on the status quo of minimal food waste diversion and the other based on full diversion of food waste.

Figure 5: Paths to 30x30 Based on Status Quo of Minimal vs. Full Food Waste Diversion

Option	Reduction from Total U.S. Methane (2020 Level)	
	Minimal Food Waste Diversion Scenario	Full Food Waste Diversion
Food Waste Redistribution & ADs	0%	7.5%
Advanced Landfill Tech	8%	3.8%
Manure ADs	6.1%	6.1%
Plugging Stripper Wells	10.7%	10.7%
Other	5.2%	Over 1.9%
Total	30%	Over 30%

Source: Energy Vision Calculations

33 <https://energy-vision.org/wp-content/uploads/2024/06/EV-National-AD-Report-1.pdf>

Path to 30x30 Based on Status Quo of Minimal Food Waste Diversion

- If all three advanced tech options were implemented at municipal solid waste landfills (affecting roughly 1,000 sites, including lower-flow landfills via stretch goals), that would cut 8% from U.S. methane (as per 2020 levels).
- If about 4,000 manure ADs were built at all feasible dairy and swine farms in the U.S., that would cut 6.1% from U.S. methane.
- If all roughly 700,000 low-output “stripper” oil and gas wells were plugged, that would cut 10.7% of U.S. methane.
- The three bullet points above total 24.8%. The remaining 5.2% could likely come from a combination of other smaller options:
 - advances in cutting methane from enteric fermentation (i.e., cow belches); this is the subject of a forthcoming Energy Vision report
 - adopting secondary methane mitigation measures at municipal solid waste landfills (see box at the end of Section II)
 - adopting the three advanced tech options at industrial landfills as well as any secondary methane mitigation measures there
 - cutting methane in the oil and gas industry (through cost-effective measures like replacing leaky components with more efficient ones)
 - reducing methane from abandoned coal mines and rice cultivation
 - redistributing some edible food that would otherwise be disposed in landfills which are too small to support gas collection systems
 - diverting some food waste that would otherwise be disposed in landfills which are too small to support gas collection systems to instead go to ADs or to well-aerated composting sites.

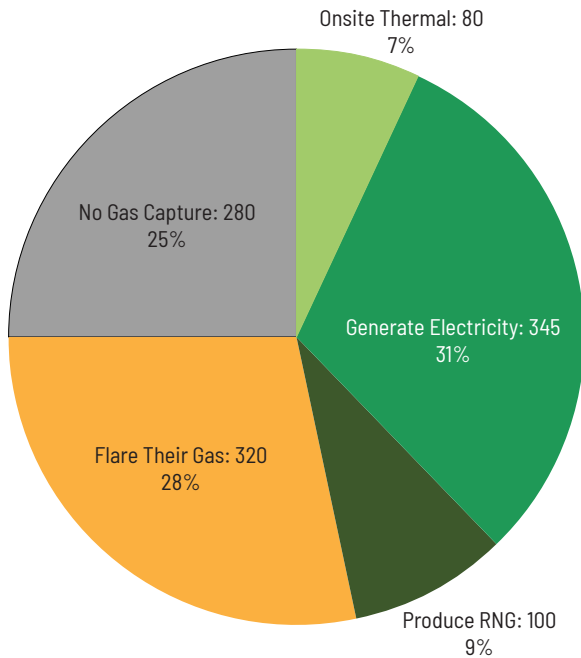
Path to 30x30 Based on Full Food Waste Diversion

- If the edible half of all food currently discarded were redistributed and the inedible half were diverted from landfills to about 700 food waste ADs, that would cut 7.5% of U.S. methane (from the 2020 level).
- If real-time tech and new gas capture systems were implemented at municipal solid waste landfills, (affecting roughly 1,000 sites, including lower-flow landfills via stretch goals), once food were totally diverted that would cut 3.8% of U.S. methane (from the 2020 level).
- If about 4,000 manure ADs were built at all feasible dairy and swine farms in the U.S., that would cut 6.1% from U.S. methane.
- If all roughly 700,000 low-output stripper oil and gas wells were plugged, that would cut 10.7% of U.S. methane.
- The four bullet points above total 28.1%. The remaining 1.9% could likely be attained and exceeded from a combination of other smaller options:
 - advances in cutting methane from enteric fermentation (i.e., cow belches); this is the subject of a forthcoming Energy Vision report
 - adopting secondary methane mitigation measures at municipal solid waste landfills (see box at the end of Section II)
 - adopting the three advanced tech options at industrial landfills as well as any secondary methane mitigation measures there
 - cutting methane in the oil and gas industry (through cost-effective measures like replacing leaky components with more efficient ones)

IV. Policy Options to Accelerate Implementation

Recognizing the current political reality of the Trump administration systematically dismantling federal environmental and climate regulations, near-term progress in tackling landfill emissions will likely happen at the state and local levels as well as in the private sector. Many of the same policy options noted below could be enacted at the federal or state levels. They would make a bigger overall difference if enacted at the federal level, however unlikely this is at present. State-level policies could be very impactful within the much smaller subset of landfills within their borders, and some progressive states are indeed tackling landfill methane emissions (see the Colorado case study below).

Figure 1: How the 1,125 Landfills Reporting to the GHGRP in 2023 Used Their Gas



Source: Energy Vision chart based on EPA [GHGRP Re-reporting Year 2023](#) data, EPA Landfill Methane Outreach Program ([LMOP](#)) data from September 2024, Energy Vision-Argonne National Laboratory [RNG Database](#) 2023 Calendar Year

As noted previously, 100 of the 1,125 municipal solid waste landfills (almost 10%) reporting to the Greenhouse Gas Reporting Program (GHGRP) in 2023 produced RNG. About 80 others used their gas for onsite thermal uses (i.e., as boiler fuel), around 345 other GHGRP landfills generated electricity, and roughly 320 others reporting to the GHGRP flared their landfill gas. The remaining 280, about a quarter of the total, did not have gas collection systems.

Tighter Federal/State Regulations

The policy options to accelerate implementation, as detailed in the EPA white papers³⁴ and exemplified in the Colorado case study below, include:

- **Changing the landfill size threshold requiring GCCS installation to be actual tonnage of waste in place rather than permitted capacity.** Federal regulations require GCCS installation if a landfill has a permitted design capacity of at least 2.5 million megagrams and at least 2.5 million cubic meters of municipal solid waste. By contrast, California, Oregon, Washington State, and Maryland have all enacted regulations requiring GCCS installation based on much smaller thresholds of waste in place: typically 450,000 tons (408,000 megagrams), meaning less than one fifth of the 2.5-million-megagram federal design capacity threshold. Oregon's threshold is the tightest at 200,000 tons (181,000 megagrams).
- **Lowering the emissions thresholds for landfills that must install a GCCS.** Whether based on emissions of non-methane organic compounds or methane, the threshold for having to install a GCCS can always be made more stringent while still being at a feasible level for operators to comply with.
- **Mandating earlier installation of GCCS, including in working faces.** As noted in Option 2 (Early Action), there is untapped yet massively cost-effective potential to capture methane emissions from food waste in active faces through horizontal collection wells.

34 <https://www.epa.gov/stationary-sources-air-pollution/non-regulatory-public-docket-municipal-solid-waste-landfills>



A horizontal gas collector with real-time tech at a landfill working face. Photo Source: LoCI Controls.

- Requiring more frequent and accurate emissions reporting, including through such options as real-time tech and aerial/satellite monitoring.** The minimum federal reporting requirements for an operating GCCS are that collection points must be monitored once per month and surface emissions must be monitored once per quarter to ensure the system is working properly. But these are wholly inadequate, given how much landfill emissions vary over time (as noted in Option 1, Real-Time Tech) and how limited and error-prone walking surface measurements are (as noted in the Box on Additional Landfill Options). More frequent and more accurate monitoring and reporting requirements would identify problems sooner and spur corrective action, whether mandated or incentivized. And if this leads to wider adoption of real-time tech at landfills, all the better. Option 1 shows the hugely cost-effective methane reduction potential of installing real-time tech at all landfills with GCCS.

Overall, these measures would result in more high-emitting landfills having to install GCCS. That would entail unexpected costs for landfill owners, but as noted in Option 3 (New Gas Capture Systems), this would capture large amounts of methane very cost-effectively. By pairing enhanced regulation with expanded access to renewable energy/fuel markets, it's likely that the economic incentives and benefits can outweigh concerns about increased compliance costs.

Colorado Sets the Pace with Proposed MSW Landfill Methane Reduction Plan

In April 2025, Colorado released its proposed draft of what would be the country's most stringent MSW landfill methane emissions standard.³⁵ Landfills are the state's third-largest source of methane emissions. Addressing them is a near-term priority given that Colorado has passed legislation requiring a 26% reduction in GHG emissions by 2025 compared to 2005 levels; this will extend to a 50% reduction by 2030, 65% by 2035, 70% by 2040, 95% by 2045, and net-zero emissions by 2050.

Colorado's proposed landfill methane reduction plan, which will proceed to a rulemaking hearing in August 2025, incorporates the three advanced tech options and many of the secondary impact best practices as described in this report. It is based on a methane emissions threshold and actual waste in place, unlike the existing federal regulations. More Colorado MSW landfills would be required to install GCCS under this plan to manage their emissions. The rules would also require that corrective action be taken in a timely manner to address any malfunctions or detected leaks.

1. Real-time tech is highly encouraged if not de facto required

- Under the proposed rules, owners/operators of landfills subject to the GCCS requirements must install a sampling port and measuring devices, or an access port for measuring devices, at all wellheads. On at least a weekly basis at each wellhead, they must monitor and record nitrogen or oxygen concentrations in the landfill gas, the gauge pressure, and the temperature of the landfill gas.
 - In the case of measuring any positive gauge pressure or temperature exceedance, owners/operators must complete corrective action within 5 days; if it would take longer than that, they have to do a thorough system-wide investigation and take corrective action according to the findings.

- Overall, GCCS must be designed to:
 - Handle the maximum expected gas generation flow rate over the lifespan of the waste.
 - Maintain a negative pressure at all wellheads without causing air infiltration, including any new wells added to the system.
 - Collect gas to comply with the surface methane emission limits, minimize or prevent equipment leaks, and meet all other performance standards.
 - While these criteria don't explicitly mandate real-time monitoring and automated tuning systems, those are the type of gas capture systems that would enable compliance with all of these requirements for frequent monitoring and adjusting to minimize leaks.

2. Early action is mandatory

- Colorado's proposed landfill regulations require that a GCCS be capable of expansion, including installation of horizontal collecting wells.
- For an MSW landfill accepting less than 200,000 tons per year of solid waste, GCCS must be expanded so that it is operational collecting from areas where solid waste has been in place for 12 months.
- For an MSW landfill accepting at least 200,000 tons per year of solid waste, GCCS (including horizontal collecting wells) must be installed prior to solid waste being placed and while further waste is added.
 - These systems must begin operations after at least 15 vertical feet of solid waste has

35 See REG.SBAP.pdf at https://drive.google.com/drive/folders/1oU06xyMI5ejJTylYvmaVF_ijWRqbvjIV

been placed over a horizontal collector, and when landfill gas pressure is detected by mandatory weekly pressure monitoring or the waste has been in place for at least 12 months.

3. New gas capture systems are required based on tighter criteria

- Unlike the federal landfill regulations based in part on a large permitted capacity of 2.5 million megagrams and 2.5 million cubic meters of municipal solid waste, Colorado's proposed rules use a much smaller threshold of actual waste-in-place (450,000 short tons, equivalent to 408,000 megagrams) triggering regulatory coverage.
- Colorado's proposed landfill rules require regular methane emissions measurements and/or calculations, and they require GCCS installation based on a methane threshold (at least 1,814 metric tons per year). This is in stark contrast to the federal landfill regulations based on emissions of non-methane organic compounds.
- Owners/operators of landfills meeting these thresholds would also have to install and operate GCCS sooner under Colorado's proposed regulations than under federal ones.
 - Active MSW landfills required to install and operate GCCS must do so within 18 months after the deadline for submitting the design plan to the state authorities.
 - Inactive or closed MSW landfills required to install and operate GCCS must do so within 24 months after the deadline for submitting the design plan to the state authorities.

4. Other best practices are required or eligible

- Colorado's proposed rules incorporate the usage of remote monitoring, including from third parties as approved by the Colorado Hazardous

Materials and Waste Management Division (referred to as "the Division") or by the EPA.

- The Division can send notification to operators within 7 days of receiving complete monitoring data for a given incident.
- Within 5 days of receiving such a notification, the owner or operator of an MSW landfill must investigate the cause of the emissions and perform any necessary corrective actions. In some cases this may mean installing a gas capture system if one is not in place already.
- The owner or operator must report the results of the investigation and any corrective actions to the Division within 15 days of being notified, plus send a follow-up report within 7 days of the mitigation measures being completed.
- Owners/operators must also implement measures to prevent emissions from landfill working faces, such as minimizing the size of working faces based on how much waste is being deposited.
- Surface emissions monitoring must be conducted at 25-foot spacing on landfills rather than the 100-foot spacing required under federal regulations, improving detection of leaks.³⁶
- If regular surface emissions monitoring detects a leak above the stringent allowed threshold, owners/operators must take corrective action such as cover repair and well vacuum adjustments. This must be initiated no later than 3 days after detection and completed no more than 5 days after detection.
- Horizontal collection wells must be properly sloped to drain liquids that accumulate.
- Permitted flares can be enclosed or open for the next few years. But open flares will no

36 See EIA.pdf at https://drive.google.com/drive/folders/1oU06xyMl5ejJTylYvmaVF_ijWRqbjvIV

longer be allowed at any MSW landfill starting in 2029, unless the methane generation rate is less than 664 metric tons (732 tons) per year, or the open flare is used as a backup, or it was recently installed (between 2020 and 2025). The latter two caveats don't apply if the open flare is within one mile of a disproportionately impacted residential community.

- Owners/operators must use a biocover (a porous layer such as sand or gravel and an organic layer such as compost) as part or all of a landfill's intermediate cover, specifically to promote activity by methanotrophs (microorganisms that break down methane).
- For active or inactive MSW landfills with at least 450,000 tons of waste in place, owners/operators must monitor cover integrity and implement any necessary cover repairs or maintenance on a monthly basis.

Anticipated Costs

Colorado's proposed landfill methane reduction plan would impose additional costs for MSW landfill owners/operators, especially if GCCS would have to be built at landfills that currently lack them. If the rules are enacted, 18 MSW landfills that do not have GCCS currently would be required to build them or conduct surface emissions monitoring to determine if a gas capture system must be installed.³⁷ For the 14 Colorado landfills with existing GCCS (12 of which are required to have them under federal regulations and 2 others have installed them voluntarily), costs would rise to a lesser degree to come into full compliance if the rules are enacted.

According to the Economic Impact Analysis (EIA) submitted by the Colorado Department of Public Health and Environment, the capital cost of installing GCCS over the 956 acres of filled-in area across the 18 landfills that do not yet have GCCS is \$49 mil-

lion. (That surface area is expected to increase by an average of 10 acres per year collectively among the 18 landfills.) Annual opex for GCCS at those 18 landfills would be \$7.5 million. Additionally, it would cost each landfill an estimated \$14,400 to prepare the waste-in-place, methane generation, and annual compliance reports (\$4,800 apiece), and surface emissions monitoring would be another \$29,200 per year. Between 2029 and 2050, the total cost of compliance (using a 2.5% discount rate), including reporting, early installation of horizontal collectors, and GCCS, would be \$175 million.

Staff from major landfill owner/operator companies Waste Management and Republic Services voluntarily joined a state-convened Technical Working Group whose input helped inform balanced and thorough recommendations for curbing landfill methane emissions. Over the course of six meetings, they provided feedback on matters including operational and maintenance requirements for GCCS as well as the timing for when those systems should be installed.³⁸ Some expressed the need for further testing, with Waste Management's senior director of air programs noting, "Landfills are complicated, emissions vary over time, and we have emissions 24/7. Drones produced a lot of false positives—and we need more work understanding how fixed sensors can be applied in a landfill environment."³⁹

Many of the landfills that would likely have to install GCCS under the new rules are operated by counties. An open letter in support of the rules was signed by 42 local officials including commissioners from Boulder, San Miguel, Adams, Larimer, Eagle, and Pitkin Counties.⁴⁰ "Landfills across Colorado, including in Eagle County, are leading sources of methane pollution – a powerful greenhouse gas and significant contributor to the climate crisis," said Eagle County Commissioner Matt Scherr. "When it comes to reducing these emissions, we should take advantage of every tool in the toolbox. As a local elected official, I support a robust rule that embraces advanced technologies to cut pollution, protect public health,

37 See EIA.pdf at https://drive.google.com/drive/folders/1oUQ6xyMl5ejJTylYvmaVF_ijWRqbvjIV

38 <https://www.wastedive.com/news/colorado-landfill-methane-rule-proposal-public-meetings/741641/>

39 <https://www.fastcompany.com/91343766/colorados-landfills-generate-as-much-pollution-as-driving-1-million-cars-for-a-year>

40 <https://www.americaissallin.com/elected-officials-cdphe-cut-landfill-methane>

and help the methane mitigation industry thrive.”⁴¹ Such county support is not universal, though. At a hearing on the proposed rules in February 2025, Delta County Commissioner Craig Fuller said, “We are a small rural county, and a multimillion-dollar containment system is going to be more than we can build. The financial equation of this whole thing is absolutely mind-boggling—we are struggling as it is to provide health and human services.”⁴²

However, state health officials suggested that the costs of installing GCCS could be offset by putting the captured landfill gas to beneficial use – i.e., generating electricity or producing renewable natural gas. Several grant programs may be available to help fund GCCS, including Colorado’s Clean Air Program Grants to reduce industrial air pollution and the Closed Landfill Remediation Grant Program to remediate closed landfills that are owned by eligible local governments.⁴³ There are also precedents for publicly owned landfills complying with such thresholds in other states (California, Oregon, Washington, Michigan, and Maryland), for example helping to meet the additional funding obligations by issuing municipal bonds.

The EIA also noted that based on the experiences of other states, the proposed rule would not be expected to raise tipping fees for consumers to deposit waste at landfills. After passing their own state-level landfill methane rules, California saw tipping fees increase by \$5 and Oregon saw tipping fees decline by \$14. Rather than the methane rules, the most important factors affecting those tipping fees were the cost of vehicles, fuel, labor, and negotiated contracts between landfills and haulers.⁴⁴ But even if the full cost of annual compliance with Colorado’s proposed rule were transferred to the nearly 350,000 affected households, it would only amount to a \$22.90 increase in the average annual tipping fee per household.

Expected Emissions Reductions and Cost-Effectiveness

All told, the proposed rule would lead to the capture and destruction of 12.3 million metric tons of CO₂ equivalent from Colorado MSW landfills between 2029 and 2050. This would avoid \$1.05 billion in direct and indirect climate change damages, based on the U.S. government’s 2021 social cost of carbon and a 2.5% discount rate. That means that between 2029 and 2050, the total cost of compliance (\$175 million) with the proposed rule would avoid six times that amount in climate change costs (\$1.05 billion).

Based on these results, the cost per metric ton of CO₂ equivalent reduced under Colorado’s proposed plan would be \$14.28 – near the middle of cost estimates for similar rules in other states, which have ranged from \$6 to \$25 per metric ton of CO₂ equivalent reduced. The EIA also calculated that the plan would create 402 direct jobs and 1,382 indirect jobs by 2050.

41 <https://www.americaisallin.com/colorado-leaders-call-nation-leading-landfill-methane-rules-advance-climate-goals-protect-public>

42 <https://www.fastcompany.com/91343766/colorados-landfills-generate-as-much-pollution-as-driving-1-million-cars-for-a-year>

43 <https://energyoffice.colorado.gov/cap-grants>; <https://cdphe.colorado.gov/hm/closed-landfill-remediation-grant-program>

44 <https://erefdn.org/product/analysis-of-msw-landfill-tipping-fees-2023/>

Expanded Federal/State Incentives

- **Expand incentives for beneficial use at landfills implementing best practices in gas capture.** Incentives to put landfill gas to beneficial use – RNG production or electricity generation – are the largest driver of real-time tech adoption and new GCCS construction. Some states have enacted “compliance offset protocols” – for example, directives to reduce power emissions by a certain percentage – in which additional landfill gas captured could generate credits if the end use is transportation. Updating compliance offset protocols to include landfill methane emission reductions from real-time tech would facilitate broader adoption for landfills, whether or not they include beneficial use projects for the captured gas. Additional states can adopt

their own incentives for beneficial use tailored to their needs and preferences.

To incentivize the greatest climate benefits, eligibility could be limited to landfills that are following best practices as noted in this report (real-time tech, early action, minimized working faces, appropriate cover, remote monitoring, etc.) and which are not leaking significant amounts of methane (for example, from areas producing lower-quality landfill gas that would be more expensive to upgrade to RNG). This aspect of comprehensive stewardship is important because significant methane emissions have been detected through remote aerial monitoring from over 20 large landfills that have RNG projects, especially from working faces.⁴⁵

45 <https://pubs.acs.org/doi/10.1021/acs.est.4c07572>

Lifecycle Carbon Intensity of Landfill RNG

Most landfill RNG projects are destined for the transportation sector. The RNG is typically sold into state-level Clean Fuel Standard programs in California, Oregon, and Washington (New Mexico has enacted one due to take effect in 2026 and about 10 other states are considering adopting one of their own). Under a Clean Fuel Standard, each fuel's lifecycle greenhouse gas emissions are calculated, either generating credits or deficits as the overall target for decarbonizing the transportation sector gets more stringent each year.

According to approved pathways in California's Low Carbon Fuel Standard as of Q3 2024, landfill RNG used in the transportation sector had an average lifecycle carbon intensity of 47.9 grams of carbon dioxide equivalent per megajoule (g CO₂e per MJ),

52.4% less than the 100.6 g CO₂e per MJ of gasoline/diesel. For reference, the 47.9 g CO₂e per MJ from landfill RNG was just above the 44.8 g CO₂e per MJ from electric vehicles using electricity from the California grid (which still had considerable fossil fuel generation in addition to renewables).⁴⁶

If these state-level Clean Fuel Standard programs were to recognize the avoided upstream methane emissions at sites adopting advanced landfill tech beyond regulatory requirements, then the applicable projects could verifiably achieve lower lifecycle carbon intensity scores. Those projects would therefore generate more credits, improving their economic viability and accelerating the uptake of advanced landfill tech elsewhere to follow suit.

46 See chart on p. 14 of Energy Vision's report, *A Path to a Healthier America: Ditching Old Diesel Trucks* <https://energy-vision.org/wp-content/uploads/2025/03/ditching-diesel.pdf>



A vertical landfill wellhead with real-time tech. Photo Source: LoCI Controls.

- At the federal level, the creation of eRINs (credits for electricity used in transportation under the Renewable Fuel Standard) could help drive more landfills to generate electricity from their captured gas, but this pathway was proposed a decade ago and has not yet been implemented by US EPA. It is also unlikely to materialize under the Trump administration, as the latest Renewable Fuel Standard proposed rulemaking (released in June 2025) would eliminate any eligibility for eRINs.⁴⁷

The current incentive structure for landfill gas heavily favors RNG. There are over 100 operational landfill RNG projects, and the overwhelming majority (103) of landfill beneficial use projects under construction or being planned are pursuing RNG rather than electricity (13), according to EPA's Landfill Methane Outreach Program.⁴⁸ There is very little new investment in landfill electricity generation, and it mostly consists of add-ons to current projects. Most

landfill electricity generation facilities are seriously considering or actively pursuing a transition to RNG after their existing Power Purchase Agreements expire.

- **Provide direct subsidies for GCCS.** Installing and maintaining GCCS both entail significant costs. The EPA white paper on landfill size threshold cites one estimate showing that capex for traditional GCCS (without real-time tech or deployment at active faces) can be in the range of \$1-3 million. Meanwhile, opex for traditional GCCS is \$150,000-\$400,000 per year, plus another roughly \$60,000 annually for monitoring, recordkeeping, and reporting requirements.⁴⁹ EPA's LFG Energy Project Development Handbook also provides cost estimates on a per acre basis. Adjusted for inflation from the 2020 figures provided in the handbook to 2024 figures, GCCS installed capital costs for a mid-sized landfill are \$39,850/acre, and annual O&M costs are \$6,680/acre.⁵⁰

47 <https://www.epa.gov/system/files/documents/2025-06/420f25008.pdf>

48 <https://www.epa.gov/lmop/lmop-landfill-and-project-database> (updated September 2024)

49 EPA, MSW Landfill Size Threshold, October 2024. <https://www.epa.gov/stationary-sources-air-pollution/non-regulatory-public-docket-municipal-solid-waste-landfills>

50 https://www.epa.gov/system/files/documents/2024-01/pdh_full.pdf; <https://www.minneapolisfed.org/about-us/>

Adding real-time tech would increase these costs, again on the baseline 75% coverage of wellheads at a typical landfill being sufficient to significantly improve overall results. Each wellhead equipped with real-time tech would cost an incremental \$7,000 in capex as well as \$1,500 in annual opex.

Given the significant costs involved with GCCS, any subsidies would facilitate their adoption. Subsidies are more realistic at the state level than at the federal level given EPA funding cuts and hostility to methane mitigation measures from the Trump administration. For example, the State of Washington offers landfill methane emissions reduction grants, including for GCCS construction, maintenance, and maximization of gas capture beyond regulatory requirements; the most recent application round in 2024 had a total of \$9.6 million available.⁵¹

On a separate but relevant note, voluntary carbon offset markets do include non-mandatory methane capture at landfills, based on multiple certification protocols using the best available science. Some landfills that were not required to install gas capture systems have done so in part to generate voluntary carbon credits (VCCs). Even landfills that are required to install GCCS can generate VCCs by going above and beyond the regulations to enhance gas capture with advanced tech, proving the additionality of the captured gas. Many of the landfills that voluntarily installed GCCS have subsequently grown to the point where they are required to operate such systems and no longer generate VCCs (unless they capture more gas than the minimum requirements). That said, between 35 and 50 U.S. landfills have been generating VCCs over the past few years through voluntary GCCS operation or by implementing advanced technologies to increase methane capture.⁵² However, the prices for these VCCs are relatively low, because demand has been limited.

A Proven, Cost-Effective Solution Deserving of Serious Consideration

As noted above, the current market incentives heavily favor landfill RNG production and more than 100 landfill RNG projects are planned or under construction. We therefore anticipate that virtually all of the captured methane from implementing the Total Feasible Today combination of the three advanced landfill tech options in this report would likewise be upgraded to RNG. (For this big picture conclusion we exclude the stretch goals for lower-flow landfills that don't have GCCS, since they would probably not be able to put their captured gas to beneficial use and would instead flare it.)

The additional methane captured by the Total Feasible Today combination, once upgraded to RNG and factoring in a conservative 5% leakage rate in pipelines, would amount to a very substantial 93 million MMBTU/year.⁵³ That would be more than double the amount of RNG produced by landfills and used in the U.S. transportation sector (the overwhelming end use) in 2023: 73.5 million MMBTU. Of note, landfills produced two thirds of all RNG for the U.S. transportation sector in 2023. Another 93 million MMBTU would be close to the total amount of RNG produced in 2023 that went to the transportation sector: 108.4 million MMBTU.

Together, almost 900 landfills would be candidates for the three options feasible today featured in this report (845 with GCCS could adopt real-time tech, including 432 open ones with GCCS also adopting early action, plus 43 high-emitting, high-flow landfills could install new gas capture systems). They would be capturing and putting to beneficial use far more energy than they are today, where much of it is wasted.

While every site has its own unique characteristics, overall there is a very compelling business case to implement the Total Feasible Today combination.

[monetary-policy/inflation-calculator](#)

51 <https://ecology.wa.gov/about-us/payments-contracts-grants/grants-loans/find-a-grant-or-loan/landfill-methane>

52 <https://gspp.berkeley.edu/berkeley-carbon-trading-project/offsets-database>

53 Calculated by dividing the Total Feasible Today emissions reductions of 49.4 million metric tons of CO2 equivalent per year (which factors in a 5% loss in the RNG upgrading process and another conservative 5% loss from pipeline leakage in distribution to end consumers) by the Global Warming Potential of 28 for methane, then multiplying by 52.7 MMBTU per metric ton of methane, which amounts to 93 million MMBTU/year of RNG.

Conservatively valuing the additional 93 million MMBTU/year of RNG produced at \$20/MMBTU (environmental attributes plus the commodity gas) in the years ahead, that equates to \$1.86 billion annually in new gross revenue generated. Meanwhile, the estimated cost of the Total Feasible Today combination is \$1.3 billion in onetime capex and \$250 million in annual opex. Aggregated across all the candidate landfills, this means an overall payback period of less than a year once the new equipment is operational, after which this would be a significant net revenue earner for many years. (As noted previously, this is based on the direct costs of all the advanced landfill tech feasible today and the additional revenue from the incremental gas capture; it excludes capex or opex associated with RNG plant installation.)

Plus, adopting advanced landfill tech is among the lowest cost carbon abatement options available. The technology is proven, commercial, and scalable. And it specifically cuts fugitive methane emissions, which means each new installation provides “additionality” – often a preference for potential renewable energy and voluntary carbon credit buyers, and a key component of reaching 30x30 in time to forestall the worst effects of climate change.

It was beyond the scope of this report to model the air quality and public health benefits from adopting advanced landfill tech, but they would be significant, based on two facts. One is that methane is a precursor to the formation of ground-level ozone, a toxic air pollutant that is particularly harmful to people and vegetation (including crop yields).⁵⁴ The second is that landfills emit other hazardous air pollutants alongside methane, such as volatile organic compounds, ammonia, and hydrogen sulfide, which would likewise be captured in GCCS and burned off, which is far better than being breathed in by landfill workers and nearby residents.

The bottom line: adopting advanced landfill tech is a major, quick win at a very low cost relative to many other climate solutions. Because it also addresses potent methane emissions, it should be a very high near-term priority.

54 <https://www.ccacoalition.org/short-lived-climate-pollutants/methane>



*Horizontal gas collectors with real-time tech at a landfill.
Photo Source: LoCI Controls.*

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