# TURNING DOWN THE HEAT

How the U.S. EPA Can Fight Climate Change by Cutting Landfill Emissions



A report by Industrious Labs

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### **About Industrious Labs**

Industrious Labs exists to deliver unstoppable policies, people power, and analysis to drastically reduce dangerous emissions, hold industry accountable to communities and workers, and develop a circular economy.



Waste

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# **Executive Summary**

Reducing methane emissions is the most impactful way to slow global warming in the next twenty years-years that we know are pivotal in efforts to meet ambitious climate targets. One straightforward path to dramatic methane reduction is addressing emissions from our country's more than 2,600 municipal solid waste (MSW) landfills. According to estimates reported to the U.S. Environmental Protection Agency (EPA)'s Greenhouse Gas Reporting Program (GHGRP), MSW landfills are the country's third-largest source of methane emissions. Compounding research reveals that the reality is likely much more severe, with unchecked levels of methane hiding in plain sight. Despite being unseen and often under the radar of policymakers, trash and the greenhouse gas emissions it generates represent an enormous opportunity to press the emergency brake on climate change.

Mitigating emissions from MSW landfills will require a full-circle approach. Policy solutions to reduce and divert organic waste have a vital role to play in limiting future new emissions; however, waste diversion and prevention only address new emissions. To mitigate emissions from previously landfilled waste, strong, effective and comprehensive federal air emissions regulations for MSW landfills are vital. In July 2024, the EPA committed to updating the Clean Air Act standards for how landfills monitor, capture, and control methane-the New Source Performance Standards (NSPS) and Emission Guidelines (EG)-in 2025.1 The EPA is to be commended for this commitment, and its acknowledgement of the waste sector's outsized role in driving potent methane emissions.

There is a broad suite of available technology and best practices to lower methane emissions that the EPA can and should consider as it works to draft updated NSPS/EG standards. To inform policymakers as they work to put in place strategies and policies to meet global climate commitments and to support the EPA in its work to update the standards, Industrious Labs modeled a number of improvements to landfill operations. In our analysis, we employed the Afvalzorg Multiphase model, which is designed to account for varying waste degradation rates and provides detailed estimates of landfill gas generation, recovery, oxidation, and emissions over time. The model results reveal that embracing two categories of solutions – improved landfill cover requirements and gas collection and control systems (GCCS) – would yield a methane emissions reduction of 56% cumulatively through 2050. These emissions reduction total 104 million metric tons (MMT) of methane, which equal:

- 2,922 MIMT of carbon dioxide equivalent on a global warming potential of 100 years
- 8,289 MMT of carbon dioxide equivalent on a global warming potential of 20 years<sup>2</sup>



### Figure 1: 2025-2050 Cumulative Emissions and Reduction Potential from Model Results

The modeling used is based on a validated, datainformed baseline of landfill gas recovery rates of 43%, termed "Updated Assumption Baseline." EPA assumptions in the GHGRP have relied on an assumed national landfill gas recovery rate of 75%, recently downgraded to 65%.<sup>3</sup> While studies have demonstrated that this recovery rate is achievable, it requires stringent landfill



management practices that aren't reflected in current federal regulations. Additionally, a significant proportion of landfills in the United States remain unregulated. However, even using EPA's baseline assumption of 75% gas recovery rate as a starting point, the emission reduction potential by adopting these two categories of improvements to the NSPS/EG is highly significant, totaling 47.9 MMT of methane (1,341.2 MMT  $CO_2e$ ) at an overall reduction of 42% cumulatively between 2025 and 2050. It is also important to note that there are additional measures, such as more effective and comprehensive monitoring to quickly find methane leaks, that were not modeled and thus represent even more potential emissions reductions. While improving gas collection and landfill cover practices would yield significant emissions reductions, especially when paired with a robust organics diversion strategy, they are not an exhaustive representation of readily available solutions that should be considered by the EPA as they update their NSPS/EG standards.

Timely and accurate emission detection is also crucial. Advanced technologies such as airborne imaging spectrometers have been utilized to conduct extensive surveys of active landfills, revealing substantial sources of methane emissions that often go undetected by traditional methods.

Curbing polluting emissions from landfills requires a two-pronged approach. First, we must address the waste already buried in the ground. Despite broad availability, proven results, and costeffectiveness, many municipal landfills do not use established strategies to control methane emissions, necessitating action to update federal landfill emissions standards. Second, policymakers must prioritize solutions to keep organic waste out of landfills in the first place. In order to illuminate the emissions potential of at-scale organics diversion, Industrious Labs modeled zero organic waste landfilled by 2050.

The implementation of zero organic waste landfilled by 2050 combined with earlier installation and expansion of gas collection and control systems is projected to achieve a substantial cumulative emissions reduction of 100 MMT of methane, representing a 54% decrease from the Updated Assumptions Baseline. This reduction equates to 2,801 MMT CO₂e,calculated using a Global Warming Potential (GWP) of 28.

## Key Improvements to New Source Performance Standards/Emission Guidelines Standards (NSPS/EG)

In June 2023, a coalition of 14 environmental and community advocacy groups petitioned the EPA for more effective regulations to better control methane pollution from municipal landfills.<sup>4</sup> The petition outlines a number of improvements to the NSPS and EGs for MSW landfills that would improve methane mitigation. This analysis focuses on several key categories of improvements and models their impact on methane emissions. The categories are as follows:

- Gas Collection and Control Systems (GCCS):
  - » Lowering size and emission rate thresholds for GCCS Installation.
  - » Earlier installation and expansion of GCCS.
  - » Improving GCCS design and operation.
- Enhanced cover systems.

This section will provide basic information on the current federal regulatory parameter and the proposed key improvements to that parameter. Recognizing that there is a plethora of evidence and information supporting each of these improvements, we provide citations to resources rather than reproducing here.

Beginning on the next page, we outline current NSPS and EG standards for each practice, as well as proposed improvements to yield significant methane emissions reductions.



### **Gas Collection and Control Systems (GCCS)**

There are several key improvements needed for the installation and operation of GCCS in municipal solid waste landfills.

### Lowering Size and Emission Rate Thresholds for GCCS Installation

### **Current EPA Standards**

The current EPA regulations require GCCS if an active landfill has:

- A design capacity greater than or equal to 2.5 million megagrams (Mg) and 2.5 million cubic meters (m<sup>3</sup>).
- A Non-Methane Organic Compounds (NMOC) emission rate of 34 Mg/year or more.<sup>5</sup>

### **Proposed Improvements**

The proposed improvements to the standards involve adopting lower size and emission rate thresholds to install GCCS, as follows:

- 200,000 tons of waste-in-place.
- Greater than 664 tons/year methane generation rate.<sup>6</sup>

### **Earlier Installation and Expansion of GCCS**

### **Current EPA Standards**

Current landfill GCCS expansion practices are not aligned with EPA's own research findings.

Current EPA standards require that an active gas collection system must "(ii) Collect gas from each area, cell, or group of cells in the landfill in which the initial solid waste has been placed for a period of 5 years or more if active; or 2 years or more if closed or at final grade."<sup>9</sup> Yet EPA research indicates that half of the carbon in food waste degrades into methane within just 3.6 years and food waste is the largest input to landfills. This discrepancy in timelines leads to significant methane escape, with EPA estimating that 61% of methane is released before gas collection systems are in place—highlighting the urgent need to adjust regulatory timelines to better match the rapid degradation rate of food waste and mitigate methane emissions.<sup>10</sup>

### **Proposed Improvements**

The proposed change would require the installation and expansion of GCCS within one year after waste is placed.<sup>11</sup> Implementing earlier installation and expansion of GCCS captures methane emissions from earlier in the life cycle waste disposal, preventing large amounts of methane from escaping into the atmosphere in the initial years. Early installation also increases the efficiency potential of the GCCS, improving overall methane reduction outcomes. Finally, by capturing methane and other harmful air pollutants sooner, the overall environmental impact of the landfill can be significantly reduced.

### **Current EPA Standards**

The design and operation standards for GCCS in the EPA NSPS/EG standards are not stringent, leading to variations in effectiveness and efficiency across different landfills.

#### **Proposed Improvements**

Strong landfill management practices such as advancements in landfill gas collection systems significantly improve gas recovery rates, thus yielding emissions reductions. For instance, a study by the American Institute of Physics highlights effective landfill gas management strategies that optimize methane control and enhance gas recovery efficiency.<sup>12</sup> Enhanced systems, such as those incorporating more efficient gas collection wells, advanced flaring systems, and improved leachate management, have been shown to significantly reduce methane emissions and increase the volume of gas captured for energy production. The proposed change involves the development and implementation of more robust and comprehensive GCCS design plans. This includes:

- Horizontal gas collection systems: Implement horizontal gas collection systems in cells with larger footprints to ensure more efficient gas collection.<sup>13</sup>
- Integration with leachate collection systems: Integrate gas collection systems into leachate collection systems to enhance overall performance.<sup>14</sup>
- Updating the GCCS design and realization of GCCS improvements in the field if necessary to achieve higher gas recovery rates.<sup>15</sup>

### **States Leading the Way**

Various states have reported positive outcomes from adopting improved regulations, from landfills that previously lacked GCCS subject to minimum federal performance and operations standards.

**California:** The California Air Resources Board (CARB) noted in its state plan that the new landfill methane rule (LMR) mandates regulated GCCS at 30 landfills that were not previously covered under the existing guidelines. This is in addition to the 105 landfills already regulated under the existing guidelines.<sup>7</sup>

**Oregon:** The Oregon Department of Environmental Quality estimated that lowering the waste-in-place threshold to 200,000 MT and the methane generation threshold to 664 MT of methane per year could potentially require eight additional landfills to install GCCS, on top of 15 landfills already regulated.

**Maryland:** The Maryland Department of the Environment projected that nine landfills with existing GCCS would fall under the new landfill methane regulation, with an additional thirteen landfills potentially needing to install GCCS.<sup>8</sup>

Lowering these thresholds would require more landfills to implement GCCS, significantly increasing overall methane capture and reducing emissions. Aligning federal regulations with the successful state practices outlined above ensures a more uniform approach to methane reduction across the country, enhancing the overall effectiveness of environmental protection measures.

### **Enhanced Cover Systems**

### **Current EPA Standards**

Despite the ability of effective landfill cover to dramatically reduce emissions, the current EPA NSPS/ EG standards do not contain any requirements related to type and timing of landfill cover. Federal regulations around landfill cover are found in solid waste regulations issued under the Resource Conservation and Recovery Act, but they are not crafted to limit methane emissions.

Traditional landfill covers typically consist of a layer of soil or synthetic material primarily designed to contain waste and minimize water infiltration. However, these covers may not be optimized for methane oxidation, as EPA air emissions regulations currently omit this parameter. Instead, the primary function of these covers has been to prevent leachate formation and control odor rather than address methane mitigation comprehensively. Consequently, methane produced from anaerobic decomposition of organic waste within landfills can escape into the atmosphere, contributing to greenhouse gas emissions. Methane leakage through landfill covers is a well-documented problem. Soils are prone to cracking due to desiccation, especially during dry periods. These cracks create pathways for methane to escape, compromising the effectiveness of the cover as a gas barrier.<sup>16,17</sup> Even though microbial methane oxidation can occur, it may only mitigate a small portion of these emissions without additional gas distribution layers.<sup>18</sup> Aerial surveys conducted by CARB in 2021 and 2023 identified leaks through the cover materials as a recurring problem.<sup>19</sup> This issue is widely recognized in landfill management and underscores the need for improved cover design and ongoing monitoring to minimize methane leakage.

### **Proposed Improvements**

- Optimized design and implementation standards: Ensure in each individual case that climate conditions (soil moisture and soil temperature) allow microbial organisms to substantially oxidize methane over most of the year. Develop and enforce more robust design standards for landfill covers, specifying the thickness and composition of cover materials to ensure effective gas containment and oxidation.
- Use of biocovers for remote landfill areas: Biocovers are an engineered system that can achieve much higher methane oxidation rates, but they use materials with more permeability than traditional landfill covers and they work best under specific environmental and operating conditions such as requiring biocovers in areas where the GCCS cannot be extended, such as on steep slopes. Ensure biocovers have greater porosity and thermal insulation than traditional landfill covers to promote methane oxidation. The design should incorporate features that maintain soil moisture and temperature, enhancing microbial activity year-round. The biocover should consist of two layers:
  - » A gas distribution layer made of gravel, broken glass, sand, or similar coarse material.
  - » An oxidation layer made of soil, compost, mulch, peat, or other organic material with demonstrated oxidizing capacity.

The oxidation layer should be stabilized with vegetation to prevent erosion and control moisture. Enhanced biocovers can significantly increase methane oxidation by providing an optimal environment for methanotrophic bacteria, ensuring a high rate of methane conversion to carbon dioxide.

#### **Proposed Improvements (cont.)**

- Oxidizing materials for intermediate cover: Use materials with demonstrated oxidizing capacity for intermediate cover and establish requirements related to permeability, including the compaction of soil. This practice ensures that even temporary covers contribute to methane oxidation, reducing emissions during periods between waste deposits.
- Earlier installation of immediate/final cover: Implement the earlier installation of intermediate and final cover systems to enhance methane oxidation and reduce emissions. This practice should include specifications for cover thickness and material composition to optimize conditions for methanotrophic bacteria, which convert methane into carbon dioxide and water vapor. By advancing the timing of cover installation, landfills can significantly lower methane flux at the surface, preventing gas escape and improving the efficiency of GCCS.
- Maintenance and monitoring: Implement rigorous maintenance and monitoring protocols for biocovers. Regular inspections and maintenance activities, such as moisture control and vegetation management, are critical to sustaining the oxidizing capacity of the cover material. Monitoring should include periodic measurements of methane flux to assess the effectiveness of biocovers in reducing emissions.

### How Cover Materials and Practices Influence Methane Emissions

Research indicates that the type and application of cover materials significantly influence landfill methane emissions. The CARB demonstrated that intermediate covers applied within days, using oxidizing materials, effectively control methane emissions.<sup>21</sup> Properly compacted daily covers in areas with GCCS reduce permeability and improve efficiency. Studies show that welldesigned final covers, liners, and GCCS can achieve collection efficiencies as high as 90%.<sup>22</sup> In a pilot-scale study conducted at the AV Miljø Landfill in Denmark, the biocover system achieved methane oxidation efficiencies ranging from 81% to 100%, with methane oxidation rates reaching up to 124 g/m<sup>2</sup>/day under optimal conditions. Similarly, research indicates that modifying landfill cover soils with aged refuse

significantly enhances their methane oxidation potential, achieving high rates of methane conversion, especially when the cover is maintained at optimal moisture and temperature levels.

Research has shown that the earlier installation of intermediate and final cover systems on landfills can substantially reduce methane emissions.<sup>25,26,27</sup> These covers enhance the conditions for methane oxidation by methanotrophic bacteria, which helps in converting methane into less harmful gasses such as carbon dioxide and water vapor. Moreover, early and thick cover installations prevent methane from escaping into the atmosphere, improving the overall efficiency of GCCS.

### Recommended Changes That Are Out of Scope for this Analysis

While improving gas collection and landfill cover practices would yield significant emissions reductions, especially when paired with a robust organics diversion strategy, they are not an exhaustive representation of readily available solutions that should be considered by the EPA as they update their NSPS/EG standards.

Timely and accurate emission detection is also crucial. Advanced technologies such as airborne imaging spectrometers have been utilized to conduct extensive surveys of active landfills, revealing substantial sources of methane emissions that often go undetected by traditional methods. For instance, a study led by Carbon Mapper, U.S. EPA and its partners found that 52% of surveyed landfills had significant methane emissions, with many plumes persisting over months or years.<sup>28</sup>

The use of available remote measurement technology to detect methane emissions has been embraced by state and federal policymakers, in addition to the scientific community. For example, the state of Pennsylvania sponsored overflights over voluntarily participating methane emitters like oil and gas and landfills, and then they gave the results of methane emissions they found to the landfill operators. The overflights resulted in a 37% emissions reduction from the landfills that were super emitters—the largest percentage reduction out of any of the surveyed sectors.<sup>29</sup> In July 2024, EPA awarded Climate Pollution Reduction Grant funding to the state of Colorado to "deploy advanced methane monitoring technology that will inform regulatory policy with a focus on measuring and addressing methane emissions in low-income and disadvantaged communities."<sup>30</sup>

While these detection methods have been highly effective at identifying super emitter events,<sup>31</sup> there is currently insufficient data to accurately model the impact of fixing methane leaks. Consequently, this analysis does not incorporate more accurate emissions detection methods.



Methane plume observed by Carbon Mapper during aerial monitoring at a landfill in Texas.

# **Methodology Overview**

This section outlines our methodology, detailing the approaches and techniques employed in our analysis. We used a comprehensive approach to model landfill methane emissions, incorporating multiple baselines and data sources to ensure accuracy and completeness.

First, we established baselines using both the EPA's default assumptions and direct measurement evidence from recent research. This dual-baseline approach allows us to cross-validate our results and improve reliability.

To account for all landfills nationally, particularly those not covered by the GHGRP, we utilized waste-in-place data from the National Inventory Report (NIR) covering the years 1990 to 2021.<sup>32</sup> This data helps bridge gaps where GHGRP data is unavailable, ensuring a more accurate and inclusive national estimate of landfill methane emissions.

We simulated different policy scenarios, such as enhanced GCCS and improved cover techniques, to estimate their impact on methane reductions. Our scenarios have been adjusted based on gas recovery rates and oxidation rates aligned with proposed regulatory changes. Each scenario's effectiveness is evaluated based on its ability to capture and oxidize methane, taking into account variables like cover type and oxidation rates. This methodology allows us to project future emissions and assess the potential of various mitigation strategies.

For this analysis, the reported waste-in-place was treated as one collective landfill, and a multiphase model was employed to simulate methane production across the country. A blended decay value was used to represent all climatic zones, ensuring a comprehensive national estimate. Although more granular models and approaches exist, they require extensive data for each landfill, which is currently unavailable due to gaps in available public datasets. Consequently, waste-inplace was used as the best proxy for estimation and to evaluate the impact of these policies nationwide. The simulated emissions from this model closely replicate the data reported in the NIR,<sup>33</sup> utilizing the EPA's parameters for calculation. For the year 2009, the NIR estimated methane emissions at 4,928,910 metric tons, while the EPA Assumptions Baseline in this analysis was 4,930,504 metric tons. This strong correlation between the simulated data and the reported figures provides confidence that the results presented in this report accurately reflect the current state and offer realistic projections for the impact of various landfill management adjustments.

#### Modeling Approach Incorporates Lower Gas Collection Efficiencies, Reflecting Latest Research

In our modeling we utilize two baselines: 1) EPA Assumptions Baseline and; 2) Updated Assumptions Baseline. In this section we describe our rationale. The EPA Assumptions Baseline reflects the EPA's use of a 75% default gas recovery rate for landfills, which it substantiates through research and modeling, primarily using the Landfill Gas Emissions Model (LandGEM).<sup>34</sup> LandGEM, developed by the EPA's Office of Research and Development, utilizes both sitespecific data and default parameters from the Clean Air Act and AP-42 emission factors to estimate gas recovery. The EPA's method for estimating landfill methane emissions assumes that well-managed landfills can achieve a 75% recovery rate, based on limited empirical data and performance benchmarks from various landfill sites. While there have been studies that show effective gas collection can be achieved at a 75% recovery rate, this is only true for well-managed landfills with gas collection systems and requires sustained effort to reach this high recovery rate.<sup>35</sup>

Landfill gas collection systems are less common and less effective than anticipated: A study on landfills in Maryland<sup>36</sup> demonstrates that landfill gas collection systems are less common than expected. Of the 40 landfills in Maryland that produce gas, only 21 have gas collection systems in place. Of these, 10 landfills use systems that only flare the gas, while the remaining 11 landfills have devices that convert some or all of the collected gas into heat or electricity. It's important to note that gas collection systems are not capable of capturing and combusting all the gas produced by a landfill. In Maryland, reported collection efficiencies in 2017 ranged from 5% to 95%, with an average efficiency of 59%—much lower than 75%.

Nesser et al. (2024) compared LMOP<sup>26</sup> and GHGRP data with satellite methane observations for 38 landfills, revealing an average gas recovery efficiency of 50% (ranging from 33% to 54%).<sup>37</sup> At the six facilities among the top 10 methaneproducing landfills, the study found a mean gas recovery efficiency of 33%. The report utilized observations from the TROPOMI satellite instrument to quantify methane emissions from 70 landfills across the contiguous United States that report to the EPA's Greenhouse Gas GHGRP. The authors observed a median 77% increase in emissions (13 Gg/a) compared to reported emissions (7.2 Gg/a), indicating significant underreporting. For the 38 facilities that recover gas, the authors observed an average gas recovery efficiency of 50% (ranging from 33% to 54%). The discrepancies were attributed to overestimated recovery efficiencies and the failure to account for site-specific operational changes.<sup>38,39</sup>

In an analysis of Maryland MSW landfills, the Environmental Integrity Project (EIP) found data on system efficiency for 16 out of the 17 unregulated systems. These gas collection systems at the 16 unregulated landfills had a reported collection efficiency of 55%.

Regulated landfills are required to adhere to certain standards and best practices, which significantly enhance the performance and efficiency of their GCCS. These practices include proper design, construction, and ongoing monitoring and maintenance, aimed at ensuring optimal gas capture and reduced emissions. In contrast, unregulated landfills often lack these rigorous standards and oversight, leading to less effective gas collection and higher emissions. This disparity underscores the importance of regulatory frameworks in ensuring the effectiveness of GCCS in reducing landfill gas emissions.<sup>40,41</sup>

Another study evaluated five to eight years of annual methane collection data from 114 closed landfills nationwide and determined that MSW landfills emit more methane than estimated using EPA's AP-42 factors and GHGRP methods.<sup>42</sup> Additionally, research by CARB/CalRecycle and California Polytechnic State University observed real-world collection efficiencies at landfills ranging from as low as 23% to above 99%.<sup>43,44,45</sup>

In 2024, the EPA downgraded the default landfill gas collection efficiencies within the GHGRP formulas by ten percentage points to better reflect real-world conditions and operational variabilities observed in landfill gas collection systems.<sup>46</sup> This adjustment aimed to improve the accuracy of reported methane emissions from landfills, ensuring that the data collected under the GHGRP more accurately represents actual emissions. Since this adjustment, more measurement data from satellite detection from Nesser et al.47 that found that the actual methane recovery rates at U.S. landfills are significantly lower than previously estimated. On average, methane emissions from the 70 high-emitting landfills analyzed were 77% higher than the values reported to the EPA, with some landfills showing emissions up to 200% greater than reported when considering gas recovery. This suggests that the assumed gas recovery efficiencies used in official estimates are often overly optimistic, particularly for these highemitting sites.

### **Updated Assumptions Baseline**

As described previously, there is increasing evidence that the default value of 75% gas recovery rate assumed by the EPA is too high, resulting in an underestimation of methane emissions from landfills. This analysis aims to determine a more accurate baseline using a gas collection recovery rate that has been validated by independent studies and direct measurements of methane emissions from landfills. The EPA's NIRs indicate that waste landfilled over 30 years ago continues to contribute approximately 10% to overall methane emissions from landfills. This 10% of emissions largely come from unregulated landfills without GCCS, therefore a small if not existent gas recovery rate. Meanwhile, NIRs from European nations suggest that recovery rates average around 29%.

Comparison of tracer plume measurement data with methane generation data from Danish landfills with operational gas recovery systems showed that actual recovery efficiencies ranged between 13% and 86%, with an average of 50%.<sup>48</sup> Similarly, an analysis of gas recovery monitoring data from 56 Dutch landfills with operational GCCS suggests an average recovery rate of 25%.

Considering the European experience, the observed recovery efficiency of approximately 400 LMOP landfills,<sup>49</sup> and the likelihood that the remaining 1,200 landfills perform less efficiently, along with emissions from unregulated landfills, a more realistic overall gas recovery efficiency for the entire USA is estimated at 43%. The derivation of this recovery rate started with a baseline of 50% gas recovery efficiency (from Themelis et al.),49 subtract 5% to account for decreased efficiency in landfills with waste older than 30 years, and then subtract an additional 2% to account for landfills that don't participate in the LMOP, which likely have lower recovery rates. This results in our Updated Assumptions Baseline of an estimated 43% gas recovery efficiency for U.S. landfills.

Additionally, the Greenhouse Gas Inventory (GHGI) scales up reported emissions from the GHGRP, which only covers larger landfills, to account for smaller, non-reporting landfills. This further supports the 43% estimated overall recovery efficiency for U.S. landfills.

Validating Our Baseline On Direct Measurements

An analysis of satellite methane observations by Nesser et al.<sup>50</sup> estimated that nationally, 6.9 MMT of methane were emitted by MSW landfills in the US in 2019. In contrast, the EPA NIR reported 4.6 MMT of landfill methane emissions for the same year. The Updated Assumptions Baseline scenario calculates 6.6 MMT of landfill methane emissions in 2019. Despite uncertainties inherent in all three approaches, the close agreement between the satellite observations and the Updated Assumptions Baseline scenario suggests that the latter is more plausible than the NIR submissions. This results in an underestimation of emissions in 2024 of over 62% when the Updated Assumptions Baseline is compared with the EPA Assumptions Baseline and reported figures.

Given the stronger alignment of the Updated Assumptions Baseline with independent satellite observations, we have chosen the Updated Assumptions Baseline as the foundation for all subsequent scenarios.

Description	Assumed Gas Recovery Rate	Assumed Organics Diversion	Assumed Methane Oxidation Rate
EPA Assumptions Baseline	1% in 1986 increasing to 65% in 2021	None	10%-20%
Updated Assumptions Baseline	1% in 1986 increasing to 43% in 2021	None	10%-20%
Proposed Gas Collection and Cover Improvements	1% in 1986 increasing to 43% in 2021 increasing to 80% in 2040	None	20% increasing to 35% in 2040

### Table 1: Assumptions for Gas Recovery, Organics Diversion, and Methane Oxidation Rates AcrossDifferent Baselines

To align EPA Assumptions Baseline with the NIR data, no excessive assumptions were needed. The average values used were:

 DOCf (Degradable Organic Carbon fraction): 0.5 DOCf represents the fraction of Degradable Organic Carbon (DOC) in the waste that will eventually degrade and generate methane. A value of 0.5 means that 50% of the organic carbon present in the waste is expected to break down into methane and carbon dioxide under anaerobic conditions in a landfill. This value is essential for estimating the potential methane generation from the waste.

» k (Decay Rate Constant): 0.045 per year

The decay rate constant, denoted as "k," is a measure of how quickly the organic material in the waste decomposes over time. A value of 0.045 per year indicates that 4.5% of the degradable organic carbon in the waste will degrade each year under landfill conditions. This constant is critical for predicting the rate at which methane is produced over time, influencing the shape of the methane generation curve.

» MCF (Methane Correction Factor): 1.0 The Methane Correction Factor (MCF) accounts for the efficiency of methane capture in a landfill environment. An MCF of 1.0 indicates that the landfill operates under fully anaerobic conditions, meaning that the entire DOCf has the potential to produce methane. This value assumes optimal conditions for methane generation, with no aerobic degradation processes reducing methane production.

We assumed that the gas recovery rate in the EPA Assumptions Baseline gradually increased from 1% in 1986 to 65% in 2021. Methane oxidation rates were set at 10% from 1960 and increased gradually to 20% by 2010, remaining constant thereafter. The NIRs do not provide detailed fluctuations in these parameters over the years, so gradual increases or decreases were assumed in the model. After 2021, the parameters in EPA Assumptions Baseline remain unchanged, resulting in no further reductions in methane emissions. Instead, emissions grow due to the increasing total amount of waste-in-place. Waste-in-place takes on linear growth as an average of the previous 11 years of waste-in-place.

### Model

In our analysis, we employed the Afvalzorg Multiphase model<sup>51</sup> to estimate landfill gas generation, recovery, methane oxidation, and emissions. This advanced tool is particularly advantageous for providing a national estimate for emissions from landfills, especially when evaluating the impacts of various policy changes such as gas collection efficiency improvements, enhanced cover systems, and organics diversion.

The Afvalzorg Multiphase model is appropriate for detailed analysis of landfill gas dynamics at landfill sites with diverse waste streams and comprehensive waste registers. It accounts for multiple phases of waste degradation, allowing for precise estimations of landfill gas generation and recovery. A multiphase model is a sophisticated tool that simulates the generation, collection, oxidation, and emissions of landfill gas over time. The most important difference between multiphase and single-phase models is that multiphase models account for the varying degradation rates of organic carbon types—easily degradable (like food waste), moderately degradable, and less degradable (like wood). Food waste decays quickly and almost completely, while wood decomposes slowly and incompletely. This distinction was introduced by the Intergovernmental Panel on Climate Change (IPCC) in their 2019 update for landfill methane generation modeling. A multiphase model is more appropriate for detailed organics diversion policies, particularly when focusing on food waste diversion. These stages each produce different gasses, and the model estimates gas generation based on factors like waste composition and environmental conditions. It also simulates the efficiency of GCCS and accounts for methane oxidation in the cover soil, reducing surface emissions. The advantage of using a multiphase model lies in its ability to provide more accurate and detailed projections of emissions. By considering the distinct decomposition phases, it offers a better evaluation of gas collection efficiencies and methane oxidation processes.

#### Data

This analysis incorporates data from the NIR<sup>52</sup> for waste input information. The NIR provides comprehensive data on methane emissions from landfills in the United States, as reported annually by the EPA to the UNFCCC since 1990. This extensive historical dataset allows for trend analysis and the assessment of emission reduction strategies over time. The NIR includes detailed waste input data, which is crucial for accurately estimating methane emissions based on the types and quantities of waste deposited in landfills. The EPA's standardized methodologies ensure that these estimates reflect actual measurements and consider factors such as waste composition, landfill management practices and climatic conditions. The NIR data supports compliance with international reporting requirements, informs policy and planning for reducing landfill methane emissions, and promotes transparency and accountability by providing public access to emission data. This data is essential for researchers, policymakers, and environmental planners in developing strategies to mitigate the environmental impacts of landfills.

### **Scenario Parameters Used in This Estimate**

We modeled the proposed gas collection and cover improvements outlined in the "key improvements" section. Table 1 outlines the key assumptions.

We assumed that at peak implementation of the proposed updates to regulation there would be a significant increase of gas recovery rates across the board. Research has demonstrated that advancements in landfill gas collection systems significantly improve gas recovery rates. For instance, a study published by the American Institute of Physics<sup>53</sup> highlights effective landfill gas management strategies that optimize methane control and enhance gas recovery efficiency. Enhanced systems, such as more efficient gas collection wells, advanced flaring systems, and improved leachate management, have significantly reduced methane emissions and increased the volume of gas captured for energy production.

Themelis and Bourtsalas<sup>54</sup> reported that wellmanaged U.S. landfills can achieve methane capture efficiencies of approximately 85% with advanced gas collection and control systems.<sup>54</sup> Duan et al.<sup>55</sup> found that some landfills achieved recovery efficiencies close to 80%, with one landfill reaching 86%. Oonk demonstrated that improved gas collection technologies could achieve recovery rates up to 90% under optimal conditions.<sup>56</sup> Berger and Lehner<sup>57</sup> noted that optimizing gas treatment in older landfills could lead to recovery rates of up to 87%.

Further supporting these findings, the EPA and CARB have both reported that stringent regulations and the implementation of state-of-the-art gas collection systems can significantly increase methane capture efficiency, with some sites achieving rates above 85%.<sup>58,59</sup>

# Results

#### Model Results of Updated Assumptions Baseline Shows Emissions From Landfills Higher Than Currently Reported Estimates

Proposed gas collection and cover improvements deliver large methane reductions under either EPA or Updated Assumptions Baselines.

The combination of gas collection and cover improvements delivers an estimated **56% reduction** in landfill methane emissions from 2025 until 2050 resulting in a reduction of **104 MMT methane** or **2,922 MMT CO₂e** during this period, under the Updated Assumptions Baseline.

Under the Updated Assumptions Baseline, methane emissions are projected to be 63% higher than the EPA's baseline. However, when implementing gas collection and cover improvements, the reduction potential is also greater—64% compared to 42% under the EPA baseline. This highlights the increased impact of mitigation strategies under updated higher-emission projections.

The annual emissions decrease significantly when gas collection and cover improvements are implemented, with methane reductions reaching up to 2.7 MMT  $CH_4$  and  $CO_2e$  reductions of 75 MMT  $CO_2e$  by 2060. The percentage reduction in  $CO_2e$ emissions increases over time, from 10.7% in 2024 to 53.8% by 2060, showing a substantial mitigation impact from the proposed measures.

#### Landfill Methane Emissions Reductions Modeled On Par With Oil and Gas Sector Proportion of Emissions Reductions

Thanks to the Biden-Harris Administration's demonstrated commitment to making methane reduction a cornerstone of its climate strategy, these reductions would build on the existing methane emissions mitigation success of the Administration's updated emissions regulations from the oil and gas sector. According to the finalized EPA rules announced in late 2023, the

#### Figure 2: Annual Estimated CO₂e Emissions Projections Comparing EPA to Updated Assumptions Baseline (2025-2050)



Figure 2 shows that by 2050, the Updated Assumptions Baseline projects  $CO_2e$  emissions to be approximately 64% higher than the EPA Assumptions Baseline (185 MMT  $CO_2e$ vs. 113 MMT  $CO_2e$ ). This significant difference underscores the potential underestimation of future emissions in the EPA's original baseline, suggesting that without enhanced mitigation strategies, actual emissions could be much higher than initially anticipated.

administration aims to reduce methane emissions from the oil and gas sector by 58 MMT between 2024 and 2038.<sup>60,61</sup> This new phase of regulations represents an additional 10-15% reduction, reinforcing the administration's commitment to cutting methane emissions from the oil and gas industry by a total of about 40-45%.<sup>62</sup> The impact of the improvements to the NSPS and EGs for MSW landfills outlined in this assessment, including the proposed gas collection and enhanced cover policies, are roughly equivalent to those of the oil and gas sector regulatory improvements, resulting in a reduction of 55% or 41 MMT of methane between 2025 and 2035.

### Figure 3: Comparison of CO₂e Reductions from Proposed Gas Collection and Cover Improvements, EPA Assumptions Baseline and Updated Assumptions Baseline



emissions by 47.9 MMT CH<sub>4</sub> (42%) and CO<sub>2</sub>e emissions by 1,341.20 MMT CO<sub>2</sub>e cumulatively from 2025 through 2050. However, the reductions are even more significant under Industrious Labs' Updated Assumptions Baseline, with potential decreases of 104 MMT CH<sub>4</sub> (56%) and 2,922 MMT CO<sub>2</sub>e cumulatively.

### Table 2: Comparing EPA and Updated Assumptions Baselines Projected Cumulative EmissionsReductions between 2025 and 2050

Source	Cumulative Emissions 2025 Through 2050	MMT CH <sub>4</sub>	MMT CO₂e*	%
EPA	EPA Assumptions Baseline	114	3,191	
	Emissions with Proposed Gas Collection and Cover Improvements	66	1,850	
	Overall Reduction	48	1,341	42%
Industrious Labs	Updated Assumptions Baseline	186	5,197	
	Emissions with Proposed Gas Collection and Cover Improvements	81	2,275	
	Overall Reduction	104	2,922	56%

Table 2 compares two scenarios for cumulative emissions reductions from 2025 to 2050.

 $^{\star}\mathrm{CO}_{2}\mathrm{e}$  calculated at a 100 year Global Warming potential 28 GWP

### Table 3: Annual Emissions and Reduction Potential from Proposed Gas Collection and CoverImprovements—Updated Assumptions Baseline

	Updated Assumptions Baseline		Emission with Proposed Gas Collection and Cover Updated Assumptions Baseline Improvements		Annual Avoided Emissions from Proposed Gas Collection and Cover Improvements from Updated Assumptions Baseline		
Annual Emissions	MMT CH <sub>4</sub>	MMT CO₂e*	MMT CH <sub>4</sub>	MMT CO₂e*	MMT CH <sub>4</sub>	MMT CO₂e*	% Reduction
2024	6.6	183.6	5.7	159.9	0.8	23.7	12.9%
2030	6.8	190.9	4.3	120.4	2.5	70.4	36.9%
2040	7.2	202.9	2.1	58.5	5.2	144.4	71.1%
2050	7.7	215.0	2.2	61.3	5.5	153.7	71.5%
2060	8.1	227.0	2.3	64.7	5.8	162.3	71.5%

Table 3 provides, utilizing the updated assumptions baseline, annual emission estimates as well as modeled emissions avoided results for the proposed gas collection and cover improvements. The Updated Assumptions Baseline projects higher methane emissions across all years, with 2024 emissions at 6.6 MMT CH<sub>4</sub> (183.6 MMT CO<sub>2</sub>e) compared to 4.03 MMT CH<sub>4</sub> (112.8 MMT CO<sub>2</sub>e) under the EPA baseline. By 2060, emissions under the Updated Baseline reach 8.1 MMT CH<sub>4</sub> (227.0 MMT CO<sub>2</sub>e), significantly higher than the EPA's 4.98 MMT CH<sub>4</sub> (139.4 MMT CO<sub>2</sub>e). Proposed gas collection and cover improvements lead to substantial reductions in emissions. The reduction potential grows over time, with a 36.9% reduction in 2030 under the Updated Assumptions Baseline, increasing to 71.5% by 2050 and 2060. The avoided emissions in 2060 amount to 5.8 MMT CH<sub>4</sub> (162.3 MMT CO<sub>2</sub>e), emphasizing the effectiveness of these improvements, especially under higher emission scenarios.

\*CO2e calculated at a 100 year Global Warming potential 28 GWP

### Table 4: Annual Emissions and Reduction Potential from Proposed Gas Collection and Cover Improvements—EPA Assumptions Baseline

	EPA Assumptions Baseline		Emission with Proposed Gas Collection and Cover Improvements		Annual Avoided Emissions from Proposed Gas Collection and Cover Improvements from EPA Assumptions Baseline		
Annual Emissions	MMT CH <sub>4</sub>	MMT CO₂e*	MMT CH <sub>4</sub>	MMT CO₂e*	MMT CH <sub>4</sub>	MMT CO₂e*	% Reduction
2024	4.0	112.8	3.6	102	0.4	12.0	10.7%
2030	4.2	117.2	3.0	85.1	1.2	33.3	28.4%
2040	4.5	124.6	2.1	58.5	2.4	65.8	52.8%
2050	4.7	132.0	2.2	61.3	2.5	70.3	53.3%
2060	5.0	139.4	2.3	64.7	2.7	75.0	53.8%

Table 4 displays annual methane (CH<sub>4</sub>) emissions and CO<sub>2</sub>e for selected years from 2024 to 2060 under the EPA Assumptions Baseline as well as modeled emissions avoided results. The emissions decrease significantly when gas collection and cover improvements are implemented, with methane reductions reaching up to 2.68 MMT CH<sub>4</sub> and CO<sub>2</sub>e reductions of 75 MMT CO<sub>2</sub>e by 2060. The percentage reduction in CO<sub>2</sub>e emissions increases over time, from 10.7% in 2024 to 53.8% by 2060, showing a substantial mitigation impact from the proposed measures.

\*CO<sub>2</sub>e calculated at a 100 year Global Warming potential 28 GWP

# **Organics Diversion**

### Background

Organic waste, including food scraps, yard trimmings, and paper products, makes up a significant portion of landfill contents and is a primary source of methane emissions when decomposed anaerobically. Diverting these materials to alternative treatments such as composting and animal feed can drastically reduce new methane production in the long-term, and must be pursued alongside other reduction and control measures.

Studies have shown that reducing organic waste disposal in landfills has a vital role to play in preventing new methane generation. **The EPA highlights that diverting 75% of food waste to composting facilities or anaerobic digesters can reduce methane emissions by 80–90% over the waste's lifetime compared to landfilling.**<sup>63</sup> It is worthwhile to emphasize that burning waste via municipal incinerators should not be viewed as an acceptable alternative to landfilling, given their large polluting emissions and disproportionate impact on environmental justice communities.

The NSPS/EG federal regulations can play a role in encouraging organics diversion, by updating them to allow the use of organics diversion as an alternate compliance mechanism. The EPA would then establish rules for state, local, and tribal agencies to consider and approve landfill operator's plans to divert organic waste rather than landfilling it.

There are also a multitude of other relevant policy levers that would promote organics diversion. Released in 2024, the White House National Strategy to Reduce Food Loss and Waste and Recycle Organics, which focuses on preventing food waste and increasing recycling rates for organic materials, is a critically needed wholeof-government strategy to reduce organics landfilled or burned. This plan includes strategies such as food waste reduction, national consumer education campaigns and developing recycling infrastructure.<sup>64</sup> The U.S. EPA is also advancing organics diversion through the Solid Waste Infrastructure for Recycling (SWIFR) grant program, funded by the Bipartisan Infrastructure Law, which allocates \$275 million over five years to enhance recycling infrastructure, including composting facilities and anaerobic digesters.<sup>65</sup> SWIFR grants have supported projects in jurisdictions across the country aimed at expanding food scrap collection and composting capabilities.<sup>66</sup>

Many state and local governments have taken action: Washington and California are the latest states to pass laws that institute organics diversion goals, food rescue and municipal-run organics recycling programs. **More than 20 states have enacted yard waste disposal bans.**<sup>67</sup> And states such as Maryland, Connecticut, Massachusetts, New York and Rhode Island have all adopted state organic waste bans for large commercial organic waste generators under certain circumstances.<sup>68</sup>

Several European countries have implemented regulations for organic waste diversion from landfills, achieving notable reductions in emissions.

- In Germany, a 2005 regulation banned the landfilling of biodegradable municipal waste, necessitating recycling and biogas production. This regulation has significantly reduced landfill methane emissions, contributing to a 42% reduction in waste emissions in the EU between 1995 and 2017.<sup>69,70</sup>
- Austria introduced a landfill ban on untreated municipal solid waste in 2004, ensuring that organic waste is composted or converted into biogas. This regulation has significantly decreased landfill methane emissions, aligning with the overall reduction in waste emissions observed in the EU.<sup>72</sup>
- In Belgium's Flemish Region, a 2000 regulation banned the landfilling of organic waste, emphasizing waste separation at the source and promoting composting. This policy has substantially reduced landfill methane emissions and improved composting rates.<sup>73</sup>

 Sweden, starting in 2005, banned the landfilling of combustible and organic waste, directing efforts towards recycling, composting, and energy recovery. This regulation has led to a notable reduction in landfill methane emissions and supports the overall decline in waste emissions within the EU.<sup>74</sup>

To achieve long-term reductions in methane emissions, it is essential to integrate organics diversion with improved waste-in-place methane mitigation regulations.

### **Key Improvements**

By integrating organic waste diversion with enhanced gas recovery and other methane control measures for waste-in-place, it is possible to achieve substantial, long-lasting reductions in landfill methane emissions, thereby contributing to climate change mitigation and the advancement of a more sustainable circular economy.

The policy levers for achieving substantial organics diversion are diverse. Within the context of the EPA NSPS/EG regulations, the EPA could allow the use of organics diversion as an alternate compliance mechanism, establishing parameters for state, local, and tribal agencies to consider and approve landfill operator plans to divert organic waste rather than landfilling it.

Considering the unknown of how many landfill operators would voluntarily choose this alternative compliance mechanism, unlike in the previous sections we are not attempting to model that explicit proposed change in the NSPS/EG regulations. Rather, we provide several scenarios where organics diversion is achieved, to demonstrate the overall efficacy of pursuing organics diversion policies and strategies alongside more effective methane controls at existing landfills.

#### Methodology

Organics diversion was translated into the model as a reduced proportion of biodegradable waste. This includes all organic waste including food waste, yard waste, etc.<sup>75</sup> The proportion of organic waste diverted in 2022 per the NIR<sup>76</sup> was used as the baseline for diversion and this was increased at different rates depending on the scenario. Specific scaling is explained in more detail in the Appendix.

In this study, changes in the Degradable Organic Carbon (DOC) content of residual waste following organics diversion were not accounted for, based on several considerations. MSW comprises a variety of organic and inorganic components, and organics diversion typically involves not just the removal of food waste but also the intensified separate collection of other materials, such as paper, cardboard, and garden waste. Additionally, initiatives like deposit fees for bottles and cans, separate collection for packaging materials, and post-collection sorting further influence the composition of residual waste. Consequently, the overall biodegradable carbon content in the residual waste may not undergo significant changes. Although detailed documentation on this phenomenon is limited, particularly in Northwestern European countries with longstanding biodegradable waste landfill bans, industry observations and experiences suggest that the DOC content remains relatively stable. Furthermore, altering the DOC content for modeling purposes introduces complexity and potential controversy regarding the appropriate adjustments. Therefore, to avoid such complications, the DOC content was kept constant in this analysis. The methodology aligns with the broader approach of reducing landfill inputs by diverting MSW to other waste management processes, such as recycling and composting, as part of organics diversion strategies. Although adjusting the DOC content could be considered, it presents significant challenges due to the unpredictable nature of intensified collection and recycling schemes, making the current approach the simplest and most practical for modeling purposes.

Given the stronger alignment of the Updated Assumptions Baseline with independent satellite observations, we have chosen the Updated Assumptions Baseline as the foundation for all subsequent scenarios.

### **Scenarios Modeled**

The Proposed Gas Collection Improvements + Zero Organics by 2050 scenario represents a comprehensive approach to reducing methane emissions from landfills by combining GCCS policies with a complete halt to the landfilling of organic MSW by 2050. This scenario is designed to maximize the impact on methane emissions reductions through enforced regulations and significant changes in waste management practices.

When stacking more than two interventions in a scenario, it becomes challenging to discern the individual contributions of each intervention. Beyond two interventions, the specific impact of each measure becomes unclear, making it difficult to maintain the rigor needed for accurate analysis. For this reason, we focused on two key interventions: gas collection improvements and organics diversion. While methane oxidation or enhanced cover could add more benefits, limiting the scope to these two interventions ensures we can clearly differentiate their individual impacts. This approach provides a scientifically sound comparison, avoiding confusion around the contributions of each measure.

### Key Elements of Proposed Gas Collection Improvements + Zero Organics 2050 scenario

**1. Proposed Gas Collection Improvements:** As described earlier in this paper, improvements to gas collection systems are needed in the NSPS/EG regulations. To ensure efficient gas collection and control across all landfills, rigorous GCCS policies must be implemented, including the installation and expansion of systems within one year after waste placement to minimize methane emissions from new deposits. Horizontal gas collection systems should be incorporated in cells with larger footprints to avoid the inefficiencies associated with buried vertical systems. Additionally, integrating gas collection with leachate collection systems can enhance overall performance. Regular monitoring and comparison of GCCS data with modeled gas generation are crucial, allowing for necessary updates to the design and improvements in the field.

### 2. Zero Organics Landfilled by 2050:

Our goal is to illuminate the emissions potential of at-scale organics diversion, by modeling zero organic waste landfilled by 2050. To ensure that no organic municipal solid waste is landfilled from 2050 onwards, as Table 5 shows, a gradual increase in organics diversion capacity is necessary, with continuous growth to match rising waste generation. This approach will prevent new organic waste from contributing to landfill methane emissions, leading to significant reductions in overall methane emissions as the elimination of organic waste from landfills takes effect.



# **Results of Organics Diversion Modeling**

### Proposed Gas Collection Improvements + Zero Organics by 2050

As Table 6 shows, from 2025 to 2050, the implementation of enhanced gas collection is projected to achieve a substantial cumulative emissions reduction of 100 MMT of methane, representing a 54% decrease from the Updated Assumptions Baseline. This reduction equates to 2,801 MMT  $CO_2e$ , calculated using a GWP of 28. As Table 7 shows, extending the timeline to 2099, the reduction becomes even more significant, with methane emissions reduced cumulatively by 485 MMT–a 79% reduction from the updated baseline. This translates to 13,567 MMT  $CO_2e$  by 2099.

Proposed gas collection and 100% organics diversion by 2050 shows a progressive decrease in annual methane emissions, with notable impacts emerging after 2040 due to the combined effects of enhanced gas collection and control system (GCCS) policies as well as improved cover and the complete diversion of organic waste from landfills. Methane emissions continue to decline well into the future, as even the waste landfilled prior to the policy's implementation generates methane at increasingly reduced rates. The proposed methane reduction strategies offer substantial impact, with a projected reduction of 100 MMT of methane emissions by 2050 compared to the updated assumptions

### Table 5: Assumptions for Recovery Rate, Organics Diversion, and Methane Oxidation inDifferent Scenarios

Scenario Description	Recovery Rate	Organics Diversion	Methane Oxidation Rate
Updated Assumptions Baseline	1% in 1986 increasing to 43% in 2021	None	10%-20%
Proposed Gas Collection Improvements + Zero Organics 2050	43% increasing to 80% by 2040	No landfilling of organic MSW by 2050	20%

### Table 6: Comparing the EPA and Updated Assumptions Baseline's Cumulative Methane and CO₂e Reductions Between 2025 and 2050

Source	Cumulative Emissions 2025 through 2050	MMT CH <sub>4</sub>	MMT CO₂e*	%		
EPA	EPA Assumptions Baseline	114	3,191			
	Emissions with Zero Organics 2050 and Proposed Gas Collection Improvements	82	2,285			
	Overall Reduction	32	907	28%		
Industrious Labs	Updated Assumptions Baseline	186	5,197			
	Emissions with Zero Organics 2050 and Proposed Gas Collection Improvements	86	2,396			
	Overall Reduction	100	2,801	54%		
*CO a calculated at a 100 year Clabal Marning resential 29 CM/D						

### Table 7: Emissions with Organics Diversion and Proposed Gas CollectionImprovements (2025-2099)

Source	Cumulative Emissions 2025 through 2099	MMT CH <sub>4</sub>	MMT CO₂e*	%
Industrious Labs	Updated Assumptions Baseline	615	17,209	
	Emissions with Zero Organics 2050 and Proposed Gas Collection Improvements	130	3,642	
	Overall Reduction	485	13,567	79%

Table 7 presents the cumulative methane (CH<sub>4</sub>) and CO<sub>2</sub>e emissions reductions projected from 2025 to 2099 under Industrious Labs' Updated Assumptions Baseline. Without any intervention, the cumulative MSW landfill methane emissions are expected to reach 615 MMT CH<sub>4</sub> (or 17,209 MMT CO<sub>2</sub>e). However, with the implementation of organics diversion and proposed gas collection improvements, emissions could be significantly reduced to 130 MMT CH<sub>4</sub> (or 3,642 MMT CO<sub>2</sub>e). This represents a substantial overall reduction of 485 MMT CH<sub>4</sub> (or 79%).

\*CO2e calculated at a 100 year Global Warming potential 28 GWP

baseline. This leads to a corresponding reduction of 2,801 MMT CO<sub>2</sub>e, achieving a 54% overall decrease. Without organics diversion, emissions are still significantly reduced, from 186 MMT CH<sub>4</sub> and 5,197 MMT CO<sub>2</sub>e to 82 MMT CH<sub>4</sub> and 2,285 MMT CO<sub>2</sub>e by 2050. These figures highlight the critical role of improving gas collection in cutting methane emissions.

Figure 4 compares the cumulative  $CO_2e$  emissions from 2025 to 2050 under the EPA Assumptions Baseline and the Updated Assumptions Baseline by Industrious Labs. The left side of the graph illustrates that under the EPA assumptions, cumulative emissions are projected to reach 3,191 MMT  $CO_2e$  by 2050. Implementing organics diversion and improved gas collection could reduce this by 907 MMT  $CO_2e$ , resulting in net emissions of 2,285 MMT  $CO_2e$ .

On the right side of Figure 4, the Updated Assumptions Baseline projects much higher emissions, with cumulative emissions reaching  $5,197 \text{ MMT CO}_2e$  by 2050. However, the same mitigation measures would lead to a larger reduction of 2,801 MMT CO<sub>2</sub>e, bringing the resulting emissions down to 2,396 MMT CO<sub>2</sub>e, similar as under the EPA baseline. This comparison highlights the much greater reduction potential under the Updated Assumptions Baseline due to its higher initial emissions projections.

For the period from 2025 to 2050, the EPA Assumptions Baseline shows a 28% reduction in methane emissions (32 MMT  $CH_q$ ), while the Updated Assumptions Baseline shows a 56% reduction (100 MMT  $CH_q$ ). Under both baselines, the proposed mitigation strategies are effective in reducing emissions to similar levels in the long-term.

### Long Term Benefits

The Proposed Gas Collection Improvements + Zero Organics 2050 scenario highlights the importance of integrating stringent enforcement of gas recovery policies with comprehensive organics diversion strategies. This scenario demonstrates that while immediate impacts are driven by enhanced gas recovery, the long-term benefits are maximized through the complete diversion of organic waste, contributing significantly to climate change mitigation and improved waste management practices.

Table 7 shows that under the Updated Assumptions Baseline, the emissions reductions from 2025 to 2099 would lead to a significant cumulative decrease of 485 MMT  $CH_4$ , or 13,567 MMT  $CO_2e$ , representing a 79% reduction by 2099. This

### Figure 4: Cumulative Emissions Reductions from 2025-2050: EPA and the Updated Assumptions Baseline for Zero Organics 2050, Proposed Gas Collection Improvements Policies



underscores the critical role of organics diversion in achieving sustained reductions in landfill methane emissions and highlights the extensive long-term environmental benefits of implementing such comprehensive waste management policies.

# Conclusions

The EPA has an opportunity to press the "emergency brake" on climate change by taking common sense steps to reduce methane emissions from landfills. By requiring landfill operators to start using available best practices and technologies, the EPA can make an immediate impact on climatewarming emissions, while delivering cleaner air and water for local communities. In the absence of federal action, the problem will only spread. The scenario modeling results emphasize the critical importance of implementing a combination of organics diversion, enhanced gas recovery systems, and optimized cover measures to effectively reduce methane emissions from landfills.

Our modeling shows that in the short-term, large methane emissions reductions will come from improvements to gas collection and cover, while organics diversion measures result in methane reductions in the long-run, as it takes time for these measures to have an impact.

**Proposed Gas Collection and Cover Improvements** Proposed gas collection and cover improvements achieve methane emissions reductions fast. A combination of changes to gas collection and control systems and landfill cover practices will ensure a higher rate of gas collection across a higher number of regulated landfills. This is crucial as demonstrated in the Proposed Gas Collection and Cover Improvements Scenario, **a cumulative reduction of 104 MIMT CH**<sub>4</sub> (56%) by 2050 or 2,922 MMT CO<sub>2</sub>e.

### **Integrated Policy Approach**

Combining organics diversion with proposed gas collection improvements provides the most comprehensively effective methane reduction strategy. The Proposed Gas Collection Improvements + Zero Organics 2050 Scenario achieves the highest long term reductions with **a cumulative reduction of 100 MMT CH**<sub>4</sub> (54%) **or 2,801 MMT CO**<sub>2</sub>**e by 2050 and 485 MMT CH**<sub>4</sub> (79%) or 13,567 MIMT CO<sub>2</sub>**e by 2099.** This integrated approach ensures substantial short-term and long-term benefits, making it a comprehensive strategy for methane reduction.



# Appendix

### **Additional Scenarios**

In analyzing landfill methane reduction, various scenarios were considered, each reflecting different mitigation strategies such as improvements in gas collection systems and organics diversion. The scenarios offered in the main report highlight the highest potential for emissions reductions, both with and without organics diversion. These scenarios highlight the critical impact of combining gas collection improvements with organics diversion to achieve significant methane reductions. The selected ones were prioritized for their clear potential to drive the largest  $CO_2e$  reductions by mid-century, which is essential for meeting climate goals.

### **Proposed Gas Collection Improvements**

In this scenario, we assume a number of improvements to gas collection systems, including increased gas collection wells and earlier and extended gas collection periods. It is anticipated that by 2040, an overall average recovery efficiency of 80% will be achieved, the minimum value proposed for adoption in regulations by Scheutz and Kjeldsen (2019). Achieving this level requires more than just enforcing current policy, as unregulated landfills with no gas recovery will persist. Consequently, the gas recovery rate at regulated landfills must exceed 75% on average. Implementing stricter gas recovery regulations will be necessary, such as replacing the allowance to cease gas recovery after 15 years with a methane mass flow threshold value.

### **Better Landfill Cover**

This scenario proposes that the methane oxidation efficiency in landfill cover soil increases from 20% in 2021 to 35% in 2040. The current 20% efficiency is based on a mixture of landfill conditions as reported in the US-NIR. Achieving a 35% oxidation efficiency requires a suitable cover and methane flux rate of less than 10 grams per square meter per day. For a medium-sized landfill (150,000 metric tons of MSW per year) with an average height of 25 meters, it takes 80 years to reach this low flux rate without active gas recovery. This scenario has limited impacts unless organics diversion is done in parallel with gas collection efforts.

### **Research Based Metrics, 0% Oxidation**

Microbial methane oxidation relies on sufficient gas-filled soil porosity to allow oxygen to diffuse into the soil. This slow process limits microbial methane oxidation to low flux rates. Additionally, the microbes need adequate moisture and moderate temperatures. In dry or cold climates, making microbial methane oxidation ineffective for large parts of the year. To illustrate the impact of the NIR's assumption of 20% methane oxidation, we designed scenario E with 0% methane oxidation. As expected, the scenario B line (with methane oxidation increasing from 10% in 1990 to 20% in 2010) is 20% below the scenario E line post-2010. Similarly, the scenario D line (further increasing from 20% in 2010 to 35% in 2040) is 35% below the scenario E line post-2040.

### **Triple Diversion Scenario**

The Triple Diversion Scenario suggests that the current rate of organics diversion triples by 2050. According to the most recent EPA NIR, an average of 331 MMT of MSW were generated annually between 2017 and 2021, with 65% (214 MMT) landfilled and 18% (60 MMT) either incinerated, composted, or anaerobically digested. The remaining 17% was likely recycled directly (e.g., paper, cardboard, glass, metal). Given the time required to plan, site, and realize waste management facilities, Triple Diversion Scenario assumes that increased organics diversion starts to take effect from 2030 onwards, with a linear increase in diversion capacity between 2030 and 2050. After 2050, the diversion capacity remains constant, leading to a growing amount of waste landfilled as waste generation continues to rise. The Triple Diversion line starts to deviate from the Direct Measurement Baseline from 2036, as waste landfilled before 2030 and between 2036 continues to generate methane. The impact of organics diversion on methane emissions is longterm, becoming evident post-2070 as emissions rise again due to increased waste landfilled after 2050.

### Zero Organics 2050

Zero Organics 2050 envisions a more stringent organics reduction strategy, with gradual increases in organics diversion capacity to ensure no organic MSW is landfilled from 2050 onwards. This requires continued increases in diversion capacity to match growing waste generation. Consequently, this scenario's methane emissions decrease continuously until after 2099.

### Zero Organics 2030

To emphasize the delayed impact of organics diversion on observed methane emissions, we created the Zero Organics 2030 Scenario, which assumes no landfilling of degradable organic carbon from 2030 onwards. Though unrealistic, Zero Organics 2030 Scenario demonstrates that it only has lower methane emissions than the Proposed Gas Collection Improvements Scenario post-2050. Between 2024 and 2050, Zero Organics 2030 emits 36 MMT more methane than Proposed Gas Collection Improvements Scenario, highlighting that organics diversion is not an alternative to enhanced gas recovery; both measures are essential for optimal landfill methane emission reduction. It is also important to note that even with this complete stop in organics landfilling the waste that was previously landfilled before 2030 continues to produce methane well into 2099.

### **Enforced Proposed Gas Collection Improvements & Triple Diversion**

To illustrate the impact of enforced gas recovery policies and organics diversion on landfill methane emission reduction, Proposed Gas Collection Improvements Scenario was combined with the Triple Diversion Scenario to create this scenario. From 2024 to 2040, this scenario follows the trajectory of the Proposed Gas Collection Improvements Scenario. Post-2040, this scenario gradually shows lower methane emissions than the Proposed Gas Collection Improvements Scenario. This demonstrates that while enhanced gas recovery has the most significant short-term impact, organics diversion contributes to a slower, long-term effect.

### **Table 9: Scenario Assumptions**

Scenario Description	Gas Recovery Rate	Organics Diversion	Methane Oxidation Rate
EPA Assumptions Baseline	1% in 1986 increasing to 65% in 2021	None	10%-20%
Updated Assumptions Baseline	1% in 1986 increasing to 43% in 2021	None	10%-20%
Updated Assumptions Baseline, 0% Oxidation	1% in 1986 increasing to 43% in 2021	None	0%
Proposed Gas Collection Improvements	1% in 1986 increasing to 43% in 2021 increasing to 80% in 2040	None	20%
Better Landfill Cover	1% in 1986 increasing to 43% in 2021	None	20% increasing to 35% in 2040
Proposed Gas Collection Improvements	1% in 1986 increasing to 43% in 2021 increasing to 80% in 2040	None	20%
Triple Organics Diversion by 2050	43%	Triple 2023 diversions rate by 2050	20%
Zero Organics 2050	43%	No landfilling of organic MSW by 2050	20%
Zero Organics 2030	43%	No landfilling of any DOC by 2030	20%
Proposed Gas Collection Improvements & Triple Diversion	43% increasing to 80%	Triple 2023 rate by 2050	20%
Proposed Gas Collection Improvements & Triple Diversion	43% increasing to 80%	No landfilling of organic MSW by 2050	20%

### Table 10: Scenarios' Cumulative Methane Emissions Reductions From Updated Assumptions Baseline

<b>Cumulative Emissions</b>	2024-2050		2025-2099			
Scenario	MMT CH <sub>4</sub>	MMT CH₄ Reduced	% Reduced	MMT CH <sub>4</sub>	MMT CH₄ Reduced	% Reduced
Updated Assumptions Baseline	186			615		
Proposed Gas Collection Improvements	93	93	50%	244	371	60%
Enhanced Landfill Cover	159	27	14%	507	107	17%
Proposed GCCS Policies & Enhanced Cover	81	104	56%	204	411	67%
Triple Organics Diversion by 2050	176	10	5%	472	143	23%
Zero Organics 2050	165	20	11%	292	323	53%
Zero Organics 2030	128	57	31%	182	432	70%
Proposed Gas Collection Improvements & Triple Diversion	89	96	52%	193	421	69%
Proposed Gas Collection Improvements & Triple Diversion	86	100	54%	130	485	79%

#### Endnotes

- 1. White House (2024) FACT SHEET: Biden-Harris Administration Announces New Actions to Detect and Reduce Climate Super. Pollutants The White House.
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