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June 30, 2022

Draft Scoping Plan Comments
c/o NYSERDA
17 Columbia Circle
Albany, NY 12203-6399

*Via Email: scopingplan@nyserda.ny.gov*

**RE: CLCPA Draft Scoping Plan Comments (Due July 1, 2022)**

Dear NYSERDA,

We appreciate the opportunity to submit the following comments on the Climate Leadership and Community Protection Act (CLCPA) Draft Scoping Plan.

## Introduction

Casella Waste Systems, Inc. is a regional solid waste and recycling resource management company with operating locations across New York State (NYS) including collection facilities, transfer stations, recycling facilities, four active municipal solid waste landfills, three of which are direct landfill gas to energy (LGTE) facilities, and one construction and debris (C&D) landfill. We have been operating in NYS for approximately 40 years and provide good green jobs to 831 environmental service professionals, and in addition to our own employees, employ many contractors and temporary workers to support our operations in NYS. We also manage over 3 million tons of solid waste, recyclables, and organics in NYS, per year, while servicing 245,000 households and businesses across the state.

Casella is committed to acting responsibility and sustainably as our industry evolves from traditional solid waste disposal to a modern resource recovery model. For decades, we have invested in the northeast's infrastructure for solid waste management, including collection fleets, recycling facilities, organics recovery facilities, and landfills. We own, operate, and develop an integrated resource management infrastructure in the Northeast, and are positioning our business to adapt, evolve, and thrive in a rapidly changing world.

In 2012, we received the EPA's Excellence in Greenhouse Gas (GHG) Management award, celebrating the company's achievement of a 45% reduction in total GHG emissions from 2005 to 2010. We achieved those reductions through investments in landfill gas collection, landfill gas to energy facilities, energy efficiency, and alternative fuel vehicles. Having achieved our first goal, the company has developed a new target to reduce our GHG emissions to 40% below 2010 levels by 2030. We will achieve this goal through further investments in landfill gas collection and beneficial use through fleet and facility efficiency measures. Currently, for every ton of carbon we generate managing our customers' and communities' waste and recyclables, 2.9 tons of carbon are eliminated elsewhere through Casella's recycling, energy production, and carbon sequestration efforts.

As explained in further detail below, we request the CAC consider the following as part of the CLCPA Final Scoping Plan:

- Adopt requirements for zero emission (ZEV) trucks, busses, and non-road equipment, thoughtfully and over time, using a stakeholder engagement process.
- Consider all organic waste, and the build out of their end markets, as part of NYS' organics planning, including renewable natural gas.
- Ensure the existing robust recycling infrastructure remains part of NYS' recycling process, and further to define the term "single use," to ensure materials are put to their best reuse as resources.
- Establish local, domestic markets to support the current recycling system and promote potential opportunities for material recovery.
- Limit extended producer responsibility (EPR) initiatives to what is needed as determined via a needs assessment and stakeholder engagement process.
- Allow for all biogas to be used in the same manner as on-site only uses vary widely and seasonally.
- Base requirements to improve landfill methane mitigation, such as enhanced cover, improvement gas collection, or gas collector dewatering, on site specific performance, as demonstrated by refined emissions quantification and direct measurement technologies.
- Create a state-wide GHG inventory of WRRFs that differentiates between WRRFs capable of controlling emissions efficiently and those that do not control emissions.
- Maximize renewable energy production from biogas as a key strategy in the state energy transition plan.
- Clarify initiatives for local governments to incorporate climate change into comprehensive plans, regulations, planning programs, and environmental reviews.

## Sector Strategies

## Chapter 11 – Transportation

### T2. Adoption of ZE Trucks, Busses, and Non-Road Equipment

Casella supports the CAC's commitment to reducing greenhouse gas (GHG) emissions from the mobile sector and NYS' commitment to converting its medium and heavy-duty fleets where technically feasible. However, the enactment of legislation, establishment of procurement, and contract rules, to align with this goal, should be done thoughtfully, and over time, using a stakeholder engagement process.

Proposing the New York Department of Conservation (NYDEC) adopt regulations similar to California's Advanced Clean Fleets rule does not seem appropriate at this time, due to lack of vocation, product, and infrastructure, all of which are important factors to consider as part of this concept. It may be necessary to consider the use of renewable fuels as a supplement and option if operational performance cannot be met with electric fleets. Alternate Powered Zero Emission Vehicle (ZEV) Technology is not fully developed, and electrified heavy-duty (>26,001 lbs) vehicles are not widely available. ZEV technology is developing slowly to address industry specific needs – longer distance travel, hours of operation, power needs, steeper geographies, and charging station infrastructure. Supply chain issues may also have an impact on availability.

CNG vehicles play an important role in our industry's transition away from diesel fuel reliance. They have a lower carbon footprint and a cleaner emission profile compared to standard diesel trucks. There is also an option to run these vehicles using Renewable Natural Gas (RNG), opening the possibility that our trucks may one day be fueled by the gas produced at our landfills. Today CNG vehicles make up 4% of our routed vehicle fleet. In markets with available CNG fueling infrastructure, 19.6% of our routed fleet runs on CNG. Increased access to CNG would influence our vehicle purchasing strategy in the future.

Throughout the northeast Casella operates over 130 facilities and over 843 collection vehicles. We are investing in fuel efficiency and alternative fuel vehicles while maintaining a daily focus on meeting and exceeding out environmental compliance requirements. Over the past five years, we have worked to standardize and modernize our fleet. Alternative fuel technology for refuse vehicles has advanced markedly in recent years and we look forward to deploying more compressed natural gas (CNG) and electric vehicles in our fleet over the coming years. Incentivizing companies to transition to CNG and electric vehicles should be a continued initiative of NYS.

Waste hauling is an essential service, servicing millions of residents in NYS, meaning the financial impact of fleet electrification will be substantial. If it is in the interest of the CAC to promote emissions reductions for this sector based on electrification, initiatives such as tax incentives, supplemental funding, or other compensation, should be made available to the offset cost of fleet overhauls and charging station infrastructure. The concept of assessing fees on fuel or fuel-based vehicles should not be considered for implementation because as consumption declines available funding will no longer exist.

It would also be valuable to conduct a pilot study to roll out electrified trucks in urban and rural areas. Casella is exploring this concept, and we understand that the City of New York Department of Sanitation, did so as well, in 2020. We believe an extension of the NYC pilot program covering diverse areas of NYS should be conducted before any such requirements are developed.

CAC may also want to consider working with the biogas and EV industry to develop a low-cost, reasonable transition plan. Organization of a round-table to bring experts, including waste haulers, together to gain a better understanding of the currently available technology and thought on progression or advancement in this area would put the state on the path to low-carbon heavy-duty vehicle use throughout NYS to reach the goals of the CLCPA.

In addition to on-road vehicles, landfills also use non-road vehicles, and including them in conversations of what operations require, and what technology is appropriate for operational use, is important in determining eligible equipment. Not much is known as to the storage capability of ZEV vehicles and their ability to haul waste, which should be studied further before committing to a conversion to ZEV.

## W1. Organics Reduction Recycling

Creating infrastructure for the processing and reuse of organic residuals is essential to strengthening NYS' efforts to reduce in-state waste. For this reason, we believe all organic waste should be considered in NYS' organics planning. Casella is at the forefront of this initiative having developed our organics collection program in 1999 and expanding to create our Casella Organics division in 2001. We currently operate organic recovery facilities that capture approximately 450,000 tons per year, including wastewater biosolids, wood ash, paper mill fiber, and food waste. To recover the most value from these materials, we invest in on- and off-site processing equipment, such as depackaging, to make material available for reuse in composting, anerobic digestion, and land application processes.

NYS' expansion of avenues for food waste diversion, via education, regulation, and provision of financial support to programs traditionally managed on a small-scale basis, are essential to the forward progression of in-state reuse efforts. However, while small-scale food donation and recycling composting programs can be very effective on a case-by-case basis, scaling up these types of operations to manage millions of tons of material a year, will likely present significant logistical and economic challenges. Access to end markets, economics, and facility capacity, must be carefully considered as part of the development of any system that encourages market based competitive solutions rather than depending on subsidy to remain viable.

Of concern is the proposal for large food waste generators to use "viable" organics recyclers within 25 miles of their facility. We believe this requirement should be considered in conjunction with initiatives to build-out existing end markets. Food waste composting facilities base their production on end use markets, and current markets are limited in density, meaning access within 25 miles may not be practical. This will make it necessary for facilities to ship products further, increasing cost, GHG emissions, and potentially leading to less economic and beneficial value, of this initiative. While larger facilities will be more practical in terms of logistics and capital cost/handling capacity, ramping up development of the many small, local organics recycling facilities at once, could also result in vastly different disposal costs on a facility-by-facility basis, due to capacity issues.

There are additional factors that should be also considered as part of any food waste diversion program. Requiring separation of the food waste stream prior to collection, transfer, and disposal, will be necessary as transfer stations and disposal facilities are not designed to manage organics separation as part of on-site mixed municipal solid waste (MSW) processing. There are also growing concerns over emerging contaminants such as per- and polyfluoroalkyl substances (PFAS) and microplastics. Large scale operations faced with these issues will encounter end use market availability and the economic viability of their product (e.g. compost). In addition, the term "viable" is undefined, raising the issue of what potential infrastructure looks like, and whether there are economical components, or environmental standards, that will apply.

Although wastewater treatment plant (WWTP) biosolids are mentioned in other parts of the CLCPA Draft Scoping Plan, we believe there is a strong argument for also considering them as part of NYS' organics reduction and recycling efforts. WWTP biosolids contribute to methane generation as they are a significant source organics and moisture when landfilled. Biosolids, principally a byproduct of wastewater treatment plant facilities (WRRFs), represent a significant organics waste stream that is well quantified, and already source separated from other wastes prior to collection. Logistically, this waste stream represents an organic material that can be diverted from disposal on a statewide basis within a much shorter timeline, compared to food waste.

We are also supportive of NYS' efforts to research and develop recycling markets for organics and solid amendments and end uses. However, such initiatives would be strengthened by developing and supporting programs, regulations, and legislation that require the use of organics/soil amendments on state projects such as highway construction and rights of way maintenance. Such initiatives should also support the use of these materials in private projects. If organics/soil amendments do not have an end use, the investment to build facilities, and recycle the organic waste, will fail. To further this initiative, NYS should consider a sale tax to reduce consumption, instead of a tax on solid waste disposal, to incentivize biosolids diversion.

**W2. Waste Reduction, Reuse, and Recycling**

While Casella agrees with the CAC that emissions reductions are needed to achieve the targets and goals of the Climate Act, avoiding waste disposal in general, cannot be the mitigation measure used to achieve them. We believe defining the term "single-use" is essential to this effort. Careful consideration is needed to ensure materials are put to their best use as resources, and existing infrastructure is part of the process.

However, mitigation measures, such as renewable energy production from captured landfill gas, also should be taken into consideration. To the extent large amounts of solid waste continue to be generated and are unsuitable for reuse or recycling, it is also important to rank disposal options in a manner that reflects modern technology and a modern understanding of environmental and climate impacts. Landfill gas is derived from biogenic material whereas energy from waste combustion derives primarily from plastic, which is a fossil fuel, and therefore has a higher rate of GHG emissions.

A December 2020 analysis reviewed the climate impact of 36 solid waste disposal facilities in the northeast, including 13 incinerators and 23 landfills, using publicly available date from GHG and energy reporting.[1] The review determined the carbon footprint of solid waste incineration is 26% higher than that of landfilling. Specifically, the analysis found incinerators emit on average 0.65 tons of CO2e per ton of waste disposed whereas landfills average 0.48 tons of CO2e per ton of waste disposed. Landfills with energy recovery had an even smaller footprint than landfills in general

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[1] **<u>See</u>** Sanborn, Head & Associates, Inc. 2020. Solid Waste Management Hierarchy Policy: Managing Waste to Reduce Greenhouse Gas Emissions: Comparing Per Unit Waste from Incinerators and Modern Landfills. File No. 2343.20. Sanborn, Head & Associates findings were subsequently peer reviewed and published. **<u>See</u>** Luke C. Teal & Jeffrey J Doris, *Renewable Natural Gas and the Implications for Waste Management Hierarchies*, EM Magazine, June 2021.

with the former averaging 0.44 tons of CO2e per ton disposed, which is 32% lower than incineration.

Production requirements and minimum recyclable content standards for commercial and consumer products will also play an important role in the reuse and recyclability of products. Implementation of legislation in NYS to this end would garner our support.

The CAC is supportive of creating convenient recycling collection programs throughout the state and Casella shares this goal. We agree with and support several of the CAC's initiatives to provide educational and financial aid for reuse and recycling of materials and phase out of single-use products. Local community reuse and recycling systems are essential to achieving NYS' climate goals. To this end, we support state funding for local reuse centers, material exchanges, repair shops, and the expansion of existing campaigns for reduction, reuse, and recycling, targeted towards residents and businesses.

Casella is generally unsupportive of the concept of a fee per ton for solid waste as these funds are usually not earmarked and put into a general fund. However, if the purpose of collecting fees is to fund state recycling efforts, Casella would be supportive, as long as it is clear where those funds would go. Making sure those funds are used to support initiatives such as, workforce development, job training, supporting existing state recycling infrastructure, and supporting local community and reuse recycling systems, is essential to the continued forward progression of NYS' work toward goals under the CLCPA.

Enhancement of municipal recycling initiatives, container deposits, and implementation of textile recycling programs, need to take into consideration NYS' existing recycling infrastructure, otherwise NYS cannot achieve its goal of conveniency. Casella supports initiatives to further existing infrastructure and process hard-to-recycle materials, like textiles, as discussed further below in Section W3. Extended Producer Responsibility.

Since the implementation of the existing container deposit program, significant capital investments have been used to develop recycling infrastructure in NYS. Recycling solutions and infrastructure, such as single stream curbside recycling services for residents, already exist to handle the containers being considered under an expanded container deposit program. Promoting a system separate and apart from the existing infrastructure ultimately undermines the entire recycling system. A popular belief is that collecting less materials in recycling trucks via curbside pickup means savings to communities. The reality is consumers will pay for two recycling systems – an expanded container deposit system and a residential curbside or dropoff service for other recycling and trash. Drivers will still need to cover the same routes and stops – providing the same service they do today.

Costs will also increase and be relayed to consumers in two ways – as a per container upfront deposit fee on deposit containers and as a hidden fee relayed as higher costs of groceries, as producers pass along their handling costs. In addition, claims that single stream processing cannot meet the specifications for material reuse are unfounded. Despite global market dynamics, Casella has marketed and moved our recyclable materials in the same or similar markets as bottle bill commodities. This means, for our materials, the total percentage of recoverable materials in a bale collected as part of a bottle bill process and in a bale collected and consolidated at a MRF are equivalent.

## W3. Extended Producer Responsibility

Casella agrees with and is supportive of polices that reduce waste and encourage recycling in NYS. We are supportive of NYS enacting legislation requiring a minimum level of recycled content in certain products and packaging. This is in line with New York's interest to further develop recycling programs, cut the need for virgin materials, and boost market demand for processed, recycled commodities.
We also support efforts focused on convenient recycling collection programs and ensuring adequate funding. However, enactment of broad Extended Producer Responsibility (EPR) and/or product stewardship legislation, to further these initiatives, may not be the answer.

The goal of EPR is to reduce waste and recycling costs for the public while incentivizing producers to design products and packaging for recycling. Casella shares this goal. However, any EPR system must be carefully designed to enhance and supplement existing infrastructure, rather than compete against it. NYS has a rich history of municipal, county, and authority-based recycling and reuse programs, that needs to be protected. This includes a robust infrastructure of existing in-state collection equipment and processing facilities.

We believe the best way to improve recycling streams is to further invest in existing infrastructure. Casella has made significant investments including single stream collection and processing systems, which serve thousands of municipalities and businesses. We recover hundreds of thousands of tons per year of recyclable materials. Despite recent market challenges this infrastructure remains the most efficient and effective way to recover recyclables from households and businesses.

More recent Casella investments have focused on improving processing and increasing outbound quality to meet new market specifications. We are also interested in future infrastructure investment opportunities that would advance recycling including film plastic, flexible pouches, carpet, tires, textiles, solar panels, wind turbines, batteries, appliances, and mattresses, all of which are problematic in today's recycling programs.

Existing NYS EPR programs have been successful because of their focus on efficient management of hard to recycle materials that cannot be processed by existing infrastructure. Targeting new types of materials should be the reason behind development of any additional EPR legislation. For these reasons, we would support legislation for the creation of an advisory committee to research existing infrastructure, in place of the enactment of broad EPR/ product stewardship requirements. This would allow NYS to balance the interests of all stakeholders, while still allowing for implementation of measures to meet the state climate goals, in a timely manner.

The need for an EPR program should be determined only after a comprehensive state-wide assessment of current collection infrastructure, processing capacity, and market conditions or opportunities. This includes taking into consideration the concerns and recommendations of relevant stakeholders including producers, PROs, municipalities, residents, retailers, private haulers, and processors. Any assessment should begin with the creation of an advisory council, made up of a diverse group of those stakeholders, responsible for conducting the assessment, and tasked with making recommendations to increase recycling of certain materials in a targeted manner. Those recommendations should then be used to set goals, performance targets, and service expectations, for increased materials management.

To be successful an EPR program must also have realistic timelines for the creation, review, and approval of effective PRO plans, that protect and utilize existing recycling infrastructure, and promote future infrastructure investments. Robust consumer educational efforts concerning recycling must be implemented and a sustainable demand must be created for processed, recycled commodities.

## W4. Water Resource Recovery Conversion

Casella agrees with the CAC's prioritization of water resource recovery conversion, however, it is imperative that review of PFAS and emerging contaminants are part of this process, to avoid potential environmental impacts. PFAS is a significant technical and regulatory challenge for Water Resource Recovery Facilities (WRRF) seeking to introduce food scrap waste, establish organic de-packaging facilities, and divert biosolids from disposal to beneficial use (i.e. land application). WRRFs and landfills are often associated with being generators of PFAS, however, this is not the case. Both manage materials containing PFAS from their waste streams. Strategies to reduce the use of PFAS in products such as packaging, and foods, should be pursued on a local and national level. We encourage CAC to further assess preventative measures designed to address primary sources of PFAS in waste streams as part of the CLCPA Final Scoping Plan. This could potentially include additional voluntary phase outs, replacement products/chemicals, and increased disclosure of PFAS in consumer products.

Incentivization of biogas production is also a good strategy as it will promote capture and collection for beneficial use. However, limiting the use of WRRF biogas to offsetting onsite needs is unworkable. The energy requirements at WRRFs, principally heat and electricity, tend to be highly variable, fluctuating with seasonal changes in energy demand and WRRF system loading (throughput). Matching WRRF biogas production to its exact energy demand is improbable, impractical, and will result in either unutilized biogas, or a need for significant supplemental energy supply from traditional distributed energy supply systems to meet WRRF needs. In addition, the value of renewable energy environmental attributes generated by biogas (i.e. RINs, RECs, offsets etc.) can be significantly more valuable in other markets than the energy being offset at the WRRF. Therefore, to maximize economic benefits to a WRRF biogas project and ensure complete utilization of biogas produced, connection to traditional energy distribution systems (e.g. electrical grid or gas transmission system) is the best strategy.

In the context of general biogas production the term “transmission infrastructure” should be further defined. Renewable natural gas provides one of the most attractive renewable energy transition opportunities in the short term (i.e. < 10-15 years). NYS should encourage and incentivize these projects whole heartedly to utilize the massive existing infrastructure system already in place (i.e. state gas transmission system). This will enable rapid transition in NYS to renewable based energy, displacing petroleum natural gas, and provide greater economic benefits to WRRFs (and other small biogas producing facilities), which in turn will help capitalize the required infrastructure improvements proposed to expand organics management capacity at WRRFs.

## W6. Reduce Fugitive Emissions from Solid Waste Management Facilities

Casella agrees with capture, collection, and reuse of landfill gas and we have made significant financial investments in our landfill gas collection systems that have resulted in substantial GHG emissions reductions. However, the CAC should make clear goals and objectives before requiring further monitoring techniques, quantification of fugitive GHG emissions, and evaluation of the most appropriate uses for gas during the transition to state-wide electrification. This will ensure facility owners can be confident in existing markets for end-products (i.e. RNG vs. electricity) before committing to a large capital investment. Any requirements for investment in further technology or gas-capture and development of infrastructure would be costly.

Potential incentives such as grant funding, tax benefits, or other incentives, should also be considered, to assist with any such requirements.

Requirements to improve methane mitigation at individual landfills, such as enhanced cover, improving gas collection, or gas collector dewatering, should be based on site specific performance, as demonstrated by refined emissions quantification and direct measurement technologies. Solid waste landfill facilities that can demonstrate effective methane mitigation systems should be an important part of the waste management transition from the current state to a zero-disposal model.

We agree GHG emissions can vary significantly from one individual landfill facility to another, including when different landfill facilities are compared in terms of GHG emissions, scaled to equivalent per ton of waste disposal. The California 'super emitter' study presents how new surveillance technologies can be utilized to identify large sources of methane, however, it also shows not all facilities are large emitters. That study, along with other subsequent studies and inventories, continually demonstrate that a minority of facilities (including landfills, composting facilities etc.) emit a large portion of the methane in a source category, while a majority of facilities emit a smaller relative share of the total.

The statement that the landfill sector is 'under reported' (e.g. using current inventory methods) has not been supported by empirical data, including the California 'super emitter' study. Although, the study does point to two important observations which have been long recognized by the landfill industry itself; the current models, developed for national and global wide inventory systems, have a very large potential error when applied to a single unique facility and, second, although some facilities are large (or 'super') emitters, many facilities are operated effectively, controlling emissions much better than inventory models predict.

Based on numerous industry and academic papers going back over 25-years, it is clear current estimation models, principally developed (deliberately) to conservatively over estimate emissions (e.g. applicability for clean air act permitting programs) or for use in broad inventory assessments (e.g. Part 98 subpart HH methodology, AP-42, etc.), do not categorically 'underestimate' landfill emissions but rather show there is tremendous inaccuracy between model results and the actual emissions at one landfill or another based on many site specific factors, including such as actual gas collection and surface emissions monitoring data, which are not considered (as model input parameters) by these widely used models.

NYS uses the USEPA State Inventory Tool (SIT) to estimate total landfill methane generation and emissions from all waste disposed in landfills annually. This model uses broad assumptions on gas generation, gas collection efficiency, oxidation rates etc. applied to all landfilled NYS solid waste. The accuracy of this assumed state-wide landfill emission rate should be viewed with some skepticism, with actual emissions from this sector potentially much less certain.

A key objective of this strategy should be first to accurately quantify emissions in this waste sector. A facility's effectiveness at controlling emissions should be evaluated on a site-specific basis, using site specific methane monitoring data to calibrate predictive models to site specific conditions and therefore improve accuracy overall. Predictive methane emission models should consider already available monitoring data such as surface emissions, ambient gas measurement, gas collector monitoring data and gas recovery operations data, already being collected at most active facilities. Methane measurement technology advancements over the next couple years will provide tools needed to assess 'bad' actors from those responsibly operated facilities. emerging methane detection and quantification technologies, along with data the types of monitoring data already being obtained can be used to enhance estimation models and the state inventory for this sector. Additionally, recognition of the fossil fuel free energy from landfill gas must be recognized as positive GHG reduction.

## W7. Reduce Fugitive Emissions from Water Resource Facilities

Refinement of fugitive emissions from WRRFs would be beneficial to the CAC and implementation of the CLCPA Final Scoping Plan. Little information is available related to fugitive emissions associated with WRRFs and we are supportive of improving the accuracy of the state-wide inventory of GHG emissions from this sector. An important first step should be differentiating between WRRFs capable of controlling emissions efficiently and those that do not control emissions at all.

We believe capture and utilization (i.e. energy) of methane from WRRF anaerobic digestion processes should be an important part of the strategy to reduce emissions. However, onsite energy demands and gas generation at WRRFs can be highly variable on a monthly and seasonal basis. Matching actual energy generation potential to energy needs at a single facility is difficult, if not impossible to achieve, resulting in unutilized energy resources in many instances. Energy projects at WRRFs should be developed to maximize energy generation potential via connection to electrical grid or pipeline injection. Interconnection for WRRF energy projects should be streamlined and subsidized through utilities as not to present economic barriers to smaller projects.

## W8. Recycling Markets

Valid markets for recyclables are crucial. Increases in recycling collection and efficiencies need to be made with a material end use in mind. Otherwise, the resulting products may end up being landfilled anyway. One of the most significant challenges to recycling expansion is sustainable market development. Establishing local, domestic markets will help to support the current recycling system and promote potential opportunities for material recovery.

The CAC should consider how domestic recycling markets can be developed. As NYS saw in 2017-2019, recycling markets can be volatile. Municipalities saw more than a 1,000% increase in their costs to process residential curbside recyclables. A state survey in 2020 of NY municipalities found that estimated the cost impact to be $40 million in 2019, and nearly $60 million in 2020 (excluding New York City). Local governments and the private sector cannot risk this type of volatility. Without support from NYS, 800,000 tons of recyclable material are at risk of being landfilled or burned at waste-to-energy facilities.

This also includes investments in recycling education. Education and outreach are essential to ensuring NYS residents continue to recycle more in a responsible manner and aids to alleviate contamination issues.

### W9. Biogas Use

Maximizing renewable energy (RNG, electricity generation, direct use) production from biogas should be a key strategy in the state energy transition plan. If all landfill gas (LFG) was consumed at existing landfills in NYS, 3,940,015 MW-hrs of electricity could be generated to power approximately 368,000 homes for a year. Instead, 7,352 million cubic feet of LFG is flared annually without any beneficial use.

The CAC has identified renewable biogas energy, and combustion in general, as a short term (i.e. <30 years) phase in a transition to 100% renewable energy system. Biogas energy projects should be incentivized to maximize methane collection for conversion to energy in the short term. Since these projects are envisioned under the CLCPA Draft Scoping Plan with a finite life span, within the transitional phase, they could utilize existing commercially proven technologies and energy infrastructure, to maximize project development and economics.

Casella does not support methane (biogas) fuel cells as a preferable energy conversion technology. Fuel cells are extremely costly, and require energy intensive treatment and conditions upstream, all the while producing GHG emissions as a reaction byproduct along with criteria pollutants similar to traditional technologies such as engines (albeit at lower emission rates).

Waste-to-energy (WTE) facilities are designed for a fixed maximum process throughput of waste. To operate in an economically viable manner they must be operated at or close to their design capacity. They also require an immense initial capital investment, for example, a 2,000 ton per day waste facility could cost upward of $400 million. Such large capital investment requires many years of operation to justify investment, making a long-term commitment to such technology and waste disposal strategy via an investment in infrastructure. This combination of large capital investment and a fixed/required waste capacity throughput to operate effectively does not integrate well into CAC's proposed waste management transition, which seeks to incrementally reduce waste disposal through an increasing program of diversion, reuse and recycling, eventually minimizing or eliminating the need for traditional disposal method within the next 25 years.

Landfills invest in disposal infrastructure incrementally as constructed airspace and are only expanded to meet disposal needs. They are a resource that can be utilized as required, decreasing disposal rate as needed, to meet evolving NYS disposal requirements. Landfills can also incrementally step back disposal rate as recycling, organics, and other proposed diversion/beneficial reuse programs are ramped up and expanded, to meet NYS' waste reduction goals, unlike WTE facilities. This allows a reduction in traditional disposal capacity without giving up the contingent disposal capacity which may be needed in event of natural disasters or other unplanned flux in disposal capacity requirements nor with the economic challenges of having fixed waste disposal capacity/throughput to remain economically viable.

When combined with energy recovery (RNG, electricity generation, LFG direct use or landfill geothermal heat recovery), displacement of fossil fuels within the economy is derived as a significant benefit. In addition, it is well documented that landfills provide significant carbon sequestration of all petroleum based organic waste and some portion of biogenic based organic waste materials disposed. Well managed landfills, that control emissions and recover energy through utilization of captured methane, present an opportunity to contribute towards NYS' climate change GHG reduction strategy, while continuing to provide an economical, scalable waste disposal resource, which can be used to provide economical, scalable waste disposal capacity for NY during the transition to a diversion, recycling based waste management system.

## Chapter 20 – Local Government

NYS' overarching goal under the Climate Act is to reduce in-state emissions and Casella is supportive of its efforts to do so. However, those efforts must be made with existing infrastructure in mind. For this reason, Casella is supportive of the CAC's initiative to prioritize methane recovery from landfills. This includes the consideration of alternative uses for biofuels generated from methane recovery such as building heating, difficult to electrify mediums, heavy-duty transportation, and industrial applications. Casella is also supportive of efforts to increase recycling rates in municipal operations and communities, and enhancements to existing infrastructure, as we are committed to helping at the local level.

## Chapter 21 – Adaptation and Resilience

We agree with and are supportive of efforts to increase resiliency in New York. In the face of increasingly frequent and severe storms, we are making our business more resilient, so we pass that resilience along to our customers and communities. To ensure that we can continue to meet the service needs of our customers and communities during major storms, we maintain priority response plans and natural disaster guidance in our facility operating manuals. This includes planning for rapid deployment of workers and equipment to affected areas as well as operational, communication, and safety best practices. Our field operations at transfer station and disposal facilities are directly impacted by climate factors such as the size and frequency of rain events and the timing and frequency of freeze-thaw cycles. Shifts in these factors require us to revise aspects of our facility design and operating practices.

Casella is also supportive of strengthening meaningful community engagement, public education, and the building of adaptive capacity. In particular, we support the creation of vocational training, and driving job growth. We recently developed our own CDL program to provide success and growth for our employees. The program is paid for entirely by the company, with employees entering into the program already assigned to a position upon graduation. To date we have had 70 graduates receive their CDL licenses. In addition to the CDL program, we also provide development and career growth through our apprenticeship program for technicians, recruiting new team members from many backgrounds and helping them to build skills to thrive. Supporting more programs like these will ensure state goals and initiatives do not restrict residents, and instead, enable residents to align their job skills, and develop careers in conjunction with state initiatives.

We would like to thank NYSERDA, NYSDEC, and the CAC, for consideration of our comments.

Sincerely,

**CASELLA WASTE SYSTEMS, INC.**

Karen Flanders
Vice President, Sustainability & Regulatory

# SOLID WASTE MANAGEMENT HIERARCHY POLICY

## MANAGING WASTE TO REDUCE GREENHOUSE GAS EMISSIONS

*Comparing Emissions Per Unit Waste from Incinerators and Modern Landfills*

*Prepared for Casella Waste Systems, Inc.*
*File No. 2343.20*
*December 2020*

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**TABLES**

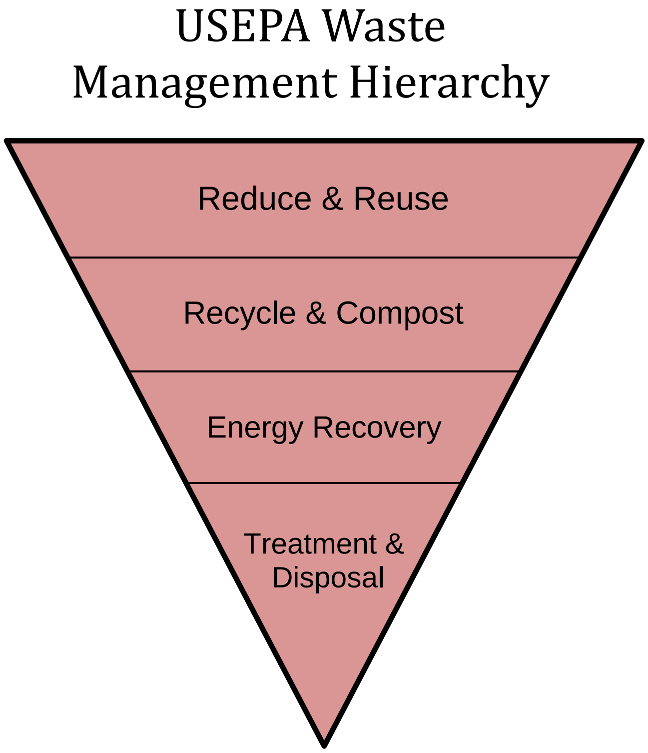
## 1.0 INTRODUCTION

On behalf of Casella Waste Systems, Inc., (Casella), Sanborn, Head & Associates, Inc. (Sanborn Head) prepared this report to present the findings of a study of greenhouse gas (GHG) emissions from solid waste landfills and incinerators. The purpose of the study is to assess the relative position of end-disposal options (solid waste landfills and incinerators) in solid waste management hierarchies. The results presented below indicate less GHG emissions per unit mass of waste from modern landfills than incinerators. Based on the results, solid waste management hierarchies should be organized such that landfills are at least on par with incinerators or, in fact, higher on the hierarchies to reflect GHG reductions goals.

## 2.0 BACKGROUND

Solid waste management hierarchies guide solid waste policy and decisions. Some state-level hierarchies rank incineration above landfilling, which is inconsistent with the U.S. Environmental Protection Agency's (USEPA's) hierarchy and does not properly reflect modern technology or emission data.

The USEPA promotes a solid waste management hierarchy (presented below) in which waste reduction/reuse and recycling/composting are the top two sets of waste management priorities. The next level on the USEPA hierarchy notably includes waste management practices that include energy recovery, followed by the least desirable strategy of treatment/disposal. Modern landfills with energy recovery (e.g., landfill gas-to-electricity, renewable natural gas, etc.) and incinerators are classified as energy recovery facilities.


USEPA Waste
Management Hierarchy

**USEPA guidance ranks landfills with energy recovery on par with waste-to-energy incinerators.**

Waste management hierarchies provide guidance on the prioritization of options for managing waste, setting the tone for the forms of handling and disposal that are perceived as better for the environment and public health. As general guidelines, such hierarchies can be helpful policy tools; as rigid and unchanging mandates, they can hinder innovation and drive environmentally harmful outcomes.

State-level waste hierarchies are generally similar in that the top tiers call for waste reduction, reuse, recycling, and composting. Some states' hierarchies differ, however, in their treatment of the lower tiers, namely in the relative ranking of landfilling and incineration.

Many state-level waste hierarchies were established at a time when landfill gas collection was not common practice, landfill gas-to-energy facilities were rare, and facility-level greenhouse gas emission reporting was not widely available. In this context, landfills were viewed as inferior to waste-to-energy incinerators. Today's active landfills are equipped with comprehensive gas collection systems and many have added energy recovery facilities.

In 2010, the USEPA began requiring facilities to report GHG emissions annually. Federal GHG data reported by landfills and incinerators have been used in this study to compare GHG emissions per unit waste.

## 2.1 Site Data

To compare GHG emissions per unit waste, we downloaded the most recent available Federal GHG reports[1], from 2018, for representative incinerators and modern landfills in the nine northeastern states: Vermont, New Hampshire, Maine, Rhode Island, Connecticut, Massachusetts, New York, New Jersey, and Pennsylvania. We downloaded Federal GHG reports for 13 incinerators and 26 landfills. We selected sites to have at least 10 types of each facility and to try to include at least one type of each site from each of the nine states. For landfills, we selected sites with collection efficiencies greater than 75 percent in Federal GHG reporting and focused on larger sites based on total GHG emissions. We also included each Casella landfill in these states and each applicable landfill in Maine and New Hampshire. For each of the incinerators, and for seven of the landfills, we also downloaded data from the United States Energy Information Administration (EIA)[2].

### *2.1.1 Incinerator Data*

We downloaded Federal GHG Reports and EIA data from 2018 for the following incinerators:

- Delaware Valley Resource Recovery Facility in Chester, Pennsylvania;
- Covanta Hempstead in Westbury, New York;
- SEMASS Partnership Resource Recovery Facility in Rochester, Massachusetts;
- Essex County Resource Recovery Facility in Newark, New Jersey;
- Wheelabrator Westchester L.P. in Peekskill, New York;

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[1] Federal Greenhouse Gas Reports are from: https://ghgdata.epa.gov/ghgp/main.do.
[2] EIA data are from: https://www.eia.gov/opendata/qb.php?category=1017.

- Wheelabrator Bridgeport L.P. in Bridgeport, Connecticut;
- Covanta Haverhill, Inc. in Haverhill, Massachusetts;
- Wheelabrator Falls in Morrisville, Pennsylvania;
- Wheelabrator Millbury, Inc. in Millbury, Massachusetts;
- Union County Resource Recovery Facility in Rahway, New Jersey;
- Wheelabrator Concord Company L.P. in Concord & Penacook, New Hampshire;
- Penobscot Energy Recovery Co. in Orrington, Maine; and
- Regional Waste Systems Incorporated/EcoMaine in Portland, Maine.

From the Federal GHG reports, for each incinerator we took the GHG emitted in units of carbon dioxide equivalents ($CO_2e$), including biogenic $CO_2$. From EIA, for each incinerator we took the electricity produced in units of megawatt-hours (MWh) and the tons of waste incinerated, including biogenic waste.

### *2.1.2 Landfill Data*

For the following landfills, we downloaded Federal GHG Reports from 2018, which include the total methane ($CH_4$) collected in units of metric tons (i.e., megagrams [Mg]) and the Mg of $CH_4$ used beneficially, such as for electricity generation:

- High Acres Landfill & Recycling Center in Fairport, New York;
- State-Owned Landfill in Old Town, Maine;
- North Country Environmental Services, Inc. Landfill in Bethlehem, New Hampshire;
- Ocean County Landfill in Manchester, New Jersey;
- Conestoga Landfill in Morgantown, Pennsylvania;
- Crossroads Landfill in Norridgewock, Maine;
- Keystone Sanitary Landfill in Dunmore, Pennsylvania;
- Middlesex County Landfill in East Brunswick, New Jersey;
- Modern Landfill in York, Pennsylvania;
- Modern Landfill, Inc. in Model City, New York;
- Monmouth County Reclamation Center in Tinton Falls, New Jersey;
- Seneca Meadows SWMF in Waterloo, New York;
- Windsor Bloomfield Landfill in Windsor, Connecticut;
- WM of NH - TREE (Turnkey Landfill) in Rochester, New Hampshire;
- Chemung County Landfill in Elmira, New York;
- Four Hills Landfill in Nashua, New Hampshire;
- Lebanon Landfill and Recycling Center in Lebanon, New Hampshire; and

- Mount Carberry Landfill in Berlin, New Hampshire.

For the following landfills, we downloaded the 2018 Federal GHG Reports and EIA data on the amount of LFG used for LFGTE:

- Fitchburg/Westminster Landfill and Recycling Center in Westminster, Massachusetts;
- Pennsauken Sanitary Landfill in Pennsauken, New Jersey;
- Rhode Island Resource Recovery Corporation in Johnston, Rhode Island;
- Southbridge Recycling & Disposal Park in Southbridge, Massachusetts;
- Clinton County Regional Landfill in Morrisonville, New York;
- Hyland Landfill in Angelica, New York; and
- Ontario County Landfill in Stanley, New York.

For the final landfill listed below, we downloaded the 2018 Federal GHG Report and we used data from the LFGTE operator website[3] to estimate the percentage of LFG collected during 2018 that was used beneficially:

- NEWSVT Landfill in Coventry, Vermont.

For each landfill, we took the following data from the Federal GHG reports:

- Collection efficiency;
- Combustion efficiency;
- Total $CH_4$ collected;
- Soil oxidation factor; and
- Methane generation rate constant.

#### 2.1.2.1 Methane Generation Potential

To model GHG emissions from each landfill per unit mass of waste, we assumed typical municipal solid waste (MSW), including biogenic waste, with a methane generation potential ($L_0$) of 100 cubic meters per megagram of waste ($m^3/Mg$). An $L_0$ value of 100 $m^3/Mg$ is the default value in the USEPA Compilation of Air Pollutant Emissions Factors Section 2.4 (AP-42). USEPA describes 100 $m^3/Mg$ as appropriate for most landfills, and our experience modeling landfills also supports using this value as representative of typical LFG generation. The default methane generation potential in Federal GHG reporting is equivalent to approximately 98.5 $m^3/Mg$.

#### 2.1.2.2 Methane Generation Rate

The methane generation rate constants (k) for LFG generation were taken from the Federal GHG reports for each site. For this modeling study, we considered 100 years of waste degradation, which results in near complete degradation of the waste with even the lowest

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[3] https://35coti2fdydv27b6wjrhdxq9-wpengine.netdna-ssl.com/wp-content/uploads/2019/04/April2019.pdf

k value. The different k values for the different sites, therefore, only have a minor impact on the results.

#### 2.1.2.3 Collection Efficiency

Estimated emissions from landfills are sensitive to the estimate for collection efficiency. Modern or low-emissions landfills (LELFs) use cover materials such as soil and geosynthetic membrane to increase collection efficiency, reducing GHG emissions and nuisance odors. Based on Table HH-3 of the Federal GHG reporting rule (40 CFR 98 Subpart HH), the efficiency of gas collection is as follows:

- 60 percent for areas with daily soil cover and active gas collection;
- 75 percent for areas with an intermediate soil cover, or a final soil cover not meeting the criteria for 95 percent collection; and
- 95 percent for areas with final soil cover of three feet or thicker of clay or final cover (as approved by the relevant agency) and/or geomembrane cover system and active gas collection.

According to AP-42, reported collection efficiencies typically range from 60 to 85 percent, with an average of 75 percent most commonly assumed. AP-42 states that higher collection efficiencies may be achieved at some sites (i.e., those engineered to control gas emissions). To focus on modern landfills, we selected landfills with reported collection efficiencies greater than 75 percent.

#### 2.1.2.4 Beneficial Use of Landfill Gas

For each site, we used the mass of $CH_4$ collected and the mass of $CH_4$ used beneficially to estimate the percentage of gas collected that is used beneficially. For the landfills that use gas beneficially, the predominant use is in landfill gas-to-energy (LFGTE) engines that combust the gas to produce electricity. Gas not used beneficially is flared.

An emerging technology is Renewable Natural Gas (RNG), which uses the LFG to create natural-gas pipeline quality gas, which can be used to power vehicles and reduce fossil fuel emissions from transportation. For this study, emissions offsets from beneficial use of LFG are based on LFGTE. RNG is expected to provide even greater emissions offsets.

#### 2.1.2.5 Combustion Efficiency

The default combustion efficiency for $CH_4$ in the USEPA's required Federal GHG reporting is 99 percent. For the purposes of estimating total GHG emissions from a landfill site, Federal GHG reporting considers methane conveyed offsite for combustion (e.g., to another facility) to be 100 percent combusted.

Estimated GHG emissions from the landfills are not sensitive to the combustion efficiency being 99 percent or greater than 99 percent. This has a minor effect compared to uncollected gas that is assumed to escape to the atmosphere. The collection efficiency discussed above has more influence on estimated GHG emissions.

#### 2.1.2.6 Soil Oxidation Factor

Landfills report soil oxidation factor based on Federal GHG reporting methodology. Depending on soil cover and USEPA equations in 40 CFR 98 Subpart HH, estimated oxidation of uncollected (i.e., fugitive) methane passing through the soil cover layer is 0, 10, 25, or 35 percent. We used the reported soil oxidation factor for each site associated with Equation HH-8, the final estimation equation in Subpart HH for methane emissions.

## 3.0 ESTIMATION METHODS

Based on the incinerator and landfill data discussed above, we estimated GHG emissions per ton of waste in units of $CO_2e$ for each incinerator and landfill. The methods used are discussed below.

### 3.1 Incinerators

For each incinerator, we have the following data from 2018:

- GHG emitted in units of $CO_2e$;
- Electricity produced in units of MWh; and
- Waste incinerated in units of tons.

Our goal is to estimate net emissions per ton of waste ($CO_2e$/ton). We estimated this by subtracting the estimated offsets (i.e., reductions in emissions elsewhere) from the reported 2018 emissions, and then dividing by the tons of waste combusted. We considered offsets for electricity production and metals recovery.

$$\textbf{Net Incinerator Emissions} = \frac{\textbf{Direct Emissions} - \textbf{Energy Offset} - \textbf{Metals Recycling Offset}}{\textbf{Tons of Waste Incinerated}}$$

For incinerators, the GHGs are emitted immediately upon combustion, whereas for landfills, the release of GHG emissions is slowed by the waste degradation process.

### *3.1.1 Offsets for Electricity Production*

We used the electricity produced at each site to estimate offsets based on USEPA's published values for non-baseload pounds of $CO_2e$ per MWh (lb $CO_2e$/MWh) by subregion[4].

### *3.1.2 Offsets for Metals Recovery*

For an offset for metals recovery, we used a factor from the documentation for USEPA's Waste Reduction Model (WARM)[5]. According to the document, 0.04 tons of $CO_2e$ are avoided per ton of mixed MSW combusted at incinerators due to steel recovery. The documentation states that EPA does not credit increased recycling of nonferrous materials due to a lack of data on the proportions of those materials being recovered.

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[4] https://www.epa.gov/sites/production/files/2020-01/documents/egrid2018_summary_tables.pdf

[5] https://www.epa.gov/sites/production/files/2019-10/documents/warm_v15_management_practices_updated_10-08-2019.pdf

### *3.1.3 Incinerator Emissions per Ton of Waste*

As mentioned above, for each incinerator, we estimated net GHG emissions per ton of waste. As shown in the attached incinerator Table 1, the average estimate from the 13 incinerators is 0.65 tons of $CO_2e$ per ton of waste.

| **Disposal Option** | **Estimated Emissions** (ton $CO_2e$/ton of waste) |
|---|---|
| Incinerator | 0.65 |

## 3.2 Landfills

To estimate total GHG emissions per ton of waste for each landfill, we modeled waste degradation using reported data for:

- Methane generation rate constant (k);
- Collection efficiency;
- Combustion efficiency;
- Soil oxidation factor; and
- Percentage of LFG used beneficially.

Modeling was performed using USEPA's Landfill Gas Emissions Model version 3.03 (LandGEM). We used the AP-42 default for methane generation potential, $L_0$, of 100 $m^3$/Mg. We assumed typical concentrations for $CH_4$ of 50 percent and carbon dioxide ($CO_2$) of 40 percent. Subpart HH Federal GHG reporting for landfills is for methane only, but we included $CO_2$ emissions, including biogenic $CO_2$, to estimate $CO_2e$ per ton of waste from each landfill. $CO_2$ comes from waste degradation in the landfill, from methane combustion, and from methane oxidized by cover soils.

We used the USEPA global warming potential for methane to estimate $CO_2e$. According to USEPA, a ton of methane has the global warming potential of 25 tons of $CO_2$.

LandGEM modeling was performed using each site's reported k value, which is based on annual average precipitation in the landfill area. LandGEM estimated LFG generation from waste degradation over a period of 100 years in units of standard cubic feet (scf).

Given the reported collection efficiency for each landfill, we estimated scf of collected LFG and scf of fugitive LFG. For collected LFG, we estimated stack emissions of $CH_4$ and $CO_2$ using the reported combustion efficiency for each landfill. For fugitive LFG, we estimated surface $CH_4$ and $CO_2$ emissions using the reported soil oxidation factor for each site.

Similar to incinerators, to estimate net emissions per ton of waste ($CO_2e$), we considered direct emissions and offsets. Landfills with energy recovery have an energy offset.

$$\textbf{Net Landfill Emissions} = \frac{\textbf{Direct Emissions} - \textbf{Energy Offset}}{\textbf{Tons of Waste Accepted}}$$

### *3.2.1 Offsets for Electricity Production*

We had two primary data sources for the percentage of gas that was used beneficially for each landfill: Federal GHG Reports and EIA. Federal GHG reporting allows different landfills to enter data differently (e.g., depending on the site's air permit), and only some sites include the mass of methane that goes to beneficial use. For the remaining sites, we used EIA data for the amount of LFG used beneficially in units of million British thermal units (MMBtu) and converted to units of Mg of $CH_4$ using the heat content of $CH_4$ (1,012 Btu/scf) and the molar volume of gas at standard conditions (379.5 scf/lbmol).

Based on the percentage of LFG used beneficially at each site, we estimated potential electricity generation. A typical LFGTE engine produces 1.6 megawatts from 550 scf per minute (scfm) of LFG with 50 percent $CH_4$. As with the incinerators above, offsets are based on USEPA's published values for non-baseload pounds of $CO_2$e per MWh (lb $CO_2$e/MWh) by subregion.

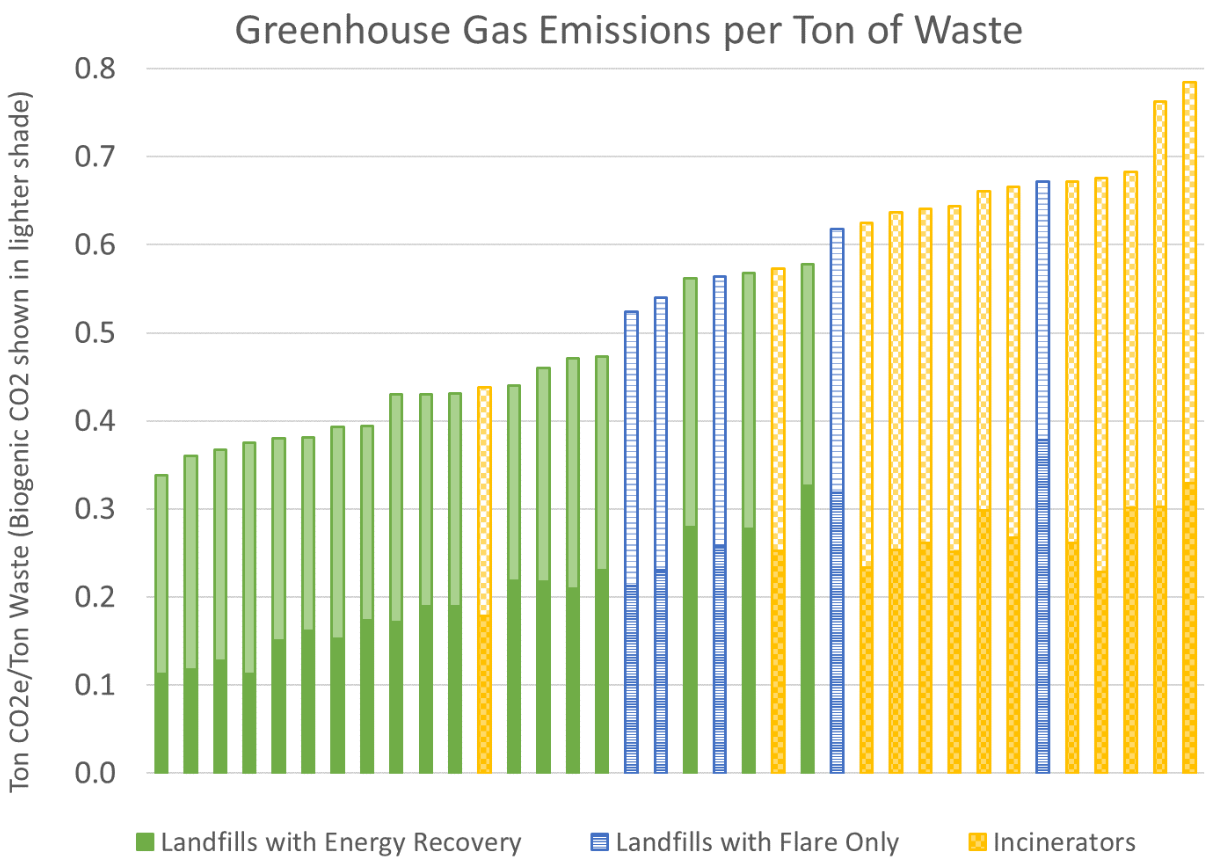
### *3.2.3 Landfill Emissions per Ton of Waste*

For each landfill, we estimated net GHG emissions per ton of waste by subtracting the estimated electricity offset, for the sites with beneficial use projects, from the reported 2018 emissions and then dividing by the tons of waste accepted. As shown in the attached landfill Table 2, the average estimate from the 26 landfills is 0.48 tons of $CO_2$e per ton of waste.

| **Disposal Option** | **Estimated Emissions** (ton $CO_2$e/ton of waste) |
|---|---|
| Landfill | 0.48 |

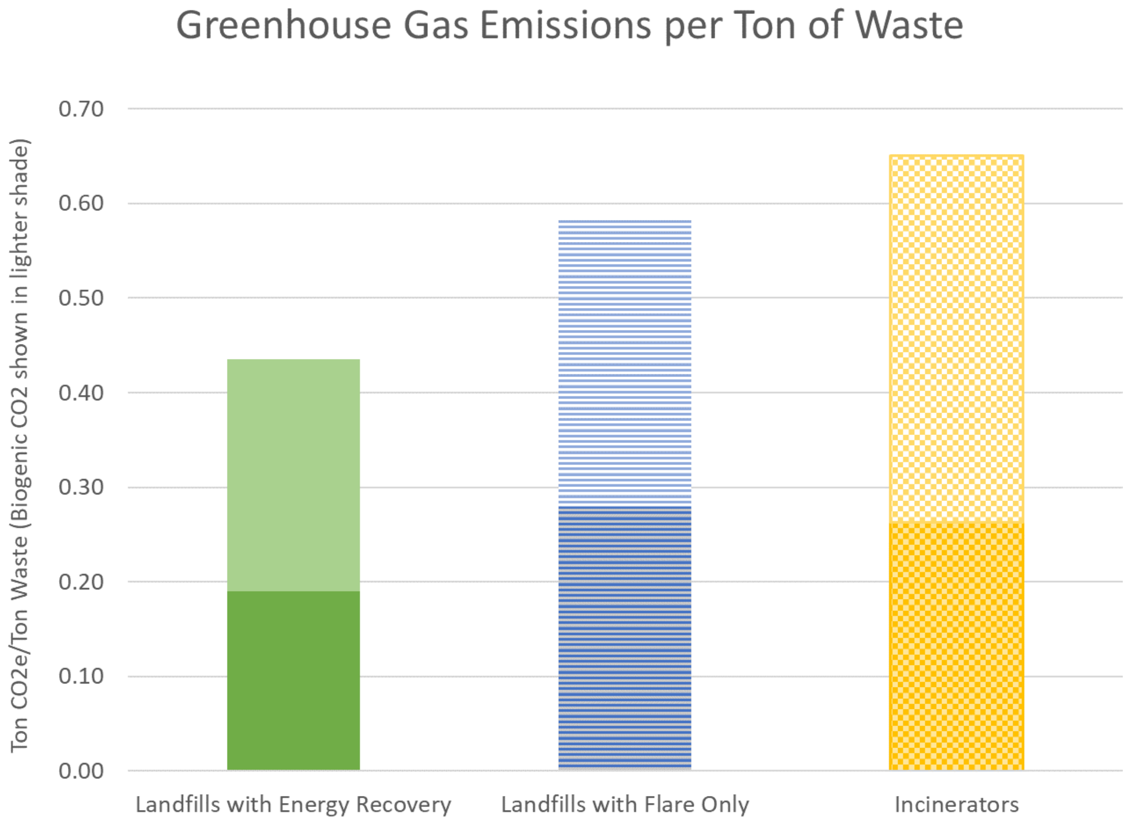
## 4.0 RESULTS AND CONCLUSIONS

The results of the study are summarized in the following chart which illustrate GHG emissions per ton of waste for individual landfills (energy recovery and flare-only facilities) and incinerators evaluated in this study. For the purposes of estimating total GHG emissions per ton of waste, we included the total $CO_2$ emitted per ton of waste, including $CO_2$ emissions defined as biogenic. Biogenic emissions of $CO_2$ are shown in a lighter shade. As shown, landfills with energy recovery as a group emit lower GHG emissions than incinerators.

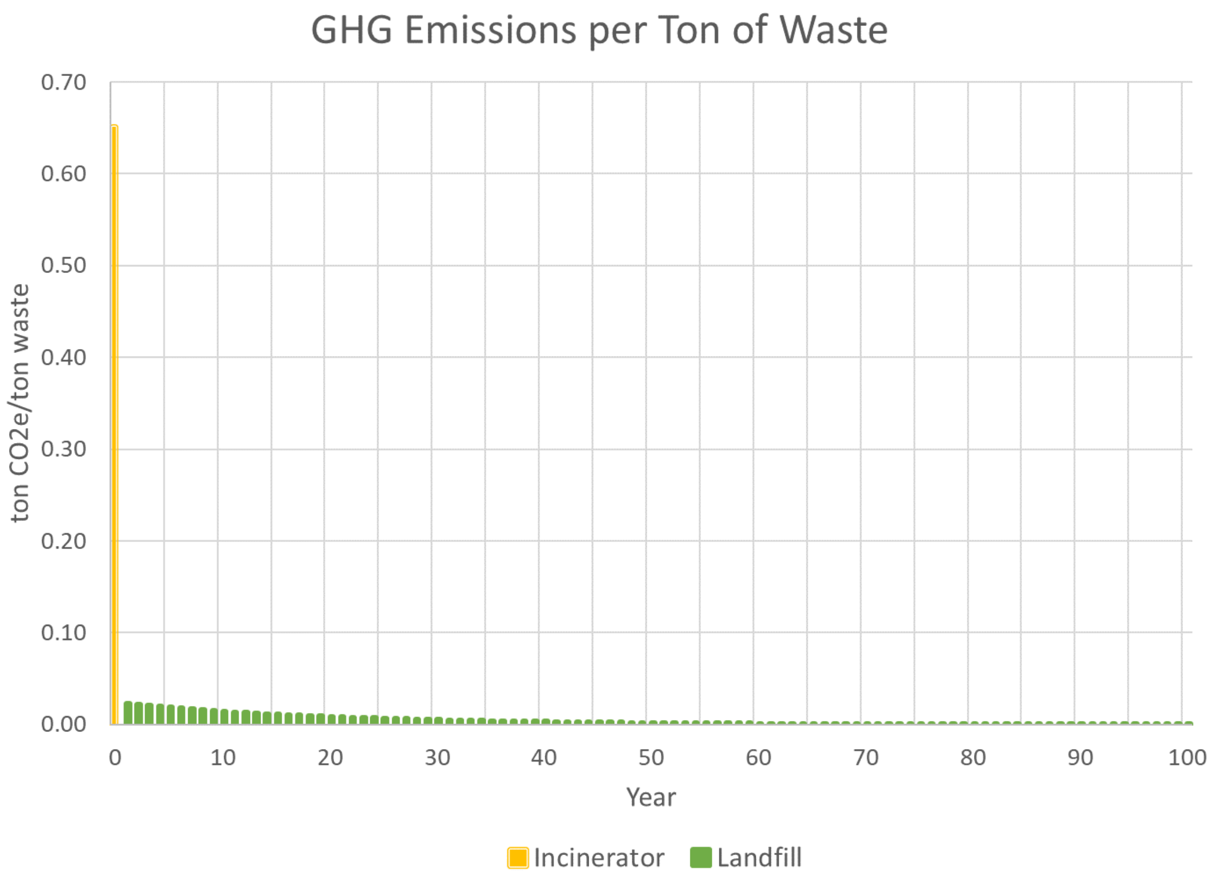


Average GHG emissions by group for each of the facilities (landfills [energy recovery and flare-only facilities] and incinerators) are summarized in the chart below. The values presented below include:

- 0.44 tons GHG emissions ($CO_2e$) per ton of waste for landfills with energy recovery;
- 0.58 tons GHG emissions ($CO_2e$) per ton of waste for landfills with flare only; and
- 0.65 tons GHG emissions ($CO_2e$) per ton of waste for incinerators.



Further, in addition to producing less GHG per ton of waste, landfills slow the release of the GHG. With an incinerator, the emissions are released immediately upon combustion, whereas in a landfill, the emissions are spread over decades.



Greenhouse gas reporting shows that modern landfills have significantly reduced emissions relative to landfills without energy recovery and modern landfills are often less carbon intensive than incinerators. The results of our study indicate that waste disposal in landfills instead of incinerators reduces total GHG emissions. Landfills with energy recovery offer even greater GHG savings. Promoting disposal of waste in landfills would help regulatory agencies meet GHG reductions goals.

Beneficial use of landfill gas through landfill gas-to-electricity, or renewable natural gas-to-vehicle fuel or direct natural gas pipeline injection; and the associated greenhouse gas reductions relative to incineration are important considerations to guide solid waste policy and decisions. Modern landfills with energy recovery should be ranked on solid waste hierarchies as equal to, or better than, incineration.

# TABLES

# Table 1 - Incinerator Summary

| Incinerator Number | Non-biogenic GHG Emissions in 2018 (ton $CO_2e$) | Biogenic GHG Emissions in 2018 (ton CO2e) | Total GHG Emissions in 2018 (ton $CO_2e$) | Total Waste Incinerated in 2018 (ton) | Electricity Produced in 2018 (MWh) | Non-baseload power offset factor (lbs $CO_2e$/MWh) | Power Offset (ton $CO_2e$) | Metals Offset (ton $CO_2e$) | Total Net Incinerator Emissions (ton $CO_2e$) | Non-biogenic Net Incinerator Emissions (ton $CO_2e$/ton waste) | Biogenic Net Incinerator Emissions (ton $CO_2e$/ton waste) | Total Net Incinerator Emissions (ton $CO_2e$/ton waste) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 409,646 | 597,739 | 1,007,384 | 1,273,440 | 629,079 | 1,249 | 392,734 | 56,161 | 558,490 | 0.18 | 0.26 | 0.44 |
| 2 | 405,796 | 680,978 | 1,086,774 | 1,037,652 | 593,975 | 1,323 | 392,855 | 45,762 | 648,157 | 0.23 | 0.39 | 0.62 |
| 3 | 390,473 | 608,321 | 998,794 | 1,064,442 | 568,249 | 937 | 266,083 | 46,943 | 685,768 | 0.25 | 0.39 | 0.64 |
| 4 | 388,583 | 587,907 | 976,490 | 985,055 | 489,973 | 1,249 | 305,890 | 43,442 | 627,158 | 0.25 | 0.38 | 0.64 |
| 5 | 307,248 | 469,189 | 776,437 | 700,475 | 394,972 | 1,069 | 211,093 | 30,892 | 534,452 | 0.30 | 0.46 | 0.76 |
| 6 | 291,862 | 433,741 | 725,603 | 745,227 | 420,625 | 937 | 196,958 | 32,866 | 495,780 | 0.27 | 0.40 | 0.67 |
| 7 | 272,303 | 377,092 | 649,395 | 594,055 | 335,821 | 937 | 157,248 | 26,199 | 465,948 | 0.33 | 0.46 | 0.78 |
| 8 | 223,084 | 323,482 | 546,566 | 509,371 | 316,470 | 1,249 | 197,572 | 22,464 | 326,529 | 0.26 | 0.38 | 0.64 |
| 9 | 219,521 | 278,289 | 497,809 | 479,326 | 319,457 | 937 | 149,586 | 21,139 | 327,085 | 0.30 | 0.38 | 0.68 |
| 10 | 217,112 | 340,578 | 557,690 | 537,192 | 277,403 | 1,249 | 173,183 | 23,691 | 360,817 | 0.26 | 0.41 | 0.67 |
| 11 | 81,468 | 98,842 | 180,310 | 191,053 | 97,300 | 937 | 45,561 | 8,426 | 126,324 | 0.30 | 0.36 | 0.66 |
| 12 | 67,893 | 132,912 | 200,805 | 201,043 | 119,823 | 937 | 56,107 | 8,866 | 135,831 | 0.23 | 0.45 | 0.68 |
| 13 | 65,294 | 82,877 | 148,172 | 176,169 | 84,173 | 937 | 39,414 | 7,769 | 100,988 | 0.25 | 0.32 | 0.57 |
| | | | | | | | | | **Average** | **0.26** | **0.39** | **0.65** |

| | | |
|---|---|---|
| Metals offset | 0.04 | Mg $CO_2e$/ton MSW |

# Table 2 - Landfill Summary

| **Landfill Number** | **Modeled LFG Generation (scf at 50% $CH_4$/ ton waste)** | **Modeled LFG Generation (Mg $CH_4$/ ton waste)** | **Reported Soil Oxidation** | **Reported Collection Efficiency** | **Reported Combustion Efficiency** | **Modeled Landfill Non-Biogenic Emissions (ton $CO_2e$/ ton waste)** | **Modeled Landfill Biogenic Emissions (ton $CO_2e$/ ton waste)** | **Modeled Landfill Emissions (ton $CO_2e$/ ton waste)** | **Reported Total $CH_4$ Collected in 2018 (Mg)** | **Beneficial Use Reported in Federal GHG Rpt** | **$CH_4$ Used Beneficially in 2018 (Mg)** | **Source for $CH_4$ Used Beneficially** | **Modeled Beneficial Use (Mg $CH_4$)** | **Modeled Electricity Generation (MWh)** | **Region for Offset** | **Non-Biogenic Offset (ton CO2e)** | **Biogenic Offset (ton CO2e)** | **Modeled Offset (ton $CO_2e$)** | **Modeled Net Non-Biogenic Emissions (ton $CO_2e$/ ton waste)** | **Modeled Net Biogenic Emissions (ton $CO_2e$/ ton waste)** | **Modeled Net Emissions (ton $CO_2e$/ ton waste)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6,407 | 0.0614 | 0.25 | 0.77 | 0.99 | **0.30** | **0.302** | **0.60** | 30,920 | LFGTE | 10,215 | Federal GHG Rpt | 0.020 | 0.08 | NYUP | 0.02 | 0.02 | 0.04 | 0.28 | 0.28 | 0.56 |
| 2 | 6,407 | 0.0614 | 0.1 | 0.87 | 0.99 | **0.21** | **0.311** | **0.52** | 6,775 | flare only | 0 | Federal GHG Rpt | 0.000 | 0.00 | NEWE | 0.00 | 0.00 | 0.00 | 0.21 | 0.31 | 0.52 |
| 3 | 6,407 | 0.0614 | 0.1 | 0.82 | 0.99 | **0.29** | **0.303** | **0.59** | 11,730 | LFGTE | 11,537 | WEC Newsletter | 0.060 | 0.25 | NEWE | 0.06 | 0.06 | 0.12 | 0.23 | 0.24 | 0.47 |
| 4 | 6,407 | 0.0614 | 0.1 | 0.76 | 0.99 | **0.38** | **0.293** | **0.67** | 11,599 | flare only | 0 | Federal GHG Rpt | 0.000 | 0.00 | NEWE | 0.00 | 0.00 | 0.00 | 0.38 | 0.29 | 0.67 |
| 5 | 6,407 | 0.0614 | 0.1 | 0.90 | 0.996 | **0.16** | **0.317** | **0.47** | 28,004 | LFGTE | 24,065 | Federal GHG Rpt | 0.053 | 0.22 | RFCE | 0.05 | 0.09 | 0.14 | 0.11 | 0.23 | 0.34 |
| 6 | 6,407 | 0.0614 | 0.25 | 0.84 | 0.9995 | **0.20** | **0.312** | **0.52** | 29,779 | LFGTE | 25,297 | Federal GHG Rpt | 0.052 | 0.22 | RFCE | 0.05 | 0.08 | 0.14 | 0.15 | 0.23 | 0.38 |
| 7 | 6,407 | 0.0614 | 0.35 | 0.79 | 0.99 | **0.24** | **0.308** | **0.55** | 4,662 | LFGTE | 4,651 | Federal GHG Rpt | 0.061 | 0.25 | NEWE | 0.05 | 0.07 | 0.12 | 0.19 | 0.24 | 0.43 |
| 8 | 6,407 | 0.0614 | 0.25 | 0.82 | 0.99 | **0.25** | **0.307** | **0.55** | 11,578 | LFGTE | 8,090 | EIA | 0.043 | 0.18 | NEWE | 0.04 | 0.05 | 0.08 | 0.21 | 0.26 | 0.47 |
| 9 | 6,407 | 0.0614 | 0.1 | 0.92 | 0.9903 | **0.14** | **0.319** | **0.46** | 58,624 | "Offsite Control" | 29,820 | Federal GHG Rpt | 0.031 | 0.13 | RFCE | 0.02 | 0.06 | 0.08 | 0.11 | 0.26 | 0.38 |
| 10 | 6,407 | 0.0614 | 0.25 | 0.77 | 0.996 | **0.30** | **0.302** | **0.60** | 20,505 | LFGTE | 20,416 | Federal GHG Rpt | 0.061 | 0.25 | RFCE | 0.08 | 0.08 | 0.16 | 0.22 | 0.22 | 0.44 |
| 11 | 6,407 | 0.0614 | 0.25 | 0.83 | 0.99 | **0.23** | **0.309** | **0.54** | 24,379 | flare only | 0 | Federal GHG Rpt | 0.000 | 0.00 | RFCE | 0.00 | 0.00 | 0.00 | 0.23 | 0.31 | 0.54 |
| 12 | 6,407 | 0.0614 | 0.25 | 0.82 | 0.99 | **0.24** | **0.308** | **0.55** | 15,152 | LFGTE | 15,112 | Federal GHG Rpt | 0.061 | 0.25 | NYUP | 0.05 | 0.07 | 0.12 | 0.19 | 0.24 | 0.43 |
| 13 | 6,407 | 0.0614 | 0.1 | 0.85 | 0.98 | **0.24** | **0.308** | **0.55** | 9,682 | Turbines | 9,485 | Federal GHG Rpt | 0.060 | 0.25 | RFCE | 0.07 | 0.09 | 0.16 | 0.17 | 0.22 | 0.39 |
| 14 | 6,407 | 0.0614 | 0.1 | 0.86 | 0.99 | **0.23** | **0.309** | **0.54** | 1,212 | LFGTE | 1,183 | EIA | 0.060 | 0.25 | RFCE | 0.07 | 0.09 | 0.16 | 0.16 | 0.22 | 0.38 |
| 15 | 6,407 | 0.0614 | 0.25 | 0.89 | 0.99 | **0.15** | **0.317** | **0.47** | 41,338 | LFGTE | 38,793 | EIA | 0.058 | 0.24 | NEWE | 0.04 | 0.08 | 0.11 | 0.12 | 0.24 | 0.36 |
| 16 | 6,407 | 0.0614 | 0.25 | 0.84 | 0.997 | **0.21** | **0.312** | **0.52** | 65,199 | LFGTE | 48,485 | Federal GHG Rpt | 0.046 | 0.19 | NYUP | 0.04 | 0.05 | 0.09 | 0.17 | 0.26 | 0.43 |
| 17 | 6,407 | 0.0614 | 0.1 | 0.82 | 0.99 | **0.29** | **0.303** | **0.59** | 9,568 | LFGTE | 1,813 | EIA | 0.012 | 0.05 | NEWE | 0.01 | 0.01 | 0.02 | 0.28 | 0.29 | 0.57 |
| 18 | 6,407 | 0.0614 | 0.1 | 0.84 | 0.99 | **0.26** | **0.306** | **0.56** | 1,201 | flare only | 0 | Federal GHG Rpt | 0.000 | 0.00 | NEWE | 0.00 | 0.00 | 0.00 | 0.26 | 0.31 | 0.56 |
| 19 | 6,407 | 0.0614 | 0.25 | 0.85 | 0.996 | **0.20** | **0.313** | **0.51** | 31,752 | LFGTE/Solar Turbines | 31,175 | Federal GHG Rpt | 0.060 | 0.25 | NEWE | 0.05 | 0.07 | 0.12 | 0.15 | 0.24 | 0.39 |
| 20 | 6,407 | 0.0614 | 0.1 | 0.80 | 0.99 | **0.32** | **0.299** | **0.62** | 3,813 | flare only | 0 | Federal GHG Rpt | 0.000 | 0.00 | NYUP | 0.00 | 0.00 | 0.00 | 0.32 | 0.30 | 0.62 |
| 21 | 6,407 | 0.0614 | 0.1 | 0.90 | 0.99 | **0.17** | **0.316** | **0.48** | 6,086 | LFGTE | 5,925 | EIA | 0.060 | 0.25 | NYUP | 0.04 | 0.08 | 0.12 | 0.13 | 0.24 | 0.37 |
| 22 | 6,407 | 0.0614 | 0.1 | 0.76 | 0.99 | **0.38** | **0.293** | **0.67** | 9,296 | LFGTE | 7,250 | EIA | 0.048 | 0.20 | NYUP | 0.05 | 0.04 | 0.09 | 0.33 | 0.25 | 0.58 |
| 23 | 6,407 | 0.0614 | 0.1 | 0.83 | 0.99 | **0.27** | **0.304** | **0.58** | 17,209 | LFGTE | 16,982 | EIA | 0.061 | 0.25 | NYUP | 0.06 | 0.06 | 0.12 | 0.22 | 0.24 | 0.46 |
| 24 | 6,407 | 0.0614 | 0.1 | 0.90 | 0.997 | **0.17** | **0.316** | **0.48** | 3,560 | LFGTE | 2,998 | EIA | 0.052 | 0.22 | NEWE | 0.03 | 0.07 | 0.10 | 0.13 | 0.25 | 0.38 |
| 25 | 6,407 | 0.0614 | 0.1 | 0.83 | 0.98 | **0.27** | **0.304** | **0.58** | 1,472 | flare only | 0 | Federal GHG Rpt | 0.000 | 0.00 | NEWE | 0.00 | 0.00 | 0.00 | 0.27 | 0.30 | 0.58 |
| 26 | 6,407 | 0.0614 | 0.0 | 0.78 | 0.99 | **0.39** | **0.292** | **0.68** | 6,758 | LFGE-Mill | 6 | Federal GHG Rpt | 0.000 | 0.00 | NEWE | 0.00 | 0.00 | 0.00 | 0.39 | 0.29 | 0.68 |
|  |  |  |  |  | **Average** | **0.25** | **0.31** | **0.56** |  |  |  |  |  |  |  |  |  | **Average** | **0.22** | **0.26** | **0.48** |

Waste Management Corner

*EM* is expanding its content coverage of waste management issues with a special section of waste-themed articles, called *Waste Management Corner*. In this month's article, the authors consider the implications of carbon emissions profiles for the landfill industry.

# Renewable Natural Gas and the Implications for Waste Management Hierarchies

### by Luke C. Teal and Jeffrey J. Doris

> *"Climate-related risks will continue to grow without additional action. Decisions made today determine risk exposure for current and future generations and will either broaden or limit options to reduce the negative consequences of climate change."*
> –2018, Fourth National Climate Assessment, Volume II[1]

We are living in a world with a changing climate and professionals across disciplines are making efforts to identify how their industry can be part of the solution. So, what about the landfill industry in particular? What technological advances has the industry made to reduce its carbon footprint? In addition, how does the carbon emission profile for landfills that employ carbon reduction technology compare with the profiles for other methods of managing waste within typical waste management hierarchies? This article presents a recently completed study that addresses this question, and briefly describes the study methods and findings.

## Landfills and Climate Change

Overall emissions of greenhouse gas (GHG) from landfills are attributable primarily to the emissions of landfill gas (LFG), consisting mostly of the two GHGs: methane ($CH_4$) and carbon dioxide ($CO_2$). Landfill gas is generated by the anaerobic decomposition of waste in landfills and is about 50% $CH_4$ and 50% $CO_2$. Landfill operators capture landfill gas and combust it, converting the $CH_4$ to $CO_2$, reducing the environmental impact ($CH_4$ has an estimated global warming potential 25 times greater than $CO_2$). Often this combustion is done in a flare, but if there is enough LFG to warrant the capital costs, the $CH_4$ can become a resource with energy production potential, namely, a biogas fuel product.

Landfill gas-to-energy (LFGTE) engines capitalize on that potential by combusting LFG as a fuel to generate electricity.

The electricity generated can offset power produced by fossil fuels, reducing the landfill's environmental impact even further. However, burning LFG in engines produces byproduct emissions (e.g., nitrogen oxides [$NO_x$] and formaldehyde) at concentrations that can make it challenging for these LFG beneficial-use projects to meet air quality standards. This along with other economic factors have shifted the industry focus away from LFGTE toward renewable natural gas (RNG).[2]

## An RNG Primer

According to the U.S. Environmental Protection Agency's (EPA) Landfill Methane Outreach Program (LMOP), as of August 2020, 52 of the 67 LFG energy projects that are reported to be in the planning or construction phase in the United States are RNG projects.[3]

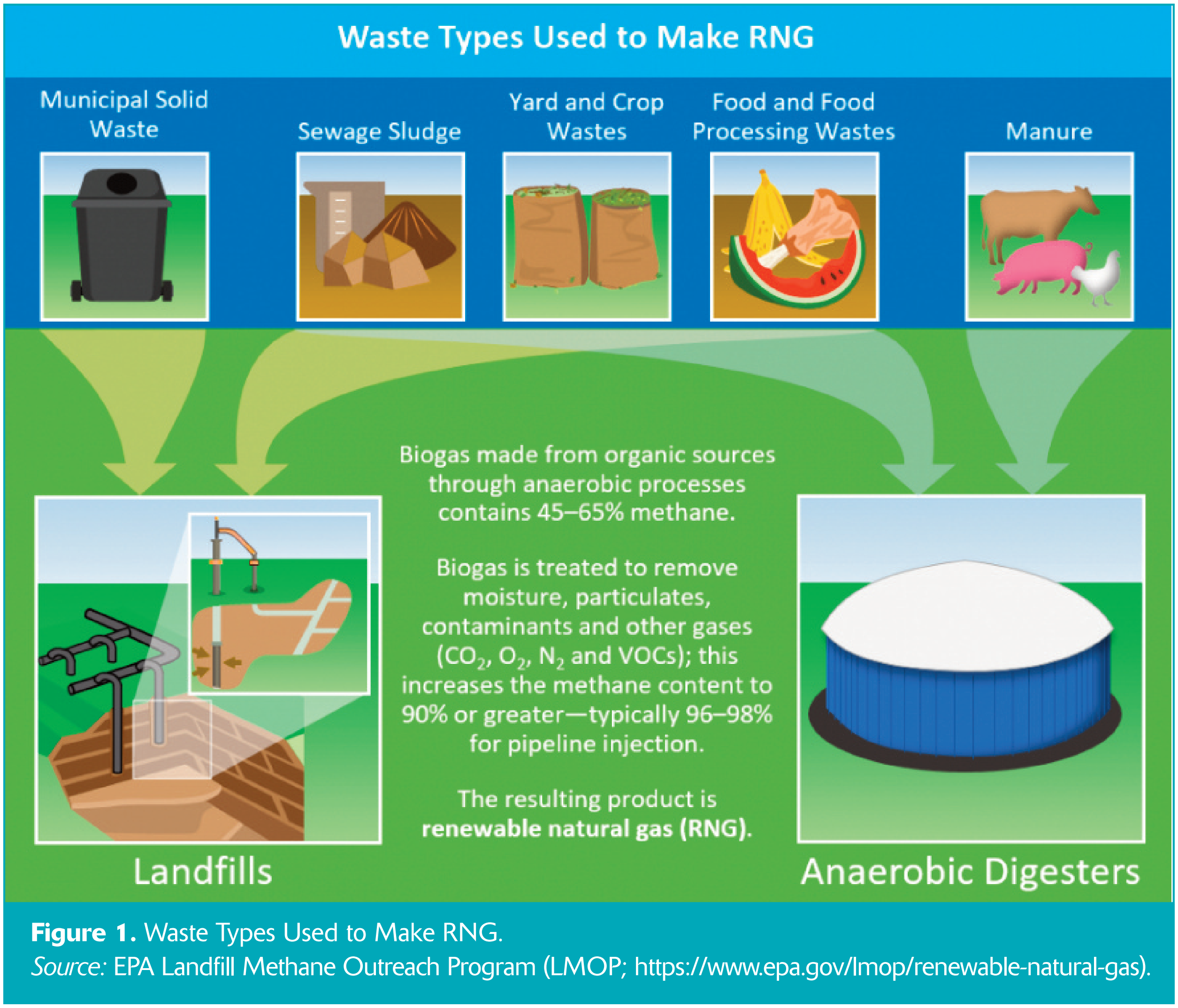
RNG is a refined biogas and can be produced at landfills by removing the contaminants in the collected LFG to increase the $CH_4$ concentration to near 100% (see Figures 1 and 2). Typical treatments include dewatering, siloxane removal, and filtering to remove contaminants such as oxygen, nitrogen, $CO_2$, and volatile organic compounds (VOCs). A thermal oxidizer is typically used to manage waste gas. The resulting RNG is similar in quality to natural gas and can be injected into the natural gas pipeline system for use by natural gas customers. In a similar way to LFGTE facilities, RNG is used to offset fossil fuel use, specifically, natural gas use. Using landfill RNG to displace the use of natural gas reduces the net GHG emissions from landfills.

The use of landfill RNG to reduce GHG emissions begets the question, "where should landfilling with RNG production sit within the waste management hierarchies that guide waste disposal methods?" We address this question next.

## Waste Management Hierarchies

Waste management hierarchies provide guidance on the prioritization of options for managing waste, setting the tone for the forms of handling and disposal that are understood to be better for the environment and public health.

EPA promotes a solid waste management hierarchy (see Figure 3) in which waste reduction/reuse and recycling/



Biogas made from organic sources through anaerobic processes contains 45–65% methane.

Biogas is treated to remove moisture, particulates, contaminants and other gases ($CO_2$, $O_2$, $N_2$ and VOCs); this increases the methane content to 90% or greater—typically 96–98% for pipeline injection.

The resulting product is **renewable natural gas (RNG).**

**Figure 1.** Waste Types Used to Make RNG.
*Source:* EPA Landfill Methane Outreach Program (LMOP; https://www.epa.gov/lmop/renewable-natural-gas).

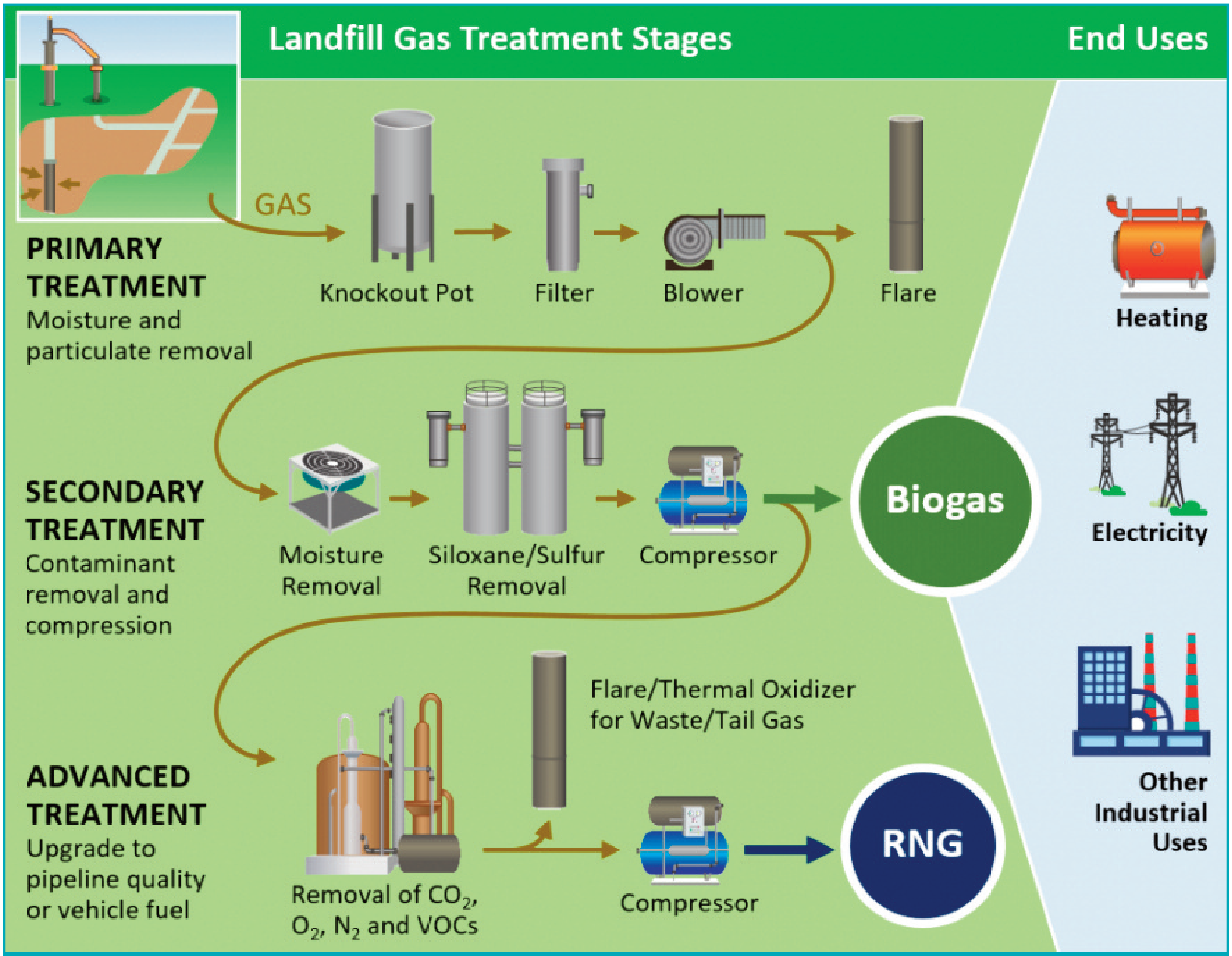


**Figure 2.** Landfill Gas Treatment to Produce Biogas and RNG.
*Source:* EPA Landfill Methane Outreach Program (LMOP; https://www.epa.gov/lmop/renewable-natural-gas).

composting are the top two sets of waste management priorities. The next levels on the EPA hierarchy are waste management practices that include energy recovery, followed by the least desirable strategy of waste treatment/disposal. Modern landfills with energy recovery, such as with RNG production, and waste-to-energy (WTE) combustion plants are considered energy recovery facilities.

According to EPA, landfilling in the United States is often considered a more viable option than WTE facilities due to the low economic cost of building a municipal solid waste (MSW) landfill versus an MSW combustion facility.[4] Despite having an economic advantage, at the state and local levels, some hierarchies rank landfills, even with energy recovery, lower than WTE facilities. These hierarchies may have been established when landfill gas collection was not common practice, landfill gas-to-energy facilities were rare, and facility-level greenhouse gas emission reporting was not widely available. In this context, landfills may have been considered a less desirable option.

To evaluate the proper ranking of RNG Landfills in waste management hierarchies, this assessment estimated the GHG emissions per ton of waste going to a landfill and producing RNG that is used to power vehicles, versus the GHG emissions per ton of waste going to a WTE facility. The vehicle type was assumed to be larger vehicles that are normally fueled with diesel fuel, such as long-haul trucks, that would be converted to RNG fueling instead. Simply stated, this assessment evaluates how total facility GHG emissions compare for an RNG landfill versus a WTE facility.

## Methodology

To comparatively assess the GHG emissions, federal GHG emission reports[5] from 2018 were used for representative WTE facilities and modern landfills operating in the Northeast United States. Data were also used from the U.S. Energy Information Administration (EIA)[6] for the amount of waste combusted in and the electricity generated by these WTE facilities.

### Selection of Representative WTE Facilities and Landfills

For this evaluation of comparative GHG emissions, 13 WTE facilities and 23 landfills were selected from nine northeastern states: Vermont, New Hampshire, Maine, Rhode Island,

**Figure 3.** Hierarchy of Waste Management. *Source:* EPA (https://www.epa.gov/smm/sustainable-materials-management-non-hazardous-materials-and-waste-management-hierarchy ).

Connecticut, Massachusetts, New York, New Jersey, and Pennsylvania. WTE facilities were selected by screening for the largest GHG emitters in the Northeast and then adding WTE facilities to provide representation from each state (note that Vermont does not have WTE facilities that report federal GHG emissions).

Landfills were similarly selected based on size and geography, as well as LFG collection efficiency. According to the EPA Compilation of Air Pollutant Emissions Factors Section 2.4[7] (AP-42), reported collection efficiencies typically range from 60% to 85%, with an average of 75% most commonly assumed. To focus on modern landfills, landfills with reported collection efficiencies of 75% or greater were selected.

### Estimating Comparative GHG Emissions

To estimate the net GHG emissions per ton of waste combusted for each WTE facility, reported site-specific values were used for:

- total GHG emitted in units of carbon dioxide equivalents ($CO_2e$);
- tons of waste combusted; and
- electricity produced in units of megawatt-hours (MWh).

Electricity generated at WTE facilities offsets electricity generated at other power plants. In accordance with EPA guidance for an avoided emissions analysis, energy offsets were estimated using EPA's published values for non-baseload lb $CO_2e$/MWh by sub-region.[8] WTE facilities also avoid emissions through metals recovery. EPA's Waste Reduction Model (WARM)[9] documents tons of $CO_2e$ avoided per ton of mixed MSW combusted due to steel recovery. The net WTE emission of GHG per ton of waste combusted was calculated per the following equation:

$$\textbf{Net WTE Emissions} = \frac{\textbf{(Direct Emissions - Energy Offset - Metals Recycling Offset)}}{\textbf{(Tons of Waste Combusted)}}$$

To estimate GHG emissions from each RNG landfill per ton of waste landfilled, MSW of a typical composition was assumed with a landfill $CH_4$ generation potential ($L_0$) of 100 cubic meters per megagram of waste ($m^3$/Mg). An $L_0$ value of 100 $m^3$/Mg is the default value in the EPA Compilation of Air Pollutant Emissions Factors[7] Section 2.4 (AP-42) and is described as appropriate for most landfills.

For each landfill, reported site-specific values were used for:

- $CH_4$ generation rate constant (k);
- landfill gas collection efficiency; and
- soil methane oxidation factor.

The reported k values were used to model the rate of waste degradation using the EPA Landfill Gas Emissions Model (LandGEM)[10] to show how the modeled emissions of $CH_4$ are spread over decades, as opposed to WTE facilities that emit GHGs immediately upon combustion.

As noted above, the landfill gas collection system at a modern landfill is assumed to collect at least 75% of the LFG; this means that the remaining fraction of LFG becomes a "fugitive" GHG emitted through the landfill cover to the air. As the fugitive GHG passes through the landfill cover, some of the $CH_4$ is converted to $CO_2$ (between 10% and 35% based on EPA reporting guidance). This is the soil $CH_4$ oxidation factor. Reported site-specific values were used to estimate both the landfill gas collection efficiency and soil $CH_4$ oxidation factors to estimate this significant GHG emission in the calculation of net GHG emissions for an RNG landfill.

It was assumed that the collected LFG from each landfill would go to an RNG plant that refines the LFG to RNG, and then provides the RNG (now nearly 100% $CH_4$) for use as a vehicle fuel to offset diesel use. The process of refining LFG to RNG does result in other emissions of GHG at the RNG plant. The operation of the RNG plant results in GHG emissions from the waste gas thermal oxidizer and from the source of power used to run the plant. Based on EPA guidance, the RNG plant has an estimated energy consumption of 0.009 kilowatt-hours per standard cubic foot (scf) of LFG.[11]

Finally, the reduction in tailpipe GHG emissions was estimated for vehicles when those vehicles are fueled with RNG rather than diesel fuel. Specifically, the net GHG emission reduction was determined when the GHG emissions from diesel-fueled vehicles are offset by the lower GHG emissions from RNG-powered vehicles. This was done using Argonne

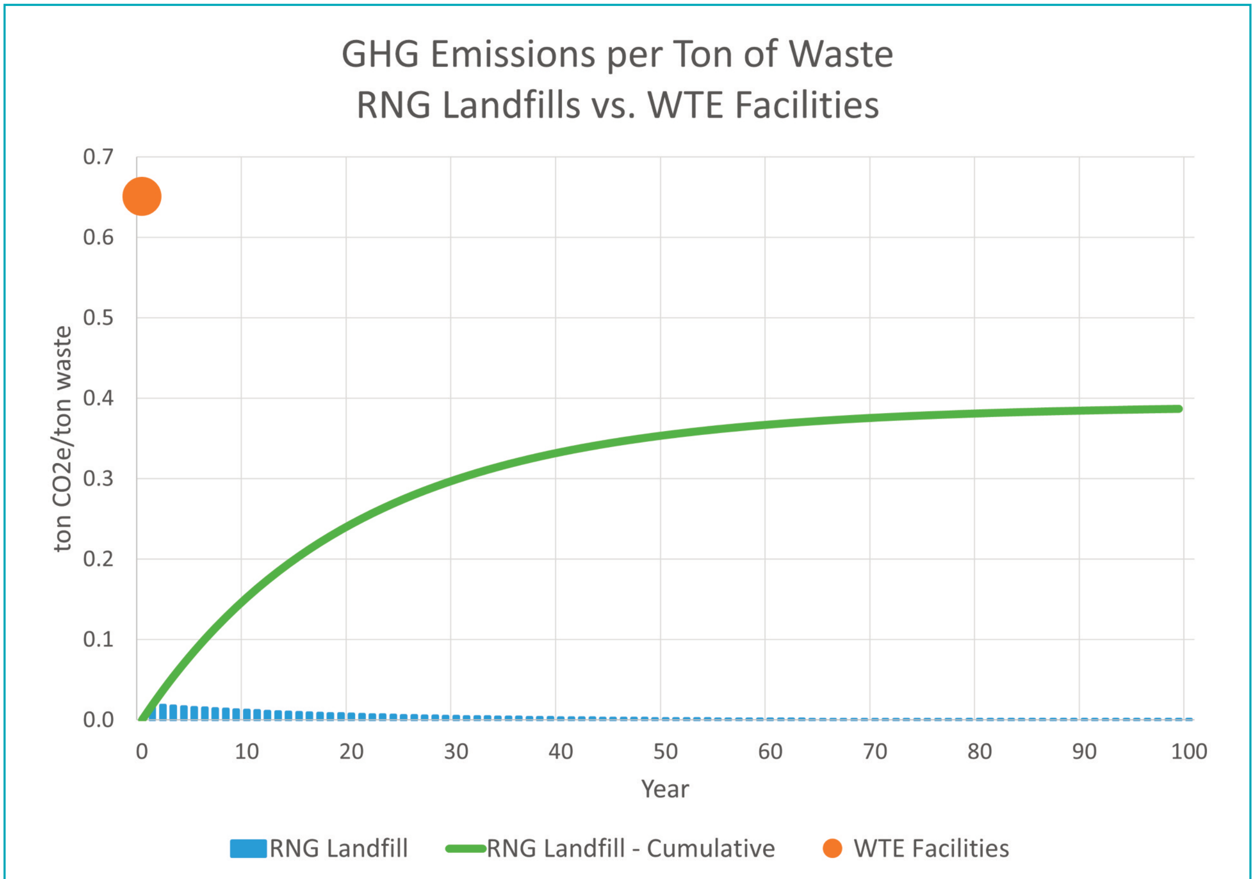


**Figure 4.** GHG Emissions: RNG Landfills vs. WTE Facilities.
*Notes:* Average total GHG emissions per ton of waste over time. WTE Facility (orange) emissions are immediate. Emissions from landfills with RNG accumulate over time (green), decreasing each year (blue).

*Source:* Sanborn Head & Associates.

National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy use in Technologies Model (GREET).[12]

$$\textbf{Net Landfill RNG Emissions} = \frac{\textbf{(Direct Emissions - Energy Offset)}}{\textbf{(Tons of Waste Accepted )}}$$

This methodology allows for the use of real-world data using established EPA modeling methods to fill in the gaps.

## Results and Observations

Using these methods, the average estimated net GHG emissions per ton of waste for WTE facilities and for landfills producing RNG were 0.65 and 0.39 tons $CO_2$e/ton of waste, respectively. Figure 4 shows how a single ton of waste combusted or landfilled today (year zero) would produce emissions over the following 100 years. With a WTE facility, the emissions are released immediately upon combustion, while in a landfill, the emissions are spread over time.

From a GHG emissions perspective, these results support the EPA waste hierarchy that recognizes the GHG benefit of energy recovery from LFG. Figure 4 demonstrates how advancements in landfill operations can contribute to the global effort of limiting GHG emissions and can help state and local planners with their task of effectively managing solid waste in an environmentally conscious manner.

In other studies that have been completed to compare the emissions impacts of WTE and landfilling, results have been varied.[13,14] Common reasons cited for the discrepancy about which option results in lower estimates for GHG emissions are (a) how (or if) an analysis accounts for the sequestration of carbon in landfills, and (b) the estimate for LFG collection efficiency.

In a landfill, some waste does not completely degrade and the carbon from that waste becomes permanently stored or sequestered. In particular, fossil-fuel based waste such as plastics remain undegraded, but also some waste that would typically degrade completely if left in an aerobic environment.[9] Because the methane generation value for $L_0$ from EPA is based on observed LFG generation instead of theoretical anaerobic decay, and because the evaluation is based on total emissions (biogenic and anthropogenic), the approach used in this study reflects the reality that a portion of the carbon remains stored in the landfill, not generating $CH_4$ or $CO_2$.

Modern landfills designed for energy recovery projects typically achieve collection efficiencies greater than 75%. This study was based on collection efficiencies reported by landfills ranging from 76% to 92%. Another study estimated that the emissions per ton of waste from landfills become less than the emissions from WTE facilities when the LFG collection efficiency reaches the range of approximately 50–70%.[14]

Comparative assessments of GHG emissions such as presented here for RNG landfills versus WTE facilities are based on the application of specific methods and assumptions. As noted above, results could vary from those discussed here if different assumptions are made regarding certain factors, such as the estimation method for landfill carbon sequestration and estimates for LFG collection efficiency. **em**

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