Landfill Gas-to-Energy Projects May Release More Greenhouse Gases Than Flaring

Prepared by Jim R. Stewart, PhD,[1] January 2013

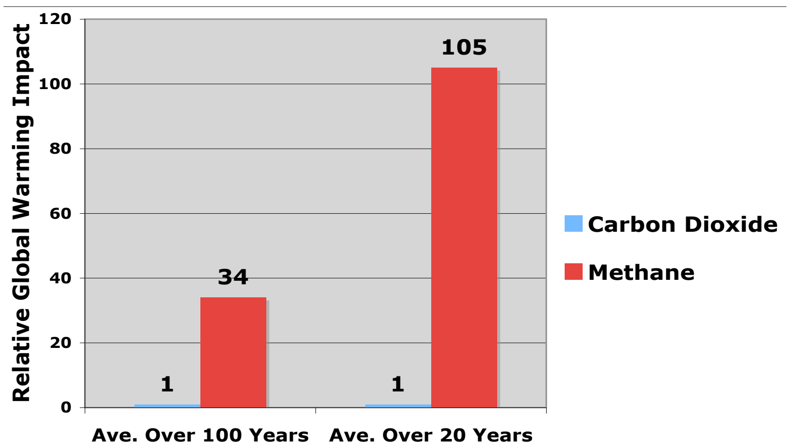
Executive Summary

This paper compares the net greenhouse gas (GHG) effects of most landfill-gas-to-energy projects with the traditional practice of burning the captured methane in a flare. Based on studies by government agencies, consultants to the waste industry, and academic institutions, a potential result is **3.8 - 7.8 times more net GHG emissions for energy recovery projects compared to flaring**. This outcome is based on the larger fugitive emissions from "wet" landfills used for energy recovery compared to those from "dry" landfills used for flaring. Since the GHG savings from replacing fossil fuel with the landfill methane could be negated by GHG impacts of the fugitive emissions, "renewable energy" credits should not be given to landfill gas, except when operators can demonstrate no more emissions than flaring.

Introduction

All decomposing organic materials in landfills release methane,[2] a greenhouse gas (GHG) much more potent than carbon dioxide. The Intergovernmental Panel on Climate Change (IPCC) estimated in 1995[3] that the global warming effect of methane was 21 times that of CO2, averaged over a 100-year period, or 75 times CO2, averaged over a 20-year period. The latest research from NASA in 2009 shows the impact of methane to be 34 times that of carbon dioxide over 100 years and 105 times over 20 years.[4] The next 20 years are critical because of the imminent danger of releasing billions of tons of Arctic methane clathrates,[5] which could lead to irreversible runaway global heating.

Figure 1. Global Warming Impact of Carbon Dioxide (set arbitrarily at 1) compared with Methane over a hundred year period and over a twenty year period



Many organizations urge the **diversion of all organics** from landfills (estimated at 54% in the U.S. in 2010[6]). This practice would end new methane emissions from landfills. A key concern is the fact that nearly all the emissions from wet organics occur in the first three years[7] (81% from food waste, with

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[2] Methane is emitted from the bacterial process known as anaerobic digestion, which requires liquids, organic materials, and absence of oxygen.

[3] IPCC Second Assessment Report: Climate Change 1995 (not available on line – replaced by the 2007 report).

[4] Drew T. Shindell, *et al., "*Improved Attribution of Climate Forcing to Emissions*," Science* **326**, 716 (2009).

[5] Climate Progress, Vast East Siberian Arctic Shelf methane stores destabilizing and venting, March 4, 2010 (http://climateprogress.org/2010/03/04/science-nsf-tundra-permafrost-methane-east-siberian-arctic-shelf-venting)

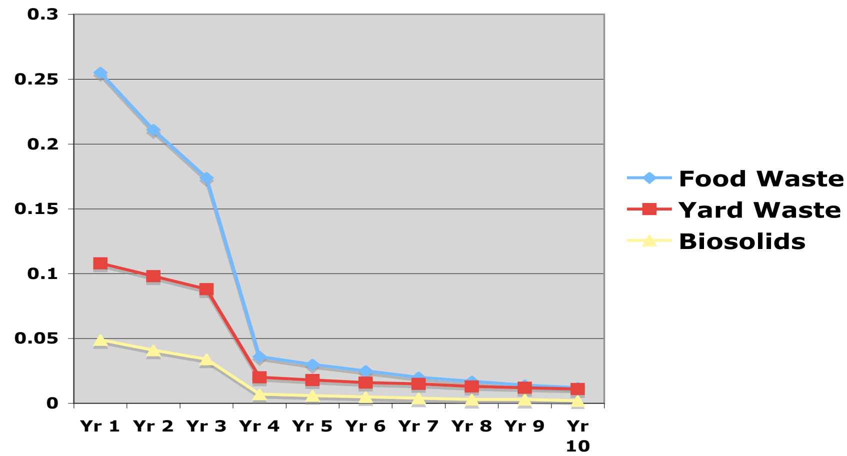
[6] Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2010, US EPA. (http://www.epa.gov/osw/nonhaz/municipal/pubs/2010_MSW_Tables_and_Figures_508.pdf)

[7] Chicago Climate Exchange, Avoided Emissions from Organic Waste Disposal, Offset Project Protocol, 2009, p. 22 (https://www.theice.com/publicdocs/ccx/protocols/CCX_Protocol_Organic_Waste.pdf) Note this report does not show the later wave of gas generation expected decades hence, after the landfill closes, maintenance ends, the protective cover begins to leak, and rain water stimulates more anaerobic digestion.

32% in the first year alone) (see Figure 2.), usually before the gas cap and capture systems are put in place. The normal reason for the delay putting on the cover is the operator is still adding waste to that section of the landfill.

Figure 2. Over 80% of the Methane from Food Waste Escapes in the First 3 Years, Usually Before Capping

[Emissions in tons of methane (CO_{2e}) per wet ton of waste]

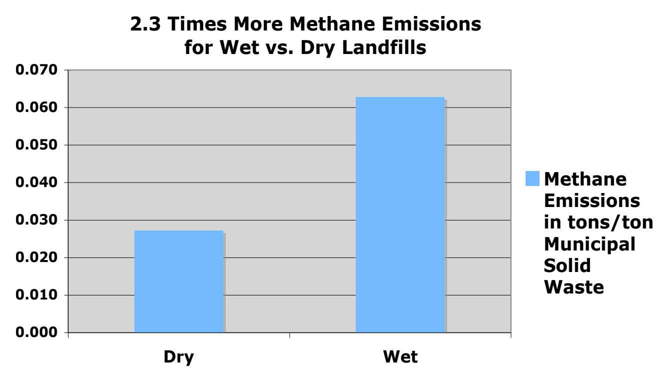


To get the above data, the Chicago Climate Exchange uses a decay model to calculate GHG emissions from a landfill, which is described in detail in their paper. [8] The bottom line is, if there are any organics in the landfill, we need to deal with the ongoing methane emissions from the remaining waste. For many years people installed impermeable caps and gas collection systems to capture the methane and put it into a flare to burn it. Every ton of methane captured and burned avoids the equivalent of adding 104 tons of CO2 to the atmosphere (calculated over a 20-year period).[9]

Wet vs. Dry Landfills

But then people thought, why waste that biomethane burning it in a flare? Why not use it to replace fossil fuels? It sounded like a good idea, except, if you take the methane from a dry landfill and try to burn it in an engine or turbine, it is inefficient. The normal methane flow from a "dry tomb" landfill is so slow and impure, that the operator doesn't make enough money to pay for the additional capital and operating expenses of an engine or turbine. So they need more moisture in the landfill. As the chart below from research done for the U.S. EPA shows, **wet** landfills generate 2.3 times more methane than **dry** ones (based only on measuring the collected gas, not the total emitted, which was not looked at in these studies).[10] If the collection efficiency were the same in both cases, the result is up to **2.3 times more GHG emissions** for energy recovery sites.[11]

Figure 3. Moisture Greatly Increases Methane Emissions



[8] Chicago Climate Exchange, Avoided Emissions from Organic Waste Disposal, Offset Project Protocol, 2009, p. 22. (https://www.theice.com/publicdocs/ccx/protocols/CCX_Protocol_Organic_Waste.pdf)

[9] Calculated from methane global warming factor 105 minus the 1 part CO_2 from the flare burning the methane.

[10] Reinhart, D.R. et al. First-Order Kinetic Gas Generation Model Parameters for Wet Landfills, report prepared for US EPA, 2005, p. 4-5. (nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100ADRJ.txt). See also Sally Brown, "Putting the Landfill Energy Myth to Rest," *BioCycle*, May 2010, p. 5.

[11] We note that these data are from experimental sites; some energy recovery sites may not be this wet.

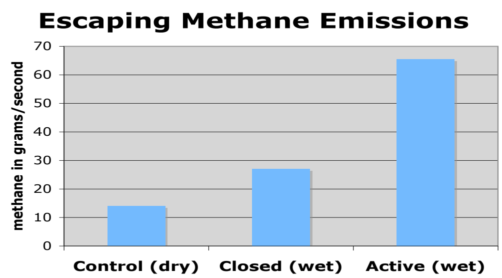
Since it is supposed to be illegal to deliberately add water to a landfill, waste engineers came up with a variety of ideas to increase the gas production in the short term and decrease costs so they could make more money, including such methods as[12]:

- Leaving the cap off as long as possible so more water from rain and snow can enter.
- Regrading the slopes to drain rain into the landfill.
- Recirculating the liquid leachate flowing from the bottom of the landfill back into the top.[13]
- Turning off gas collection wells on a rotating basis in order to give each field time to recharge moisture removed by the gas extraction process itself.
- Reducing the vacuum pump pull on gas collection wells when imperfections in the landfill cover allow air to be drawn into the waste mass. Pulling lower amounts into the collection system allows more methane to escape. (Note: While landfills that just flare gas can accept 3%-5% oxygen infiltration before risking igniting fires, those recovering energy are restricted to as low as 0.1% because a high rate of methane production depends upon having an oxygen-starved environment.)
- Installing more gas collection wells at the center of the landfill, where methane ratios are greatest, and less at the periphery, which could allow more gas to escape with no wells to capture it.

Result of Increasing Moisture is More Uncollected, Fugitive Emissions

The problem is that these aids to more profitable "energy recovery" result in much more uncaptured methane. A report for the US EPA analyzed fugitive emissions for three types of approaches: (1) normal dry tomb landfill, (2) closed landfill, but circulating leachate to provide moisture for energy recovery, and (3) active landfill circulating leachate to provide moisture for energy recovery. The results are shown in Figure 4. The closed, but wet landfill had 1.9 times more escaping emissions, while the active wet landfill designed for maximum energy production had 4.7 times more emissions.[14]

Figure 4. Moisture Increases Fugitive Methane Emissions from a Landfill, by up to 4.7 times



[12] List compiled in March 2010 by Peter Anderson, RecycleWorlds Consulting, based on these publications:
- Augenstein, Don, Landfill Operation for Carbon Sequestration and Maximum Methane, (http://www.osti.gov/bridge/purl.cover.jsp?purl=/795745-EMfXDz/native).
- Institute for Environmental Management (IEM), Emission Control: Controlled Landfilling Demonstration Cell Performance for Carbon Sequestration, Greenhouse Gas Emission Abatement and Landfill Methane Energy, Final Report, February 26, 2000.
- Augenstein, Don, et. al., Improving Landfill Methane Recovery - Recent Evaluations and Large Scale Tests (2007) (http://www.globalmethane.org/expo_china07/docs/postexpo/landfill_augustein_paper.pdf)
- Oonk, Hans, Expert Review of First Order Draft of Waste Chapter to IPCC's 4th Assessment Rpt, 2008 (available from Peter Anderson, anderson@recycleworlds.net)
- SCS Engineers, Technologies and Management Options for Reducing Greenhouse Gas Emissions From Landfills, 2008 (http://www.calrecycle.ca.gov/Climate/CATSubgroups/2008Feb26/Report.pdf).
- U.S. Environmental Protection Agency, 40 CFR Part 60 WWW (proposed and final rule).
- Sierra Club LFGTE Task Force, Sierra Club Report on Landfill-Gas-to-Energy, January 2010 (http://sierraclub.org/policy/conservation/landfill-gas-report.pdf)

[13] "[Director of Butte County's solid waste program] Mannel explained that in this process, liquid is introduced into the sealed "waste cells" in the landfill. The addition of the liquid improves the production of methane up to five times more than the unaugmented process." Chico Enterprise-Record, 6/14/2010 (chicoer.com/news/ci_15292646)

[14] Mark Modrak, et al., Measurement of Fugitive Emissions at a Bioreactor Landfill (2005) (available at http://clubhouse.sierraclub.org/people/committees/lfgte/docs/measurements_fugitivieemissions.pdf)

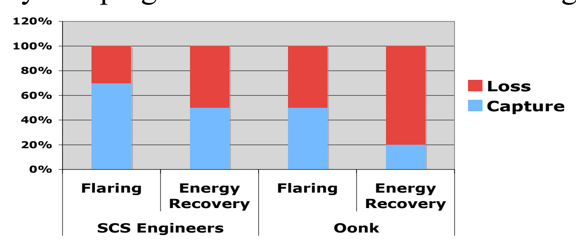
The IPCC estimated that, over the long term, including the extensive times (before and after installation of the gas capture systems) when there is little or no gas collection, the average total fraction captured may be as low as 20%.[15] U.S. EPA's *Compilation of Air Pollutant Emission Factors* (AP-42) assumes a range from 60 to 85 percent, with 75 percent as "typical" for sites having a well-designed active collection control system in place.[16] However, EPA gives no estimates of the amounts lost before the installation of the gas capture system and after landfill maintenance ends, which often are very large.[17]

A report by consultants for the solid waste industry[18] provides their view of the ranges of gas collection values: 50-70% for an active landfill, 54-95% for a inactive landfill or portions of a landfill that contain an intermediate soil cover, or 90-99% for closed landfills that contain a final soil and/or geomembrane cover systems. Their view is stated as, "The **high ends** of the range of these values are proposed for sites with NSPS or similar **quality LFG collection** systems which are designed for and achieve compliance with air quality regulations and surface emissions standards." "The **low end** of the range would be for full LFG systems that are installed and operated for other purposes, such as **energy recovery**, migration control, or odor management; . . ." (emphasis added). Our interpretation of these statements is the high ends of the ranges apply to sites using flaring, while the low ends apply to those doing energy recovery.

However, we note that the Palos Verdes landfill study in the 1990s, which was cited by SCS Engineers for its "capture efficiencies above 95%,"[19] was for a landfill that had been closed for nearly 20 years and had a 5-foot thick clay cap installed. That study was recently reevaluated by the California Air Resources Board, which found a collection rate of only 85%.[20] Thus for closed landfills with a final cover, 85% capture is a more substantiated upper limit, meaning that more than 15% is escaping.

In any event, the SCS report indicates the waste industry recognizes the potential losses in the collection efficiency of energy recovery compared to state of the art flaring. This means that an active landfill (shown in the left two columns in Figure 5 on the next page) using an energy recovery system could have a collection efficiency as low as 50%, compared to about 70% for one using flaring, which implies 1.6 times more methane is likely escaping when a landfill is used for energy recovery. A study of Dutch landfills[21] shown in the two right columns found that, averaged over the life of the landfill, flaring gas extraction systems designed for minimizing emissions could realize collection efficiencies only up to 50%, while energy recovery systems averaged only 20% efficiency. However, the numerical factor is the same, 1.6 times more methane is likely escaping when a landfill is used for energy recovery.

Figure 5. Methane Capture Efficiency at Flaring sites is 1.6 Times greater than at Energy Recovery sites.



[15] Intergovernmental Panel on Climate Change, *Fourth Assessment Report*, Waste Chapter 10, p. 600 (2008). (Note that 54% of all waste x 75% collection efficiency x 50% when collecting = 20%.)
[16] Office of Air Quality Planning and Standards and Office of Air and Radiation, *Emission Factor Documentation for AP-42, Section 2.4, Municipal Solid Waste Landfills* (Revised 1997) (http://www.epa.gov/ttnchie1/ap42/ch02)
[17] "Critique of SCS Engineers' Report Prepared for California's Landfill Companies on Gas Collection Performance," by Peter Anderson, Center for a Competitive Waste Industry, 2008 ().
[18] SCS Engineers, *Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills*, for the Solid Waste Industry for Climate Solutions (June 2008), p. 16-17 (http://www.scsengineers.com/Papers/FINAL_SWICS_GHG_White_Paper_07-11-08.pdf).
[19] California Integrated Waste Management Board, Overview of Climate Change and Analysis of Potential Measures to Implement Greenhouse Gas Emission Reduction Strategies, May 8, 2007.
[20] "Initial Statement of Reasons for the Proposed Regulation to Reduce Methane Emissions from Municipal Solid Waste Landfills," (May 2009) p. IV-5 and Appendix D (http://www.arb.ca.gov/regact/2009/landfills09/isor.pdf).
[21] Oonk and Boom, 1995, *Landfill gas formation, recovery and emissions*, Chapter 7, TNO-report 95-130.

We note that a recent report[22] by Patrick Sullivan, senior vice president of SCS Engineers, consultants for the solid waste industry, states, "Opponents of landfills claim development of LFGTE projects will increase methane emissions at landfills [in comparison with flaring]. . . This is simply not true." Some of the points he makes are quoted in italics below:

1. *"The landfill is required by federal regulations to achieve the same surface emission limits and LFG system operational requirements in either case."* Our response is the landfill operator must demonstrate there is no increase in fugitive emissions from practices that aid LFGTE, such as the six strategies mentioned on page 3 above.
2. *"Landfill opponents suggest that LFG engines, which represent the largest majority of LFGTE devices, do not destroy methane as well as flares. Indeed, the capacity of flares to destroy methane is greater than most LFGTE equipment, but the true difference between the two devices is very small with flares and other control devices achieving more than 99% control and lean-burn LFG engines achieving more than 98% control of methane (Solid Waste Industry for Climate Solutions [SWICS], 2007)."* He is referencing his own company report, but the report cited actually states that methane destruction efficiency of flares is 99.96% compared to internal combustion engines 98.34%. As we will show later, this **1.6% difference is very significant**, even using the outdated GHG multiplier of 21 (and much worse using the 20-year multiplier 105).[23] This means that it is impossible to use engines and have less net impact than flaring, but turbines with high destruction efficiency are acceptable, as are systems that inject the methane directly into natural gas pipelines for normal uses.
3. *"There are some landfills, which are not required by regulation to collect and control LFG, that are developed for LFGTE."* Our response is this is a valid point. Voluntary LFGTE projects undertaken before the NSPS standards require temporary capping and collection could significantly reduce GHG emissions compared to cases where operators wait as long as possible (up to 5 years is allowed for active cells) to cap and install collection systems. A consultant report found the very large collection of methane before the five year limit produced substantial carbon reduction credits.[24] However we feel the EPA needs to drastically tighten the NSPS standards, especially in light of the analyses reported above that the largest emissions from wet organics occur within the first three years.

Combining the Two Effects Produces Much More Net GHG Emissions for Energy Recovery

In addition to the 1.6 times increase in fugitive emissions at energy recovery sites, there is the effect reported above that **wet** landfills produce 2.3 – 4.7 times more methane than dry ones. If we combine these two observed effects, the net result would be **3.8 - 7.8 times more net GHG emissions for energy recovery compared to flaring** (this value is irrespective of the value of the GHG multiplier for methane, but the GHG impact is five times greater when using the 105 multiplier for methane).

The charts in Figure 6 indicate the actual global warming savings using the captured methane from energy recovery to replace the burning of fossil methane are very small (0.0007 tons of carbon dioxide equivalent per typical ton of municipal solid waste (MSW)), much less than the overall impacts of the escaping methane. The left chart shows a net increase of GHG emissions of 0.034 CO_2 equivalent tons/ MSW ton using the old (1995) multiplier of 21 (which is still used by the US EPA for "consistency").

The right chart shows a net increase of GHG emissions of 0.172 CO_2 equivalent tons/MSW ton using the latest (2009) multiplier of 105 over the next critical 20 years. Below the large right red bars for energy recovery in both figures, there is a very tiny blue line (that looks almost like a shadow) that

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[22] Patrick Sullivan, SCS Engineers, The Importance of Landfill Gas Capture and Utilization in the U.S., April 2010, p. 28-30.
(http://www.scsengineers.com/Papers/Sullivan_Importance_of_LFG_Capture_and_Utilization_in_the_US.pdf)

[23] It is very unfortunate that EPA 40 CFR Part 98 allows the use of a default 99% destruction efficiency for methane for all types of LFG combustion devices, including engines, ignoring this large GHG impact.

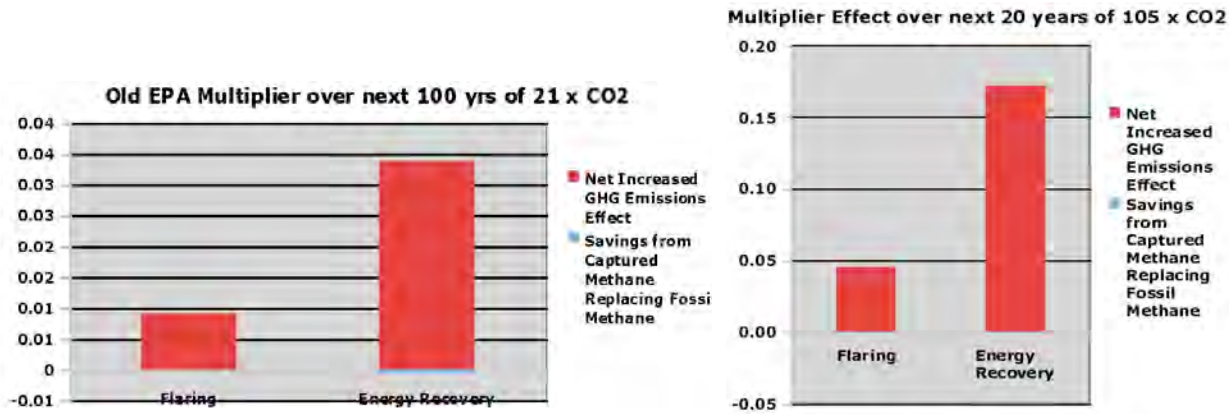
[24] McCommas Bluff LFGTE Project, Voluntary Carbon Standard Assessment, Jan. 2010, by Blue Source LLC, available from the author, Annika Colson, (212) 253-5348, acolston@bluesource.com

represents the amount of benefit from offsetting the use of fossil fuels, which in each case is only 0.0007 tons of carbon dioxide equivalent per typical ton of MSW.

Note that the charts essentially apply to landfills with active gas collection systems, and do not include the methane lost before the landfill is capped, or after the permanent landfill cap is no longer maintained and starts to leak, adding moisture from precipitation, which will increase methane emissions.

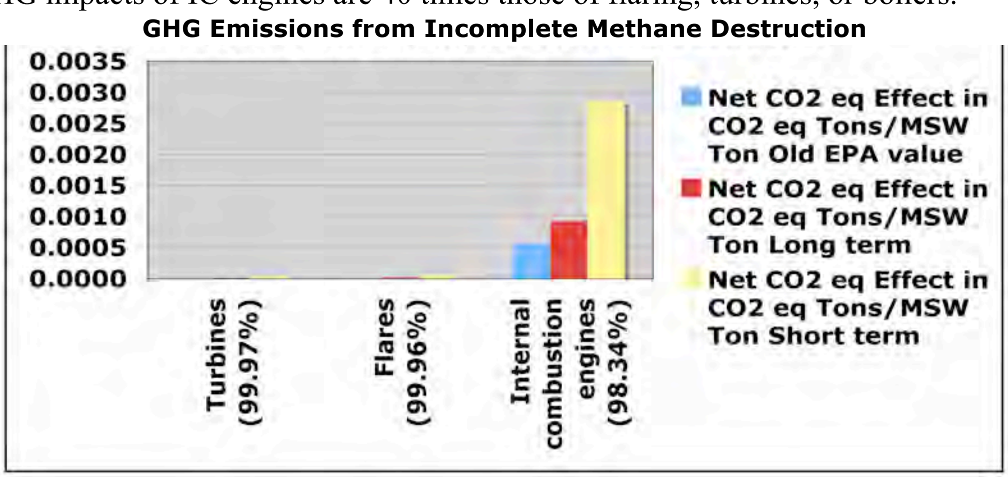
Figure 6. Energy recovery procedures increase global warming impact by at least 3.8 times using either multiplier of 21 or 105, even considering the savings from "energy recovery."

The GHG emissions from escaping methane are expressed in $CO_{2\ equivalent}$ Tons per MSW Ton



Methane Destruction Inefficiency of Internal Combustion Engines Increases GHG Impact

It is important to include recent data from the waste industry of average methane destruction efficiency of flares (99.96%) compared to internal combustion (IC) engines (98.34%) and turbines (99.97%).[25] Their analysis indicates turbine destruction efficiency is essentially equivalent to a flare, but an internal combustion engine adds significant GHG impact from its 1.6% lower destruction efficiency. An EPA report found that a boiler was similar to a flare.[26] But using an engine increases the GHG impact from energy recovery by 0.0006 CO_2 equivalent tons per MSW ton, using the old multiplier of 21, or 0.0028 CO_2 equivalent tons per MSW ton, using the latest 20-year multiplier of 105. The methane destruction **in**efficiency of an internal combustion **engine** (0.0006) essentially **negates its global warming savings** from replacing fossil methane at the old multiplier (0.0007). Using the short-term multiplier of 105 shows the GHG impacts of IC engines are 40 times those of flaring, turbines, or boilers.

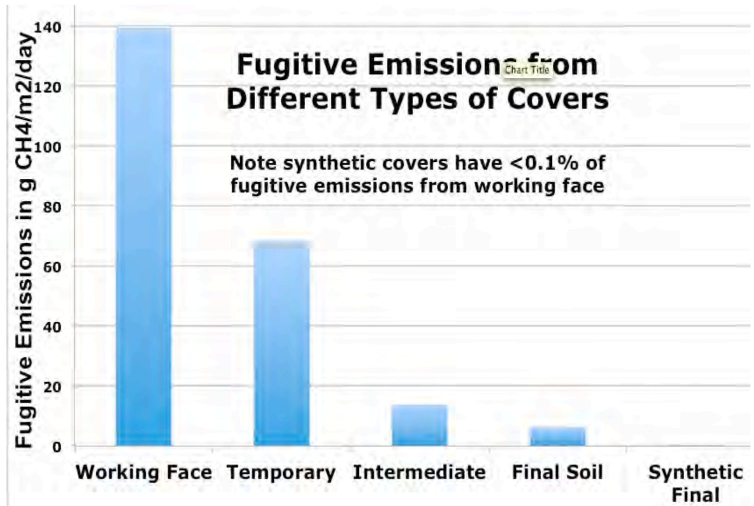


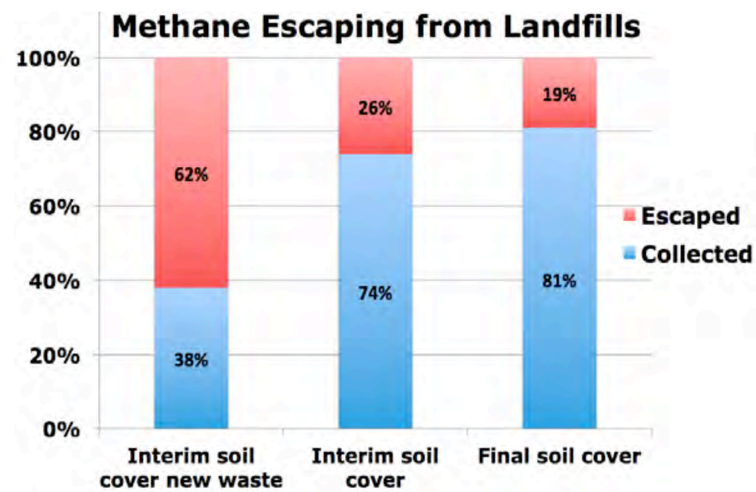
[25] SCS Engineers, *Current MSW Industry Position and State-of-the-Practice on Methane Destruction Efficiency in Flares, Turbines and Engines*, prepared for the Solid Waste Industry for Climate Solutions (July 2007), p. 2.

[26] Roe, S.M., Fields, P.G., and Coad, R. Methodologies for Quantifying Pollution Prevention Benefits from Landfill Gas Control and Utilization. EPA/600/SR-95/089, July 1995. (http://www.p2pays.org/ref/07/06277.pdf)

Effects of Different Types of Covers

A recent paper by Goldsmith et al.[27] compares the efficacies of different types of flat landfill covers in reducing fugitive emissions. Goldsmith et al. discuss the impact of different climates on the fugitive emissions, but since they found such a wide range of emissions for a given cover type within each climate zone, this chart compares the averages of all the results they obtained for the five cover types. Even a temporary cover reduces emissions by over 50%, an intermediate cover by 90%, final soil by 95%, and a synthetic final cover by 99.9%.





A recent EPA report[28] using tracer gas data and optical remote sensing measurements to analyze fugitive emissions from both the tops and side slopes found collected gas for intermediate covers ranged from 70% to 77% for a site with interim soil cover and 73-88% for a site with a final soil cover. Both sites had not accepted waste for years. The one that had just stopped receiving new waste had only 38% capture rate. The gas was being flared with no energy recovery. Note that this EPA report contradicts the report mentioned in footnote 17, by SCS Engineers, consultants for the solid waste industry, which claims collection efficiencies of 90-99% for closed landfills that contain a final soil cover. The results of the Goldsmith and EPA reports make it even more urgent that all landfills install a waterproof, airproof synthetic final cover and efficient gas collection system as soon as each small cell is filled, preferably within a few weeks.

Policy Recommendations

In summary, to reduce global warming requires the following steps to be implemented immediately:

1. Use current GHG impact value of 33 (over 100 years) or 105 (over 20 years) for methane to calculate the **impacts of methane** emissions from landfills.
2. **Divert all organics** (except sewage sludge) from landfills to reduce uncollected emissions.[29]
3. **Either compost all organics or digest them in sealed processors** that capture all methane.

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[27] Goldsmith, Jr., C.D., Chanton, J., Abichou, T., Swan, N., Green, R., and Hater, G., *Journal of the Air & Waste Management Association*, 62(2):183–197, 2012.

[28] Quantifying Methane Abatement Efficiency at Three Municipal Solid Waste Landfills. EPA/600/R-11/033, report prepared in 2012 by ARCADIS U.S. for Susan A. Thorneloe.

[29] We note that clean organics can be processed by aerobic composting or by anaerobic digesters that can capture all the methane for energy purposes and produce high quality compost, with only small amounts of inert waste remaining for a landfill. However, toxic contaminated organics such as sewage sludge/"biosolids" digestate should be monofilled in separate cells in existing landfills because of the high contamination.

4. **Segregate remaining organics in landfills for the most effective and cost-efficient gas collection** (always maintaining high suction)**.**
5. **Keep out all liquids** from landfills (including not recirculating leachate) to reduce fugitive emissions.
6. **Cap landfills with temporary covers** over the working face to keep out rain and **then install permanent synthetic covers and gas collection systems as soon as possible** (within months is important). (The current 5-year NSPS requirement harms our environment and health.)
7. **All captured methane should be burned in a flare, boiler or a high efficiency turbine**, or used to replace natural gas for heating or fuel cells (after proper filtration to remove harmful gasses); internal combustion (IC) engines should not be used because of unburned methane releases.
8. **Stop new landfill gas to energy projects and don't give "renewable energy" credits to landfill gas** (unless capture rates over the entire landfill and destruction efficiencies are constantly monitored and demonstrated[30] to be equal to those of a flare.) (The argument that credits should be given if gas collection projects are installed earlier than local or NSPS requirements should not apply, since fugitive emissions have been found to be so large. The only way to eliminate these fugitive emissions is to eliminate organics from landfills, which would make landfill gas to energy projects uneconomic. Giving renewable energy credits to landfill gas allows it to undercut clean sources like wind and solar and, most importantly, puts source reduction, reuse, recycling, diversion, composting, and anaerobic digestion at a competitive disadvantage.)

[30] Peter Anderson mentions monitoring costs in "Critique of SCS Engineers' Report Prepared for California's Landfill Companies on Gas Collection Performance," Sept. 5, 2008, p. 12 (anderson@recycleworlds.net). However, a spectroscopy method developed by Picarro proposes efficient monitoring, Rella, Chris, et al., 2009, (http://www.picarro.com/assets/docs/Quantfying_Methane_Fluxes_Simply_and_Accurately_-_Trace_Dilution_Method.pdf).